

U. S. NAVY
BUREAU OF ORDNANCE
IN
WORLD WAR II



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DEPARTMENT OF THE NAVY

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Lieutenant Commander, USNR

WILLIAM B. BOYD
Lieutenant, USNR

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FOREWORD

After the close of World War I, work was begun on a volume covering the activities of the Bureau during the war period. Published under the title *Navy Ordnance Activities, World War, 1917-18*, this volume proved of great assistance to Bureau officials in the interwar years.

Because of the much greater complexity and scope of Bureau activities during World War II, work on a comparable record was initiated while the war was in progress. The objective was to make readily available a realistic account of what was done in naval ordnance and how it was done. The present volume therefore records the problems faced by the Bureau, its accomplishments, and its failures. Any treatise which attempted to cover all the ramifications of the Bureau would run into several volumes and by sheer bulk repel reader interest. For this reason a good deal of relevant but not-too-important material has been eliminated from this volume.

Although security considerations and technological complexity conspire to keep ordnance a somewhat mysterious realm, it is hoped that this history will prove of value to all those who work with Naval Ordnance and provide the layman who underwrites the effort with a better understanding of the armament upon which his security depends in part.

M. F. SCHOEFTEL
Rear Admiral, U. S. Navy
Chief, Bureau of Ordnance

PREFACE

During fiscal year 1943 the Bureau of Ordnance processed 2,500,000 pieces of mail. That workload, devoted to communiqués that affected global strategy as well as to the more numerous and mundane byproducts of daily routine and red tape, was a kind of index to the administrative problems involved in running a material bureau during a world war. A volume could profitably be devoted to those problems. A chronicle of the accomplishments and mistakes might insure or prevent their repetition, as the case might be. On the other hand, during that same period the Bureau of Ordnance procured 3938 gun directors and 20,388 torpedoes. No Navy had better fire control than the United States Fleet, but, according to the submariners, none had poorer torpedoes. The facts underlying that kind of discrepancy claimed priority over administrative problems. Lacking pages to give both their due, this volume was devoted largely to weapon development and production. Each chapter tells a separate and complete story. Since each covers roughly the same period, continuity was impossible and a certain repetition was inevitable.

The sources for this history were drawn almost entirely from the files of the Bureau. Documentation was not attempted, partly for obvious security reasons, and partly because citations could have little meaning for readers outside the Bureau. Objectivity was a goal, but the volume is not free of prejudice. Although reservists and not members of the "gun club," the authors are naval officers who wrote with a pride based on the conviction that the Bureau of Ordnance, while batting many a fungo, supplied the world's mightiest fleet with the firepower that is nearly synonymous with sea power.

BUFORD ROWLAND.
WILLIAM B. BOYD.

ACKNOWLEDGEMENTS

This volume represents the culmination of a wartime history project which was established by the Bureau of Ordnance in the spring of 1943. During the 3½ years of its existence, 14 Reserve officers were engaged, at one time or another, in compiling material relating to the Bureau's war effort. The project was successively headed by Lt. Comdrs. Bernard Brodie, J. J. Mathews, and Buford Rowland. The personnel included Lt. Comdr. Helen M. Coen; Lts. W. H. Heicher, Thomas E. Cotner, Catherine Atwood, William Haselden, Russel Gubbins, C. E. Petersen, Betty Wolcott; Lts. (jg.) James D. Ewing, Rita M. Whitney, Helen Knuth, and Aerographers Mate Mal Maclay. The professional competence of this group in the collection, appraisal, organization, and presentation of source material immeasurably facilitated the writing of this history.

The chapters on torpedoes and aviation ordnance are based in part on R. J. H. Powel's excellent monograph on the Newport Torpedo Station and on Lt. Comdr. R. V. Brown's detailed study of the development and procurement of the Norden Bombsight. The voluminous publications of the NDRC and the OSRD, both technical and nontechnical, proved invaluable.

Adm. W. H. P. Blandy and Vice Adm. George F. Hussey, Jr., read the entire manuscript and their encyclopedic knowledge of the Bureau and its weapons resulted in the elimination of many errors. Rear Adm. W. R. Furlong and Vice Adm. Willard A. Kitts 3d, read several chapters and offered valuable criticism. Rear Adm. M. F. Schoeffel, Chief of the Bureau, and Rear Adm. W. S. Parsons, Deputy Chief, found time to read portions of the manuscript and offer suggestions for its improvement. Several chapters profited from the criticisms of Rear Adms. John B. Heffernan, Director of the Office of Naval History, and J. A. Furer, wartime Coordinator of the Office of Naval Research and Development. Capts. F. L. Robbins, H. L. Jukes, and F. G. Gould, directors of the Administrative Division and in immediate charge of the history program, were most helpful throughout the project.

The personnel of the Publication Branch of the Bureau—particularly Mr. H. E. Marschalk, Mr. C. H. Grover, Mr. C. W. Pierrot, Mr. Stanley Smith, Mrs. Irene Garvey, Mrs. M. A. Pflaging, and Mrs. Helen Stearns—were most cooperative in preparing the manu-

script for the printer. The staff of the Ordnance Technical Library proved adept at furnishing pertinent documents and publications. Mrs. Sara C. Guilford, secretary of the historical unit, not only typed many drafts of the manuscript, but throughout the project assumed many of the tedious details of a busy office.

Thanks are due Mr. Victor Gondos, editor of *Military Affairs*, for permission to reprint Lieutenant Commander Rowland's article on nets which was published in the 1947 fall issue of that magazine.

Unless otherwise noted, all pictures are official United States Navy photographs.

CONTENTS

<i>Chapter</i>	<i>Page</i>
1. The Bureau and Its Work.....	1
2. Ordnance and Science.....	16
3. Armor.....	32
4. Projectiles.....	52
5. Degaussing.....	69
6. Torpedoes.....	90
7. Depth Charges.....	131
8. Mines.....	156
9. Nets and Booms.....	172
10. Ammunition.....	186
11. Antiaircraft Machine Guns.....	219
12. Double-Purpose, Intermediate, and Major Caliber Guns.....	248
13. The VT Fuze.....	271
14. Rockets.....	291
15. Aviation Ordnance.....	330
16. Fire Control.....	368
17. Fire Control Radar.....	408
18. Machine Tools.....	433
19. Contract Procedures.....	448
20. Inspection Administration.....	461
21. Incentive and Award Programs.....	470
22. Personnel.....	481
23. Army-Navy Cooperation in Ordnance.....	496
24. Korea.....	505
Appendix.....	523
Index.....	529



Pearl Harbor.

BUREAU OF ORDNANCE
IN
WORLD WAR II

Chapter 1

THE BUREAU AND ITS WORK

THE contribution of sea power to victory in World War II is already familiar, at least in its broad outlines. Starting with the rebuilding of a fleet after Pearl Harbor, it is the story of ships and men, of task forces and individual heroism. Less familiar is the role of naval ordnance, the broad category of defensive and offensive weapons that make the difference between a mere seagoing vessel and a real man-of-war. United States armament was not invariably superior to that of the enemy, but it was generally better; in some cases it was so markedly superior in quantity and quality that the degree of its superiority proved the margin of victory over a powerful enemy.

Modern naval ordnance includes everything that is thrown at the enemy, the weapons for throwing them, the instruments for insuring their accuracy, and many of the protective devices that parry the enemy's blows. The design, production, issue, and maintenance of that armament is the responsibility of the Bureau of Ordnance, one of the material Bureaus in the Navy Department. Where its field was once confined to the surface of the sea, it now extends to hundreds of feet below and thousands of feet above the ocean.

Founded in 1842, the Bureau supplied ordnance for 4 wars prior to World War II, but the activity of the whole first century of its existence was dwarfed by comparison with the 4 years that followed. Even World War I, with its ordnance expenditures of approximately \$1 billion, provided no adequate comparison with the \$13.8 billion program required little more than two decades later. Moreover, the growth occasioned by that war was of small value when a new demand for sea power arose after 20 years of peace. The United States soon reduced naval appropriations to the prewar level, and ordnance activity became largely a matter of maintaining the armament on the active fleet. Even that part of the Bureau's mission became less of a task after the United States took a leading part in the disarmament programs after World War I. The Washington Conference of 1922 had disastrous results for the United States Navy. Two hundred thirty-six ships, some recently completed and others still under construc-

tion, were scrapped or towed to sea and sunk, offering the Navy little for its loss but a few hours target practice.

Even that essential became a curtailed luxury in the following years, as a lack of interest in naval power forced the Bureau to operate with an economical but crippling budget. By 1930 the mission of lending punch to the ships at sea had to be accomplished by a Bureau force of only 22 officers and 64 civilians spreading an appropriation of \$31,092,020 over the wide range of ordnance activities. While every effort was made to continue the development of new and improved weapons, little but maintenance of the existing force was possible. The shore establishment through which the Bureau fulfilled much of its mission was reduced to a bare minimum—a move permitted by the low workload of the Bureau and dictated by budgets which could not stand the overhead costs of maintaining a sizable shore establishment.

The process of retrenchment came to a stop in 1933, just when Hitler was preparing to destroy the Weimar Republic. In the years that followed, the naval picture in the United States changed perceptibly. Appropriations remained low, but Navy funds were supplemented by money made available through the National Industrial Recovery Act and the Public Works Administration. With the increased funds, the Bureau of Ordnance began a gradual and orderly expansion of its activities. Quantitatively, ordnance procurement increased about $2\frac{1}{2}$ times; total appropriations rose from the 1923–32 average of \$23,300,000 annually to a yearly average of \$59,500,000 during the period from 1933–39. The dollars spent during this period of expansion can easily be envisioned in terms of weapons for battleships 55 to 60, destroyers 409 to 436, and submarines 188 to 203. To the extent that appropriations were used for new personnel, the significant increases took place at the four ordnance shore establishments actually engaged in production—the Naval Gun Factory, Washington, D. C., the Naval Powder Factory, Indian Head, Md., the Naval Torpedo Station, Newport, R. I., and the Naval Ordnance Plant, Baldwin, N. Y. Procurement was drawn from three main sources—the Navy's own, Army arsenals with a surplus capacity, and from private manufacturers. While the latter originally claimed the smallest share of the money spent, a trend developed in the opposite direction. By 1939 contracts with private firms exceeded the cost of government production. Within that broad trend, another became apparent: the tendency to decrease dependence on eastern firms and spread naval production over the Nation.

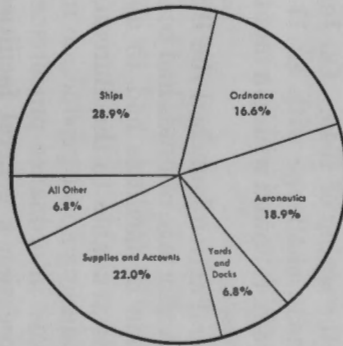
NAVY WAR PROGRAM BY BUREAU

INCLUDING LEND LEASE

JULY 1, 1940 — AUGUST 31, 1945

PERCENTAGE DISTRIBUTION OF AUTHORIZATIONS

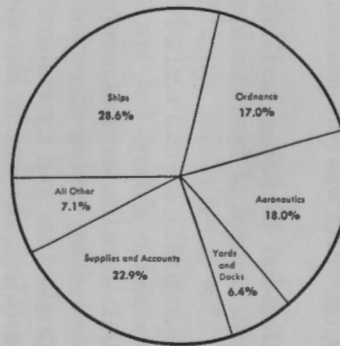
TOTAL AUTHORIZATIONS — \$139.0 BILLION



Ships	\$40.2 Billion
Ordnance	23.1
Aeronautics	26.1
Yards and Docks	9.5
Supplies and Accounts	30.6
All Other	9.5

PERCENTAGE DISTRIBUTION OF APPROPRIATIONS

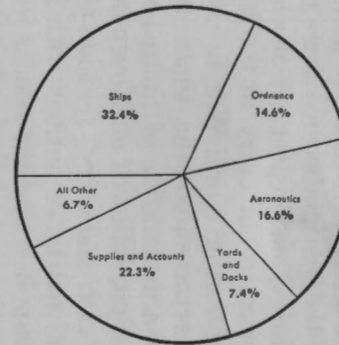
TOTAL APPROPRIATIONS — \$133.0 BILLION



Ships	\$38.0 Billion
Ordnance	22.6
Aeronautics	23.9
Yards and Docks	8.5
Supplies and Accounts	30.5
All Other	9.5

PERCENTAGE DISTRIBUTION OF EXPENDITURES

TOTAL EXPENDITURES — \$94.5 BILLION



Ships	\$30.6 Billion
Ordnance	13.8
Aeronautics	15.7
Yards and Docks	7.0
Supplies and Accounts	21.1
All Other	6.3

While the change in emphasis from maintenance to expanding production indicated the direction of future Bureau growth, the problems to be solved and the programs followed were subject to many changes in the years between 1939 and 1945. As war broke out in Europe and the Nation became more conscious of the need for preparedness, the expansion program accelerated until ordnance production rates prior to our entry in the war were in excess of anything witnessed during World War I. But as great a growth as this expansion represented, the times demanded more. On September 8, 1939, a declaration of limited emergency was made by President Roosevelt, followed on November 4 by congressional enactment of the "cash and carry" revision of the Neutrality Act. This revision permitted those nations with access to the United States to tap our supplies, and the results were a stimulus to the Nation's war production. As beneficial as that ultimately proved to our own services, the effect was competition and higher prices for war material.

Industrial mobilization planning had been predicated on an M-day, when overall control of facilities and materials would be legally possible. The substitution of a gradually deepening emergency for that original plan had real advantages in terms of a slow growth of productive ability, but not until the Lend-Lease Act of March 11, 1941, were the services in a position to take advantage of the war abroad by giving direction to the expansion of facilities for war production and by controlling the allocation of scarce items. Meanwhile, the war in Europe had taken a critical turn when the Nazis overran Denmark, Norway, France, and the Low Countries in the spring of 1940. On June 14, 1940, Congress answered the German challenge with an 11 percent raise in the shipbuilding program, followed within a month by the "two ocean" or 70 percent increase.

That congressional action launched the Bureau of Ordnance on a new program. A shortage of funds had been the perennial problem; now expansion of facilities had to absorb the energy and much of the funds available to the Bureau, for its task was essentially that of building a war production machine in peacetime. The general increase in ordnance procurement prior to 1939 was not sufficient to occasion a general facilities expansion program over the Nation. The facilities and the knowledge of ordnance manufacturing were hopelessly inadequate for anticipated needs, and a shortage of machine tools, intensified by the "flatness" of the machine tool industry, threatened to cripple the effort at the outset. Even before United States entry into the war, the demands of

lend-lease and a growing fleet at home outstripped the production sources available to the Bureau. Relief came from efforts in two different directions—the creation of new manufacturing plants within the Ordnance Shore Establishment, and the harnessing of private industry to the defense effort.

Naval Ordnance Plants were not newcomers to armament manufacture. Three such plants, located at Dayton, Ohio, South Charleston, W. Va., and Baldwin, N. Y., were commissioned during World War I. The last two remained under Navy ownership and made important contributions again in World War II. When the creation of additional plants became an obvious requirement, Congress responded in July 1940, with an initial authorization of \$50,000,000 for the project. For its part, the Bureau surveyed over 200 sites which seemed to offer the advantages of inland location, adequate labor, and good transportation, then recommended 5 locations for construction. At each of these—Louisville, Ky.; Macon, Ga.; Indianapolis, Ind.; Canton, Ohio; and Center Line, Mich.—a Naval Ordnance Plant was erected. These facilities were bolstered early in 1942 by the construction of additional NOP's at Forest Park, Ill.; St. Louis, Mo.; and Pocatello, Idaho. The total number of new facilities reached 9 when a Milledgeville adjunct of the Macon plant was given separate status as an independent plant, then climbed to 10 when a Navy financed plant at York, Pa., was taken over and designated a NOP. The cost of the 10 new NOP's exceeded \$150,000,000.

The operation of the facilities was an interesting compromise between private enterprise and a public venture. Ownership was entirely in government hands, but management was exercised by private contractors who operated the plants for costs plus a fixed fee. The system was applied to all of the NOP's except Pocatello; in every case but one, the experiment worked well. Aside from making industrial facilities available, Naval Ordnance Plants offered other advantages: production could be shifted quickly from one weapon to another without the delaying restrictions imposed by conventional contract procedures, thus permitting the kind of productive flexibility that the everchanging tactics of war demanded; by allowing exact calculations of cost, the production at NOP's aided the Bureau in its determination of fair prices in negotiations with private manufacturers.

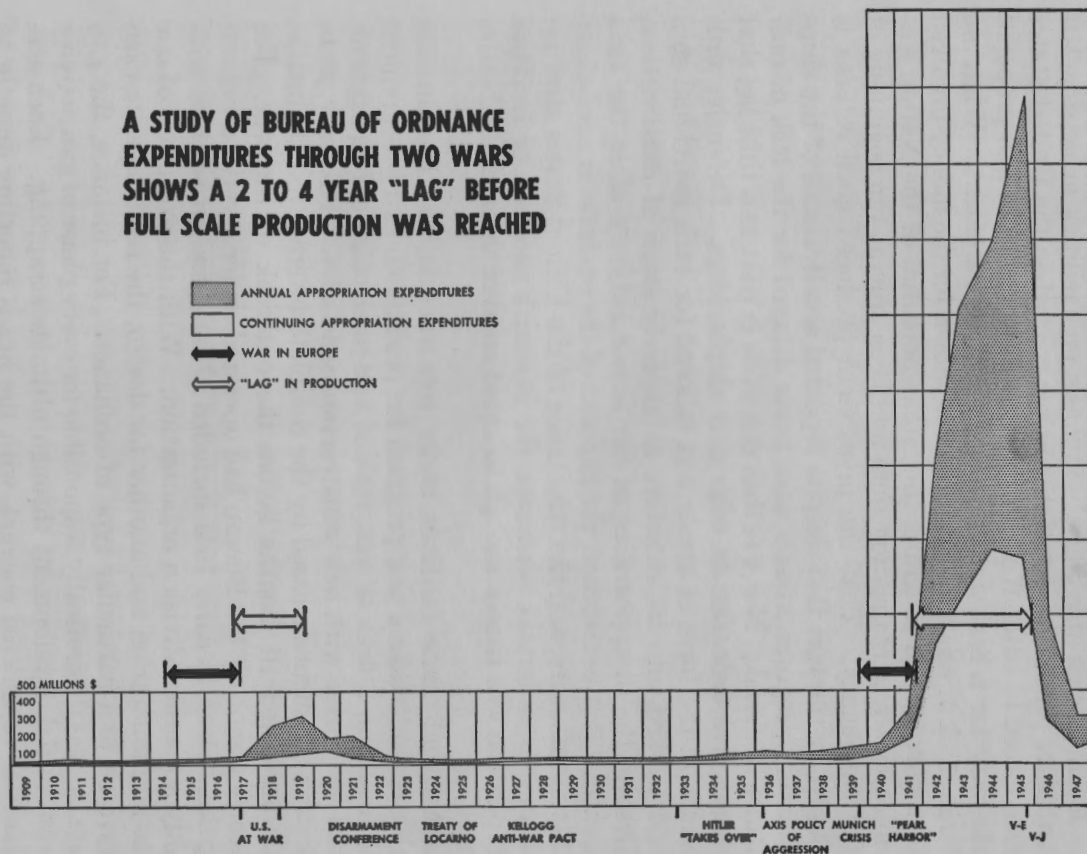
Complementing the work of the Naval Ordnance Plants and the other manufacturing facilities were the rest of the ordnance field establishments—magazines, ammunition depots, laboratories, test

stations, and a variety of other facilities devoted to some special ordnance task. While their role was not primarily productive, they performed supplementary roles such as loading, assembly, and handling—jobs which were all important in a field where procurement was normally confined to components rather than a finished product. In some cases, they actually entered production when the scope of procurement was limited or urgency demanded "crash" programs that gave manufacturing a higher priority than the primary mission of the establishment involved. The shore establishment continued its steady growth during the war until it reached a capital value of one and a quarter billion dollars.

The expansion of Navy facilities under the Bureau of Ordnance was an important approach to the vital problem of assuring an adequate supply of naval armament, but the need to exploit the enormous productive capacity of American industry was apparent even before the demands of war revealed the inadequacy of peacetime plans. Prior to Pearl Harbor, however, there were many obstacles to tapping the Nation's commercial sources. Profits were high, the world market for consumer and heavy goods was absorbing production, and the incentive of patriotism was still unaroused. Naturally, but unfortunately, private capital was hesitant to invest in costly expansion for production of problematical duration, especially since much of the equipment necessary for the production of armor and armament had almost no commercial value. That hesitancy to invest was intensified by the profit-limiting features of the Vinson-Trammell Act, originally designed to protect the Government from excessive costs on naval contracts, but ultimately serving to produce timid manufacturers. On the shoulders of the Bureau of Ordnance fell the task of seeking government action which would open the door to private capital, while using public funds to speed that essential work.

Facility contracts involving vast sums of money followed in rapid succession; before the attack on Pearl Harbor funds to the extent of a billion and a half dollars were involved and the Bureau of Ordnance was administering the expansion of many manufacturing plants and imparting the knowledge of ordnance manufacture to the new participants—a complex and expensive program which involved supplying and keeping up to date the millions of blueprints required, the inauguration of training programs for management and labor in both government and private plants, and the establishment of an adequate inspection system to guarantee the requisite quality of ordnance products. Bureau prime contractors at the end of 1941 totaled 2381 firms, plus approximately 5000 sub-

A STUDY OF BUREAU OF ORDNANCE EXPENDITURES THROUGH TWO WARS SHOWS A 2 TO 4 YEAR "LAG" BEFORE FULL SCALE PRODUCTION WAS REACHED



contractors who furnished parts for assembly. Because of the experience and success of the Bureau in its facilities expansion program, the heavy forging procurement for the Bureau of Ships and the Maritime Commission was delegated to Ordnance.

Even though this initial emphasis on facilities expansion left ordnance production in relatively low gear when the United States was forced to enter World War II, Bureau foresight had prepared the way for a real wartime program of procurement. While no large stock of war materials could be shown for the money involved in the expansion program, the latent potential of the Nation was much closer to realization than had been true at the beginning of the emergency. That the investment produced good returns is shown by the fact that despite repeated accelerations of the shipbuilding program, vessels were never delayed for the lack of ordnance material. Nor was that due even in part to a time lag that might give ordnance an edge over shipbuilders. Defensive ordnance in the form of armor was tailored for each individual ship and worked into its structure at an early stage of construction. Despite the disappearance of our armor industry after the 1922 disarmament conference, the expense of the equipment needed for its manufacture, and the reluctance of the United States steel industry to undertake contracts, the Bureau's program of facilities expansion was timely enough to avoid an ever threatening bottleneck.

With adequate facilities under construction, the Bureau was able to undertake a new program for production and procurement to maintain a fleet at war, replace and modernize old equipment, and keep pace with new construction schedules. This new problem was immensely eased by the complete internal reorganization accomplished 10 months before the outbreak of the war. For nearly a century the Bureau had operated under a vertical organization, which in early 1941 included 17 independent sections with only a nominal division organization. With the exception of one for administration and another for design, the sections were each devoted to a particular type of ordnance. For instance, the gun section was theoretically responsible for every phase of gun activity from initial development through ultimate scrapping. Each section was considered coequal, with the heads reporting directly to the Chief of the Bureau or his assistant, and coordination depended upon the direction of the Chief or the personal cooperation of the officers in the various sections. For many years, even during World War I, the organization worked well. Concentration and



Adm. W. H. P. Blandy, as Commander in Chief, Atlantic Fleet, headed the Bureau of Ordnance as a rear admiral from February 1941 to December 1943.

specialization were combined, and responsibility was easily pinpointed.

Despite its history of success, the vertical organization began to show serious defects when the national emergency created a workload in excess of anything witnessed during World War I. No longer was there time for the large measure of voluntary communication between sections upon which success depended, and the centralization of authority placed the Chief and his assistant under mounting pressures. Moreover, when they or an authority outside the Bureau needed general information on research, or procurement, or on any of the other functional activities of the Bureau, there was no one logical person to supply it. Instead, all of the section heads had to be summoned, since each directed operations in each phase of Bureau activity. A backlog increased with the growing workload until reorganization became a matter of real urgency.

In the latter part of 1940, Rear Adm. W. R. Furlong, Chief of the Bureau from August 1937 to February 1941, appointed a board of officers to study the problem and recommend a plan for reorganization. The Chief hoped to accomplish the change within the framework of the existing organization, but before the study was completed he was detached and sent to Pearl Harbor for a new command. His relief, Rear Adm. W. H. P. Blandy, had more radical ideas. As a member of the board studying reorganization, he became convinced that scrapping rather than mere revision was in order, and his first move as Chief was to abandon the vertical organization in favor of a horizontal or functional arrangement. The traditional sections were abolished. In their place Admiral Blandy created five divisions, each with its mission declared in its title—Administrative, Financial, Research and Development, Production, and Fleet Maintenance. Within each of the latter three, a section was devoted to each major type of ordnance equipment. Instead of all gun activity being concentrated in one section, for instance, research and developmental work was accomplished by the cognizant section in one division, procurement was directed by the related section in another, and maintenance by still a third.

Authority was delegated to the various division directors, who had full responsibility for executing the mission of their divisions. Now 5 men instead of 17 reported to the Chief, who could, in turn, call on any one of them for information on a broad area of Bureau activity. In addition, the Chief was aided by an assistant chief and several special assistants, who were responsible for coordinating critical projects that required special attention. With no direct



Vice Adm. George F. Hussey, Jr., Chief, Bureau of Ordnance, December 1943 to September 1947.

authority of their own, they constituted a staff for the Chief of the Bureau. The new organization decentralized the Bureau, yet concentrated the sources of information into a small group of division directors and assistants. The keynote of the system was expressed in Admiral Blandy's admonition to division and section heads: "Don't try to do it all yourself—organize, deputize, supervise."

Placed in effect on February 20, 1941, the functional organization worked fairly well from the start. The workload of the Bureau was still increasing, however, and that mounting pressure exposed weaknesses in the new arrangement, just as it had earlier outdated a system with a century old reputation for adequacy. The crux of the problem was that there was no unit in the Bureau, aside from the Chief and his assistants, responsible for planning, initiating, and coordinating major Bureau projects. As the number of such projects rose, reinforcements were essential. The solution came in September 1941, with the creation of the Planning and Progress Division, which assumed the coordinating and directing functions earlier exercised by the special assistants to the Chief. In their place, the division served as his staff for overall planning, policy formulation, issuance of directives, and the maintenance of progress information.

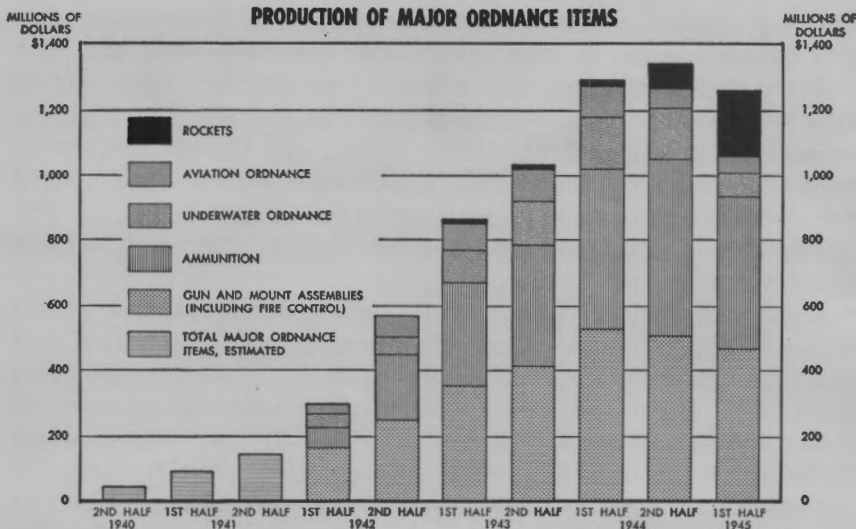
The new organization fitted in well with that of the Navy Department as a whole. The Bureau of Ordnance, though under the direct administrative control of the Secretary of the Navy, received its orders from the Chief of Naval Operations, who stipulated what was needed and stated the when and the where for delivery. Within that broad framework, the Bureau decided how the requirements should be met, then performed whatever design, development, and procurement the task required. And even the what, when, and where, though defined by CNO directives, were influenced by the Bureau itself. The creation of the new division facilitated the procedures within the Bureau. CNO directives received by the Chief were passed on to cognizant officers within the Planning and Progress Division, where the overall task was broken down into specific assignments to the various divisions. They, in turn, issued periodic progress reports to Planning as work went forward on the assigned project.

The new division was more or less intertwined through the others, preventing the "bulkheading" that otherwise might have occurred within a functional organization. The system was further refined in early 1942 with the creation of type assistants within the Planning Division to coordinate the progress of pro-

grams so critical that the normal procedures were not adequate. Air defense, aviation, and underwater ordnance were the first fields to be so designated, and a fourth type assistant for ammunition was later created. Corresponding to the special assistants created in February 1941, they rounded out the reorganization work that permitted the Bureau to cope with the workload created by a national emergency, and multiplied many times by war itself. Remodeled and expanding, the Bureau was ready to meet the increasing needs for firepower.

During the prewar period and in the early months of actual combat, emphasis was necessarily placed on the production and procurement of nonexpendable items, such as armor, guns, and fire control apparatus, without which there could be no need for ammunition. In the interest of rapid production, weapons had to be along the lines of prewar development, while research for better ordnance ran concurrently with that production. Later in the war the production emphasis shifted from nonexpendables to expendables and weapons that at the beginning of the emergency had been mere dreams—or even Buck Rogers fantasies. As the war progressed there were inevitable major shifts in production to meet the changing tactics of warfare. Examples are legion, but a few can illustrate the kind of factors the Bureau constantly had to consider. The enemy developed influence mines, so the Bureau had to conduct an extensive degaussing program to protect United States naval and merchant ships; the enemy emphasized submarine warfare, so the Bureau countered with an array of anti-submarine equipment; aircraft, ranging from great strategic bombers to the kamikaze expendables, played an ever-increasing role, so the Bureau conducted an antiaircraft program that gave the lie to those who had seen in planes the doom of capital ships.

Those were decisions dictated by the enemy. Our own tactical developments demanded a parallel advance. New techniques of submarine warfare, for example, demanded a faster, longer ranged torpedo, even though that weapon already represented the epitome of mechanical complexity. Just as tactical changes were demanding new weapons, the resulting technological advances were producing ever more efficient, though costly, ordnance. The new torpedo, for example, required a novel type primary battery which, until production techniques were improved, cost almost as much as the midget submarine it propelled. The whole trend had a snowballing tendency. Improved planes called for new and lighter armor, then for ammunition that could fell an armored plane and fire control apparatus that would cope with the in-



creased problems of higher speeds and more rapid firing. Unless one technological change was accompanied by others in related material, the effect of improvement was nullified. The result was that cost figures rose rapidly, while price comparisons were made meaningless by considerations of performance.

The procurement of old and new weapons grew so rapidly during the war that until the rate of production began to accelerate less rapidly in the last of 1943, production in each successive 6-month period of the crisis surpassed the record of the previous year. By 1944 some decline was possible, though newer programs like rockets and high capacity ammunition were still gaining momentum when the surrender of Japan posed new problems of re-conversion. Once production had reached the desired monthly levels, the Bureau shifted its program emphasis to still further research and development. As industry had first been harnessed to the needs of national defense, science soon became the essential companion. A total of 250 naval establishments, universities, and private corporations were brought into research projects at a cost in excess of \$300,000,000, and before war's end, many spectacular weapons were pushed through the gray zone between laboratories and the assembly line.

That gap was a large one, as was that between factories and the fleet. Closing them both was the challenge of the Bureau of Ordnance. The variety and complexity of modern weapons led the Bureau into a large and varied number of activities. The enor-

mous quantity of ordnance required for modern war demanded a gargantuan research, development, and production program. The inherently dangerous character of much of the material required close tolerances in manufacturing, rigid standards in proving, and troublesome safety precautions in handling and use. Those factors of variety, complexity, magnitude, and danger added up to a sum total of problems with few counterparts.

Chapter 2

ORDNANCE AND SCIENCE

IF three weapons—radar, the proximity fuze, and the atomic bomb—had been developed by the enemy rather than the Allies, Tojo might well have fulfilled his dream of dictating peace in the White House. Hundreds of other factors helped thwart that dream and turn it into a nightmare of defeat, but no others were more decisive in the military arena. The trio was not alone spectacular in performance. Almost as unusual was the fact that they were largely creations of the war they influenced. New ordnance had been developed during wartime before, of course, but never in time to exert a decisive influence on the outcome. Developmental energy had normally been absorbed in countermeasuring weapons devised by the enemy in peacetime, while each side fought with the armament on hand at the beginning of hostilities.

The difference lay in the concept of total war and in the success of the free nations in translating that idea into reality. Total war meant a complete absorption of industry into the defense effort. Out of that came a flood of material that amazed even a nation accustomed to the miracles of mass production. Total war also meant a similar exploitation of the Nation's scientific resources. The extent to which that was accomplished is illustrated by the fact that naval ordnance research and development work was spread over 250 naval establishments, universities, government agencies, and private corporations. Out of that effort came new, decisive weapons, and a host of improvements to conventional armament.

For the most part, the administrative machinery used to harness science to the war effort was established after the declaration of a national emergency in the fall of 1939, but its origins extended back many years. There was no precedent for total war, but the need for scientific aid was recognized at least as early as 1863, when President Lincoln sought technological aid for the Union forces through the establishment of the National Academy of Sciences, a self-perpetuating, independent body of scientists. The exclusive group, drawing no pay beyond compensation for actual expenses, was chartered to aid the government upon request—a stipulation that later restricted the usefulness of the Academy by

depriving it of the right to initiate research. Meanwhile, the institution furnished yeoman service and grew in prestige through the years.

World War I made new demands on its services. A generation of peace found the democracies typically unprepared for war. Submarines, tanks, airplanes, and gas were all new threats against which the military had no adequate defense. The luxury of inadequate preparation had to be paid for by a frantic mobilization of scientific resources. The National Academy of Sciences provided the basic machinery for that effort, but the pace at which government agencies submitted projects to the Academy exposed the need for reinforcements. The result was the creation of the National Research Council in 1916, to serve as an agent for the Academy in complying with the many requests for assistance. Staffed by representatives of the Nation's principal scientific and technical societies and by government appointees nominated by the President of the Academy, the Council introduced new talent to the war effort.

The National Academy and its agent handled the bulk of the Government's research projects, but the novelty and scope of the problems introduced by the advent of the airplane led to the creation of another quasi-official body—the National Advisory Committee for Aeronautics. Officially chartered by Congress in 1915, the committee's function was broadly conceived to encompass fundamental and applied research in the new science of aeronautics. Both the Army and the Navy were represented on the NACA, but the executive authority of the organization was vested in a special committee that served without salary. Like the National Academy, it remained free of political influence; unlike the older body, the NACA was provided with laboratories in which it could conduct its own research. These facilities came too late for service in the First World War, but they guided many of the developments that made airplanes so important in the Second.

Both the NACA and the National Academy of Sciences furnished advisory aid to the Navy Department. Of more direct assistance, however, were the two naval laboratories conceived during World War I. The first of these was the Naval Research Laboratory, Washington, D. C., which was authorized in 1916 and opened in 1923. The NRL was provided with a broad charter and followed the organizational pattern of the National Research Council by having divisions for each of the fields of science that might have an application to naval problems. The very breadth of the NRL's work created administrative problems, since

bureaus proved reluctant to support basic research that might prove of no value to their specific mission. That dilemma resulted in frequent transfers of cognizance over the Laboratory, so that its administration moved from the Secretary of the Navy to the Bureau of Engineering, back to the Secretary's office, to the Bureau of Ships, and finally, to the Office of Naval Research and Inventions, a late World War II creation. Although the Bureau of Ordnance was never responsible for the administration of the Laboratory, it did make use of the facilities available there. Some of the early research on the Naval torpedo was conducted at the Laboratory, and Bureau interest stimulated the development of radar for both search and fire control purposes. Much of the Nation's basic work in radio detection was pioneered by the Naval Research Laboratory.

Of much more importance to the Bureau of Ordnance was the Naval Ordnance Laboratory—the second of the institutions established as a result of World War I experience. The original laboratory, created by merging two experimental units, was erected at the Washington Navy Yard in 1918, but the end of the war stunted the early growth of the institution. At one time during the inter-war years, the technical staff was reduced to two men.

Even after war began in Europe, there were only 50 employees at the NOL, and hardly one-fifth of that limited staff were scientific or technical personnel. Growth was rapid, however. Before the end of 1940, the Bureau turned to the Laboratory with a group of urgent problems that demanded an extension of both facilities and personnel. By the middle of 1941 the NOL was working on approximately 100 separate projects. The number continued to grow as rapidly as the extension of facilities and personnel would permit. Before the end of World War II, the existing quarters were too restricted for the role of the NOL, and a new location was chosen in nearby Maryland. When peace permitted, the Laboratory moved to the new site, where additional facilities made it the most modern institution of its kind in the world.

Although the Naval Ordnance Laboratory was the most important single research institution under the control of the Bureau during World War II, many other facilities performed experimental work in a restricted field or as a secondary function. Among these were the Naval Proving Ground, Dahlgren, Va., the Naval Torpedo Station, Newport, R. I., the Naval Mine Depot, Yorktown, Va., the Naval Mine Warfare Test Station, Solomons, Md., the Naval Ordnance Test Station, Inyokern, Calif., the Bureau of Ordnance Test Unit, Dam Neck, Va., and the Explosives Investigation



Original NOL Mine Building at the Washington Navy Yard (now U. S. Naval Gun Factory).



Expansion of NOL from the Mine Building to modern plant indicates the importance accorded research activity.

Laboratories at Stump Neck, Md., and Port Townsend, Wash. The listing is by no means all-inclusive. The Powder Factory at Indian Head, Md., for instance, was the site of important developmental work on explosives and propellants, and many of the Naval Ordnance Plants were equipped with test ranges which contributed to the Bureau's program. Before the end of World War II, the laboratory facilities at the Bureau establishments represented an investment of approximately \$40 million.

Within the Bureau itself the prewar organization did not afford research activities an important place. The only specific provisions for research and development lay in the existence of a small experimental section devoted to work on pyrotechnics, explosives, and fuzes, and in a Special Board on Naval Ordnance, which conducted studies on any assigned project. There was also a design section, but its activities were more closely related to engineering than to development. Aside from those three units, the Bureau depended for its research and developmental work on the technical sections that also guided procurement.

For a peacetime organization the system had many obvious advantages. Research and development for a particular weapon or device were perfectly integrated with production and maintenance. In most cases the lines separating design and development from production and maintenance engineering were hazy, at best. The beauty of the vertical organization was that the lines did not even need a clear definition.

The chief theoretical disadvantage was the difficulty of coordinating the work on related though separate ordnance items, but even that problem was not too great during peace. The relatively light workload permitted desks to confer with one another frequently enough to maintain a common effort on research and development policies. Moreover, the ordnance engineers were organized as a separate unit. Since the bulk of the design work necessarily fell to that group, it provided a focal point for the coordination of projects initiated by offices with different interests.

In practice, the chief problem proved to be that while research could be coordinated without special difficulties, it almost inevitably tended to be subordinated to the other functions of the various desks. Procurement and maintenance problems were naturally the most pressing ones faced in day to day activities. When funds were short—as they invariably were during the years of peace—long range research projects to provide better ordnance took second place to projects designed to supply and maintain the fleet's existing armament. When the torpedo group was attempting to

develop an electric model back in the late 1920's, for instance, an experimental Mark ¹ was allowed to lie unrecovered on the bottom of the range for 2 years. Intermittent efforts to find the torpedo were made, but the more pressing problems of procurement and maintenance received priority.

In still another way, the integration of research and development with procurement and maintenance proved a detriment to experimental work. Funds might be appropriated for the development of particular items of ordnance, then spent for design and procurement as well once the weapon was developed, rather than for further research in the same field. Moreover, officers whose primary concern was with procurement were not prone to ask for research funds that might come at the expense of some other aspect of ordnance activity. Congress was not generous with appropriations during the peace years, but to the extent that ordnance development was hindered by a lack of funds, the Bureau had to share the blame. The problem was less that money was not granted than that it was not requested or was diverted to other purposes. Despite all the obstacles, however, some notable accomplishments were made under the peacetime organization. The 5"/38 double-purpose gun, perhaps the most outstanding naval gun used in World War II, the 6"/47 cruiser mount, and excellent fire control equipment were all developed and designed in the years between the two wars.

The chances for such progress diminished with the buildup of the fleet that started after 1933, and practically disappeared after the declaration of national emergency in 1939. Too much depended upon voluntary cooperation between sections and upon the personal direction of the Chief or his assistants. As the workload increased month after month, the inadequacies of the arrangement became apparent and led to the complete reorganization of the Bureau in February 1941. Thereafter, a separate division was charged with responsibility for guiding the development of new weapons, with a mission that ranged from the conception of an idea to production engineering.

The execution of that mission involved a series of distinct functions. Fundamental to the whole process was basic research, the kind that uncovered the laws of science and produced the theories that served as tools for further exploration. While basic research was more a function of universities and private institutions than

¹ A new equipment, component, or extensive redesign was assigned a mark number, a modification number indicated a minor variation in a given mark.

of service laboratories, the Bureau sponsored some fundamental work and needed to be fully aware of the work being done elsewhere in the Nation. The second phase of the division's function was applied research to exploit the fundamentals of science on behalf of naval firepower. The relationship between the two types was illustrated in the development of the atomic bomb, where the knowledge of nuclear physics uncovered by years of basic research was applied to the development of a specific weapon.

The third step in the evolution of an ordnance item was the actual development of a piece of equipment. This was followed by the design and production of a prototype that could be subjected to tests, then used as a model for subsequent manufacture. Once an item reached a satisfactory form and proved desirable as a weapon, it went through the final engineering that prepared the design for actual production. At that point an item passed from the cognizance of the Research and Development Division to that of the Production Division, but the former was still not free of responsibility. Improvements to service weapons and methods of maintenance were as much a function of research as the development of new ordnance.

To cope with the wide range of problems involved, the division was subdivided according to types of ordnance equipment into five major sections: Ammunition and Explosives; Armor, Projectiles, Bombs and Ballistics; Fire Control; Guns and Mounts; and Underwater Ordnance. Neither the organization of the Bureau nor the structure of the division remained static, but the changes of early 1941 established the framework for the future growth. Individual problems were met as they arose and the organizational structure was readjusted as occasions demanded.

The Research and Development Division was not designed to function as a true research organization. Neither the facilities nor the personnel were available and little actual research and development work was done within the division. It operated as a coordinating and directing activity. Line officers rather than scientists held the key positions. While many of them were Reserve officers drawn from the laboratories of universities and industry, their role was supervisory. Bureau officers were project managers for the research accomplished in the field stations or through contracts with outside agencies. The arrangement was insurance that every development would be realistic from the fleet's point of view. In research, as in all phases of ordnance activity, the policy of the Bureau required that weapons be produced by those who would use them in action.

By the time the reorganization was accomplished there were important new agencies to which the Bureau could turn for help with its problems. The acceleration of the defense program that antiquated the Bureau's desk arrangement also served to point up the inadequacies of the preemergency relationship between science and government. The National Academy of Sciences was as competent as ever and its National Research Council provided a comprehensive coverage of the fields of science, but there were several weaknesses in the prescribed arrangement. The Academy was a high consulting group, but it furnished advice or information only upon government request. Unsolicited assistance was beyond the intent of its charter; even had the Academy wished to give more than was requested of it, it would have been handicapped by a lack of research facilities, independent funds, and knowledge of what was needed.

The restrictions on the scope of the Academy's activity were based on the assumption that the War and Navy Departments would know what they wanted and turn to the agency with specific problems. Once a valid assumption, it became increasingly erroneous with the specialization of scientific fields. Moreover, officers naturally conceived of tactics and strategy in terms of existing ordnance. To base a nation's defense on desirable rather than available weapons would obviously have been a perilous gamble. New ideas were developed within the services, of course, but conservatism was inherent in the military establishment. Scientists, on the other hand, were also subject to limitations. They were aware of the practical applications of their fields, but they had no way of knowing of military or naval problems unless they were submitted through existing channels. Coordination was haphazard and cooperation was inadequate. In commenting on the situation, Admiral Hussey stated that the Nation used its "native potentialities to less advantage in peacetime in ordnance research than in almost any other field of activity."

The services and the scientists alike recognized that fact, and remedial action came from both directions. Within the Navy Department the first steps were made in December 1939, when the Bureaus were directed to create a section devoted to research, and designate its head as liaison officer to the Naval Research Laboratory. Those officers, in turn, became members of the Navy Department Council for Research, which was headed by the director of the Laboratory. Since he also served as technical aide to the Secretary of the Navy, the move represented a centralization of authority. The Bureau of Ordnance was hardly affected by the

change, however, since even before its reorganization it had a liaison officer at the Laboratory and the rough equivalent of a research section.

In the following year, attention was given to the possibility of continuing the trend toward centralization by making the NRL the center for all naval research, but the material bureaus successfully opposed the proposal. The Navy could not hope to be self-sufficient in fundamental research. That being true, closer contact with civilian science offered the best hope of obtaining the basic knowledge needed to cope with the pyramiding problems of national defense. Applied research, on the other hand, could be better directed by the bureaus with the primary responsibility for the various fields of activity. That concept was in line with the experience of private industries, which rarely tried to conduct basic research in any but restricted fields. The idea prevailed, and to provide the necessary contacts with civilian science, a board of consultants was designated in the summer of 1940 to advise the Navy on scientific matters. Headed by Frank B. Jewett, president of the National Academy of Sciences, its distinguished membership made a broad scope of knowledge available to the Navy, yet left the individual bureaus free to pursue their own projects.

Early in 1941 still more machinery was created. A Naval Research Council was established to advise the Secretary on research policies and to coordinate the work assigned to various naval establishments. Then, to regulate the growing contacts with civilian science, the Office of the Coordinator of Research and Development was created in July 1941. While this office did concern itself to a degree with coordinating the research work of the various bureaus, it was primarily concerned with liaison with non-naval and non-governmental activities. In some cases it initiated research projects of a fundamental nature, but for the most part the office merely served to keep order in the mushrooming research and development programs and to assure the widest possible application of the results of research accomplished for the Navy.

Meanwhile, civilian scientists had taken even more important steps to deal with the basic problem of harnessing scientific talent to the defense effort. Shortly after Germany attacked Poland in September 1939, a few of the members of the National Academy of Sciences met to discuss means for achieving a complete utilization of the Nation's scientific potential. The intention of the scientists was to reverse the old assumption that the military

leaders were well enough informed to direct the utilization of science for war. Instead, they hoped to create a situation whereby the scientists could become informed in military problems, then aid in seeking solutions to those problems. When these views were presented to the Government, the President and his military and naval advisers concurred with the scientists' opinions. The result was the establishment on June 27, 1940, of the National Defense Research Committee, with Dr. Vannevar Bush as chairman.

The new committee was not expected to take over the work that the services were doing in their own laboratories or through contract with commercial firms, but was designed to correlate and support their scientific research. No separate facilities were authorized for the NDRC. Its research and developmental activities were carried out through existing government establishments or by contracts with universities, individuals, and private industries. The cost of the programs was met either by direct congressional appropriations to the committee or by the transfer of funds from the War or Navy Departments.

Internally, the NDRC was organized along functional lines that provided divisions for the various fields of applied science and sections to supervise the work being done in specific fields like fire control, proximity fuzes, and rocket propellants. Sections were added as new problems were presented by the armed services, so that the organization of the committee remained dynamic throughout its existence. An extensive organization of Army and Navy liaison officers was also provided to educate the scientists on military requirements and guide them through the red tape incidental to dealing with the many service agencies involved.

The new source of aid was freely tapped by the Army and Navy. In most cases the research projects were outlined by the services, but in many others the original suggestions were advanced by the NDRC itself, then supported by the interested government agency. As the workload increased, however, it became apparent that the committee could operate more effectively if it were more closely associated with the top executive agencies. To cope with this administrative problem, President Roosevelt issued an executive order on June 28, 1941, creating the Office of Scientific Research and Development. The new organization, headed by Vannevar Bush, was directed to coordinate and supplement scientific research relating to the defense effort. The OSRD was an administrative and contracting agency. Some special laboratories were constructed to carry out work authorized by it, but the office con-

ducted no research of its own. The National Defense Research Committee was placed under its authority and became its operating machinery. The change gave the organizations of civilian scientists more independence and led to a wider scope of activity on behalf of the armed services.

The early projects of the National Defense Research Committee tended to emphasize research that might lead to the development of weapons, rather than the actual development of the equipment needed by the services. That was in accordance with the original conception of the committee's role, but it had the effect of returning to the shoulders of the services a substantial part of the burden from which they were attempting to find relief. After the creation of the Office of Scientific Research and Development, the role of civilian science was extended. Projects were often carried through the stages of engineering design before they were turned over to the initiating services for final design and procurement. In some cases the Office of Scientific Research and Development even entered the field of production to create an interim supply of new weapons while regular contractors were found and tooled for the job. The Bureau of Ordnance benefited from these crash production procedures in the procurement of both radar equipment and rocket components. On the other hand, the OSRD sometimes merely got research projects underway, then turned them over to some cognizant service branch for completion. Two of the most important projects pursued during the war fell into this general category: the atomic program that culminated in the Manhattan Project was initiated by the OSRD, then transferred to the Army Corps of Engineers, while the proximity fuze program was turned over to the Bureau of Ordnance for administration after the civilian scientists completed their developmental role.

The Bureau made extensive use of the services of the OSRD and its agent, the NDRC. One-third of all the Navy work handled by the two agencies was submitted by Ordnance and, of all the service units, only the Signal Corps and the Bureau of Ships initiated a greater number of projects. In all, the Bureau presented 220 requests. Some were minor, but included in the total was important developmental work on fuzes, torpedoes, fire control equipment, explosives, and rockets. Some of the projects were actually initiated on the suggestion of the NDRC, but most of the ideas were presented by the Bureau.

The sources for these projects were numerous. From experience with its own and from observations of foreign ordnance the fleet furnished many of the ideas that were developed into proj-



OSRD helped the Bureau make reliable performers of aircraft torpedoes.

ects. This was particularly true of research and developmental work that was designed to improve existing weapons rather than develop new ones. In other cases, the Chief of Naval Operations and Commander-in-Chief made suggestions directly to the Bureau. Allied governments, private industries, and inventive individuals comprised still other sources. Most of the ideas, however, were conceived within the Bureau itself as tactical developments and the grim necessity of countering enemy weapons dictated the general course of ordnance development.

Once a research or development project was decided upon, it was given a priority rating that defined its relative importance and determined the urgency with which it would be pursued. Systems based on letters and numbers indicating precedence tended to break down because of the apparently inevitable tendency to overclassify each project, but the assignment of prospective completion dates proved satisfactory. Once the relative urgency of a project was determined, the Bureau placed the work through any of several channels.

Ordnance activities were able to accomplish a considerable proportion of the research and development load, especially when the goal was an improvement of existing equipment. While the Naval Ordnance Laboratory was the most outstanding of the research

activities under the Bureau, there were at least a dozen other stations that included research among their secondary functions. Some projects were of such a nature that private industries offered the best promise for the rapid development of needed equipment. The nature of ordnance material is such that it rarely has a civilian or commercial counterpart, but the various components of weapons were often closely related to commercial products. The metallurgical experience of steel companies, for instance, naturally placed them in an excellent position to aid in the development of armor, while years of research in communications made the Bell Telephone Laboratories an attractive outlet for electronic developments.

The appreciation of the practical potential of science gained by the services during World War I had been shared by American industry. Laboratories and research institutions multiplied during the two decades between 1919 and 1939. When war came again they proved an invaluable ally to the armed forces. The normal procedure followed by the Bureau in placing research contracts with private corporations was to call in the interested and competent contractors for preliminary talks. Those who felt that they could accomplish the desired work within the stipulated time would then submit estimates to the Bureau. The lowest reliable bid was accepted and contracts were drawn up to cover the intended work.

When the Bureau decided that a project could be accomplished through the Office of Scientific Research and Development, the contracts were made through the Office of the Coordinator of Research and Development and paid for by Bureau appropriations. Over \$45 million were devoted to such projects during the course of the war. Liaison officers were assigned to the laboratories selected by the OSRD for the work, and the projects were followed by cognizant officers within the Research and Development Division. Supervision was often an especially ticklish business because of the divergent points of view held by civilian scientists and naval officers, but diplomacy, the reduction of red tape to an absolute minimum, the careful selection of liaison officers, and the growth of mutual respect between the two groups eliminated most of the problems. Drawing on accumulated experience, the Bureau developed new organizational ideas to govern its relationship with civilian scientists. The two principal ordnance laboratories were placed under dual control, with a civilian technical director to supervise the scientific staff and a naval officer to direct the administration of the activity.

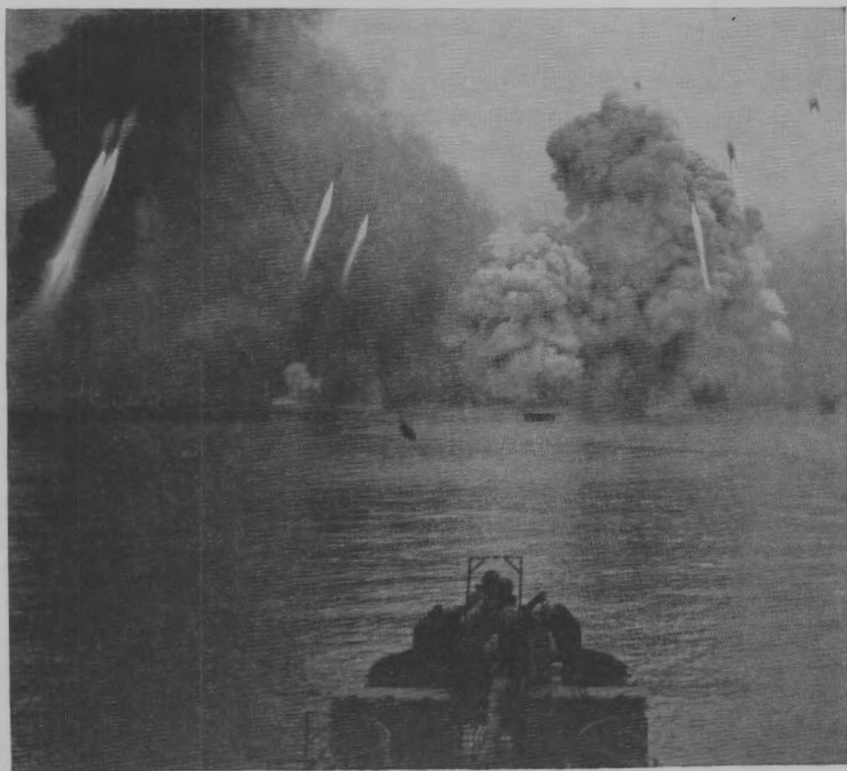
With hundreds of projects underway, mistakes were naturally made by the services and their civilian allies. Through their conservatism, naval officers were sometimes prone to discount unorthodox ideas presented by the scientists. On the other hand, through their enthusiasm for a new role, the civilians often discounted well founded service objections and pushed the development of weapons which were tactically unrealistic. Rockets furnished examples of both types of mistake. When their use was first suggested, the reception of the services was distinctly cool. Only the Bureau of Ordnance showed any interest, and even its enthusiasm for the new weapons continued to lag behind that of the operating forces. For their part, the civilian rocket developers erred by pushing ahead too rapidly, so intent on getting rockets into service that they overlooked military requirements and devised ordnance for which there was no practical use. Such instances were the exception, however, in a particularly fruitful relationship.

During the course of the war a whole series of new weapons entered the fleet as a result of the Bureau's research and development programs. Although mine warfare had been neglected in the United States during the years after World War I, the Bureau supplied both the Army and Navy with a variety of mines so effective that they were probably more instrumental than the atomic bomb in bringing Japan to her knees. Hardly less important for the economic strangulation that was the undoing of the empire were electric torpedoes. Practically unknown at the outbreak of the war, their development and production was so rapid that at war's end they outnumbered the conventional steam torpedoes in the submarines of the Pacific Fleet. Above the surface, the Bureau supplied the operating forces with the Bat, the first fully automatic guided missile used in combat by any nation. Against planes, once held as numbering the days of capital ships, the Bureau of Ordnance provided the VT fuze, a radio device that automatically exploded projectiles as soon as they got close enough to their target to inflict damage.

Rockets moved from the unknown to the commonplace. Countermeasures were devised to protect the fleet from the enemy's weapons and counter-countermeasures were developed to protect the integrity of United States ordnance. No less important than the introduction of new weapons was the improvement of the armament with which the Nation entered the conflict. Developments in armor lent new protection to planes, ships, and individuals; new guns offered increased range, muzzle velocity, and rates

of fire; the projectiles they fired multiplied in types and gained new penetrative and explosive power; fire control, revolutionized by radar, was refined until the element of human error was virtually eliminated. Maintenance, packaging, and inspection, too, were modernized through the Bureau's diverse programs, so that almost every sphere of Ordnance responsibility benefited from the application of science to naval warfare. A nation impressed early in the war by the quantitative output of American industry was soon awed by the quality and novelty of the weapons produced. A reasonable facsimile of the Buck Rogers era seemed at hand. The Bureau's share of the bill for the wartime research that made the transformation possible was over \$300,000,000, but few investments in history offered such prompt and profitable returns.

Despite the obvious results of the alliance between scientists and the military, a common but false conception existed in the United States that the Axis powers had done a more thorough job of exploiting the possibilities of applied science. Spectacular weapons like the buzz and V-2 bombs attested to a high level of scientific achievement, especially in Germany, but they were the result of an



Paced by civilian science, rockets moved from the unknown to the commonplace.

earlier start rather than a superior organization of research. As a matter of fact, the armament program of the 1930's placed Germany so far ahead of the democracies that the Nation was lulled into a false sense of military superiority. At the end of the decade, Hitler even stopped the development of radar on the assumption that the lethargy of the western powers made further progress unnecessary. German scientists, far from being accorded a place of especial esteem in the military state, were subject to a draft that ignored the contribution they might make in their civilian role. Those who were a permanent part of the military bureaucracy were generally of mediocre caliber, compared with their civilian counterparts. Moreover, the scientists who were drawn into the war effort were often held in distrust and denied information vital to the tasks they were supposed to perform. Groups were assigned to develop some component of a weapon which they never once saw assembled or in operation. True, Germany did realize the mistake and attempt to utilize scientists again after 1943, but time lost from research could never be fully recovered. The record of Japan and Italy was even poorer than that of Germany. The fundamentals of scientific knowledge knew no national boundaries, but the democracies, though tardy in organizing for defense and war, provided the independence necessary for its exploitation.

World War II heightened the appreciation of the place of research in the inexorable competition between measure and counter-measure. Ordnance development is inherently dynamic, and nothing less than a continuing program could insure the Nation against having to wage a war with weapons made obsolescent by enemy advances. In recognition of that fact, the Research and Development Division emerged from World War II as the largest in the Bureau. Programs started in the urgency of war were continued into peace, and new projects were inaugurated to deal with those problems which were still unsolved at V-J Day. The result was an imposing array of new weapons that strengthened the hand of the Nation in the subsequent cold war against the Soviet Union and the hot one against Communists in Korea.

Chapter 3

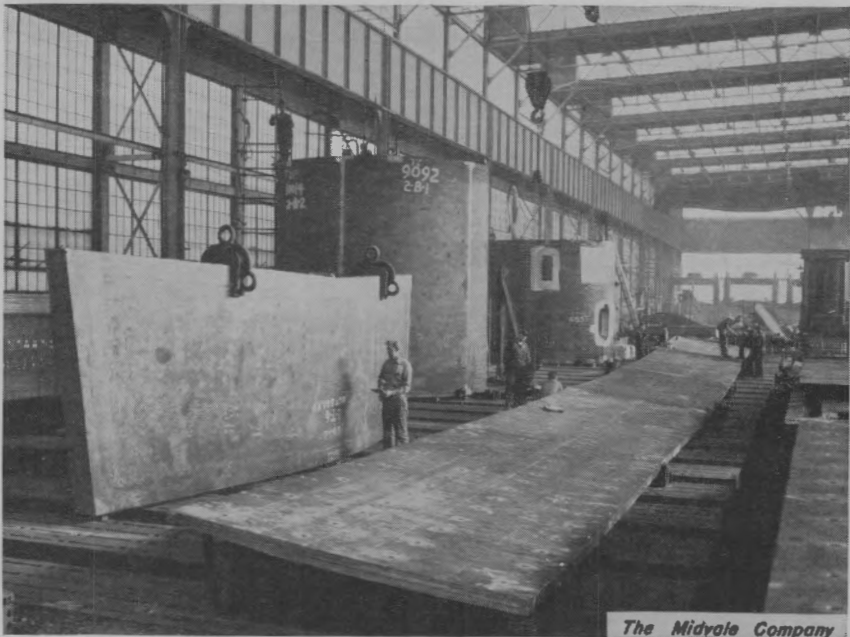
ARMOR

JEWELRY steel is the name sometimes assigned armor. Considering its value to the Navy, the difficulty of its manufacture, and the expense of its procurement, the description is hardly a misnomer. While its passive nature robs it of the glamour which attends the story of many weapons produced by the Bureau of Ordnance, armor gained the center of the ordnance stage when shipbuilding was resumed on an accelerated scale in the years after 1938. Other ordnance needs demanded that the Bureau muster a wealth of technical knowledge, but armor required more. Before new ships could be clad with projectile shattering belts, the Bureau had to deal with problems which were essentially economic and political. Nor could those problems wait for solution concurrently with development of the defense effort. Tailored for individual ships and worked into the vessels early in their construction stages, armor was the first ordnance requirement. Until it was procured ships could not be floated. Guns and ammunition are the staples of a fighting fleet, but from the point of time they were secondary considerations. That urgency which the times required was first focused on armor.

In the early history of the United States Navy the development and production of armor had been geared to the progress of the steel industry and the science of metallurgy. Their influence had been reciprocal—ordnance needs challenged the industry to produce while scientific developments permitted the Bureau to raise its sights time and time again. After 1922 this obvious and profitable relationship began to dissipate. In that year the Washington Naval Conference set limits to the naval forces of the great powers. Only capital ships were affected, but when their construction stopped the need for heavy armor disappeared. With that need passed the capacity and the techniques which the resumption of building demanded. In the next 16 years the vital know-how for armor production was dangerously reduced. Except for one man in the Homestead plant of Carnegie-Illinois, a subsidiary of United States Steel, the chief personnel familiar with the actual mill techniques were all lost to the industry. When 1939 brought the largest peacetime shipbuilding program the United States had experienced since 1919, the Bureau of Ordnance

had to take stock of its outdated facilities, then reestablish contact with the private armor-producing plants of the American steel industry. Before that could be accomplished, a multitude of problems had to be solved. One of the first developed within the Navy Department and concerned the vital issue of cognizance over armor.

Navy Regulations of 1893 gave the Bureau of Ordnance responsibility for "all that relates to . . . the manufacture of all offensive and defensive arms and . . . the material, kind and quality of the armor." The broad cognizance of the Bureau was clear enough, but inherent in the very breadth of responsibility was the problem of overlapping jurisdiction with the Bureau of Construction and Repair. Class A, or face-hardened, armor was seldom considered a factor in the strength of a ship's structure and posed no jurisdictional problem. Class B, or homogeneous, armor was another matter. As an integral part of the structure of a ship it posed a special question: in dealing with armor plate, where should the lines be drawn between ordnance and construction? For specific cases the answer had been determined by negotiations between the bureaus concerned. In March 1939, the problem became more complex and heavy forged armor joined the lighter homogeneous plates in the arena of dispute. Just prior to creating



The Midvale Company

Armor was the first ordnance requirement.

the Bureau of Ships by merging the Bureaus of Construction and Repair and Engineering, Secretary of the Navy Charles Edison ordered a change in cognizance over armor. The new Bureau of Ships was to have responsibility for "all matters relating to such armor, ballistic steel, special treatment steel, etc., as form part of the hull structure of naval vessels or are rigidly attached thereto." While the new arrangement proposed to shift jurisdiction over the production of such protective armor as shell plating, side armor, turrets, and barbettes, the Bureau of Ordnance was left with the responsibility for testing the materials involved.

A variety of factors were involved in the decision. Since Class B resembled the light special treatment steel formerly handled by the Bureau of Construction and Repair, placing armor with that Bureau seemed a logical step. The goal was coordination of all steel development and procurement. Even from an engineering view, arguments for the transfer could be supported. Regulations made Construction and Repair responsible for the structural strength, stability, draft, and weight of ships; all of those factors were affected by the armor used in ship construction. Finally, proponents of the scheme suggested that it would make possible a consolidation of inspection duties at steel plants and, by separating authority over armor from that concerned with projectiles and ballistic testing, would promote healthy competition between armor and projectiles. Cogent arguments, but not convincing enough to effect so great a change in established procedure.

Problems of defining jurisdiction had existed before without detriment to the service being a necessary concomitant. A working cooperation between bureaus had sufficed to cope with the problems involving the defensive and structural characteristics of armor. The Bureau of Ordnance and President Roosevelt preferred such collaboration to extensive changes in administration and cognizance. When Secretary Edison's plan was submitted to the President for approval, consent was withheld. Roosevelt anticipated no armor problems that could not be solved through the familiar channels. On the contrary, he feared that a change in cognizance might actually retard the vital expansion of armor production and pose bottlenecks in the overall building schedule. From the administrative point of view, the President reasoned that unnecessary changes would hinder the program for creating the new Bureau of Ships.

A further arsenal of arguments backed the President's decision to withhold approval for the change. The old Bureau of Con-

struction and Repair lacked experience with the special treatments required for the production of Class A armor, while Ordnance had already achieved a doubling of the productive capacity of the industry. At a moment of crisis such valuable experience could not be sacrificed. Moreover, since considerations of armor design had to be defensive as well as structural, the General Board was better served when discussions of vulnerability were presented by a bureau primarily concerned with defense rather than by one which emphasized consideration of weight and speed. For similar reasons there were objections to separating testing and development of armor from the closely related work with projectiles. That healthy competition between armor and projectile design that the proponents of change hoped to create by dividing cognizance needed no mourning. Lively and profitable competition between the two units was a marked feature of Ordnance activity. Even the economy arguments of those who expressed concern over the apparent duplication of inspection within steel plants failed to withstand examination. Ordnance inspectors were charged with responsibility not only for armor, but for gun forgings and projectiles as well. Even had the armor duties been transferred to other shoulders, maintenance of Ordnance inspectors would have been essential.

With the question of armor cognizance determined by President Roosevelt, a uniform procedure for armor planning and procurement was developed in conjunction with the various agencies concerned. But retaining cognizance over armor left the Bureau of Ordnance confronted with the tremendous problem of securing great quantities of armor within a country whose capacity to produce such a specialty had shrunk to dangerously low proportions. Since 1922 the development of armor had no longer been paced by the progress of the steel industry in the United States. The former correlation between armor producing capacity and industrial growth had been destroyed by the Washington Conference. By 1939 the United States, outproducing its nearest competitor by four times, had reached an annual steel capacity of 75,000,000 tons. Armor potential, on the other hand, had fallen to only 19,380 tons. A bottleneck threatened; if it were to be averted, a rapid expansion of the armor producing facilities of the Nation had to be achieved. Once that was accomplished, manufacturing and treatment procedures needed developing before armor could be brought up to modern requirements. In the cases of cast and light armor, work was in such a rudimentary stage that extensive development was required.



Armor manufacture required hydraulic presses exerting a 28,000,000-pound force.

The magnitude of the overall problem can hardly be expressed statistically, but a few figures can give some indication of the factors involved. A typical single plate of heavy armor, Class A (face-hardened), 17-inch gage, weighs approximately 133 short tons, with dimensions of 12 by 32 feet. Since the kind of equipment necessary for such heavy work has almost no commercial use, private manufacturers had neither the tools nor the skilled

labor for such a specialty. At least 6 months were required to produce the essential machinery. After tools were installed, the treatment of the plate required another 6 to 9 months to travel from design to the machined sheet needed by the builder. Despite its mass, which required hydraulic presses exerting a 28,000,000 pound force, the processes involved in finishing such a plate were delicate ones. Two kinds of steel were worked into one sheet. Each had to retain its own characteristics yet become a part of a single fused unit. The outside required hardness, the inside, toughness; treatment of one side had to be accomplished without affecting the other. A few careless minutes could ruin the labor of precious months. In the final product the hard face of forged armor was designed to break up the projectile and render it incapable of penetration. To prevent a shattering that would permit the projectile to pierce the sheet, the back of each piece required toughness and elasticity to disperse the terrific concussion taken by the hard face. Not alone the size, shape, and weight of each of the massive slabs, but even its metallurgical structure had to be determined with a precision completely out of character with the appearance of slabs so large and heavy that they required specially constructed flatcars for transportation.

The cost of such a piece ranged from \$550 to \$600 a long ton, largely because of the enormous expenditures required for its production. A Class B, or homogeneous, plate of similar size required 4 to 7 months for production and cost only \$100 less per long ton. And production of the plates by no means ended the complex process of armor procurement; before a group could be delivered, approximately 1 out of every 7 plates had to be shipped to the Naval Proving Ground at Dahlgren, Va., for ballistic testing. All too often the test results required that the plates be reprocessed through new and delaying heat treatments. If armor were withheld, building was crippled. In the case of a battleship, for instance, almost one-third of the total weight was accounted for by armor, the commodity which absorbed about one-fourth of the ordnance budget for such a vessel.

When the expansion program was ordered, one of the first steps of the Bureau was to provide for an increase in armor production. The Navy's own plant in South Charleston, W. Va., was not capable of independent production. Never completely finished, it had been inactive since the Naval Conference in 1922. Even its retention in that status represented something of a victory for the Bureau, which had been under prolonged pressure from Charles-

ton real estate men and some members of Congress to sell the equipment and let the property pass into private hands. Commercial armor production was in the hands of three companies: Midvale, Bethlehem Steel, and the Carnegie-Illinois Corp.—none of which had received a contract for battleship armor between 1922 and 1938. If they were to achieve a high level of production in forged armor, tremendous expenditures were demanded for the essential facilities.

Before those expenditures could be made, the Bureau of Ordnance had to clear an imposing political barrier. In order to protect Government expenditures, Congress had passed in 1934 a law known as the Vinson-Trammell Act, designed to limit profits made by private industry on Government contracts. The profit margin had been successively established at 12, 10, and finally, 8 percent of the contract price. While arrangements had been made to compensate for the cost of property acquired for a contract covered by the act, Treasury Department procedure had been to spread the period of amortization over the normal life of such equipment. Although the act served to secure lower prices for items procured, it was not conducive to vigorous competition for Navy contracts. On the contrary, the Bureau found the armor producers in the steel industry extremely reluctant to undertake contracts which would require the purchase of expensive tools with no future commercial value. Unless the contractor could be assured future work which would utilize his investment, the Treasury policy of amortization was considered unsatisfactory. Retarded by caution, disaffection, and the profit-limiting clauses of the Vinson-Trammell Act, the flow of private capital into armor producing plants was all too slow. The possibility of an armor bottleneck was a continuous threat.

Rear Admiral Furlong, Chief of the Bureau, led the fight to secure legislation more conducive to expansion on the part of private manufacturers. Beginning in 1938, a running battle of over 2 years duration was carried on before congressional committees and through voluminous correspondence with the Treasury Department. In the political realm the struggle had many ramifications; on more than one occasion the Bureau proposals were subject to misrepresentation. Some interpreted its position as simple opposition to the principle of the Vinson-Trammell Act. Secretary of the Treasury Morgenthau complained to President Roosevelt that the Bureau's statements were making it impossible for him to collect the excess profits as required by law. In the face of criticism, the Bureau worked to escape from an unfavorable buying



Rear Adm. William Rea Furlong.

position that threatened to retard armor expansion and ship production.

The policy of the Bureau went through several stages. Under Secretary of the Navy James Forrestal laid down the first premise of the Navy's position by declaring that he did not "as a matter of principle believe in the Government owning facilities in a private manufacturer's plant which might eventually lead to Government ownership and it would not make sense to the public to have large amounts of Government funds put into the plants of wealthy corporations." To operate within such a premise two alternatives were open to the Bureau: accomplish production through the Navy's facilities, or stimulate the flow of private capital into those three corporations with armor experience. The latter seemed the more logical choice, and although Government funds were required for equipment which manufacturers would not secure for themselves, ideas of public ownership of the facilities were not long considered. The South Charleston, W. Va., plant, especially valuable for the size of its furnaces and possession of the largest forge press in the Nation, was leased to the Carnegie-Illinois Steel Corp.

To stimulate private expansion further, the Bureau modified its policies according to circumstances. Admiral Furlong's first request was for the Treasury to clarify and publish its policies concerning amortization so that manufacturers could at least plan expansion. Since heavy capital outlays had to accompany acceptance of a contract, the Admiral desired an official ruling to guide contractors in writing off the cost of equipment used solely for a Navy contract. In the late summer of 1939 the Bureau won its first round. The Treasury Department issued a ruling which permitted contractors to figure the cost of equipment into the contract price on a short term basis. As a check against undue expenditures, the rapid amortization had to be justified by a certificate from the naval inspectors in each plant, showing that the new equipment was necessary to meet delivery dates demanded by the Government. This arrangement, reached by July 1939, was at least a partial answer to Admiral Furlong's early request to the Treasury, but the problem had grown to such proportions that further action was necessary.

Manufacturers were not yet happy. Under Bureau pressure a considerable expansion of armor capacity was achieved, but the accelerating program called for more. The industrialists were not satisfied with the wording of the Treasury directives, and the profit limiting clauses of the Vinson-Trammell Act still acted to retard expansion of facilities. Since all profits above the allowed percent-

age had to be turned into the Treasury, the tax policy tended to prevent accumulation of the surplus capital needed to absorb any portion of the cost of new equipment that had not been amortized by the end of the production period. The Chief of the Bureau had succeeded in clarifying the Government policy toward amortization, but the Treasury concessions were a case of "too little too late."

By August 1940, none of the armor companies had yet finished a contract for the Navy. If building schedules were to be maintained, a greater capacity would have to be developed. Just as armor threatened to become a bottleneck to ship construction, tax policies remained a bottleneck to armor production. On August 9, 1940, Assistant Secretary of the Navy Lewis Compton appealed to the House Ways and Means Committee for relief. He favored the outright repeal of the profit-limiting clauses of the Vinson-Trammell Act, pointing out that Congress could absorb profits through other tax policies. Climaxing the fight of Admiral Furlong, the appeal gained action.

Armor producers were partially reassured by a new statement of Treasury policy. Concerning the cost of new facilities, the ruling provided that when it was determined that "such facilities were used solely in the performance of the particular contract or subcontract, their entire and reasonable cost, less salvage value . . . [would] be generally accepted as part of the cost of performing the particular contract or subcontract." Even for cases where the equipment was not for the exclusive use of particular contracts, allowances were made for wear and obsolescence. A more important result of the Bureau's activity was the amortization law passed by Congress on October 8, 1940, as section 124 of the Internal Revenue Code. This act expanded and gave the force of law to the earlier Treasury ruling by providing for the deduction, for tax purposes, of the entire cost of a facility during the period of probable use for defense purposes. The period was set at 5 years, with a provision for shortening it should the emergency prove briefer than was expected. The law also substituted an excess profits tax for the profit-limiting arrangement of the Vinson-Trammell Act. Amortization was to be authorized through certificates issued by the Advisory Commission to the Council of National Defense and, for Bureau contracts, by the Secretary of the Navy. The obscurity and uncertainty that had plagued manufacturers seemed dissipated.

The Bureau's position was vastly improved by the new law, but still another political obstacle had to be hurdled. Brushing tech-

nicalities aside, a Department of Labor ruling placed Navy forged armor in the category of steel plate. The effect of such a ruling was to make the minimum wage law applicable to armor-producing plants. The Bureau was informed that it should stipulate in contract negotiations that the wage law be applied. Again the producers balked. One company even refused Navy contracts, pointing out that non-armor-producing plants in the steel industry escaped the wage provisions and gained a more favorable competitive position. Once more the Bureau was forced to seek relief through political channels by requesting that forged armor contracts be exempted from the law. Naval officers turned diplomat found solutions to this and other problems, but negotiations consumed valuable Bureau time and usually had to be worked out through persistent negotiations between interested offices and Government agencies. In no other way could the decks be cleared for the vital production of ever increasing armor needs.

As the Nation became better geared to the defense effort, additional machinery, such as the Office of War Mobilization, was created to iron out difficulties. The Bureau could not have waited for that. In answer to criticism of the Bureau's forwardness in championing the cause of armor production and establishing close contact with the interested companies, Admiral Blandy summed up the result with succinct comment: "If the existing service agencies such as this Bureau had not taken the bull by the horns in the beginning . . . but instead had waited for someone to form an Office of War Mobilization and then put the problem up to them, [we] would be eating nothing but fish and rice today, with damn little saki to go with it. We would also be wearing socks with the big toe separate, and clacking around the streets on 'geta'." The Bureau's success is expressed less entertainingly but with dramatic force in the story of accomplishments in armor production.

Early expansion ran concurrently with the Bureau's efforts to clear away the obstacles to all-out production. In August 1939, Congress passed a deficiency bill which made \$6,000,000 available to stimulate production at Carnegie-Illinois, Bethlehem, and Midvale steel companies. Seven months before Pearl Harbor that sum had grown to \$274,476,456 from Navy funds, plus \$19,418,379 obligated from Defense Aid funds. While these expenditures were not exclusively for ordnance work, the first contracts made with the Carnegie-Illinois Corp. provided for the expansion of the Homestead facilities and the rehabilitation of the Navy plant at South Charleston, W. Va., for integration with Homestead. By July 1940, the rehabilitation had been completed

at a cost of \$1,355,000. When the outbreak of war in Europe accelerated the shipbuilding program, two additional contracts were negotiated with Carnegie-Illinois for further expansion of facilities. The South Charleston-Homestead growth brought their capacity up to 1050 gross tons of battleship armor per month by 1940. When the second contracts were completed early in 1943, the rated potential of the two plants rose to 6700 gross tons a month. The integration of the Homestead and South Charleston plants was ultimately extended to include the Mingo plant and the rolling mill facilities of Lukens Steel Co., Coatesville, Pa. Steel was generally made at Homestead, then forged, heat treated, and machined at South Charleston. Variation of functions among the integrated plants permitted the flexibility necessary to adjust production schedules to need.

Expansion of facilities at Midvale and Bethlehem completed the story of phenomenal growth in the Nation's heavy armor potential. Assisted by the Navy, Midvale started expanding its facilities in 1941-42. The company itself contributed over \$1,000,000 to the project. By 1942 the Government had spent \$10,000,000 to augment the company's equipment, raising Midvale's rated capacity from 1200 to 4500 gross tons per month.

At Bethlehem, where \$6,000,000 worth of new armor equipment was swelled by almost \$46,000,000 in Government financed machinery for armor, gun forgings, and ship shafting, capacity increased from 1800 to 4500 gross tons of battleship armor per month. Thus between 1939 and 1942 the Nation's potential grew to 15,700 tons monthly.

The story of actual production during the war was the translation of that potential into nearly a half million tons of the armor needed to put a fleet to sea, repair battle damage, test projectiles and provide experimental armor for constant research on better defense. Viewed from any perspective, the accomplishment was a credit to all concerned. Despite early threats, armor production expanded in pace with shipbuilding and the dreaded bottleneck never developed. To maintain such a pace, most armor manufacturers kept their plants on a 24-hour day, 7-day-week schedule, throughout the war.

Though the production goal was realized, armor problems were far from ended. Even the finest new equipment could not compensate entirely for the dearth of experience in armor development. Difficulty was encountered in simultaneously maintaining the Navy's rigid ballistic specifications and shipbuilding schedules. When the first delivery of 17-inch armor was made in 1941, its

quality was below the standards demanded by current formulas. For the moment that disappointment led the Bureau to consider the possibility of substituting Class B armor, with its decreased production problems, for some uses of the heavier face-hardened armor. Despite the pressure of meeting schedules, the Bureau decided against the change—a decision vindicated by the gradual improvement of the Class A armor produced. For a while about 15 percent of the armor tested failed to meet ballistic standards. In some cases the armor was turned back for new treatments; in others, the quality was not low enough to justify the delay entailed by such procedure. As cooperation between industry and Ordnance increased, and as research developed within agencies of the Bureau, an appreciable raising of quality was achieved. A reduction of the number of physical and ballistic tests required was no index to the standards of the remaining tests, for research developments within the Bureau steadily pushed in the opposite direction.

The whole problem of research was enormously complicated by the same dormant period that had crippled the armor industry between 1922 and 1939. Fortunately, the Bureau had been foresighted enough to resume serious armor planning as early as 1933, but funds and facilities were restricted until late in the decade. Before the national emergency, for instance, the research activities of the Bureau were in the hands of two officers and three civilians. Within a month of the Pearl Harbor attack the personnel had grown to 43 officers and 282 civilians, backed by collaboration with universities and industry.

In the case of armor development, one of the first steps of the Bureau was to induce the three producers to pool their knowledge of the techniques required to make Class A armor. Beginning with the Bureau's overtures to the companies in 1933, each of the manufacturers turned out experimental plates ranging from 5 to 18 inches in gage. Results confirmed the Bureau's uneasiness about the state of armor knowledge in the United States. Numerous failures resulted during ballistic testing of both Class A and Class B armor. Investigation led to new production methods, changes in heat treatment and depth of chill, and alterations of alloy composition. Without this experimentation in the early 1930's, results in the early 40's would doubtless have been even more discouraging. Early development was stimulated by success in obtaining, through the Carnegie-Illinois Corp., two samples of the best homogeneous plate produced by the Krupp Works in Germany. While the Krupp license was never used for Ordnance

contracts, valuable information was gained through analysis of the imported plates. The result was a raising of the specifications for all armor.

Transposing knowledge from experimental research into actual production techniques has always been a problem. Between research and production existed a grey zone which much valuable knowledge failed to penetrate in usable form. To bridge that zone and establish better liaison between producers and research, an Armor Steering Committee was created in August 1938. Presided over by the Ordnance Experimental Officer, and including representatives of the principal manufacturers, the group proved a potent force in finding solutions to problems of armor development and then applying those solutions to production.

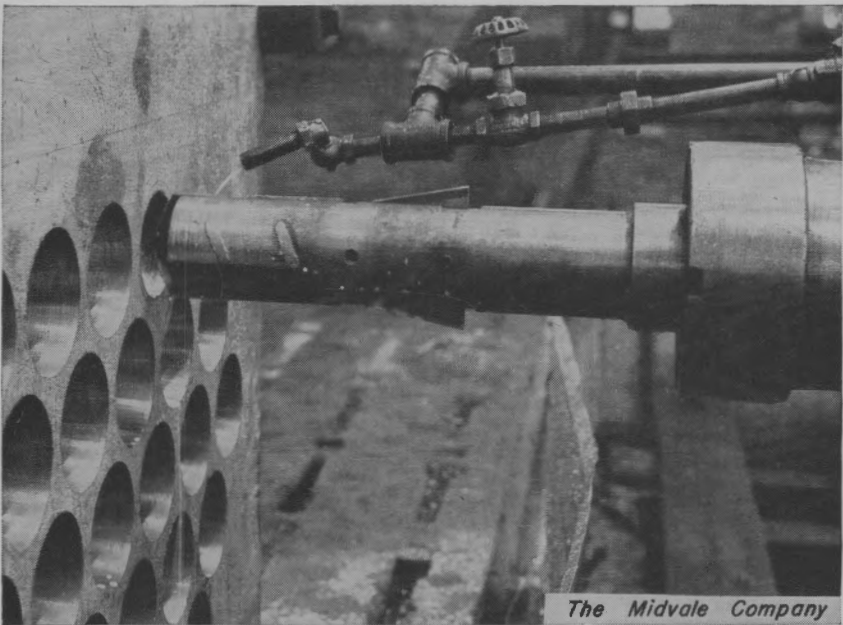
After the national emergency and war intensified its problems, the committee often branched out to include representatives from the Bureau of Ships, the Naval Proving Ground, Army Ordnance, Naval Material Inspectors, the War Production Board, and the Research Laboratory. Through its activities a real coordination of effort was achieved; at its sessions the principle of pooling knowledge became a reality. Normally jealous manufacturers sent metallurgists who discussed freely their once private discoveries. Results of individual experimentation were publicized and duplication of effort, repetition of mistakes were avoided. Out of such discussions came further changes in the depth of chill and fiber structure of armor plates. The War Department especially benefited, since the development and production of forged armor were largely Navy controlled.

With the production problem under control by 1943, the Bureau was able to intensify these earlier efforts to stimulate research activities. Again the Armor Steering Committee performed valuable service in fostering and directing the new program. Novel ideas in alloy composition and heat treatment, developed in laboratories and tested on the proving grounds, were pushed into production techniques. The use of critical materials, especially nickel, was reduced, and in conjunction with Bethlehem Steel, a radiant heat treatment for the final hardening of Class A armor was introduced. Committee efforts then led to the development of notch tests of fiber structure which could be incorporated into the manufacturing procedures before armor was ever submitted for ballistic tests.

Another major concern was planning for the BB 67-71 class of ships. Armor specifications called for a gage never before produced in the United States and one which promised to tax existing

equipment to its limit. While the plans were later cancelled, the project necessitated an experimental program to produce satisfactory forged armor of that thickness. For Class B armor, improved welding techniques were invented and experiments with high carbon content steel promised an improvement in the quality of plates delivered to shipyards. Out of all this activity came concrete evidence of success; the trend in armor ballistic quality moved upward so steadily that the test tables were stiffened for all gages up to 8-inch. Both homogeneous and face-hardened armor benefited, with the most marked improvement occurring in the projectile breaking characteristics of cruiser side belt and barbette armor.

Concurrently with developments in heavy armor, the Bureau of Ordnance undertook an extensive program of experimentation with cast varieties. Both construction and ordnance requirements often called for such intricate design that the use of homogeneous plate was almost impossible. In other cases, time schedules stimulated the search for means of substituting a foundry product for the more slowly produced plates of Class B armor. As early as 1930 such possibilities were under consideration; by 1938 the Bureau had launched an intensive search for steel castings that would



The Midvale Company

The drilling process required to make armored grating stimulated the development of cast armor.

approach the ballistic quality of armor. Within 2 years a measure of success was achieved as a result of experiments directed by Comdr. G. D. Linke, then Inspector of Naval Material at Bethlehem, Pa. From overseas, too, came valuable aid. The French had already made considerable progress in developing cast armor techniques and their experience was made available to the United States. Tentative specifications for cast armor were promulgated in the summer of 1940. By September, tests showed that cast armor could be brought within range of the ballistic quality of forged armor. Plans were made to adopt the new product for use as armored gratings in uptakes, an especially costly piece because forged armor had to be finished through a delaying hole-drilling process. Other projected uses were for sight and range-finder hoods.

The plan for armored grating ultimately had to be abandoned. No widespread interest in its possibilities was evidenced by private manufacturers, and of the 10 foundries which were induced to produce samples, only 4 companies received contracts. Blaw-Knox Co., General Steel Castings Corp., Continental Roll & Steel Foundry Co., and American Steel Foundries each turned out small orders for the Navy. Early hopes were dashed. The results of ballistic tests were so disappointing that the program was dropped and attention turned to other possible uses for cast armor.

Better results attended the program to produce castings for rangefinder and sight hoods. While the tests proved the need for further improvements, the ballistic results were encouraging enough to warrant further experiments. Production technique, chemical composition, and heat treatment were all receiving study when our entry into war gave renewed importance to the program. Manufacturers found that the chief trouble lay in pouring a sound casting. The numerous difficulties involved in the operation often produced voids and defects which only radiographic inspection could detect. Some defects were exposed only when the casting was ready for machining. While repairs could sometimes be made by removing the defective portion and rebuilding the section by weldments, a reduction of the ballistic quality sometimes meant scrapping the entire piece. Other production problems grew out of the inherent toughness of castings. Special techniques, usually developed empirically, had to be worked out for both machining and welding the raw armor.

The need for an integrated research program to coordinate work on the production and ballistic problems was recognized by the Bureau, and again the Armor Steering Committee was called on for

direction. In December 1942, new specifications for cast armor were written, and between May and December 1943, contracts for experimental castings were let to the Union Steel Casting Division of Blaw-Knox Co. and the General Steel Castings Corp. The objective of the experiments was to raise the ballistic quality to the standards required of heavy forged armor of 3-inch, 6-inch, and 8-inch gage. Early progress in that direction was overshadowed by the success of Union Steel Castings in raising the ballistic quality of one 6-inch cast plate to higher standards than were usually obtained from forged armor plate of the same gage. That achievement was made in October 1945, when the company employed a new method to kill steel in the ladle prior to casting. Thus, the immediate postwar period found the Bureau engaged in attempts to duplicate the tardy success and apply the new formula to plates of 8-inch thickness.

While the crowning success in raising the quality of castings came too late for service in World War II, considerable wartime use was found for the cheaper product. In addition to proving satisfactory for sight and rangefinder hoods, doors, and covers, castings were used for gun shield and turret installations. Approximately 5,350,000 pounds were produced for service items, plus the considerable quantities manufactured for experimental purposes. The entire output was drawn from private sources, since the ability of commercial plants to meet service requirements precluded the necessity for naval production facilities. At war's end, the two contracting companies were working with Army and Navy Ordnance to achieve ballistic standards acceptable to both services. With curves and intricate designs hard to produce in forged armor, continued success in raising ballistic standards could insure cast armor a more important place in the future of Navy Ordnance.

Paralleling developments in castings were significant advances in light armor, a classification generally given to all protective plates less than 1¼-inch thick. World War I experience had produced a demand for this new type, but early experiments had given discouraging results. All attempts to face-harden thin sheets failed during the interwar period, so the revival of shipbuilding in 1939 found light armor confined to homogeneous plates and in a rudimentary stage of development. While the Bureau conducted experiments with many expensive steels—high silicon, high manganese, vanadium, zirconium, cobalt, chrome, and nickel alloys—the desired balance between defensive strength and good ductility proved elusive. World War II, with its new emphasis

on airplanes and light amphibious craft, increased the demand for the development and procurement of light armor. Not only were those specific needs met, but by the end of the war new demands were answered with varieties of light armor that included face-hardened steel, bullet-resisting glass, and plastic body armor of a type that later gained high repute in Korea. Of no mean importance among the uses of light armor was the development by the Bureau of Ordnance of a talker's helmet late in 1941—an item which despite heavy use and wide distribution was never once the subject of a complaint to the Bureau. Use was also found for light homogeneous plate on single and twin mounts and main and secondary battery directors. Light face-hardened plate, revolutionized in the course of the war, was used on small caliber gun mounts.

As uses for light armor broadened, the research and procurement problems within the Bureau naturally increased. Even though nine manufacturers accepted contracts for light armor, the Bureau was hard pressed to develop sources of dependable ballistic quality and keep up with pressing shipbuilding schedules at the same time. Two Ordnance agencies, the Armor and Projectile Laboratory and the Light Armor Battery, received responsibility for the program. Located at the Naval Proving Ground, Dahlgren, they were well situated to study the quality of each shipment and disseminate among the armor manufacturers the information gained from their study.

For liaison work with industry, the Armor and Projectile Laboratory was especially important. Organized in the summer of 1941, it was quick to justify its existence. When manufacturers ran into the production problems common to a new field, the Laboratory would survey their methods, find their errors, and work out superior techniques for individual plants. By continual observation and close contact with the producers, the Laboratory was able to identify the companies which maintained the best productive and quality records, thus guiding the Bureau in its contract negotiations. The result was a smooth flow of high grade armor. Some of the work of the Armor and Projectile Laboratory led to improvements in heavy as well as light armor. The metallurgical characteristics required for maximum penetration resistance, for instance, were determined for both types of armor. In the case of face-hardened armor, whatever its weight, research led to more precise specifications as to surface hardness, face depth, and back properties. For homogeneous plates the variations in the relationship of optimum plate characteristics could be specified for almost any projected use.

The work of the Armor and Projectile Laboratory was supplemented by that of the Light Armor Battery, which had responsibility for acceptance testing at the Proving Ground. The Battery expanded in response to the increased uses for light armor and, in addition to its routine work, undertook experiments which initiated new developments in armor. In conjunction with the Laboratory, an imposing number of fruitful experiments were conducted. Tests were conducted at the Proving Ground that demonstrated the effect of the various processing variables on ballistic performance. Out of theory and practice came new uses for an improved quality of light armor.

From private sources, too, came new discoveries relating to development and production. One of the more important innovations was the new technique for making light, face-hardened armor, worked out in 1942 by the Allegheny Ludlum Steel Corp. Outdating the carburized steel which had formerly been the sole base for such armor plate, the corporation produced a composite armor named Pluramelt, which consisted of a hard face fused to a softer back. Ultimately, the composition gave new promise to the manufacture of light face-hardened armor, though tough problems had to be licked first. An even distribution of the two materials was hard to secure throughout a plate. Sheets presented to the Proving Ground might be almost impenetrable at one spot, yet easily pierced a few inches away. New records for ballistic quality were set at one moment, while sheets from the same group would have to be rejected in the next. Close cooperation between the company and the research laboratory at the Proving Ground finally solved the problem of producing a uniform and predictable quality in Pluramelt. By late 1944, the new type armor had exceeded the ballistic limits of carburized plate in three-eighths and one-half inch gage and was being made experimentally in thicknesses up to one inch.

Success in developing light armors of superior ballistic quality gave the Navy versatile new defensive materials. While the Bureau of Aeronautics was perhaps most interested in the production of armor which could give the greatest protection at the least cost in weight, that characteristic was demanded of all armor produced by Ordnance. As lighter varieties were developed, additional protection was made available at points that weight had made prohibitive before.

After the Bureau of Ordnance mastered the initial problem of securing production for new construction and assuring modernization of all armor types, attention was turned to the problem of

maintaining the fleet then being put to sea. Special problems are inherent in armor supply since plates are unique among ordnance equipment in being tailored by number for specific ships. No supply of spare armor was available, so needs were met by diverting plates from new ship construction to fleet maintenance. Where specific needs could not be met through those channels, as much as 9 months might be necessary for securing the armor ordered. Once production success was assured, however, more expeditious machinery was created for maintenance.

In December 1943 a new plan was adopted. Drawings of all ships in action were obtained and indexed, permitting a quick determination of the thickness and class of armor needed for any ship requirement, and a procurement program was initiated to provide replacement of 1 to 2 percent of the total amount of armor plate afloat. The spares obtained were designed for maximum interchangeability. Almost any order could be filled within 2 to 4 weeks after it was received. Storage facilities for such an extensive spare program posed a final problem, but the Naval Proving Ground, Arco, Idaho, and the plant at South Charleston, W. Va., were able to serve the two coasts. Postwar planning provided for finishing facilities at each of the two storage depots. In addition to providing repair for battle damage, the maintenance program enabled older ships to profit from the developments which accompanied the tremendous wartime expansion of the United States armor industry.

That expansion was in itself one of the most significant achievements of the Bureau of Ordnance. While cooperation within the Government and between industry and the service agencies was hard won, it formed the basis of the Bureau's success. Between the dormant armor industry of 1938 and the requirements of the world's largest fleet in 1945 lay profit conscious industrialists, tax conscious Congressmen, budget restrictions, and a technical lag of almost two decades. Nonetheless, neither the continual acceleration of shipbuilding schedules nor the constant self-imposed demands for higher ballistic standards were sufficient to create a gap between armor demands and armor supply. And postwar tests on captured German and Japanese armor showed that quantity was not gained at the expense of quality. Comparison proved that the United States armor was often superior and never inferior to that of the enemy.

Chapter 4

PROJECTILES

EVER since man has been fighting his enemies at ranges greater than arm's length, projectiles of one sort or another have been the staple of fighting forces, whether on land or at sea. Many of the models developed before the advent of explosives had a remarkable resemblance to modern projectiles; the quarrel thrown by a crossbow, for instance, was based on the design considerations that characterize a contemporary armor-piercing projectile and proved capable of penetrating the best mail of the Feudal Age. But not until the invention of guns in the fourteenth century did the real history of projectiles begin. For a short while matters seemed to retrogress. While some fourteenth century shot reached a 25-inch caliber and weighed 700 pounds, the long streamlined projectiles of the crossbow had to give way to giant stone balls. Two centuries of progress saw stone give way to iron and solid shot give way to hollow shells, but no really significant advance was made in projectile design until the nineteenth century.

Rifling was first added to cannon in 1854. Almost immediately the design of projectiles was revolutionized. Rotation of shot permitted, even demanded, elongation of the shells. Byproducts were numerous: velocity, accuracy, range, and penetrative ability were improved, and the mass which any given gun could accommodate was increased. Before the century was out the new designs were highly developed. The power of guns and the efficiency of the rotative mechanism were successively improved, producing corresponding increases in the relative length of projectiles. When the century closed with the Spanish American War, United States projectiles were often 2.5 to 3.0 calibers long. Two decades later, in World War I, length had increased to the point where the longest shells of the preceding war were considered short and projectiles 3.5 calibers long were considered standard.

The appearance of the modern projectile is the result of those long years of development and the recognition of basic principles of shell design. Though projectiles have a short life of service, the care given their design and construction must be out of all proportion to their longevity. The slightest deviation from exact-

ing tolerances might produce unpredictable range characteristics or transform the desired rotation into a crazy tumble. While projectiles vary widely according to intended use, most naval shells are designed primarily as vehicles for carrying explosives to an enemy, secondarily to provide metal fragments to extend the force of the explosion.

The modern form of the deadly vehicle resulted from attempts to reconcile opposing requirements. Good flight characteristics required that the center of gravity be placed near the center of the projectile, yet good piercing qualities demanded a blunt, heavy nose that concentrated metal in the forward end of the shell. Out of the reconciliation of the desirable but apparently incompatible factors came the light nose pieces, windshields, or false ogives that have dictated the external shape common to many service projectiles.

But while all projectiles share the same problem of flight, the similarity of function and appearance stops there. The demands of modern naval warfare have led to the development of widely dissimilar projectiles. The heavy armor carried by many ships required the design of projectiles capable of penetrating the protective belt without exploding, yet able to produce a destructive detonation inside the enemy ship. Even though the same shell designed to penetrate face-hardened armor could be used against lighter plate, the price of such convenience and uniformity would be a sacrifice of the explosive content a thinner skin could afford. Thus, the so-called common projectiles, with a more destructive ratio between shell and explosive weight, were designed. Still other service needs, such as a weapon for use against personnel, aircraft, and unarmored targets, permitted an even greater gain in explosive weight at the expense of shell thickness, and resulted in thin-walled, high capacity projectiles. Before the attack on Pearl Harbor the Bureau furnished the Navy with many shells that were inherently high capacity, but the ultimate development of the type was a wartime phenomenon and represented one of the greatest achievements of Navy Ordnance. A multitude of less used varieties, such as shells for line throwing, target practice, proof work, and illumination occupied an important place in the Navy's arsenal, but the burden of war was borne by the three main service types—armor-piercing, common, and high capacity.

The relatively late development of heavily armored naval vessels precludes a long history for AP projectiles. During the Civil War, when such ships made their appearance, piercing the protec-

tive belts with shells that could explode on the inside seemed less hopeful than smashing a solid shot against the side of the ship and depending on splinters from the shattered metal to spread the destructive force of impact. Rifling, invented just before that conflict, administered the death blow to a technique better suited for smashing medieval fortresses than modern battleships, but a new variation of the smashing idea soon gained currency. The invention of high explosives led to the theory that a detonation against the side of a ship would cave in the plates and destroy the area behind. Later, the development of modern face-hardened armor, almost impervious to surface impact, confined the smashing technique to small enclosures such as turrets and conning towers, and stimulated the search that led to the design of true armor-piercing projectiles.

The first problem was to find a metal with the requisite ballistic qualities. After experiments with cast and chilled iron failed to show sufficient promise, the Navy imported from France the techniques for producing a forged high carbon, nickel-chrome, crucible steel projectile well adapted for armor piercing. During the last decade of the nineteenth century the missile was improved by the



An assembled 16-inch projectile standing beside a body and cap. Addition of a windshield made the 2700-pound weapon taller than the man with calipers.

addition of a cap. Originally just a wrought iron jacket fitted over the nose to increase the penetrative ability of the projectile, the cap evolved into a high quality steel device with but little less carbon and chrome than the body of the projectile itself. The addition of a cap permitted the successful use of armor-piercing projectiles at greater angles of obliquity than was possible before. In other ways, too, the development of a cap represented a significant advance in projectile design. Through impact, it weakened the attacked surface, making penetration of the nose easier, then provided support for the body of the projectile as it passed through the armor.

To withstand the shock of piercing armor and still remain in bursting condition, the body of the projectile is necessarily a massive piece of steel with a small cavity for explosive filler. Bureau designers were faced with an interminable search for just the proper balance between weight of explosives and mass of steel. Too much filler reduced the penetrative power of the projectile; too little destroyed effectiveness by reducing the final fragmentation of the projectile. During the experimental period between the two world wars, explosive charges generally varied from 2.1 percent to 2.6 percent of the total weight of the projectiles, but even before the attack on Pearl Harbor a trend developed in favor of heavier projectiles with as little as 1 percent of the weight accounted for in explosives. Just as shells became heavier, the Bureau began to produce armor piercers in smaller calibers. Originally made only for 16-inch and 14-inch guns, they were finally extended to include even 3-inch—an extreme made necessary when Germany built submarines with two inches of armor plate protecting the conning towers.

Early in the war the AP projectiles furnished by the Bureau of Ordnance came under attack by those who had to use them. Suspicion as to their effectiveness stemmed from the naval action at Casablanca on November 8, 1942, when the very success of the amphibious landing seemed to depend on securing the North African port for unloading operations in support of the troops put ashore at Fedhala. One of the main obstacles was the French battleship *Jean Bart*. Though incompleated and confined to her berth, the ship's 15-inch guns served as a formidable shore battery for the port; even the landing beaches to the northeast were not safely out of their range. Supported by the cruiser *Tuscaloosa*, the *U. S. S. Massachusetts* described a giant figure 8 offshore while she searched out the *Jean Bart* at her dock with salvos of 16-inch AP projectiles. Five of the 2700-pound shells found their mark

and silenced the enemy for several hours. The ship's effectiveness was presumed destroyed since the French cannily left the barrels unremoved even after the damage was repaired. Angry evidence to the contrary, presented 2 days later when the *Jean Bart* drenched the bridge of the *Augusta* with the splash from a near miss, demanded a new aerial attack on the enemy and created an aura of suspicion around the *Massachusetts'* ammunition. A feeling of doubt was intensified by the results of the battleship's bombardment of French coastal guns during the same engagement. Lacking high capacity alternates, the *Massachusetts* used 16-inch AP projectiles for shore bombardment. While enemy gunners were temporarily driven from their positions, nothing but a direct hit on an emplacement was capable of silencing the giant guns. As near misses plowed into the soil, evidence of their potency was small.

Naval observers were disgruntled. Examining the area after the battle ended, they reported evidence of defective ammunition. Small craters following a dirt impact and apparent failure of projectiles to detonate after striking the French battleship were offered to support their contentions. Scanty evidence was multiplied by rumors and Washington was soon astir. From the President down, investigations were demanded. According to Admiral Blandy, the lines of a familiar song were changed to "Praise the Lord and damn the ammunition." The Bureau needed no prodding, and though Admiral King directed a study by the Inspector General of the Navy, two ordnance officers were sent to the scene to report their observations directly to the Bureau. French cooperation enabled a detailed examination which more than duplicated the original investigation by the forces afloat. Rumors were soon set straight. The real problem was found to be not defective ordnance but inexperience on the part of the original critical reporters. Of low order detonations, a favorite topic of rumors throughout the war, no evidence was found. Large shell fragments and the absence of craters, taken by observers to mean inadequate explosion, were in fact normal performance for AP projectiles. With a small cavity for filler, AP shells naturally had less fragmentation than common or high capacity projectiles; burying deeply into the ground before exploding, they left small evidence of their potency.

Of the 5 hits on the *Jean Bart*, 2 pierced the protective deck and detonated properly—1 in an empty magazine and the other in the steering engine room—1 encountered only light plate and passed through the ship before exploding by normal fuze action,

I was rendered inert by the side slap of a glancing blow, and the last hit at such a high angle of obliquity that it bounded off into the city streets. Ironically, it was the last that temporarily immobilized the only functioning main turret before glancing off to become game for souvenir hunters. The *Jean Bart* soon fought again, but not because of unsatisfactory United States projectiles. Performance was normal. Surveying the whole operation, the Bureau reported that duds were below the expected 10 percent, and a cause célèbre ended with confidence generally restored in an important weapon. Such criticism as continued to drift into the Bureau was answered during the course of the war by continual improvements to projectiles. Testing became more severe than ever and, since the armor plates against which projectiles had to be proved were improved ballistically as the war progressed, shells had to keep pace with progress to gain acceptance. The keen competition between armor and projectiles was a source of profit to both types of ordnance. Projectile manufacturers accepted the challenge and the seesaw battle continued through the war.

Projectile manufacturers were in a peculiarly good position to cooperate in the process. Armor piercers were made by three steel companies—Crucible, Midvale, and Bethlehem. Two of them turned out heavy armor for the Bureau; all were veterans in the projectile business and possessed the know-how to direct the complicated techniques required in the production of AP ammunition. Moreover, the three companies were experienced in projectile design, since the Bureau rarely stipulated the details of construction. Normal procedure was for the Research Division to put out a requisition drawing to serve as a guide for a final design. Working within the framework established by the Bureau, the manufacturer then produced a preliminary design for discussion at a Bureau conference. There the details of heat treatment, cap weight, and similar problems were considered. Once tentatively approved, the design was sent back to the Research Division for a final check on the myriad of factors that might make the difference between an effective armor piercer and a mediocre weapon. After years of working with such a procedure, the manufacturers were in a position to take the initiative in improving their ordnance products.

Some of the improvements made during the course of the war were obvious enough: weights were increased with no range loss, caps were more dependably secured to projectiles, and the shape of noses was changed. Just as important, however, were changes

in the ballistic quality of the shells resulting from refinements in the manufacturing techniques. From the selection of raw materials to the completion of projectiles and putting them in store, the processes were complicated ones. Fine steel was a prerequisite for good projectiles, so every item necessary for manufacture was carefully selected. Choice coal, blended according to fields of origin, was washed and selected to secure a coke which would produce the minimum of ash and sulphur. Then, a high basicity, low sulphur and silica limestone was mixed in a blast furnace with blended ores to produce a high quality iron.

The care given to the selection of raw materials was intensified in the subsequent steps. While each manufacturer used his own methods, the basic steps were the same for all. The projectiles were first forged and annealed, then rough machined to approximate size. A series of heat treatments followed, during which the shells moved from furnace to oil baths until the grain structure of the steel was considered right. After being turned to the specified dimensions, the projectiles then went through further heat treatments designed to produce the proper hardness. Between baths in molten lead and rinses in cold water, manufacturers produced steel that could withstand the terrific shock of impact. In that respect, the specifications for armor-piercing projectiles were more demanding than for any other ammunition. Finally, the base of the projectiles was tempered until the finished product resembled the structure of face-hardened armor. The hard head was designed to smash through the enemy's steel, while the tough rear could furnish support and stand the strain of an angle impact. By continual experimentation with the stages of heat treatment and variations in the hardness patterns of steel, ballistic quality moved upward. Competition between producers helped on the one hand, while on the other the wartime exchange of information between companies who once guarded every production secret allowed the Bureau to exploit industrial knowledge.

However much the manufacture of projectiles might vary from plant to plant, the inspection and testing of all went through a similar rigid pattern. After the heat treatment and rough machining of a lot of projectiles, contractors furnished the Navy inspector 500 bodies and as many caps. From those the inspector selected three projectiles for final machining, assembling, and testing. If the three met ballistic requirements by penetrating armor plate while remaining in bursting condition, the balance were finished and delivered; otherwise, they had to be retreated or abandoned. From every fifth lot the inspector selected six projectiles

for flight tests, and from the first lot of every contract one shell was subjected to fragmentation studies. Procedures were generally similar for common and high capacity projectiles. From industrial cooperation and Bureau checking, the fleet received projectiles with a failure rate considerably below the percentage considered inevitable under conditions that combined mass production with meticulous manufacture.

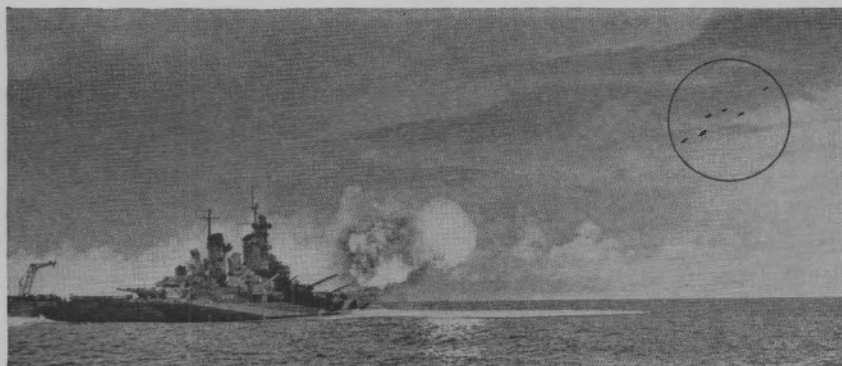
Although procurement of AP projectiles often required 6 months from the time the steel was poured until the shells were actually delivered, the program posed fewer problems than the production of other ammunition. Bolstered by Government financed facilities, the three companies were able to meet Bureau demands. While needs fluctuated with the course of the war, AP production was not subject to the spectacular increases that attended other programs. Ship to ship action, the forte of armor piercers, declined with the advent of a new kind of naval warfare, and vessels needed projectiles designed for shore bombardment. The change emphasized logistics. Preparation for amphibious support led ships to increase their quota of high capacity ammunition. Magazine space being limited, armor-piercing projectiles could not be carried in former proportions. Yet, if the Navy was to be ready for ship to ship action when the occasions arose, the proper ammunition had to be readily available. The problem was one of distribution and the answer was found by building up stores at forward areas. The steady movement of the fleet across the Pacific demanded the constant creation of new supplies, so that production of AP ammunition was geared to logistics rather than to muzzle expenditures.

The ammunition that edged armor piercers out of wartime magazines constituted the most significant development in the projectile field. When requested for an official definition of the new type, Admiral Hussey described high capacity shells as "that type of naval ammunition with a relatively large amount of explosive, compared to armor-piercing, designed primarily for bombardment of shore positions, for antiaircraft fire, and for fire against light vessels."

The genre was not entirely new. Prior to the declaration of a national emergency in 1939, the Bureau furnished the fleet with several projectile types with steel envelopes just strong enough to stand the shock of firing. The sacrifice of shell strength permitted a large cavity for explosive and created a high capacity projectile especially suited for antiaircraft and double-purpose guns. The filler often ranged from 7 to 14 percent of the total

weight of the missile and, for guns with a low muzzle velocity, the charge was sometimes one-fourth the weight of the projectile. Generally spoken of as thin-walled, the type constituted a minor portion of Bureau procurement. High capacity projectiles as such were not in existence or under development until late 1941. The nearest thing to them were the thin-walled bombardment projectiles left over from World War I.

Amphibious warfare produced a revolutionary change in emphasis. Softening up beaches and the support of troops during the vulnerable landing period required extensive shore bombardment. When the Chief of Naval Operations first called for projectiles to be used against shore installations, the Bureau answered with the revamped bombardment shells from the old World War I railroad battery. As an expedient, the projectiles were acceptable, but increasing emphasis on the type demanded that the Bureau meet tactical and strategic needs with a new program. The gap was not long in being filled. When the American armada sailed for the shore of North Africa in the fall of 1942, 6- and 8-inch high capacity projectiles occupied an important place in the magazines of some supporting ships. They proved their worth in silencing the enemy at Fedhala, just as the *Massachusetts*' experience proved the futility of using armor piercers for shore bombardment. Within another year high capacity ammunition was available in all calibers from 3- to 16-inch, though the inherently high capacity shells like the 5-inch common and AAC and the 3-inch AA were never designated HC. Use of the new weapon spread as rapidly as overworked production lines could furnish them. Between Pearl Harbor and Normandy, the Navy hurled 40,000 tons of HC projectiles at the enemy, as compared



Six 16-inch projectiles in flight. Between Pearl Harbor and Normandy, the Navy hurled 40,000 tons of high capacity projectile at the enemy.

with the 547 tons fired in naval bombardment throughout the whole of World War I.

The potency of the new projectiles was due to more than the extra explosive filler made possible by a thin skin. In the search for a versatile projectile that the fleet could use against widely varying conditions, the Bureau inaugurated a series of experiments with various Army and Navy fuzes. Among other important innovations, these tests proved that the Army point detonating fuze could be used successfully with one of the Navy auxiliary detonating fuzes, and another way to added versatility was clear. From some quarters the Bureau encountered opposition to the idea of providing interchangeable fuzes for each projectile, but the prospects of a triple-threat weapon outweighed considerations of inconvenience. Soon, projectiles were designed to receive a base fuze and, if required, could take either a point detonating fuze or a mechanical time fuze in lieu of a dummy nose plug. The result was a projectile that could be used against shore objectives, lightly armored surface craft, torpedo planes, or other forms of air attack. Even within the one category of shore bombardment, new effectiveness was gained by the novel fuzing technique. Where beach objectives were considered "soft"—hangars, dispersed aircraft, personnel—the point detonating fuze made the HC projectiles especially destructive; when "hard" objectives were encountered, the same ammunition was effective when equipped with a steel nose plug and a base fuze. Once this versatility proved itself in battle, opposition to changing fuzes aboard ship turned to enthusiasm.

Without the development of high capacity, triple-threat projectiles, the task of capturing a chain of islands leading to the enemy homeland would have been even more costly. The story of the weapons' value is told well by expenditure figures that grew as rapidly as production permitted. During the invasion of Kwajalein Atoll, Marshall Islands, in the opening month of 1944, naval support vessels lightened the task of soldiers and marines by a preliminary battering of the beach with over 30,000 rounds of high capacity ammunition. The expenditure of some \$10,000,000 worth of projectiles proved cheap, for personnel losses were only one-twelfth the total claimed by Tarawa. Six months later, at Saipan, 138,391 rounds helped rout the enemy and set a record for Navy bombardment. The record was short-lived. The Saipan total was topped in February 1945 by the 181,600 rounds of high capacity projectiles hurled ashore at Iwo Jima, then dwarfed by the more than 504,785 rounds used in naval gunfire support during the Okinawa operation of April 1945.

No other projectiles could approach the high capacity in effectiveness for amphibious support. The effect on personnel of detonating large quantities of high explosives on the beach was one of demoralization and an intense shock that frequently produced instant death. Fragments, carried by the high explosive content of the shells, created a rectangle of destruction whose dimensions grew steadily with the caliber of ships' guns. A 5-inch shell, for instance, spread fragments for 12 yards along its line of flight and threw them 35 yards on each side of its course. For a 6-inch projectile the deadly rectangle was 20 by 120 yards; an 8-inch shell spewed fragments 120 yards in every direction for 40 yards along its line of flight. And so on up the caliber range the potency of the projectiles grew.

Even when hiding in the concrete emplacements common to Japanese held islands, the enemy was not safe from the onslaught. The contrary seemed true at Tarawa, where the pill boxes appeared almost invulnerable, but the Bureau worked closely with the fleet to countermeasure such fortifications. Ordnance officers were sent to Tarawa to investigate the problem first hand. They studied the defenses, then returned to help prepare exact duplicates of the Japanese emplacements. Through successive experiments with the models, the Bureau tailored projectiles for the particular tactical problem. New nose plugs were added to increase the penetrative power of the projectiles, and fuzes were provided with enough delay to permit the shells to break through the fortifications before exploding. The solution came in time for the next Pacific operation, where casualties were only one-fifth the toll of Tarawa.

Nothing could make a landing easy in the face of a stubborn enemy, but high capacity ammunition did make them possible. Landing force appreciation of the effectiveness of naval gunfire support was humorously caught in a wartime cartoon showing a troop-laden LCVP heading for an enemy beach. Over the din of bombardment went the officer's plea on the walkie-talkie; "Enough, Admiral! Leave us something to land on." More realistic but hardly less complimentary was the combat description of an enemy island by a Marine officer who wrote that "the entire island looked as if it had been picked up to 20,000 feet . . . then dropped."

The conception and design of projectiles and fuzes that could play such a vital part in amphibious victories was less than half the Bureau's problem in the high capacity program. Supplying the thousands of tons of precision made shells imposed a pro-



The aftermath of shore bombardment.

curement problem which severely taxed the Bureau of Ordnance and the already overburdened American industry. The three veteran projectile manufacturers were able to fit enough new contracts into their production schedules to remain the only sources of major caliber projectiles, but the entire program could not be carried by plants already busy with ordnance contracts. Extending production into new factories required the mobilization of two vital and rare commodities—facilities and know-how. The latter could be imparted by industrial cooperation and the instructive work of the Armor and Projectile Laboratory. The dangers inherent in the lack of it could be guarded against by cautious inspectors. But facilities were another matter. From every direction the machine tool industry was being pressed for deliveries. Draw benches and hydraulic presses, essential tools for projectile manufacture, were almost unobtainable.

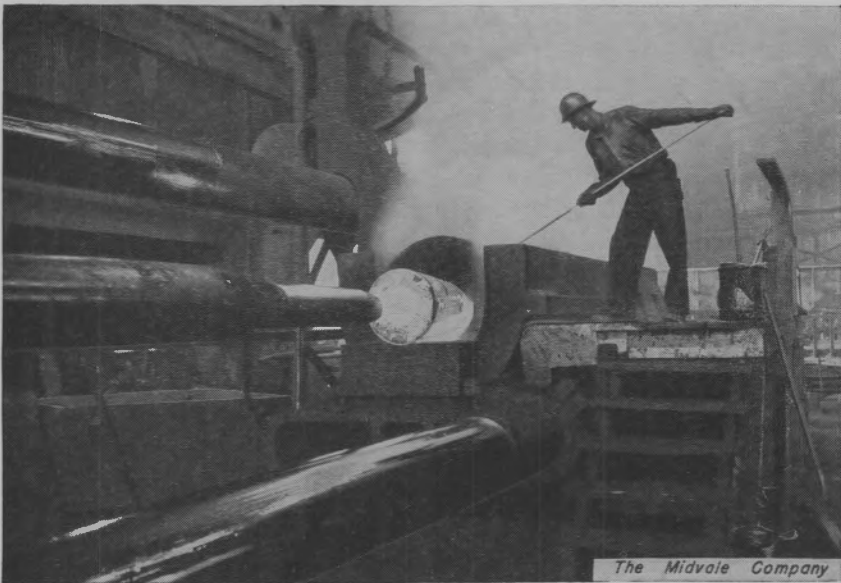
Critical at the outset, the problem grew with the progress of the war. By the spring of 1942, the need for great quantities of high capacity ammunition was foreseen by the Bureau. Requirement directives raised production goals higher and higher as the months passed, until the final demands represented an increase of 3000 percent over initial orders. To fill such orders and turn astronomical figures into projectiles on board, the Bureau searched out the Nation's machine tools, spent millions of dollars supplementing them whenever tools could be bought, and spread its high capacity orders over 15 manufacturers, most of whom were peacetime producers of heavy goods.

Early in the program, invaluable aid came from an unexpected source. In 1940, an American firm built a quantity of bomb manufacturing equipment for the Romanian Government. The vital tools got as far as the docks, then were halted in their progress overseas by the interruption of war. In the face of a world wide shortage of machine tools, such vital equipment was not without prospective buyers, yet the tools seemed destined to sit out a war at dockside. The high bidder for Romania's loss was a Netherlands' company doing business in the Orient, but the firm was only able to shift the machinery from one coast to another before wartime restrictions blocked that purchase as well as the first. By condemnation proceedings the equipment could be made available to the United States Government, but steel company engineers informed the Bureau of Ordnance that the machinery could never be adapted to American manufacturing processes. Later, when the high capacity program required a scraping of the tool barrel, the Bureau turned again to the rusting equipment.

This time the National Tube Co., Pittsburgh, accepted a challenge and moved the machinery into its plants. Before the end of 1942, the condemned tools were making a material contribution to the high capacity schedule. That the search for machinery was so thorough and that one shipment of nonstandard equipment should bulk so large in an immense program was indicative of the critical state of projectile manufacturing capacity in the United States.

Facilities were not generally found so easily. A long range program, fed by some \$6,000,000 of Bureau funds, was barely able to supply fleet demands for high capacity projectiles. Continental reserves, desired to create a safety margin and permit flexibility in delivery schedules, were out of the question. Just as the Bureau seemed to be ahead of immediate needs by mid-1944, requirements in the Atlantic Fleet wiped out the scanty reserves. From the very beginning, the forging facilities of Canada were called on to aid the program, but outside help was only a partial solution to the problem. Manufacturing short cuts, developed by the Bureau and its contractors, further expedited production.

One of the most important of the new techniques completely revolutionized the forming processes for projectiles of 8- through 16-inch calibers. During the early period the shell was formed by forging the cavity from the nose end, then later forging the nose to-



Forging from the base of the projectile squeezed extra production from existing tools.

gether to form the ogive. When that method was used, a subsequent operation was required to bore out the base of the projectile and provide a screwed base plug. Both the nosing and forging processes were tedious operations, requiring precise and time-consuming work. Ultimately, one of the veteran steel companies devised a new technique by which the forging could be accomplished from the base end of the projectile. The result was virtually to combine two operations in one and thus squeeze extra production from the existing tools. Other changes were less dramatic but no expedient was neglected.

By late 1944 naval operations were affected by the availability of less than the required quantity of high capacity ammunition; throughout the war the program remained one of the most important and most critical that the Bureau administered. Operational requirements grew from nothing to astronomical figures and neither the expenditure of \$148,000,000 a month nor the combined output of 15 plants working around the clock could satisfy fleet desires for the versatile ammunition. Satisfaction had to come not from the comfort of seeing reserves pile up in ammunition depots, but from contemplation of the destruction rained on enemy shores by several million pounds of high capacity projectiles.

Prior to the development of high capacity ammunition, common projectiles enjoyed a position of prime importance in the Bureau procurement program. Designed for use against unarmored surface vessels, exposed personnel, and earthworks, the shells were the only real alternative to the use of armor piercers. Less expensive to manufacture, the projectiles were similar to AP, but lacked a hard cap. Though thick-walled, they carried a greater proportion of explosive filler than armor-piercing ammunition. In shells of 6-inch caliber and above, the filler comprised about 6 percent of the total weight; in smaller sizes, the explosive was reduced to approximately 3 percent of the shell's weight. But even where the ratio was lowest, the common projectiles produced greater fragmentation than armor piercers and spread destruction over a wider area.

As effective as common projectiles were in filling a vital combat need, they soon lost their position as a major procurement item. The success of high capacity ammunition in meeting a wide variety of tactical needs precluded the necessity of concentrating production on an item once essential as the only alternative to the use of armor piercers. The need for channeling all available facilities into production of the vital high capacity shells further dictated

a reduction of emphasis on the common variety. As long as the HC projectiles were under development and available only in small numbers, common shells filled a vital space in the magazines of fighting ships, but HC ammunition robbed them of their function. After 1943, the production of common projectiles was limited to 4"/50, 5"/38, and 5"/54 calibers—shells that were inherently high capacity anyway.

Aside from the three main types of service ammunition, the Bureau supplied the fleet, training activities, and the proving ground with a variety of projectiles designed for some particular function. In comparison with the urgency that attended the program to provide projectiles for a fighting fleet, most of the extra shells were destined to a minor role during wartime. A notable exception was the illuminating projectile, which had a vital part to play in naval and amphibious combat. Both Army and Marine Corps amphibious troops demanded large quantities of 5-inch star shells bursting over their lines to increase the effectiveness of their perimeter defenses against enemy night attack.

A standard item of Navy ordnance long before the war, illuminating projectiles, or star shells, were especially designed as a vehicle to carry a candle over the enemy, then eject it so that it could drift down by parachute while illuminating the area. For that purpose the shell was packed with a small burster charge just abaft a nose fuze, and carried a lightly attached base plug that could be blown out by the force of the explosion. When that happened, the magnesium candle was thrown free, the parachute opened, and the area below was exposed to the glare of from 120,000 to 330,000 candlepower, depending on the caliber of the projectile. For as long as 50 seconds night became a reasonable facsimile of day.

Almost at the outset of the war these important projectiles became a Bureau problem. Reports of malperformance flowed in as soon as the shells were subjected to extensive use, and new tests had to be inaugurated. Experiments at both Army and Navy proving grounds bore out service complaints; flight tests showed erratic performance and, in some cases, the flare was never ejected from the projectile. The unsatisfactory state had doubtless existed for years, obscured by the fact that peacetime flight tests were made with inert loaded projectiles which failed to duplicate service use. Iron ore, packed into the shells to equal the weight of the missing components, actually supported the projectile cases. With that added strength, the ammunition performed satisfactorily. When regular service tests were made with fully loaded projectiles, the walls often deformed enough to engrave the bands and jam

the candle and parachute in the shell. But since the shells had already passed flight tests, the blame was normally passed on to the components, which were progressively improved in a futile attempt to end the failures.

Wartime expenditures naturally furnished evidence that many years of peacetime testing could not expose. Flares not only became jammed and failed to eject, but the projectiles fell short of their expected range. That could hardly be blamed on the components. Through a study of that problem the Bureau unearthed the reason for both types of malfunction. Deformation of the shell while it was still in the gun barrel prevented proper contact with the rifling which imparted rotation. That, in turn, caused erratic flight and reduced the range of the projectiles. The same deformation jammed the flare in the casing and caused a dud.

A better design was desired for ultimate adoption, but the Bureau had to find an immediate remedy so that existing projectiles could be pressed into service. A solution came close in the wake of the first experiments. Tests proved that the inner walls could be heat treated to provide sufficient hardness to resist the deforming pressures of service use. The Budd Induction Heat Treating Co. was able to provide the necessary industrial techniques. The device hit upon as an expedient proved to be practical as a permanent measure. Throughout the war, illuminating projectiles received the new treatment and erased from combat reports the stigma of defective ordnance.

Chapter 5

DEGAUSSING

SINCE Ordnance responsibilities are defensive as well as offensive, the development of countermeasures to negate the effectiveness of an enemy's weapon must rival in importance the interminable efforts to increase United State firepower. From the point of time, defensive measures often demand priority, for a capital ship and all its armament would be of no value if enemy measures should sink her before the might of that armament could ever be unleashed. And such a possibility bordered on probability when war broke out in Europe in the fall of 1939. All the restrictive clauses of the Versailles Treaty had not prevented German rearmament, and among the first weapons in their new arsenal was a magnetic mine which outdated with one blow the countermine and sweeping techniques developed in World War I. This was soon a problem for the Bureau of Ordnance, but proximity to the Reich and earlier belligerency forced England to make the first moves toward its solution.

In September 1939, the Germans began laying magnetic ground mines in shipping lanes off the east coast of England; within 3 months, 44 ships were lying on the bottom of the channel, victims of a weapon against which England had no defense. Temporary helplessness over the alarming rate of sinkings and the unprecedented effectiveness of the mines naturally made the development of countermeasures a problem of highest priority to the British Admiralty.

The first step toward its solution was made possible on October 20, 1939, when the suspicion that the new mines were magnetic was confirmed by the explosion of one in the Bristol channel by the "Bosun's Nightmare"—an improvised sweep made by suspending a number of permanent magnets from a cable towed between two ships. As important as that experiment was, it could only indicate the general direction of needed research. Specific countermeasures called for more detailed knowledge of the enemy weapon, and for that, German haste played into Britain's hands. During the first weeks of the war the new mines were laid by submarines—a slow process, but one which defied British efforts to secure one of

the mines for examination. Soon, however the limitations in number and location inherent in submarine laying drove the Germans to a new technique, and by November 1939, the mines were being laid at night by low-flying aircraft. While the use of planes increased the power of the enemy attack, it also speeded the development of countermeasures by aiding the British search. During the night of November 22, 1939, mines were seen dropping by parachute into the Thames estuary off Shoeburyness. Luckily, one was spotted at a point uncovered at low tide. Through a combination of good management, daring, and fortune, the magnetic ground mine was brought ashore on November 23, then rendered safe and studied in detail.

Examination disclosed a magnetic firing mechanism consisting of a gimbal-mounted dip-needle balanced horizontally by a spring mechanism designed to adjust itself automatically to the proper tension for any field in which it was laid. The needle could be deflected to close the mine firing circuit only by an increase in the vertical component of the magnetic field, a phenomenon which occurs below a ship in the northern hemisphere. There was nothing fundamentally new in the device; its success was due rather to clever designing and first-rate engineering. Documents captured at the close of the war show that Germany began research on magnetic mines during World War I in an effort to develop countermeasures to the British magnetic mines. That work was resumed as soon as the occupation forces left Germany in 1923, and within two years the first needle unit had been produced. By 1939 Hitler's scientists had both ground and moored magnetic mines ready for service, backed by a year-old research project on an acoustic type for use when England succeeded in countering the initial genre.

As far as the British were concerned, the worst feature of the new weapon was that the usual sweeping procedure against moored mines—cutting them loose from their cables and destroying them by gunfire—was useless against a type which rested on the bottom. Some entirely new method of sweeping or protecting ships had to be devised. While the British had already been experimenting with devices to neutralize magnetic mines, judgment on the effectiveness of any measures had to be reserved until the characteristics and sensitivity of the German device had been determined. But largely because of that preliminary investigation, the British were able, within a matter of days after the captured mine had been examined, to perfect workable methods for both sweeping and protection. The apparatus and the technique invented for defense

was termed "degaussing," taking its name from "gauss," the unit of magnetic flux density. It consisted essentially of a girdle of cables used as coils and wound around a ship. When high electric current, generated aboard the vessel, was passed through the cables the ship became in effect a huge electromagnet. Two defensive alternatives were offered by this new equipment; a ship's magnetic field could be so intensified that the mines would explode too far away from the hull to cause damage, or the normal field of a vessel could be neutralized so that even nearby mines would not detonate.

Degaussing application followed rapidly on the heels of development, and by the summer of 1940 over 2000 merchant ships had been fitted with the defensive coils. Nor was degaussing the only successful countermeasure to German magnetic mines. An organization of mine watchers and a system of "Q" messages were inaugurated to keep shipping informed on dangerous areas. Even more significant was the development of the "L" type magnetic sweep, made possible by the earlier invention of the degaussing technique. The combination of degaussing and magnetic sweeping complemented each other in their effect on subsequent German mine warfare tactics. Early in the war the Germans concluded that the British were conducting sweeping operations and, to complicate the problem, decreased the sensitivity of their mines. While that move accomplished its avowed purpose, the net result proved to be a boomerang to the Germans. The success of degaussing is in inverse ratio to the sensitivity of influence mines.

The mines first used against the British were the so-called "red" type which operated on an increase of the magnetic field, but just as the Germans first altered their mine settings to foil the new British sweeps, they later decided on a new counter-countermeasure designed to nullify the effects of English degaussing. Before the end of 1939 they introduced negative, or "blue" mines, in the proportion of about 10 percent, to catch overcompensated ships. Later, when faulty intelligence led them to believe that the British were following a general policy of overcompensating, Germany raised the proportion of "blues" to almost 50 percent. With the passing months of war the dreaded magnetic mines lost their initial threat and forced Germany to adopt a new mine policy. Acoustic mines, more sensitive magnetic mines, and finally, combination acoustic-magnetic mines had to replace the early and relatively simple influence types. Thus, the net effect of degaussing, in addition to the direct protection it afforded, was to force the use of mines which were more expensive to manufacture and, while

still very dangerous, were easy to sweep once their character was ascertained. A testimonial to the allied success in countering magnetic mines is the fact that Japan, fully informed on mine warfare, was convinced by Anglo-German developments that magnetic mines were not worth the cost of manufacture and distribution.

When the first surge of English casualties emphasized the power of the new German weapon, the Bureau of Ordnance was quick to recognize the threat presented by magnetic mines in the hands of a potential enemy. As soon as a dispatch from the Naval Attaché at London furnished the first technical details on the German mines, Admiral Furlong called a conference to deal with the new problem. On December 6, 1939, representatives of the Bureau met with experts from the Naval Ordnance Laboratory and the Naval Proving Ground to consider the related problems of sweeping magnetic mines and building some sort of defensive mechanism into the hulls of sweepers. Unfortunately, the meager information available proved misleading. Speculation centered on combating a "rising" mine, while the German development actually concentrated on a ground type that posed a special sweeping problem.

Concerning hull defense, Bureau thinking originally diverged from the current British trend. The conference concluded that field neutralization procedures offered no promise and that the use of powerful electric currents might distort, but could not eliminate, a magnetic field. The clearest point emerging from the conference was the need for more information on the entire subject of magnetic and acoustic mine warfare. Acting on that conclusion, the Bureau issued a project order for \$5,000, with which the Naval Ordnance Laboratory was to begin the study necessary to develop instruments to counteract from aboard ship the effectiveness of magnetic mines. A short time later, the Bureau asked Dr. Vannevar Bush, president of the Carnegie Institution in Washington, to assist the Ordnance Laboratory by furnishing information on magnetism. Tapping this new source brought optimism into the project, for Dr. Bush felt that it would be practicable, even simple, to neutralize a ship's field so that magnetic mines and torpedo exploders would not be triggered.

The first task on which the Laboratory concentrated was the study of ships' magnetic fields. A certain amount of knowledge in this area was a prerequisite both to the design of adequate degaussing apparatus and to the modernization of our own outdated mines. The major difficulties in this study were a com-

pound of its wide scope, its virtually virgin status in this country, and the speed with which it had to be made. Nevertheless, the design of degaussing equipment went forward rapidly as soon as sufficient data had been secured and analyzed. The British furnished the Navy a rough description of degaussing coils in January 1940, and at the same time conveyed the information that the process had reached a commercial basis costing about £1,000 for the largest ships.

Serious planning for the installation of degaussing coils on American ships was initiated early in the spring of 1940. Guided by specifications based on the British standard, the Bureau negotiated with the General Cable Corp. for the purchase of the rubber insulated cable necessary for use in external degaussing coils. A Navy Department appropriation bill of the Seventy-sixth Congress included \$5,629,500 "for protecting the vessels of the Navy against magnetic mines." In hearings on this bill held on May 21, 1940, Admiral Furlong gave the House a simple explanation of degaussing by testifying that this item was "to buy for ships wire to wrap around them from stem to stern . . . to neutralize the magnetic effect of the ship."

Late in May 1940, *U. S. S. Omaha*, *U. S. S. Barry*, and *U. S. S. Goff* were chosen as the first ships on which to try degaussing coils. Each vessel was to be provided with a coil around the outside of the hull a little below the main deck level. The coils were to be made up of insulated wire of various sizes bound together by canvas wrappings to form multiconductor cables. The general design was of a type later designated as temporary. On June 1, 1940, the Bureau authorized the Norfolk Navy Yard to do the work with the wire already procured from the General Cable Corp. at a cost of \$4,200 for the three ships. On June 11, 1940, the effectiveness of the installations was tested at Old Plantation Flats in Lower Chesapeake Bay. These tests showed that for reasonable protection the *Omaha* needed coils fore and aft, as well as the main coil already installed.

The degaussing of United States ships was initiated officially on June 3, 1940, when the Chief of Naval Operations directed the installation of degaussing equipment on all naval ships on duty on the east coast, except yard and district craft, and on ships slated for overhaul by east coast yards. On June 10 this directive was extended to ships of the fleet and the Naval Transportation Service operating in the Pacific, and on June 21, to Coast Guard vessels made available at Navy yards for installation of guns.

To carry out this directive the Bureau of Engineering (later Ships) conferred with representatives of east coast navy yards on details of the installations. This was followed by an official letter to the yards giving details of the installations, and stating that the size and number of conductors in each coil and the procurement of the necessary wire were matters under the cognizance of the Bureau of Ordnance. Apparently the original intention was to fit only main coils to the ships but fore and aft coils were added to the plans, probably on the basis of the experience with the *Omaha*. The Bureau's detailed specification for the first ship on the east coast program, *U. S. S. Tuscaloosa*, was issued on June 17, 1940. First specifications for vessels assigned to the Pacific and Asiatic Fleets followed on July 16, 1940, and instructions for other vessels were rapidly completed.

Procurement by the Bureau of rubber-covered wire for degaussing coils began early in June, contracts being awarded to Anaconda, Okonite, and Phelps Dodge. Some 8,000,000 feet of wire, roughly 1500 miles, were scheduled for delivery at east coast yards by July 20, 1940. Since the coils would be almost useless without proper calibration, the Bureau of Ordnance directed the Naval Ordnance Laboratory to develop and produce the necessary magnetic measuring equipment. Ten thousand dollars were provided to initiate the work in June 1940, but before the year was up \$190,000 more was needed to supply the increasing demands for the equipment.

Personnel, too, had to be supplemented. When degaussing work began in earnest in mid-1940, only five men were available to handle the project. Even though they had the active assistance of the Carnegie Institution's Department of Terrestrial Magnetism, the need for reinforcements was apparent. Civil Service processes were too slow for the emergency, so the Bureau adopted the policy of using personal service contracts to secure top-flight men. Recruiting was aided by calling to active duty reserve officers whose professional contacts gave them a wide acquaintance with experts in specialized fields allied to degaussing. By the start of 1941, over a hundred engineers and physicists had been employed for the project by the Bureau, and a similar increase of the staff at the Naval Ordnance Laboratory promised further progress in the critical field of degaussing. As the war progressed in Europe the oceans of the world became increasingly dangerous for all ships. Unable to distinguish between belligerent and nonbelligerent, merchant bottoms and men of war, mines were an enemy long before the attack on Pearl Harbor. Intellectual and financial

resources had to be tapped quickly and deeply to meet the urgency of the situation.

Before adequate degaussing was possible on any large scale, a reliable method for measuring ships' magnetic fields was essential. Compensation of a ship's magnetism—the object of degaussing—required a current adjustment impossible to regulate until the minimum magnetic field below each ship was determined. Prototype measurements were inadequate, since ships of the same class often differed widely in magnetic characteristics; even for a given ship the optimum adjustment might vary with time and latitude in a way which was only partly predictable. In its early experiments with degaussing the Bureau used an equipment called the Z-variometer with fair success, but the instrument was not adaptable to the wholesale measurements needed to defend the ships of a two-ocean navy. Time was at a premium and, once again, the Bureau of Ordnance was able to save the precious commodity by drawing on English experience. By accepting the principle and reworking the details to American needs, the Bureau developed a modification of the fluxmeter range used to measure the magnetism of British vessels.

The fluxmeter range, or degaussing range as it came to be called, consisted of a row of search coils with axes vertically spaced on the bottom along a line athwart a channel. Each search or range coil was connected to a fluxmeter which indicated and recorded the change in flux linkage as the ship passed. The procedure was fairly simple: all that was required of a ship was that it steam down the center of the range, usually marked by buoys, at a steady speed of from 10 to 15 knots. An observer marked the instant that the bow and stern crossed and the signatures obtained by the several fluxmeters gave a complete picture of the field below the ship.

Just as the design of degaussing ranges was expedited by exploiting British experience, procurement of the original equipment was speeded by adopting existing commercial materials to range requirements. Through a joint undertaking of the Naval Ordnance Laboratory, the Department of Terrestrial Magnetism, and the General Electric Co., fluxmeters were made by fitting Sensitive Research Co. pivot type elements into General Electric's photoelectric recorders. By thus skipping the time-consuming procedures normal to the manufacture of a new ordnance item, the Bureau was able to receive experimental fluxmeters as early as June 20, 1940. Range coils, made by wrapping 500 turns of wire on brass frames some four feet in diameter, were manufactured

first by the Naval Ordnance Laboratory, then by General Electric. Before the end of the summer, they too, were ready for use.

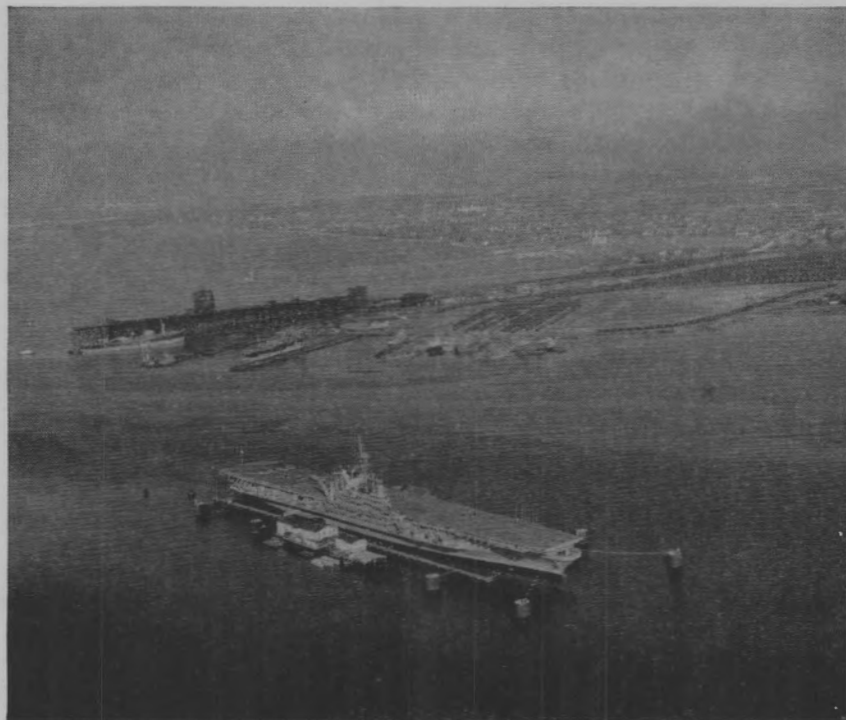
The first United States fluxmeter range was laid on an experimental basis on August 1, 1940, at Old Plantation Flats, already a familiar area to degaussing pioneers. Since shore installations would require prohibitive lengths of cable, the fluxmeters were installed aboard the *U. S. S. Cormorant*, replacing the Z-variometer formerly used by the veteran station ship. Although the *Cormorant* was soon relieved by the *U. S. S. Hannibal*, the range went into almost daily operation, calibrating the newly coiled ships of the fleet and serving as a laboratory for the development of more advanced measuring equipment. As often happened, tests under service conditions belied the promise of earlier laboratory experiments. The fluxmeters made from stock items failed to hold up under operational use; low sensitivity and excessive friction combined to make the pivot type element inadequate for fluxmeter construction. The problem was short-lived, however, since General Electric was soon able to produce a fluxmeter element of the taut suspension type with magnetic torque compensation. The new device worked well enough to remain, in essence, the Navy standard throughout the war.

Even the original search coils were soon replaced by superior equipment. Laying and leveling the large, heavy range coils copied from the British proved to be a cumbersome process. The Naval Ordnance Laboratory received the task of finding a substitute and, before the end of 1940, developed a relatively small and compact unit with a permalloy core mounted on gimbals inside a watertight brass housing. By early 1941 other range coils were developed to meet particular bottom conditions; chiefly, a type adapted to mounting on stub piles, and another to be suspended in a copper tube which could be jettied or driven into the sea bottom where a range depth greater than that of the water was required. The General Electric taut suspension-type fluxmeter and the permalloy core range coil were distinctly American contributions to the science of degaussing. Both were developed early enough for use on all but the first ranges, yet remained unaltered in type through nearly 5 years of service use. Some modifications were made to degaussing range equipment during the course of the war, but later developments were confined to other than fundamental features.

Even before the first range was completed at Plantation Flats, plans were formulated for the establishment of degaussing ranges at several additional locations. Funds in excess of \$115,000 were

provided, and on October 17, 1940, the Bureau of Ordnance authorized the purchase, assembly, and shipment of material for ranges at Pearl Harbor, Cavite, Puget Sound, San Pedro, San Diego, Balboa, and Newport, in that order of priority. Barely over 2 months later, on December 20, 1940, the first of the new ranges was placed in operation at Maui, T. H.; within a matter of weeks ships were also being serviced at San Pedro, Port Townsend, and Cavite. Almost as soon as installations were authorized, range teams consisting of an officer and two physicists were sent out from the Bureau to direct operations on location. Range officers were usually retired lieutenant commanders recalled for that duty, while the physicists were drawn from the pool of specialists recruited by the Bureau. The senior of the two was almost always a Ph. D., and before assignment, the teams were given a few weeks indoctrination in the Bureau, at the Naval Ordnance Laboratory, and aboard the station ship in lower Chesapeake Bay.

The early ranges were intended primarily for naval vessels and were located in large maneuvering areas away from traffic so that repeated runs could be made easily. It was recognized, however,



Aircraft carrier dwarfs Norfolk deperming facility.

that to degauss the merchant marine it would be more practical to place ranges in important channels and make necessary magnetic measurements as ships passed in and out of port in the course of normal business. Accordingly, the Bureau recommended that the Chief of Naval Operations authorize installations at Cristobal, Ambrose Channel, Reedy Island, Boston Harbor, San Francisco Bay, Honolulu Harbor, Galveston Bay entrance, Key West, San Pedro, Cove Point (upper Chesapeake), Mississippi River Delta, San Juan, NOB Norfolk, and Guantanamo. The most significant departures from the original recommendations were the substitution of Brandywine Shoals in Delaware Bay for Reedy Island, Wolf Trap in lower Chesapeake Bay for Cove Point, and 12-Mile Point near Violet, La., for the location on the Mississippi Delta. Work was started on the ranges in the spring of 1941, but some of the stations were not finally completed until the latter part of 1942.

Installation was usually delegated to a private contractor who worked under the technical supervision of 1 or 2 physicists from the Bureau or the Naval Ordnance Laboratory. The Bureau furnished range coils, usually 20 or 30 for each range; fluxmeters, normally 10 for each range; submarine cable, often several miles of it; and all the necessary miscellaneous instruments. Detailed plans and fabrication of control panels and mountings for meters were taken care of locally, with the result that ranges installed during this period were not of a standard pattern, as would have been desirable had there been time to work out complete designs. Construction of range houses and other facilities was usually under the supervision of the Public Works Officer, who used ordnance funds obligated for that purpose by a special arrangement with the Bureau of Yards and Docks. The original allotments, running from \$5,000 to \$20,000 per range, had to be increased several fold before construction was completed.

No further ranges were projected until late in 1941, when the Commander in Chief, Atlantic Fleet, recommended that in addition to the ranges already in operation or contemplated, facilities be placed at Portland, Charleston, Argentinia, Trinidad, Bermuda, and Iceland. All were ultimately constructed except the one suggested for Iceland, where fluctuations of the earth's magnetic field introduced unusual technical problems.

Since degaussing was already being prosecuted with maximum energy, the Japanese attack had little immediate effect on the installation of ranges, although a project for a channel range at the entrance to Pearl Harbor was given added impetus and an advanced base degaussing program was instituted.

In an attempt to simplify degaussing ranges from the standpoints of equipment and operating skill, the loop range was developed early in 1942. This consisted of a rectangular coil from 50 to 1000 feet long by 5 or 10 feet wide, laid horizontally on the sea bottom with the long dimension at right angles to the channel. The loop was made up like a rope ladder, with wooden or steel spreaders every 5 to 10 feet forming the rungs—an assembly which under favorable conditions could be laid from a small barge without divers. The terminals of the loop were connected to a single fluxmeter. Two important uses were envisioned for the new type ranges. After German submarines began planting magnetic mines along the east coast in June 1942, loop ranges seemed especially suitable for installation at section bases where they could check the degaussing of mincraft as they went out each day to sweep. Putting theory into practice, loop ranges were installed to service the bases at Portsmouth, N. H.; Cape May, N. J.; Little Creek, Va.; Morehead City, N. C.; Mayport, Fla.; Miami, Fla.; Burrwood, La.; Sabine Pass, Tex.; Coco Solo, C. Z.; Santa Barbara, Calif.; and Avila, Calif. Loop ranges were also employed to check general ship traffic where regular ranges were lacking. For this purpose loops were installed at Cape Cod Canal; Throgs Neck, East River, N. Y.; St. Petersburg, Fla.; Fort Morgan, C. Z.; Mobile, Ala.; San Francisco Harbor entrance, and Bradwood, Oreg. (Columbia River).

The loop range, unfortunately, did not prove to be as simple or useful as expected. Experience proved that unless bottom and tidal conditions were very favorable it was quite difficult to lay properly. Moreover, interpretation of the records obtained was neither easy nor even sure. As compared with the usual ranges having many separate search coils, the loop range gave at best only a crude first approximation to the magnetic condition of a ship, and its use was justified only in an emergency when technical equipment was short—a condition which, although never forthcoming, appeared likely in 1942.

During the period 1940-45, 75 ranges were equipped by the Bureau. They were not all in operation at any one time and, in a few instances, equipment was moved from one location to another as the naval forces advanced. Many of the locations had only the relatively simple loop range, while others were of the search coil type with from 8 to 18 fluxmeters each. In many cases, a single location had several separate ranges of different depths and orientations controlled from a central building. The magnitude of procurement is indicated by the expenditure of over \$2 million for the

principal technical items. Included in this total was approximately \$1,000,000 for 1813 fluxmeters, \$700,000 for 2620 range coils, and \$700,000 for 267 miles of range cable.

Even though a wide variety of ranges were developed, additional techniques and instruments were needed to cope with the varied circumstances and problems which arose in degaussing work. A range of the fluxmeter type was a relatively elaborate installation and could be justified only when many ships were to be measured in one area. Moreover, a degaussing range required that a vessel be underway for measurement, whereas, the magnetic treatment for which the fluxmeter furnished an index had to be accomplished at a berth. To prevent continual interruptions of work while the progress of degaussing was checked on a range, the Bureau needed to find an instrument to measure the intensity and direction of the magnetic field of a vessel where and when the degaussing work was being accomplished. Magnetometers were readily available for similar measurements, but none had been produced before 1940 with the sensitivity, ruggedness, and adaptability to underwater use necessary in degaussing. Plans called for a detecting element which could be placed at the point where the field was to be measured, plus an indicating or recording device and the necessary control gear. The detector had to be watertight since it was for use below the ship's keel, and it had to be adaptable to quantity production since a need for several thousand was envisioned for individual ships and deperming stations.

Ultimately, the Bureau of Ordnance developed a practicable measuring instrument of its own, but during the interim the need was served by a model based on the British inductor pistol. The Naval Ordnance Laboratory copy of the English device was first officially designated "ship's degaussing indicator" and later Magnetometer Mark 1, though it was usually called by the more familiar, if less elegant, term of "pistol pot." The first of a proposed production of 500 magnetometers was ready early in October 1940, but before half the original order was procured, a better type became available. The inductor pistol was deficient in sensitivity and gave occasional mechanical trouble because of the moving parts contained in its detector element. Something more serviceable than the pistol pot was required, and several parallel developments were carried on to produce a superior magnetometer.

The Carnegie Institution of Washington, Department of Terrestrial Magnetism, had a degaussing magnetometer in development as early as July 1940. The Pioneer Instrument Division of the Bendix Aviation Corp. had developed remote reading com-

passes which looked promising for the degaussing magnetometer application. At the same time, the Naval Ordnance Laboratory undertook the development of a magnetometer of similar type. Somewhat later the General Electric Co., working with the Naval Ordnance Laboratory, undertook its own magnetometer development. A few samples of each of these types were made and tried out under service conditions. This trial showed that only the General Electric product approached the ideal characteristics, and it was adopted as the standard instrument.

Two magnetometers were derived from the General Electric development—the portable Mark 5, and the Mark 6 for fixed installations. The first contracts for procurement of the instruments were let in the spring of 1941. Fixed magnetometers were developed for use in magnetic proving grounds, originally conceived by the Naval Ordnance Laboratory as substitutes for fluxmeter degaussing ranges, particularly where accurate data were desired for research purposes. Although no magnetic proving grounds were ever constructed purely as substitutes for fluxmeter ranges, they were installed as adjuncts to nearly all the larger deperming stations. Construction techniques varied considerably, but all magnetic proving grounds consisted of a large number of fixed magnetometers disposed over a plane on or below the bottom. The area covered was somewhat larger than the vertically projected area of the largest ships to be measured. Instead of being spaced in a uniform system, the magnetometers were placed according to a pattern that promised optimum measurements without requiring an excessive number of the instruments.

Ships were held stationary over the proving ground while the detectors, hooked up by successive connections to a control panel, gave readings which showed the essential characteristics of the ship's magnetic field. Most proving grounds were provided with automatic recorders which balanced all magnetometers in rapid succession, making a record of the readings in printed or curve form. In most locations it was desirable to place the fixed magnetometers at depths somewhat greater than that of the sea bottom. The same problem had been faced with the installation of search coils in degaussing ranges, and the Naval Ordnance Laboratory was able to adopt a similar solution for planting both range coils and magnetometers. The instruments were installed in pipes made of a nonmagnetic material, usually copper, then driven or jettied into the bottom. That procedure, first applied experimentally late in 1940, proved satisfactory for both degaussing ranges and magnetic proving grounds.

The General Electric magnetometers and associated gear, most of which was engineered by the Naval Ordnance Laboratory, were highly successful in service use. Laboratory designs for the first proving grounds, on the other hand, proved to be overelaborate. Later designs by the Bureau, based on more practical experience, represented a simplification of the original specifications. During the course of the war, 5100 magnetometers were purchased at a cost of approximately \$800,000. That total did not include large amounts of miscellaneous auxiliary equipment.

After the development of new instruments and techniques for determining the magnetic characteristics of ships, the way was open for the development of new degaussing systems. Coils built into the hulls of individual vessels were the ultimate in protection against influence mines, but universal application of the girdles was impractical. Less extensive and complex systems of protection were needed for vessels not equipped with coils, and to answer the need, deperming, wiping, and flashing techniques were developed to provide temporary protection against enemy mines.

Deperming, a process which removed the permanent longitudinal magnetization acquired during construction of vessels, was a means of protection auxiliary to degaussing coils. The two methods were complementary; unless the effects of the longitudinal magnetization were first removed by deperming, its elimination by the coils was expensive and difficult. Moreover, deperming reduced one of the greatest problems faced by coil designers by giving the magnetization of vessels a value and distribution so nearly standard that a single degaussing coil specification could be used for an entire class of ships. This auxiliary process was accomplished by winding a solenoidal coil around the hull of the ship. The coil was made up of from ten to twenty turns of cable uniformly spaced along the ship in vertical athwartship planes. The turns were connected in series and fed from a source of direct current, usually a high capacity storage battery containing hundreds or even thousands of cells. Starting with a current of several thousand amperes, a succession of current shots of decreasing magnitude and alternating direction were passed through the solenoid. After deperming, the fore-and-aft magnetization of vessels was neutralized for as long as a year, during which the current requirements for degaussing coils was considerably reduced while the ship enjoyed additional protection.

The Bureau began its deperming program in October 1940, with an experimental setup alongside the pier at the Naval Fuel Depot, Yorktown, Va. Easily available to Norfolk's heavy ship traffic,



Flashing and deperming facilities required thousands of batteries.

equipped with mooring facilities that provided a fixed east-west heading, and free from large iron masses that would disturb magnetic measurements, the site was well chosen for deperming work. The experiments, based on methods developed by the British, were conducted by physicists from the Bureau of Ordnance. Using some of the first magnetometers furnished the Bureau, ordinary automobile batteries, and cable procured from the Norfolk Navy Yard, the scientists got the project under way with an initial outlay of only one thousand dollars. On November 6-7, the *U. S. S. Sailfish* became the first United States ship to be depermed. Others followed rapidly as ships were made available to the experimental station at the rate of two a week. Experimental development, fleet servicing, and personnel training were all combined in the program at the fuel depot.

Soon after the initiation of deperming at Yorktown, consideration was given to the establishment of similar activities at Pearl Harbor and San Diego for the treatment of ships up to 3000 tons. Planning for other small deperming facilities at Boston, New York, Philadelphia, Norfolk, Mare Island, and Bremerton was under way early in 1941. By the end of May, deperming of ships up to 3000 tons was being accomplished at Boston, Philadelphia, Norfolk,

Bremerton, and Cavite, and by the first of August, facilities at Bayonne, Pearl Harbor, San Francisco, and San Diego were also in operation.

Concurrently with the program for deperming small ships, the Bureau began work on flashing and wiping—magnetic treatments designed to give a measure of protection without the use of de-gaussing coils. Both processes were similar in principle to deperming, except that vertical rather than horizontal magnetic fields were applied to the vessel. In wiping, a current was passed through turns of cable surrounding the hull in a horizontal plane at the waterline. While current flowed through them, the cables were dragged up over the hull plates, thus “wiping” the hull with a magnetic field of desired magnitude and direction. In flashing, the vertical field was provided by a large horizontal Z-loop of cable lying on the bottom or supported near the water level, but not in contact with the hull. Large shots of current—“flashes”—were passed through the loop, usually in conjunction with shots in a solenoid. At first this was thought of as an emergency measure for degaussing submarines, since installation of regular degaussing coils on such vessels promised to be almost impossible. Plans for flashing submarines at New London were initiated in February 1941; by the end of July they were being treated there as well as at Key West and St. Thomas, V. I. Facilities were no problem since direct current was normally obtained from the submarine’s own batteries.

While these modest facilities for magnetic treatment of small ships were being started, the Bureau of Ordnance directed the Naval Ordnance Laboratory to submit proposals for deperming, flashing, or wiping large ships. The Laboratory recommended the establishment of an experimental deperming station at Solomons Island, Md., in the area already proposed for degaussing experiments. The facility was to be capable of handling the largest ships and was to include a magnetometer proving ground, four-point battleship moorings to hold the vessel stationary, and a storage battery source of power. The estimated cost was \$119,000, exclusive of moorings. A station of similar scope but of more elaborate permanent construction was proposed for Pearl Harbor at an estimated cost of \$400,000.

The deperming station at Pearl Harbor was completed essentially as planned except for a substantial increase in power. It was too elaborate, however, to be finished in time to be of value as a research tool; several other less ambitious projects were pushed to successful conclusion many months before the Hawaiian station was finally

finished late in 1942, at a total cost of some \$2,000,000. This was by far the most expensive degaussing installation ever made. The deperming station proposed for the Solomons area was abandoned in favor of a site close to Norfolk off Lambert Point, where a station capable of deperming or flashing the largest ships was completed in May 1942.

Neither deperming research nor the production deperming of large ships was held up to await completion of the elaborate stations at Pearl Harbor and at Norfolk. In February 1941, the Naval Ordnance Laboratory was directed to go ahead with experiments on deperming large vessels and the flashing of submarines without waiting for completion of the ideal facilities which it was foreseen would not be ready for several months.

Experiments on the flashing of submarines were begun in March 1941 at New London and in the Solomons, Md., area. The Naval Ordnance Laboratory played some part in the initial stages of the flashing development, but Bureau physicists took the initiative at an early date. The outcome of this program was an entirely new flashing treatment which was termed Flash-D, and which had a degree of stability not approached by methods originated by the British.

Early in 1941 the Naval Ordnance Laboratory took an active interest in working out an improved deperming process. The process involved the use of much higher power than British methods and had the advantage of high stability. The first large scale applications were on *U. S. S. Castor* and *U. S. S. Omaha*. These trials were so successful that it appeared that the problem was solved. Later events showed, however, that there was much more to be learned about high-power deperming, and it was not until nearly two years later that thoroughly reliable techniques for controlling the progress of the treatment were perfected. The Laboratory continued with deperming development, particularly at Solomons Island, where an experimental facility for small ships was set up. Although the Laboratory justly deserves the credit for the introduction of high-power deperming and for the development of excellent measuring equipment, the reduction of deperming to practice was left largely to Bureau and field personnel.

To meet the need for deperming the majority of larger ships, the Bureau proposed that wooden lighters be equipped with battery power plants and portable measuring equipment. It was suggested that such floating deperming stations be located at New York, Baltimore, Norfolk, Boston, San Francisco, and San Pedro.

The first deperming facilities for large ships were not all floating ones as at first contemplated, and in many cases such facilities were established at sites alongside suitable piers. By early 1942 most of them were provided with magnetic proving grounds in place of portable magnetometers. As experience was gained and needs increased, the deperming stations were improved and expanded and new ones were added, particularly in areas where ship construction activities were being laid.

In the summer of 1942, the need for a new magnetic treatment arose when it was decided to degauss certain classes of landing craft by means of Flash-D. This required the construction of a number of small stations and the addition of equipment at some of the large ships stations. A major acceleration of the landing craft program in 1943 made a further increase in flashing facilities necessary.

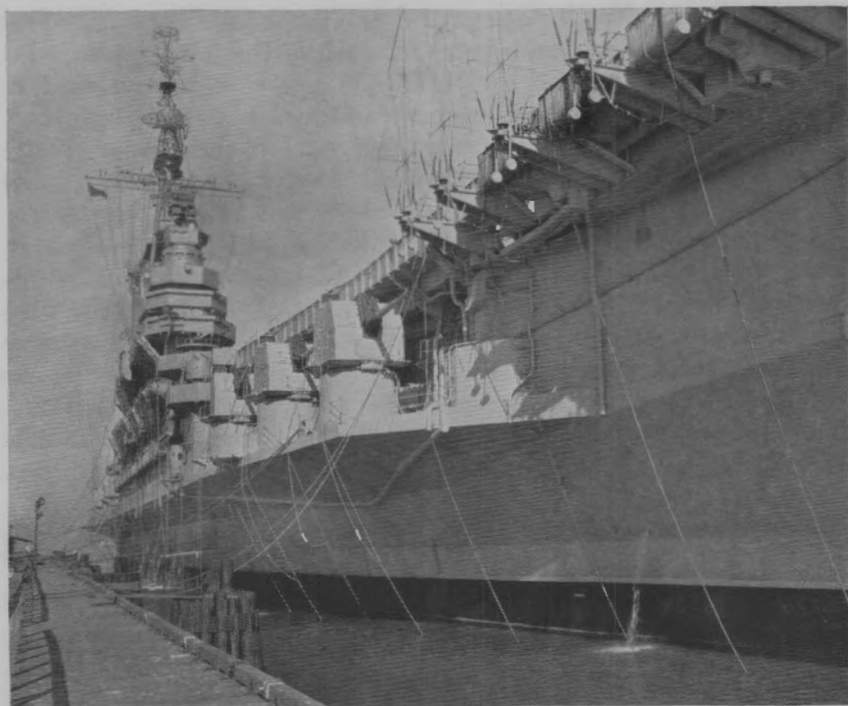
Deperming stations equipped by the Bureau during 1940-45 were located at Boston Navy Yard; Boston, Pleasure Bay; New London; Bayonne; Philadelphia Navy Yard; Philadelphia, Pier 46; Solomons Island, Maryland; Yorktown, Virginia; Norfolk, Lambert Point; Charleston, South Carolina; Key West; Mobile, Alabama; New Orleans, Industrial Canal; St. Thomas, V. I. (3); Coco Solo, C. Z.; Gatun Lake, C. Z.; San Diego, Calif.; San Pedro, Calif.; San Francisco, Pier 33; Portland, Oreg.; Bremerton; Pearl Harbor; Midway (4).

The deperming program called for the procurement of over 620 miles of cable at a cost of \$1,205,527, and of 43,850 battery cells at an approximate cost of \$1,000,000. These figures give no indication of the considerable construction costs, nor even of all the technical material such as switchboards and generator sets for charging the batteries.

The procurement of degaussing coils for ships completely dwarfed expenditures for deperming. While the exact cost is unavailable, the figures below indicate the magnitude of the program:

Number of United States ships fitted with degaussing coils, including installations on lend-lease ships

Period	Navy and Coast Guard	Merchant and Army	Total
1 Jan.-31 Dec. 1940	212	0	212
1 Jan.-31 Dec. 1941	840	121	961
1 Jan.-31 Dec. 1942	963	1629	2592
1 Jan.-31 Dec. 1943	1687	1600	3287
1 Jan.-31 Dec. 1944	1871	1988	3859
1 Jan.-15 Sept. 1945	849	933	1782
Total	6422	6271	12,693



Aircraft carrier wrapped in 5 miles of deperming cable.

For merchant and army vessels, installation costs were borne by the War Shipping Administration and the Army, respectively. The total cost to the Navy of ship degaussing coils is estimated to have been \$150,000,000.

Early in 1942, the Bureau began to assemble equipment to meet anticipated needs for degaussing and deperming facilities at advanced bases. The first three of these assemblies were designated Bureau of Ordnance Degaussing Projects X, Y, and Z. Projects X and Y were assembled at Mare Island, Z at Philadelphia. As needs in advanced areas became better known during the succeeding year and as material already assembled was committed, further "alphabet" projects were set up; in fact the whole alphabet was run through in reverse order, after which a second alphabet was started. *Espiritu Santo* received the first shipment of range material in the spring of 1942 and by the end of the war over \$700,000 worth of degaussing material had been sent to the Southwest Pacific.

In late 1942 and early 1943, the Vice Chief of Naval Operations directed the assembly and movement of several degaussing com-

ponents for the North African and Sicilian campaigns. The first requirement was for loop ranges for each of the four principal invasion ports, designated as BLOT, HULK, SNOB, and DYKE. Three of these four ranges were actually installed, but only one, that at Casablanca, was operated for any length of time. That one was continued in active use until the base was finally turned over to the French. The second shipment was a coil range for Arzeu, Algeria. The Bureau first was verbally informed of the need for this material on February 6, 1943, then given detailed instructions at a conference the next day in the office of the Vice Chief of Naval Operations. Assembly was directed for February 12, at Bayonne—a schedule which could never have been met except for the Bureau's foresight in assembling the alphabet projects. The range was established as planned, and operated continuously from early in May 1943 until turned over to the French in September 1944.

The third and last shipment of degaussing material for the African-Mediterranean area was directed by the Vice Chief of Naval Operations in March 1943. The degaussing equipment consisted of five loop ranges, portable magnetometers, and material for repair of ships' coils, but only a small fraction of the equipment was ever utilized. A loop range was established at Bizerte and an inspection activity was set up at Palermo. Although the material and personnel sent to North Africa were utilized only in part, the facilities installed played an important role in the degaussing of the minesweepers, later to operate so effectively in the Anzio and Southern France invasions, where considerable numbers of enemy magnetic mines were encountered.

During 1943 the role of the Bureau in the advanced base degaussing program was simply to supply equipment in amounts and at places as directed by the Vice Chief of Naval Operations, who assumed complete responsibility for overall planning and for ascertaining the needs in the various theatres. The policy provided a superabundance of equipment wherever there was the slightest chance that it might be useful. The Bureau made strenuous efforts, largely through conferences with cognizant officers, to have this policy modified in the direction of economy. As a result there were major cutbacks which effected tremendous savings in the degaussing program.

At the very beginning of the degaussing program it was realized that a major part of the effort would be devoted to merchant ships. In the first request for funds Admiral Furlong stated that the greater part of the more than five millions asked was to purchase

degaussing wire for ordinary merchant ships. Somewhat later, the main consideration in selecting sites for a network of degaussing ranges was the convenience of merchant vessels.

The first degaussing coil specifications for standard merchant types were forwarded officially by the Bureau to the Maritime Commission on October 14, 1940. The information was of a preliminary character for estimating purposes and supplemented informal discussions between interested technical personnel. Further specifications for the same types were forwarded a few weeks later.

Late in November 1940, a policy for installing degaussing coils on certain merchant vessels was promulgated. This policy in effect provided for installations on vessels being constructed by the Maritime Commission and on ships to be acquired by the Navy for conversion, but not on privately owned or operated vessels unless sought by the owners or operators. The first United States merchant vessel to be degaussed was the *S. S. America*, later *U. S. S. West Point*, which was fitted with very conspicuous external coils just before she left on a Caribbean pleasure cruise in January 1941.

The Merchant Marine degaussing program proceeded rather slowly during 1941, with only a few more than a hundred vessels being coiled, as compared with over 800 in the Navy. During this period, however, financial arrangements and divisions of responsibility were gradually worked out between the Navy Department and the Maritime Commission. The general division of the task agreed upon was that the Bureau of Ordnance would furnish magnetic design specifications or instructions to the Bureau of Ships or, if appropriate, to district commandants; the Bureau of Ships would furnish detailed electrical specifications and all electrical equipment; and the Maritime Commission would arrange for and finance the installation on shipboard. In addition, the Bureau of Ordnance would provide for calibration and deperming of merchant ships. These arrangements did not specify the degree of degaussing to be applied, but somewhat later the Maritime Commission called for main, fore, and aft coils on ships of over 62 feet in beam, with main coils alone on smaller vessels. This was the same policy already adopted by the British and represented less degaussing than had been recommended by the Bureau of Ships. This policy was followed throughout the war.

In 1942, the Merchant Marine degaussing program was prosecuted vigorously, over 1600 vessels being coiled. Coils were installed on vessels during construction and on operating vessels as rapidly as availabilities allowed. By the end of the war over 6000 merchantmen had been degaussed.

Chapter 6

TORPEDOES

“IF you want to fill 'em with air, bomb 'em; if you want to fill 'em with water, torpedo 'em.” Such was the succinct appraisal of the torpedo made by a veteran pilot. And the superiority he recognized over bombs could be extended to cover the wide range of projectiles, for no weapon in the war proved half as destructive to enemy capital ships as the “fish.” Yet for every complimentary comment, a host of damning ones echoed back from the war zones. United States torpedoes were variously described as running too deep, not exploding, exploding too soon, or not packing enough punch when they did explode.

The indictment unfolded point by point during the first 2 years of war. As each defect was exposed, the morale of the submariners who risked their lives to take the war to the enemy suffered, the enemy was given further respite from the full potential of torpedo warfare, and the Bureau of Ordnance was faced with the task of uncovering and correcting the mistakes of peacetime. Considering the extreme complexity of torpedoes, the job would have been a challenge under almost any circumstances, and the problem was compounded by the Bureau's reluctance to accept the fleet evaluation of its weapon. This reluctance was born not of any petty attempt to cover past errors, but from misplaced confidence in its own past work. And that confidence was occasionally bolstered even when the inadequacies of torpedoes were being exposed, because the evidence that came in from fleet commands was often contradictory.

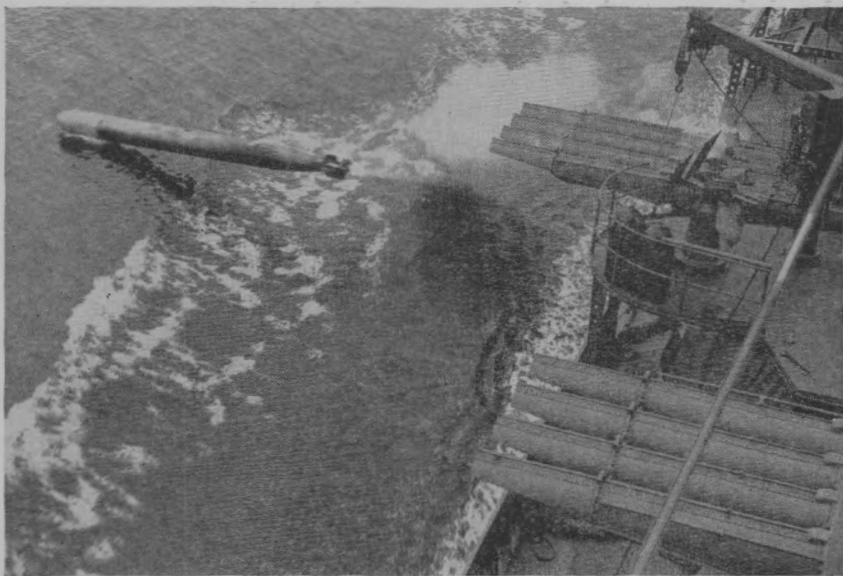
When torpedoes were finally improved to the point where they became reliable weapons, the reasons underlying their earlier failure were apparent. During the interwar period when time was available for research, the Bureau's approach to the torpedo problem was not properly scientific. Evaluation was almost invariably inadequate and tests were unrealistic. Economy was properly a goal, but improperly applied. Security, a necessary concern of the armed forces, became such a fetish that measures designed to protect a device from enemy eyes actually hid its defects from those who made the regulations. Ironically, some of those defects were

already known to the foreign powers who later became our allies or enemies.

Production planning in the prewar years was also faulty. Torpedoes were designed for meticulous, small-scale manufacture. When military requirements demanded that they be supplied in large numbers, a series of new problems were exposed. There were simply no realistic plans available for providing the weapons in adequate quantity. The old ordnance motto, "The more we sweat in peace, the less we bleed in war," hung dutifully in many an office and shop, but the sweat was apparently as misplaced as the general confidence in the Navy's torpedoes. The ebbing of that confidence became a vital part of torpedo history. Brutal facts and technical details were no more significant than the attitudes of those who interpreted the facts and directed the technical developments.

In 1937, when the international crisis began to deepen in both Europe and Asia, the United States had 3 general torpedo types ready for combat service—1 for submarines, 1 for surface vessels, and 1 for aircraft. All shared certain common characteristics. After being dropped from a plane or ejected from tubes by compressed air or gaseous pressure, steam for their propulsion turbines was generated by forcing a spray of water through an alcohol torch. An excess of combustion air at high pressure augmented the steam supply. Steering was controlled gyroscopically, while a pendulum-hydrostat device, regulated by water pressure, governed depth control. Although their military characteristics differed widely, each type carried roughly a quarter ton charge of explosive which could be detonated by contact or magnetic influence. Obsolescent torpedoes—Marks 7, 9, 11, and 12—were added to the stockpile through conversion and modification in 1941 and 1942, when quantity rather than quality seemed the vital problem, but the burden of torpedo warfare had to be borne by the latest models in stock and production on December 7, 1941—the Marks 8, 10, 13, 14, and 15.

Surface ships were normally equipped with the Mark 15 type torpedo, a rugged and relatively reliable performer. Based on a design originally conceived in 1918 for the Mark 11, this \$10,000 weapon was characterized by a unique three-speed feature designed to give it the greatest possible adaptability to various tactical situations. External speed settings gave a speed/range choice of 28 knots to 15,000 yards, 34 knots to 10,000 yards, or 46 knots to 6000 yards. In addition to the obvious tactical advantages of so flexible a weapon, designers had been influenced by the Bureau's desire to concentrate in one model the military features of torpedoes re-



Torpedo Mark 15 was a rugged and relatively reliable performer.

quired for cruisers, destroyers, and submarines. This goal, while logistically attractive, proved unobtainable; long range, a must for destroyers, required a weight and length prohibitive for submarines and aircraft. Nonetheless, the ideal was most nearly achieved in the Mark 15 type.

Most of the kinks inevitable to torpedoes deprived of actual combat trials had been ironed out of the Mark 15 before the United States entered World War II. Early models were built with a new type, top-bearing turbine mounting, but recurrent lubrication difficulties induced the Bureau to revert to the older, overhung type. This conversion was completed before declaration of the national emergency, so surface vessels had a promising weapon when war finally broke. Even the supply problem—one of the greatest the Bureau faced after wartime expenditures dwarfed peacetime production plans for war—became critical for the Mark 15 less quickly than for the other standard types. Pressure on existing stock was relieved by the tendency to reduce surface ship concentration on torpedo warfare. Also, Mark 8 torpedoes, an earlier low-speed type, were issued to cruisers, “four-piper” destroyers and, later, to destroyer escorts. The increasing emphasis on planes had the same effect, since the demand for more antiaircraft guns reduced the deck space available for torpedo tubes. Thus, at the outset of the war, the Bureau was less concerned about the supply of de-

stroyer torpedoes than about meeting requirements for aircraft and submarines.

Even before the end of 1942, however, that relatively happy picture had changed. Torpedo tubes were installed on destroyer escorts, and overall expenditures in the first year of war exceeded expectations. Looking ahead, the Bureau anticipated a shortage in the fleet by the following spring. Some relief was achieved by conversion work on Torpedoes Mark 11 and 12, but nothing short of new production schedules gave adequate promise of meeting requirements. The whole problem was further complicated by existing priorities on submarine and aircraft torpedoes, which left scanty facilities for an expansion of the Mark 15 production schedule. Retooling of plants engaged in other work threatened prohibitive delays which, always costly, were especially undesirable while the war picture was still changing. Meshing the new problem into the overall procurement pattern, the Bureau chose the new Naval Ordnance Plant at Forest Park, Ill., as the principal producer.

Difficulty followed difficulty in rapid succession. Spring brought no new torpedoes. When the first Forest Park Mark 15 was finally proved in the early summer of 1943, defects were numerous and depth failure consistent. In common with most torpedoes, the Mark 15 had earlier shown a deep running tendency, but now the behavior was accentuated. Even when the problems resulting from placing a new plant into production on an emergency basis were ironed out, manufacture stayed in low gear. This stemmed largely from previous acceptance of the notion that torpedoes could be built only by craftsmen who knew the proper trade secrets. These secrets, instead of being properly committed to writing on drawings and in specifications, were largely matters of memory or notes in some foreman's little black book at the Newport Station.

Until all production information was drawn together in a usable form, manufacturers were severely handicapped. By fall, 1943, the problem had grown to urgent proportions. Germany still possessed powerful surface units against which convoys needed torpedo carrying escorts as protection, so the Bureau reluctantly made a major shift in its procurement schedules. The experienced Newport Station was switched from work on aircraft torpedoes to production of the Mark 15. By the middle of 1944 this particular crisis was over, partly because of the combined output of the two stations and partly because the gradual disappearance of suitable targets led to further armament changes in the fleet. Torpedo tubes were removed from many destroyer escorts, light

cruisers, and some destroyers. On others, the tube load was reduced. By the end of the year, Mark 15 torpedoes were in excess supply. Within a month, however, the Bureau was aware that quantity had been gained at the expense of quality. Defects common to rapid and inexperienced production of a complex mechanism had been multiplied by shortages of critical materials. Because cadmium was in short supply, the interiors of air flask sections and water compartments of the Forest Park torpedoes were plated with zinc. Almost immediately, zinc oxide deposits began to clog water strainers, causing a flood of complaints to reach the Bureau. Erratic runs and engine failures were frequent.

In an attempt to correct this situation the Bureau of Ordnance sponsored experiments to determine the feasibility of using the "Cronak" process to inhibit the troublesome zinc corrosion. Although the process had been designed for that specific purpose, the experiments on the Mark 15 torpedoes were a failure, probably because the zinc had started to corrode before the inhibitor was applied. An interim treatment using a sodium chlorate solution in the water compartments proved successful as a temporary expedient, but extensive reworking was inevitable. Even though the war was in a critical stage, the Bureau had to recall torpedoes and authorize new facilities to strip the offending zinc and replat the flask and water compartments with cadmium or coat them with baked Heresite, a new phenolic resin product.

Once that was accomplished, destroyers were again in possession of an effective torpedo. Of approximately 11,000 Mark 15 torpedoes procured during the war, in keeping with varying armament requirements and shipbuilding schedules, almost 9000 were still in store when Japan capitulated. Production was necessarily geared to stated requirements, but the surplus vindicated the original Bureau assumption that war tactics would reduce the use of torpedoes by surface vessels. Lacking both concealment and speed, as compared with submarines and planes, these ships could rarely maneuver into a position for effective torpedo firing.

As expected, submarines were the best and most effective customers for torpedoes. During the course of the war some 5 million tons of enemy shipping were sunk and another 2½ million tons damaged by the submarines' principal weapon. Although some newer torpedoes were introduced toward the end of the war and some older models converted at the start, United States submarines fought and won their war with 3 torpedoes—the Marks 10, 14, and 18. But if submariners were the best customers, they were by all odds the most critical. Maneuvering for a war shot

placed men and machine in such jeopardy that infallible performance seemed a justifiable demand. When far from infallible performance was achieved, protests flowed in to the Bureau. When performance fell short of even the normal expectations for so complex a weapon, the criticism became a howl of protest with a paradoxical dual effect: Torpedo development was stimulated, yet made increasingly difficult. Once suspicion was engendered, improving a weapon was hardly less difficult than selling the new modification.

Of the three principal torpedo types used by submarines, the Mark 10 was the oldest, the best understood, the least used, and therefore the least criticized. About 30 years old at the start of the war, this torpedo was built for the R and S Class vessels that could not fire the longer Mark 14 type. Doubling as a reserve weapon for PT boats and for new fleet-type submarines, the Mark 10 was a 2215 pound, 21-inch torpedo with steam turbines capable of driving it 3500 yards at 36 knots. The Mark 3 exploder, a simple contact device, was used to detonate the warhead of 497 pounds of TNT or, later, of 485 pounds of Torpex. As a product of the depression, tests on the Mark 10 had been mainly characterized by economy. Within a month after the Pearl Harbor attack, the ultimate cost of unrealistic torpedo testing became evident. For the Mark 10 the price was a common one—deep running.

Without waiting for basic corrections of the fault, the Bureau of Ordnance informed the fleet in January 1942, that the type would run 4 feet deeper than set. No repercussions resulted. Very few warshots had been made with the Mark 10 before the Bureau instructions arrived in the Pacific, and a predictable error posed no problem to submarines. By the summer of 1943, when supply was no longer the pressing problem it had once been, the Bureau of Ordnance abandoned production of the Mark 10. To take its place a shorter modification of the Mark 14 was built for use on the R and S Class submarines. Increased interchangeability of parts and the abandonment of an unnecessary type—always Ordnance goals—justified the move. Earlier in the war any such added emphasis on the Mark 14 type would have been unpopular with the fleet, for this was the torpedo around which the great debate was centered.

At the outbreak of the war the Mark 14 was the most recent type placed in quantity production. Longer, faster, heavier, and longer ranged than the Mark 10, the Mark 14 approached the multispeed feature of the destroyer torpedo. Submariners could choose between two speed settings: high, 46 knots to 4500 yards, or low,

31.5 knots to 9000 yards. The low speed setting was so seldom used early in the war that a new torpedo, the Mark 23—essentially a Mark 14 with the lower power setting eliminated—was introduced as a substitute.

Good results were expected of the Mark 14. Although never tested in combat before the attack on Pearl Harbor, extensive proving at the Newport range indicated the torpedo's readiness for war. Until the spring of 1945, supply was a problem, but during the first two years it seemed almost insignificant beside the nightmare of improving a faulty weapon. A long succession of complaints poured in from submarine commands: The torpedo ran deep, the detonators were faulty, the arming distance was too great, the magnetic exploder was undependable, the anticountermining device was improperly designed, the firing spring was too weak, and, even when the torpedo exploded properly, it lacked the punch submariners desired. The situation would have been bad if discovery of all of the defects at the outset had required a redesign of the weapon; what was worse, however, was the diabolical way in which each defect concealed another. No sooner was one kink ironed out before another was exposed. Correction had to be gradual and at the expense of the fleet's confidence in the weapon supplied them. The whole situation was aggravated by differing concepts of what the torpedo was and should be. Even while it worked night and day to improve the weapon, even when it acknowledged the defects pointed out by the service, the Bureau of Ordnance felt that the Mark 14 was a good torpedo. Perfection was desired, but not expected. The fleet, on the other hand, felt entitled to an infallible weapon and remained critical of anything less.

The first major defect exposed by service use was the common one of deep running. Several factors contributed to that tendency. Torpedo depth control was governed by a device known as the Uhlan gear. Before its introduction, pendulum control had been paramount; no greater angle of dive or climb than 1° was permitted by the depth mechanism. With the adoption of the Uhlan gear, the hydrostatic element became paramount, making recovery in depth rapid, almost immediate, in marked contrast to the older system that permitted torpedos to run most of their range before recovering from the initial dive. The new device was admirable, but its good possibilities were at first canceled by an error in its placement in the torpedo. Formerly, the hydrostat which controlled depth had been carried well forward on the torpedo. With the introduction of the new mechanism it was decided to remove

the depth control mechanism aft, nearer the rudders it controlled and in an area where space requirements were less critical. The new mounting was also at a slight angle to the torpedo's axis, and for reasons not suspected, prevented the device from reacting properly to depth. Still another reason for poor depth performance was overloading the head of the torpedo. In answer to demands for additional "punch," the Bureau made successive additions to the warhead, increasing the explosive charge from 507 pounds of TNT to 668 pounds of Torpex. Each change, no matter how small or desirable, altered the running characteristics of the torpedo. The center of gravity shifted and new stresses were placed on the head.

A certain variation of performance among individual torpedoes was expected, and for that reason each torpedo sent to service was accompanied by a detailed log showing the ranging results of that particular weapon. Guided by that information, a torpedo officer could presumably calculate the proper settings. But consistent depth failures did not show up in the logs because the depth and roll recorder, the instrument designed to collect the data, was improperly used. The device recorded depth as a function of pressure, but the configuration of the torpedo at the point of water intake to the instrument exposed it to a pressure differing from that at the true running depth of the torpedo. Both the depth mechanism and the measuring device checked each other, but both were improperly placed. Before the introduction of sonic instruments at the proving range, the actual performance of a recorder in a running torpedo could only be checked by firing the weapon through one or more nets. Such tests were occasionally made, but the procedure was arduous, costly, and undependable. Nets failed to hang straight down in the least current and the distance from the top of the net to any given strand was not the same in the water as it was when the net was hung in the air or laid out on the ground. Thus, when contradictory evidence was gathered from recorders and net firings, the results of the latter were discounted.

Still another reason for the failure to expose deep running was the disparity between combat and proving conditions. In order to pack the most goods into the smallest package, conventional torpedoes were built with a considerable negative buoyancy. But that characteristic had to be altered for test shots so that the weapons could be quickly and cheaply recovered. Exercise heads, filled with some liquid that could be expelled at the end of a run, were fitted to each torpedo to provide buoyancy. For years the

exercise head closely approximated the warhead which it temporarily replaced, but that condition was altered when the Bureau began increasing the explosive charges. Testing conditions became more and more unrealistic, obscuring the effect of the heavier warhead on depth performance. Occasional shots were made with dud loaded warheads, but they were too infrequent to expose the inadequacy of the exercise heads. Thus, despite extensive proving, depth failures did not appear in the logs upon which torpedo officers depended.

Even during fleet exercises the error in depth could not be detected. To prevent impact damage to the weapon and target ship, practice shots were always set to run under the target. Concern over saving the torpedoes was so great that no one stopped to wonder just how far under the target the torpedoes were running. The Bureau of Ordnance depended on Newport to check actual depth performance, and Newport depended on the misused depth and roll recorder to collect that data. The unreliability of the recording instrument remained hidden for years—consistently erring in exactly the same manner as the control in the torpedoes. No one at Newport guessed that a defect was hidden by the very instrument designed to expose it.

The fleet possessed less blind confidence in the Station's procedures, however, and even though their normal exercises failed to expose the deep running tendency, there were warning exceptions. In 1938, for example, a destroyer command engaging in battle practice off Coronado, Calif., found that half its torpedoes failed to function properly. When many surfaced in 90 feet of water with the exercise heads covered with mud, deep running was obvious. A heated exchange of letters followed, and the Bureau dispatched a torpedo officer to the scene to investigate the failures. Unfortunately for the future, evidence of poor maintenance or rough handling impressed the Bureau representative more than the bottom sand which constituted the destroyer command's exhibit A. The incident failed to shake official faith in the procedures of the Naval Torpedo Station. For three more years the inadequacies of torpedoes were obscured by misplaced faith in faulty procedures and an inaccurate recording device.

War shots, however, were quick to expose discrepancies between logged characteristics and actual performance. A few perfect setups that produced no hits could be labeled erratic runs or blamed on poor fire control, but repeated offenses aroused grave suspicion. Acting on the complaints of his skippers, the Commander in Chief, United States Fleet, ordered net firings made during the summer

of 1942. The tests confirmed the submariners' conviction. When fired from submerged tubes, Torpedoes Mark 14 ran an average of 10 feet deeper than set. Although the Bureau still did not know why the erratic depth performance resulted, it did know of the existence and amount of the error. On August 1, 1942, the services were officially informed of the 10-foot error. Until the Bureau rooted out the causes of the failure, submariners got good depth performance by allowing for the known error when making the setting for each shot.

Although the Bureau of Ordnance and the Newport Station for which it was responsible were slow to recognize, admit, and correct the erratic depth performance of the Mark 14, their feeling that the torpedo was basically good was substantiated. Even before the serious depth difficulties were corrected, it was producing better results than either the English or the Germans got from less criticized weapons. But a good torpedo was small comfort unless its potentialities could be realized, and the improved Mark 14 remained an unreliable weapon. Elimination of the deep running tendency increased the percentage of known hits and exposed the fact that even when it struck the target the torpedo did not necessarily explode.

The villain at this point turned out to be the long secret Magnetic Exploder Mark 6. Its poor performance was obscured as



Torpedo Mark 14 was a source of much grief—for United States submarine skippers and many an enemy crew.

long as torpedoes ran so far under a target that the exploder could not be expected to perform, but by the early fall of 1942 some of its weaknesses began to become apparent. Direct hits were often duds; on perhaps 10 percent of the early war shots premature explosions made hits impossible. Both duds and prematures attracted the attention of the enemy to the attacking submarine and added hazards to its operations. In effect on the morale of submarine crews and the relations between the fleet and the Bureau of Ordnance, these exploder defects proved even more serious than the deep running tendency just eliminated. This was unexpected. The Bureau was reluctant to believe that the secret weapon long regarded as one of our greatest assets should turn out to be a liability. After considering and experimenting with several different types of exploders, the Bureau had regarded the Mark 6 as the ultimate in development.

Early United States torpedoes employed the simple contact exploder developed for the Whitehead models, but shortly before World War I the Bureau of Ordnance developed a more complex and advanced type operating on the "ball" or inertia principle. During and after the war, successive changes further improved the device. The Mark 3, for instance, employed an arming impeller which projected from the side rather than the nose of the warhead, permitting the exploder to be placed near the center of a long explosive charge. Increased effectiveness was also assured by the addition of anticircular-run and anticountermining mechanisms.

Meanwhile, however, German developments were leading the Bureau to adopt a new and secret trend in exploder development. Before the end of World War I, the Kaiser's Navy produced magnetic exploders for use in mine warfare. The possibility of adapting the same principle to torpedo exploders seemed to promise a great boost in the potential of torpedoes. With detonation produced by magnetic influence rather than by impact, a hit would not even be required. For all practical purposes, the size of the target ship was magnified. Better still, torpedoes could be exploded under the bottom of ships where no armor protected the vulnerable hull. While the point was always disputed, prevailing opinion in the Bureau considered such an explosion more desirable than a direct hit against the side of an enemy vessel.

So attractive was the goal that in the immediate postwar years the Bureau experimented with a variety of ways to produce an influence explosion. Sound controlled torpedoes, a water kite above a deep running torpedo, and the creation around a torpedo

of an electric-magnetic field that would be disturbed by the entrance of a metallic body such as a ship were all tried, then abandoned. But the idea of using magnetic influence opened a new field and on June 30, 1922, the Bureau of Ordnance instituted at the Newport Station the "G-53 Project" that eventually produced the Mark 6 exploder. The project seemed especially timely since that same year witnessed the adoption by most nations of new antitorpedo structural protection for their first line fighting vessels. More than ever, underbottom explosions seemed desirable, and the G-53 Project was allowed to suffer less from budget restrictions than the testing and development of other weapons in the arsenal of underwater ordnance.

With the help of the General Electric Co., which produced the generator and developed thyratron electronic tubes for the project, Newport had the Mark 6 ready for testing by 1926. Although the idea of employing magnetism was first crystallized by Germany, the United States' exploder represented a new line of development. The swinging of a compass needle when approached by the magnetic mass of a ship activated the German device; our mechanism utilized the variations in the intensity and direction of the earth's magnetic field adjacent to the hull of a vessel to actuate the mechanical pistol that set off the explosive charge. On May 8, 1926, 4 years of work were crowned by success. A submarine hulk was towed to sea, then sunk by the first shot of a torpedo equipped with the new magnetic influence exploder.

The occasion was memorable: It marked the greatest stride yet taken in exploder development; on the debit side, it prematurely closed realistic experimentation with the new mechanism. Never again during the 19 years of prewar exploder development was a destructive test made with a torpedo equipped with a magnetic influence exploder. How ironic that success should have been its own deterrent! Testing continued, of course, and a conscientious effort was made to duplicate service conditions, but several factors fell short of realism. Most of the tests were conducted in the same magnetic latitude, and no amount of effort could exactly duplicate the variables—age, storage conditions, handling, and targets—later encountered by the fleet. Even more important, neither laboratory nor range tests indicated the kind of performance the service would require.

Meanwhile, the fleet for which the weapon was designed did not even know of its existence. The Bureau reasoned that if secrecy were not maintained the effectiveness of the weapon might

be destroyed through enemy countermeasures and new hull designs. In this case extreme caution was ill-advised. England, Germany, and Italy all had magnetic exploders of their own before the outbreak of World War II; Japan lacked one only because she considered them impracticable and, though evidence is inconclusive, possibly knew enough about the Mark 6 to overdegauss her ships as a countermeasure. While foreign nations were developing their own varieties of influence exploders, the Bureau of Ordnance produced the Mark 5, a dummy for the Mark 6. Identical to the latter except for the secret feature, the Mark 5 was issued with each torpedo that would later receive the influence exploder. As an added precaution to guard secrecy, even the men working on the mechanism were allowed only the vaguest idea about their project. A selected group from the research section at Newport did all of the assembling and testing in rigidly maintained seclusion.

Their testing was inadequate. Evidence of that fact came in 1939, when Newport reported to the Bureau that the exploder was giving unexplained prematures. Admiral Furlong arranged for a physicist to visit the station and investigate the failures. For approximately a week, the scientist and his assistants worked with the device. Four sources of prematures were uncovered. Even more significant, the investigator reported to the Bureau that the responsible engineers at Newport were not employing proper tests on the Mark 6. Corrective steps were ordered by the Chief, but subsequent events proved that the remedial action, like the original tests, was inadequate. Exaggerated security measures obscured a multitude of sins.

Less than a year before the attack on Pearl Harbor, the policy of extreme secrecy was relaxed. Realizing that scientific ideas are an international currency, Admiral Blandy, Chief of the Bureau, decided that familiarity with the weapon within the fleet would be more valuable than hopeful refrigeration of the idea within the Bureau. During the summer of 1941 his ideas were implemented by the inauguration of a training program at Newport for selected officers, and by a limited issue of the exploder to the fleet. The classification remained secret, but the circle of the initiated grew more rapidly. Unfortunately, the move came too late to permit service testing and criticism of the exploder, and its classification remained high for so long that the men who actually used and maintained the device were barely familiar with it. The speed with which the fleet relayed its reaction to the Bureau once war made the weapon familiar is an indication of the benefits that might have been gained by an earlier introduction of the exploder. More-

over, the procedure of firing under a target during practice—inadequate as it was for exposing depth failures—would have afforded a large volume of tests for the Mark 6.

Even the deep running tendencies of the Marks 14 and 15 torpedoes were aggravated by the exploder. Early in 1942 the Bureau of Ordnance suggested that torpedoes equipped with the magnetic exploder be set to run ten feet beneath the enemy's keel. When added to the 10-foot error inherent in the torpedoes themselves, that meant a miss of such wide proportions that even an influence exploder could not always produce an explosion. Even when it did, an explosion so far from the hull was seldom effective. On the other hand, the errors could cancel themselves out to the disaster of the enemy. Many shots planned for impact against the side of a ship missed because of deep running, yet damaged the enemy due to the influence feature of the Mark 6. For other exploder-induced errors there was no such compensation, however, and two new types of failure—prematures and duds—were added to the problems that plagued submariners. Nor was that all. In addition to charges of functional failure, the Mark 6 was criticized for an inadequate physical design that permitted flooding of the exploder cavity in action-ready torpedoes and for a complexity that required excessive "babying" and long hours of testing and overhaul.

Behind the failure of the Mark 6 exploder to live up to Bureau expectations were some of the same factors that caused torpedoes to fall short of the efficiency the laboratory tests predicted for them. Undue secrecy and unrealistic testing were hardly more culpable than the extreme complexity that defied perfection. TNT being hard to detonate, even a simple exploder required mechanisms that could set off the required detonation wave. In the Mark 6 a series of three explosions were induced: First, the firing pin struck the primer cap, which set off a detonator in the base of the booster charge; then the explosion of the booster climaxed the detonation wave by setting off the torpedo warhead. Unlike other exploders, the Mark 6 contained the special feature that could initiate an explosion by sensitivity to the magnetic influence of an enemy vessel.

When the torpedo was ejected, its rush through the water spun a small turbine which, in turn, operated a gear train that pushed the detonator into the booster cavity. The 450 yards required for that operation afforded security for the firing submarine and gave the torpedo time to find its course and settle down on a normal run. During the same period, vacuum tubes within the 91

pounds of exploder mechanism warmed up and readied the influence features for operation. As soon as the torpedo entered the magnetic field created by the enemy hull, the electromotive force generated in the exploder's induction coils began to change. That change, amplified by vacuum tubes, was harnessed to release the firing pin which initiated the detonation wave at the proper theoretical moment for optimum results. Where contact rather than magnetism was to induce the explosion, impact dislodged an inertia element which released the firing pin. An anticountermining device, later proved defective and removed, added to the general complexity that led Vice Admiral Lockwood to call the exploder a "Rube Goldberg" device with 5 or 6 things that might go wrong.

Aside from the discovery in the early months of the war that the anticountermining mechanism might prevent the proper functioning of the exploder, the first indication that the Mark 6 was responsible for erratic torpedo behavior came in August 1942, when correction of deep running exposed the tendency of premature explosions. There were two reasons for the disclosure then: while torpedoes were running far under the target, the defect remained hidden; when the error was corrected so that torpedoes were set for shallower depths, one result was that the weapons entered the enemy ship's magnetic field some distance from its hull. Unless perfectly adjusted, the exploder might act promptly, causing a premature by as much as 50 feet. The exact extent of the failure was impossible to determine. Observed through a periscope, a premature explosion might well appear to be a hit, yet submariners were convinced that some 10 percent of the torpedoes they fired were prematures. The Bureau, analyzing combat reports as they were received, concluded that prematures did not exceed 2 percent of the total shots fired. Whatever the truth, ill feeling was the result. In the fleet, a distrust of their torpedoes spread; in the Bureau, remedial actions were taken.

In attempting to pin down the source of the failures, the Bureau first concluded that prematures were usually due to faulty brush adjustment on the generator and to warping of generator brush discs. Before the end of 1942, Newport was instructed to redesign the exploder, using batteries instead of a generator as the source of power. Meanwhile, experiments convinced the Bureau that the relatively short arming distance increased the tendency to premature, and it suggested to the forces afloat that the effectiveness of the Mark 6 could be increased if the arming distance was raised from 450 to 700 yards. In the Pacific, the principal arena

of torpedo warfare, the suggestion was not considered acceptable. Admirals King and Lockwood, voicing an opinion already prevalent among submariners under their commands, concurred in a recommendation that the Exploder Mark 6 be replaced by a simple, reliable exploder. Further suggestions by the Bureau, such as new instructions on depth settings for optimum results and information on the variations in performance to be expected in different magnetic latitudes, did not materially alter the situation. By July 1943, inactivation of the influence feature became a popular procedure for dealing with the Exploder Mark 6. On July 24, the practice was officially sanctioned when Admiral Nimitz, Commander in Chief, Pacific Fleet, ordered his submarine and destroyer commands to inactivate the magnetic device on all torpedoes.

Only South West Pacific submarines continued using the feature. The submarine commander there, Rear Admiral Christie, an experienced torpedo design officer, was the chief advocate of the Mark 6 in the Pacific. His defense and continued use of the weapon stemmed from no feeling of satisfaction with the mechanism, but from fear that if his command joined those to the north in inactivation, the magnetic exploder, with all its potentialities, might become a dead issue for the war. Until improvements were made, the Admiral trusted in careful use and maintenance of the device to produce satisfactory results. By the spring of 1944, however, his submarines were instructed to follow the lead of those based at Pearl Harbor in abandoning the use of the magnetic feature. The Southern Hemisphere was hardly suitable for the magnetic exploder; prematures appeared too common to justify continued use of the influence feature.

In the face of a widespread refusal to use the weapon that the Bureau had considered one of its greatest assets, efforts to improve and restore confidence in the exploder were redoubled. Admiral Blandy had already indicated the direction of such efforts with a biting directive on torpedo policy. Addressing the Newport Torpedo Station some months earlier, the Chief of the Bureau wrote:

"Even with the relatively meager funds available in time of peace, much of the work now being done after more than a year and a half of war, could and should have been accomplished years ago. . . . That the work was not accomplished during peace or earlier during this war, or, so far as the Bureau's records disclose, that no one either in the Bureau or at Newport apparently questioned the inadequacy of the design without such tests, shows a lack of practical appreciation of the problems involved which is

incompatible with the Bureau's high standards, and reflects discredit upon both the Bureau of Ordnance and the Naval Torpedo Station, Newport. The Chief of the Bureau therefore directs that as a matter of permanent policy, no service torpedo device ever be adopted as standard until it has been tested under conditions simulating as nearly as possible those which will be encountered in battle."

Admitting the failure of the Mark 6, as such, the Bureau retained faith in the principles upon which it was based. Even when no Pacific forces were using the influence feature of the exploder, the Bureau and Newport proceeded to produce successive modifications, so that a reliable weapon would be ready if a change of heart were experienced in the fleet. To supplement the efforts of the Torpedo Station, Admiral Blandy arranged developmental contracts with four additional research activities. By the end of the war two new influence exploders were considered ready for fleet trial.

Meanwhile, the Bureau argued the case for influence exploders before the fleet, pointing out that it could produce hits where incorrect settings would normally result in misses. In order to give the forces afloat a more realistic picture of what could be expected of the exploder, the Bureau distributed a new formula to guide its use, based on magnetic latitude, target course, degaussing conditions, target beam and draft, and the depth setting of the torpedo. All was to no avail. Modifications of the Mark 6, available by the fall of 1943, were regarded with suspicion afloat. Between the late summer of 1943 and the spring of 1944, the exploder was not receiving a fair trial in the Pacific; in the northern latitudes for which it was designed, the device was not used. After April 1944, it received no service tests at all. Although the Bureau soon corrected faulty design in the electrical feature of the exploder and continued to send improved stock to the fleet, the chances of getting the weapon reaccepted grew dimmer. By the late summer of 1943, complaints about duds joined those concerning prematures; when inactivation stopped prematures altogether, the full extent of outright duds was exposed. In many respects the ensuing problems were more damaging to morale and relations between the fleet and the Bureau than either the deep running or premature failures.

Almost from the beginning of the war complaints about duds had been interspersed with other torpedo criticism. Inactivation of the anticountermining device improved the situation somewhat, but after the influence feature of the Mark 6 was inactivated and the contact mechanism subjected to more severe use, the presence

of additional kinks became obvious. The origin of the problem lay back in the prewar years when inadequate testing hid the fact that exploder design was not keeping pace with changes in torpedo characteristics. In early type exploders the firing pin moved along the axis of the warhead, which meant that reliability was in direct ratio to the force of impact. In the Mark 6, however, design changes altered the relation between torpedo speed and exploder performance; the firing pin, actuated by a spring, moved vertically, or at right angles to the normal axis of the torpedo. The result was that a severe impact often produced sufficient friction against the leading edge of the pin to prevent its striking the cap quickly enough or with enough force to produce detonation. In other cases, the shock so deformed or displaced the guides that movement of the firing pin was restricted. Newport had not been blind to the problems posed by the new design. In the late 1930's the Station conducted tests of the device, then strengthened the spring to help overcome the increased friction. The expedient worked, but subsequent increases in torpedo speeds soon negated the improvement—a result that remained hidden until wartime use compensated for the inadequate peacetime testing.

Complaints from the fleet concerning duds were difficult to evaluate. Throughout the controversy over the adequacy of United States torpedoes and exploders, performance remained statistically good. In mid-1943, for instance, a report from ComSubPac showed only nine failures of contact exploders out of more than 1800 torpedoes fired by the submarines operating out of Pearl Harbor. During the same period, over 600 hits were reported. Neither the British, Germans, nor Japanese could boast of such an achievement. Of course the United States couldn't either, since the official reports did not jibe with the truth, but the report was made to, not by, the Bureau of Ordnance. Moreover, variations within our own forces suggested that human failures were being tabulated in the mechanical ledger. Some submarine skippers reported better than 60 percent hits, while others using the same equipment in the same theater registered hits for less than 10 percent of the shots fired. A further investigation of combat reports showed that 40 percent of all submarine attacks were made at periscope depth between the hours of 1900 and 0600, when conditions were not favorable for the precise estimation of enemy course and speed or of the results of shots fired.

Backed almost continually by favorable statistics, the Bureau's confidence in its weapons was slow to follow the downward curve of fleet estimation. Unfortunately, both torpedo performance and

the Bureau's attitude were exaggerated over coffee cups in Pacific wardrooms; among some submarine captains the feeling was soon prevalent that the Bureau definition of a dud was "a skipper's alibi to explain his miss." The attitude was the normal result of severe working conditions, but it was only partly justified by facts. Before the end of 1942, the Bureau recommended use of a stronger spring to actuate the firing pin for contact settings on the Mark 6 exploder, but was too involved with deep running, prematures, and production problems to recognize the full import of reported duds.

The gravity of the dud problem was demonstrated—even exaggerated—by an event of July 24, 1943, the very day that the controversy over prematures was climaxed by the official inactivation of the magnetic exploder for Pearl Harbor based ships. The submarine *Tinosa*, operating on patrol, sighted a giant Japanese oiler. Two initial spreads crippled and made a sitting duck of one of the largest tankers afloat. In all, 15 torpedoes were fired at the oiler; 12 known hits were claimed, yet the dream target drifted on. Only the first 2 spreads produced explosions. Saving 1 torpedo for investigation, the captain took the *Tinosa* back to Pearl Harbor. Within a month, still another story was added to the lore of Bureau critics. The submarine *Haddock*, after damaging a 10,500 ton tanker with 2 hits, fired 11 more torpedoes in 3 further attacks on the same ship without getting another explosion. The combined effect of the 2 stories added renewed emphasis to the search for an improved mechanism.

When an examination of the *Tinosa's* remaining torpedo proved it to be in good condition, Admiral Lockwood started a series of tests at the Pearl Harbor base that ran concurrently with the Bureau's own investigation. In Chesapeake Bay the Bureau fired torpedoes directly at armor plates suspended in the water and found that a direct impact produced more friction than the firing pin could overcome. At Pearl Harbor the submariners made the same discovery by firing into a cliff and by dropping inert-loaded torpedo warheads on steel plates from a height of 90 feet. While both series of tests gave the same results, the solutions attempted took different directions. Pending the development of a new exploder, the Bureau favored its former expedient of strengthening the firing spring; at Pearl Harbor, the submariners got similar results by lightening the firing pin. Since the submariners were justly proud of their solution of the problem, the Bureau of Ordnance endorsed the lighter pin, combined it with a stronger spring, and ended the series of misunderstandings about the Mark 6 exploder and the Mark 14 torpedo that carried the deficient mecha-

nism. Exploder development continued, however, and before the war ended 10 modifications of the Mark 6 were completed, a new magnetic exploder, the Mark 10, was available as a replacement, and a variety of influence exploders were in advanced developmental stages.

By January 1944 torpedo performance was almost uniformly good and the most controversial chapter in the history of United States wartime torpedo development ended. A lesser argument dating from the very outbreak of the war ran on, however, as an undercurrent to the interminable problem of supplying the fleet with exactly the weapons they required. Submariners suspected that even when they got hot, straight, and normal runs from their torpedoes, the weapon lacked sufficient punch. Their suspicions were stimulated by reports that both Russia and Japan used torpedoes that carried well over half a ton of explosives more powerful than the TNT with which the United States entered the war.

On the opposite side of the controversy were a few Ordnance theorists who considered the weight and content of warheads almost irrelevant to considerations of effectiveness. At the basis of their argument was the belief that although laboratory tests of different charges might show great variations, there was very little difference in their force when used underwater. That conservative theory was bolstered by a group of damage studies made by the Bureaus of Ships and Ordnance. Joint investigations in 1940 showed that 500 pounds of TNT were enough to break down two transverse bulkheads on an enemy capital ship, and that to destroy a third bulkhead would require more TNT than could be carried by a torpedo. The quarter ton charge common to United States torpedoes appeared vindicated.

Between tests that discouraged weight changes and a theory that discounted force variations among explosives, a reluctance to tamper with existing warheads was bred in certain quarters of the Bureau. Allied arguments came from officers who believed that it made almost no difference where a ship was struck and that, so long as it sank, the time factor could be disregarded. The state of mind was dangerous and it was hard dying. As late as June 1942, Admiral Blandy pondered a General Board hearing to relegate the ideas to the scrap heap. Fortunately, the theories were not so popular that the Bureau had to take drastic action. While the truth sifted through, more realistic planners were working on the problem of developing more powerful warheads without too great a sacrifice of horsepower minutes.

Prior to Pearl Harbor the proponents of larger warheads thought that lengthening the nose would have but slight effect on the characteristics of torpedoes. Overall dimensions could be but slightly altered, however, and the major problem was to compensate for the critical space additional TNT would require. Experiments centered around a shortening of the air flask compartments, but the results were not good. Both range and speed were reduced too much to justify the slight addition to the weapon's punch. Other efforts were directed toward the development of a composite torpedo, using the Mark 10 as a power plant but building it up to Mark 14 dimensions by the addition of an 8-foot warhead carrying 1600 pounds of explosives. Work continued on the project throughout the first year of war, but the weapon was never presented for service use.

Two successful expedients were found: limited additions to warhead dimensions, and the development of a new, more powerful explosive. By means of size increases, as much as 300 pounds of TNT were added to existing warheads. A related change was made by concentrating the explosive charge so that more power was obtained per cubic inch. The improvements in force proved expensive by contributing to the failure of general torpedo performance to live up to expectations, but once the kinks were removed the fleet was in possession of a more powerful weapon. Even more significant was the adoption of Torpex as a partial replacement for TNT. First used in the fall of 1942, the new explosive had half again the destructive effect of the conventional charge. Although more brittle than TNT and less immune to detonation from bullet or fragment penetration, Torpex proved safe enough for uses in both submarine and aircraft torpedoes. Thus, fleet demands for added punch were successfully met within the first year of war. Occasional charges that United States warheads were frequently subject to "low order" explosions drifted in to the Bureau throughout the war, but extensive high priority testing by the Bureau failed to lend credence to the criticism.

One beneficial result of the controversy that raged around the torpedoes with which the United States entered the war was the stimulus it gave to the development of other types. While the Bureau and Newport labored to improve the Mark 14, efforts to provide at least a partial replacement were redoubled. Most attention was given to production of an electric type, partly because it contained certain inherent advantages for submarine use and partly because it promised to pose fewer production problems than the more conventional steam torpedoes. The project was by no

means new to the Bureau of Ordnance; as early as July 1915, work had been initiated on the development of an electric torpedo.

Prior to the outbreak of World War II, work on the project was intermittent. The original specifications called for a torpedo capable of traveling 3800 yards at 25 knots and stabilized by the gyroscopic effect of the propelling engine. The Sperry Gyroscope Co. of Brooklyn, N. Y., worked on such a model throughout most of World War I, but in February 1918, just 4 months before the delivery date of a test torpedo, the contract was terminated. No satisfactory financial agreement could be worked out and the Bureau objected to proposals that amounted to underwriting any experiments the company considered necessary.

The obstacle proved to be the first of a long series that beset the project after it was returned to Navy hands. For a short while work was continued at the New London experimental station, but the postwar shrinking of facilities soon led the Bureau to move the embryonic torpedo and its personnel to the Newport Station. The site seemed well chosen, since a special board at Newport had already written tentative specifications for an electric torpedo. Once the entire project was centered in one location, the work enjoyed a short spurt. By the fall of 1919, Newport was ready to finish two torpedoes for experimental work. This progress was to no avail, however, because all attempts to produce a satisfactory battery failed. Before the obstacles could be overcome, both enthusiasm and funds were exhausted. For over 3 years, construction was limited to the pace of one machinist who worked on the electric torpedo only when he could be spared from routine duties.

Early in 1923 the popularity of electric torpedoes took an upward turn when intelligence reports showed that the Germans had made great strides with the weapon during the recent war. Foreign experience showed impressive advantages—no bubble or smoke trail, stability, economy, reduced overhaul—over steam torpedoes. Submariners were especially impressed by the wakeless feature, and the Bureau was interested in the possibility of cheap mass production of an item that usually required expensive hand work. Profiting from German developments, Newport made new test runs with the models they had completed in 1919.

Performance fell below Bureau specifications and German results. A good deal of the trouble stemmed from the incorrect winding of an armature, but the basic problem was still the lack of a battery powerful enough to give adequate speed and range. When a better battery solved those problems in 1924, the more

powerful torpedo proved too erratic to meet minimum standards for accuracy. Shop tests were invariably good, but proving runs belied the promise.

For 5 years a succession of changes was effected. New propellers, a gyroscopic control device, solenoid steering motors, new rudder throws, and an improved battery were added, and in the spring of 1928 the new torpedo, designated Mark 1, was ready for range testing. The results were tragic. The torpedo that represented 13 years of development was lost on the range. For 2 years the weapon defied every attempt to find it; when it was finally brought to the surface in 1930, the recovery was reported to the Bureau as "accidental." Work was resumed again, but results remained meager. Attention was shifted to an attempt to adapt electric propulsion to the Torpedo Mark 9, but again the project floundered on the battery problem. The Bureau, impatient of perennial delays, threatened to move the project unless Newport made more progress, but the basic obstacles were electrical, not geographical. Recognizing that fact, the Bureau concurred in a Newport recommendation and closed the project in 1931. The first phase of electric torpedo development ended with the Mark 1 nothing more than an empty title. Not for a decade was interest revived.

During the 10 years that the development of an electric torpedo lay dormant in the United States, the international outlook deteriorated. Finally, the outbreak of war in Europe required new and extensive work by the Bureau of Ordnance. One of the major problems was to plan for an adequate number of torpedoes. Looking abroad, the Bureau saw that once again Germany was obtaining good results with an electric model that could be turned out by assembly line methods. While experts held a low opinion of the military characteristics of such a weapon, production considerations alone offered ample justification for picking up the project that had been abandoned in 1931. The Bureau would have preferred that the entire project be handled by the General Electric Co., but that corporation was too busy with other contracts to accept the responsibility. A compromise solution was found, whereby Newport was assigned the development of control mechanisms, General Electric was contracted for the propulsion motors, and the Electric Storage Battery Co. (EXIDE) was given the job of producing a satisfactory battery for the projected Mark 2 electrical torpedo. By the fall of 1941 the preliminary negotiations were completed and a formal project order was submitted for ten experimental torpedoes. Half were to be of the Mark 10 type with 90 horsepower, and half of the Mark 14 type with either 90

or 120 horsepower. In each case, specifications called for a 21-inch torpedo capable of carrying 500 pounds of TNT over a range of 3500 yards at speeds between 33 and 35 knots.

As the popularity of the Mark 14 declined, Bureau enthusiasm for the Mark 2 rose. Early in 1942 the project was aided by the recovery of a German electric model which was shipped to Newport for study. Anxious to speed development, the Bureau instructed the torpedo station to abandon new and untried designs in favor of a copy of the German weapon if earlier production could be gained by the switch. A good deal was copied from the foreign discovery, but the project continued to stumble over the obstacles already familiar to the veterans of the 1920's. Divided responsibility did not help and the three interested plants were unable to coordinate their schedules. As the prospects for solving the torpedo crisis with a new electric model appeared to grow slim again, the Bureau decided on an entirely different course. Leaving Newport with responsibility for continuing the development of the Mark 2, the development and production of an electric torpedo was turned over to the Westinghouse Electric Manufacturing Co. on March 10, 1942. Designated Mark 18, the weapon was to be copied from the German model gyro, depth mechanism, and exploder, however, were to be the same as those in standard U. S. steam torpedoes. Newport was instructed to lend all requested aid to the firm before returning to work on the Mark 2.

By June 1942, Newport had finished machining pieces for the 10 Mark 2 experimental models ordered by the Bureau, but the motors were not available until fall. By the following summer the Mark 18 was ready for service use, so pressure to produce the Mark 2 was reduced. An order for 50 experimental models was placed because of interest shown by the British Admiralty, but the Bureau regarded the project largely as a means to work for the ultimate electric torpedo by incorporating the best features of the Mark 18 and subsequent electric torpedoes into the experimental Mark 2. The latter became a higher speed model with both controls and propulsion motors powered electrically. By the end of the war the Mark 2, redesignated the Mark 20, was ready for production. Powered by a 180-horsepower motor, the all electric model was considered capable of 40 knots to 8000 yards, with a potential payload as high as 1000 pounds. Only the success of the Mark 18 and the promise of other developments permitted the Bureau to keep the Mark 20 in an experimental status.

Of the several electric torpedoes considered by the Bureau, the Mark 18 alone was subjected to extensive service use. While it did

not equal the power and performance demanded of steam torpedoes, it possessed production advantages that made it popular with the Bureau. Almost immediately after the Bureau of Ordnance turned the project over to Westinghouse in March 1942, the firm made significant progress. Aided by access to Newport experience and a study of the captured German electric torpedo, the company was able to deliver test models within 4 months. The first results were not entirely encouraging, largely because torpedo construction required closer tolerances than commercial companies were accustomed to, but one by one the kinks were ironed out. One of the principal bottlenecks proved to be in testing. Observers usually watched torpedo performance from an airplane flying over the range, but the wakeless feature of the Mark 18 precluded that possibility. Night ranging of torpedoes equipped with headlights was attempted, but difficulties in recovering the weapons made the expedient unsatisfactory. On into the fall of 1942, work was retarded until sonic gear that could expose the ranging characteristics of the torpedo was perfected.

Another major problem was the usual bugaboo for electrical development—the lack of an adequate battery. A satisfactory model was found for interim use, however, and the Mark 18 was able to meet Bureau specifications by the spring of 1943. Since delays were inevitable anyhow, the Bureau decided to use the extra time to advantage by shifting the emphasis in the program from one of quick production to one of greater military desirability. The result was a torpedo capable of running 4000 yards at 29 knots. While a relatively low powered model, the weapon met the common tactical requirements for submarine use.

In the middle of May 1943, the first of the Mark 18's were issued to the fleet for service use. Even though the Mark 14 was suspect at the time, submariners were slow to accept the new weapon. Until new guide studs were placed in the tubes, the Mark 18 was susceptible to damage because of the quick starting characteristics of its motor; even after the alteration was made, the Bureau suggested that the new torpedo should only be used in port bow tubes. Since the use of two different weapons with different speeds and ranges on the same submarine would impose severe tactical limitations or fire control problems, the recommendation was not considered acceptable. Until the Bureau could solve the launching problem, most submariners preferred to use the unpopular but familiar Mark 14. Moreover, battery maintenance posed a real problem with the Mark 18, especially since explosive hydrogen tended to form within the compartment. After extensive experi-

mentation with various catalysts, the Bureau endorsed the use of coils in the top of the battery compartment to burn off the excess hydrogen. Each day the coils were lighted, air was blown in to support combustion, and the dangerous gas burned off. The expedient worked, but submariners were suspicious of the procedure. On at least one occasion, enough heat was generated to make the Torpex warhead melt and run. Until a better battery reduced the maintenance problem in the fall of 1943, the use of the Mark 18 by submarines was left on a voluntary basis.

By the spring of 1944 the first version of the Mark 18 was in large-scale production. While a few problems, such as deep running and a tendency to explode at the end of a run, still remained to be solved, most fleet criticisms had been answered. The popularity of the weapon climbed. Although steam torpedoes were still used more than electric ones during 1944, the tide turned by the end of the year. During the last 6 months of the war at least 65 percent of all torpedoes fired by submarines were of the Mark 18 type.

Before the first Mark 18 was issued for service use, still another electric torpedo was in the developmental stage at Westinghouse. The firm had ideas of its own about how an electric torpedo should be built, and on the basis of its experience with the Mark 18 and its German prototype, proposed a model of its own to the Bureau in late 1942. All electric controls and other departures from the Mark 18 specifications were planned for the new weapon. Impressed by the promise of a faster, cheaper torpedo that would require few firing adjustments and little maintenance, the Bureau requested experimental models for a Mark 19, built along the lines of the Westinghouse proposals. Although the Chief of Naval Operations and the Bureau both objected to the company's stipulation that the gyro be prespun before firing, the feature was accepted ad interim and a procurement order for 500 of the weapons was placed in mid-1943. Before many were produced, however, the performance of the Mark 18 improved to the point that the Mark 19 did not look sufficiently superior to warrant a switch in emphasis. Construction was held in abeyance pending a final decision; in the late spring of 1944 the Mark 19 joined the Mark 20 in the ranks of torpedoes designated as strictly developmental.

Meanwhile, a fourth electric torpedo had been conceived and developed to the point where test models could be built. This was the Mark 26, a fast, long-range torpedo designed to answer fleet requests for a speedy and powerful weapon. Equipped with a sea water primary battery that eliminated both the danger and care common to secondary types, the Mark 26 came very close to

meeting the standards proposed by the Bureau for its "ultimate" electric torpedo. A month before the end of the war a group of the new weapons were delivered to Newport for testing, but V-J Day and the promising status of Navol torpedoes kept the Mark 26 out of production.

In the design of torpedoes a major goal has always been to get the most possible horsepower-minutes from the least possible pounds of engine and fuel. The chief drawback of the electric torpedo was that batteries could not be produced which were capable of more than about one-third the horsepower-minutes produced by a conventional steam torpedo of the same size and explosive capacity. All countries with pretensions to naval pre-eminence attempted to beat the energy output of the steam torpedoes. Efforts have been along two general lines: to utilize chemical reactions not ordinarily thought of as combustion, or to retain conventional fuels, but supply the oxygen necessary for combustion in a more highly concentrated form than air, which is four-fifths inert nitrogen. The Navol cycle developed for United States torpedoes is properly classified in the second category, but its proposal in this country sprang from a research project intended to develop a torpedo propulsion cycle of the first type. Since the same project was continuous, the Navol is commonly referred to as a chemical torpedo.

The weapon which on the eve of victory seemed to offer more promise than the Mark 26 had a history paralleling in time that of the electric type. At Navy request, the Westinghouse Co. began experiments in 1915 to utilize the gas evolving processes of certain exothermic reactions for torpedo propulsion. Some early success was obtained, but budget variations made a permanent relationship with the private corporation impractical. After obtaining the Westinghouse patents on chemical torpedoes, the Bureau of Ordnance transferred the project to the Naval Research Laboratory in Washington. After a few years of experimentation with exothermic reactions, the original idea was abandoned in favor of an oxygen torpedo. Tank tests on early models proved successful, but a multitude of problems were exposed when the first torpedo was ranged at Newport late in 1931. The motor burned out and both the depth and steering mechanisms overheated and jammed. Leaving the mechanical work for further development at the Torpedo Station, the Laboratory then renewed work on the broad problem of propulsion. Despite an initial failure, the oxygen torpedo still promised three times as many horsepower-minutes as the steam type, plus greater flexibility in range and speed.

Two alternatives were open to researchers. Oxygen in excess of that carried by natural air could be supplied in a pure form, or in some relatively unstable compound that could be made to decompose and surrender oxygen at a controlled rate. England and Japan used the first system with success, but after a series of discouraging experiments the Laboratory decided that a hydrogen peroxide solution had the greatest promise for torpedo propulsion. In that decision the Laboratory unknowingly concurred with German scientists who, before the end of the war, powered both torpedoes and submarines with propulsion cycles utilizing the oxygen in hydrogen peroxide. Use of the solution offered two advantages that compensated for its greater weight: Not being under high pressure, containers for the liquid could be lighter than those required for pure oxygen; the reaction by which the solution surrendered oxygen was exothermic in itself. The water resulting from the decomposition of the peroxide posed no problem; it was no more than would have to be introduced into the cycle anyway to keep engine temperatures at a working level. The particular aqueous solution chosen by the Bureau was labeled "Navol."

Three years were spent in preparing a suitable power plant; then, in September 1937, tank and range tests were conducted with a converted Mark 10 type torpedo. Use of the Navol plant increased the range of the weapon 275 percent. Success gave impetus to the work, and similar tests were later made with a converted Mark 14 submarine torpedo. Carrying a stainless steel Navol tank, the weapon ran 16,500 yards at a speed of 46 knots. Encouraged by the prospects of obtaining a new high powered torpedo, the Bureau directed a close cooperation between Newport and the Laboratory and authorized the manufacture of 50 Navol propelled torpedoes. Specifications for the weapon, designated Mark 17, called for a 50 knot destroyer torpedo capable of carrying a 600 pound warhead for 16,000 yards.

While it stimulated general torpedo development, the attack on Pearl Harbor retarded work on the Navol torpedo. Although six experimental chemical models had been completed, Newport was too busy with construction of existing models to start construction work on the Navol torpedo before the spring of 1943. Sometime before work was actively resumed, the Bureau widened the project to include construction of a submarine torpedo, Mark 16, equipped with the same power plant as the destroyer type but built to the size of the Mark 14. Original specifications called for a range of 7000 yards at 46 knots, but after 59 units were produced the

range requirements was raised to 11,000 yards. Even though developmental work was not completed, both torpedo types were placed under production; by the end of the war the Newport Station had completed almost 1000 Naval torpedoes. A few of the torpedoes were shipped to Pearl Harbor in September 1945. With a heavy explosive load, long range, and high speed, these torpedoes were considered a promising answer to fleet requests for an improved weapon. Hopes proved unduly optimistic, but the potential of the weapon guaranteed continuing efforts to exploit the new propulsion cycle.

While submarines proved to be the most effective users of torpedoes, airplanes were close behind both in the quantity of the weapons expended and in effectiveness with them. Supplying planes with a reliable torpedo proved more of a problem than servicing submarines, both because the novelty of air use precluded long experience with the problem and because unique difficulties were inherent in aircraft torpedoes. The normal restrictions on torpedo design, such as the necessity for small weight and size coupled with the highest power commensurate with reliability, were intensified for aircraft torpedoes. Superimposed upon normal requirements were the need for withstanding the extreme shocks of high-altitude, high-speed drops, the need to comply with principles of aero- as well as hydrodynamics, and the problem of devising control gear that could take effect despite the forces of cavitation and deceleration which regulated torpedo performance as the weapon changed from an airborne missile to an automatic submarine. Even though specifications for explosive weight and desired speed and range necessarily froze many aspects of design, the rapid evolution of aircraft construction demanded a flexibility not required of torpedoes for surface or underwater use. Weight, a prime consideration for its own sake, also had to be considered in terms of displacement and trim, first for air, then for water.

Solution of the varied problems started at least as early as World War I, when the Bureau of Ordnance became interested in the potentialities of air warfare. Starting in 1915, experiments were conducted with launchings from aircraft and intelligence was gathered concerning all foreign developments in the field. For a short time the Bureau worked with a system whereby torpedoes were lowered from planes on a cable, then released at a predetermined altitude. Results were discouraging, however, and future experiments were with free flight releases. Between 1920 and 1923 a series of drops were made with modified Mark 7 submarine torpedoes. While perhaps as good as the torpedo planes which car-

ried it, the weapon had two distinct disadvantages for aircraft use: Built for use in submerged tubes, it lacked the structural strength to withstand the shock of high altitude release; its dimensions, 18 inches by 17 feet, gave it a shape that was hard to stabilize in flight. Even after modification increased the strength of the weapon, 25 feet appeared the absolute limit for release altitudes. The addition of a nose drogue to improve flight characteristics had such an adverse effect on ruggedness, that the benefits of the early structural changes were almost negated.

For a short time in the early 1920's development of a better weapon was stymied by a dispute over cognizance. The Bureau was not much impressed with the feasibility of using aircraft torpedoes against ships because of the tactical restrictions imposed by the low release altitudes, though it felt that radio-controlled condemned planes might use the weapon effectively. A joint Army-Navy Board finally convened to decide the issue, and in 1925 the Bureau was instructed to proceed with development. Although the Mark 7 was not without some promise of adaptability, the Bureau decided to institute a new project for a redesigned weapon. Specifications called for a 1-ton torpedo capable of carrying a 350 pound warhead 4000 yards at 35 knots. Dimensions were established at 21 inches by 18 feet, and the weapon was to be rugged enough to withstand a launching speed of 140 miles per hour at an altitude of 40 feet.

Almost immediately the Bureau found itself pushed in two different directions by the Bureau of Aeronautics and Newport. While aviators were enthusiastic about a new weapon, designed with the special requirements of aircraft in mind, the Torpedo Station opposed the new design. In the interest of standardization and decreased production problems, Newport favored routing further progress through additional modifications of the existing Mark 7 type. Success in making successful drops from 65 feet at 120 knots after eliminating the drogue by the use of balanced rudders placed Newport in a strong arguing position, and the Bureau stored its new specifications on the shelf for the time being. Bureau of Aeronautics desires were not so easily set aside, however, and late in 1929 a General Board finally ended the tug of war by recommending the development of a new torpedo for aircraft. Tentative specifications were even more demanding than those in the Bureau's recently shelved plans. The explosive charge was raised to 400 pounds while the overall weight was reduced to 1700 pounds. Although fatter by 2 inches, the new torpedo was not to exceed 13 feet 6 inches in length. Once the General Board decided the issue,

Newport dropped its opposition to the project and proceeded to build a model that approximated the Board's wishes. Work was speeded by adapting a new afterbody to the power plant and many of the parts of the existing Mark 10; by August 1930, the new type, designated Mark 13 by the Bureau, was well under way.

Subsequent development of the Mark 13 was retarded by a lag in the completion of the torpedo planes for which it was designed, by the Bureau of Aeronautics pressure for a 1000 pound weapon with great tactical flexibility, and by the inevitable process of weeding out successive defects. After war started again in Europe, however, uncertainty about the value of torpedoes as an aircraft weapon vanished and considerable strides were made to ready the unproved weapon for possible use. Before the attack on Pearl Harbor, the Mark 13 was issued to the service in a form that closely resembled the original specifications. While the General Board weight recommendations could not be met, the range of the torpedo was increased to 5000 yards at 33.5 knots and the weapon could be dropped at least 60 feet by a plane flying at 115 knots.

Although the Mark 13 was available when the Pearl Harbor attack came, it was not used effectively or extensively until almost 3 years later. The relatively low speeds and altitudes required for successful release were not destined to win popularity for the weapon. The operations at Midway emphasized the dangers involved and airmen complained bitterly of "the handicaps of obsolete tactical training, obsolete torpedo planes, and obsolete equipment." The last item in their indictment was a continual concern to the Bureau of Ordnance; although the basic similarity between the Mark 13 Mod 1 and the Mark 10 showed that the charge was overdrawn, the torpedo was not adequate for modern warfare until a series of alterations were effected.

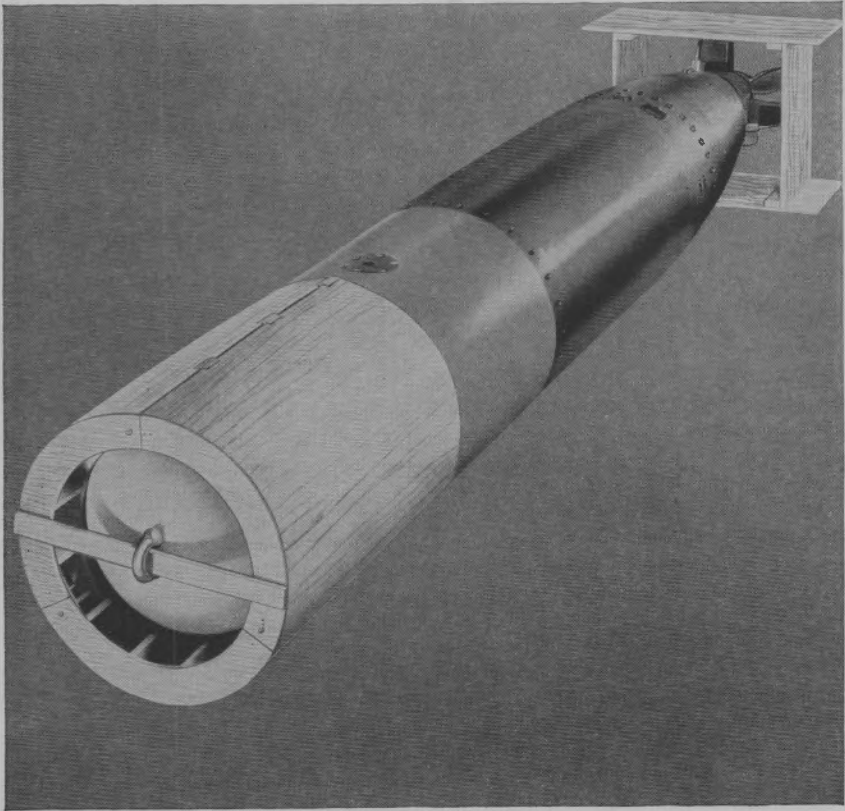
Like the Mark 14, the aircraft type went through a cycle of troubles. During the early months of use, left deflection was a persistent problem and demanded a change of the rudder throws. No sooner was that corrected than chronic depth failures were detected, the propellers were shown to be too weak to stand the shock of high speed launching, and the exploder mechanism required modification to keep it from arming in the air. Even when the apparent defects were eliminated by modification, the torpedoes remained unpopular with the men who had to use them. Underlying the problem faced by the Bureau was the fact that many failures which were attributed to poor design of torpedo components were really due to failure to control aerodynamically the angle of torpedo entry into the water. Until that was accom-

plished, delicate controls could not be made rugged enough to withstand the strain of water entry and other defects could be neither corrected nor detected. Changes in the tail surfaces, rudders, and head shapes failed to cope with that basic problem, and more drastic expedients were attempted. One method by which air stability was sought was to bolt plywood extensions to the horizontal vanes of the torpedoes. While that improved air stabilization in some cases, different extensions had to be used for different planes and each had its own speed and altitude limitations. Other vagaries further reduced their effectiveness; if the extensions were not dislodged soon enough, they ruined the water run of the torpedo; if they were dropped too soon, air stabilization was lost before water entry. In the spring of 1942 the best available solution seemed to be biplane extension stabilizers bolted to the torpedo vanes, but that was considered an expedient and not a solution to the continuing problem.

Despite the complications that were attending the other phases of torpedo development, the Bureau of Ordnance considered the aircraft torpedo problem so important that it was assigned the highest priority at the Newport Station. The improvements and modifications of 1942 and 1943 still left the weapon unpopular, however, and production problems were as great as those stemming from incomplete development. In mid-1943 an analysis of 105 torpedoes dropped at speeds in excess of 150 knots showed clearly why aviators distrusted the Mark 13: 36 percent ran cold, 20 percent sank, 20 percent had poor deflection performance, 18 percent gave unsatisfactory depth performance, 2 percent ran on the surface, and only 31 percent gave a satisfactory run. The total in excess of 100 percent proved that many torpedoes were subject to more than one of the defects, just as the bulk of the problems were still due to the effects of poor air stabilization on water behavior. Better performance at reduced aircraft speeds was small comfort since aviators could not be held down by paper restrictions that imposed serious and dangerous handicaps in combat. And even when they accepted the limitations, the water entry behavior of the torpedo produced frequent hooking and broaching. Time promised to complicate the problem still further. Unsatisfactory for existing planes, the torpedo would certainly fail to utilize the potentialities of aircraft then under development.

Confronted with such a problem the Bureau felt that it had two alternatives: it could accept the Mark 13 as an interim weapon with recognized tactical limitations and initiate the design of a new torpedo, or it could concentrate on eliminating the known

defects in the existing weapon. To attempt both might spread effort too thin to assure success in either venture. The first alternative involved predictable delay, since the Bureau estimated that 2 years would be required to move a weapon from conception to production. On the other hand, 12 known defects seemed to preclude immediate success in converting the Mark 13 into an effective aircraft torpedo. Neither alternative was considered alone, so the Bureau decided to increase its resources and follow both at once. The National Defense Research Committee was appealed to for aid, and in late 1942 it accepted a double-barreled order from the Bureau. The Committee was given a blank check to produce a new aircraft torpedo, the Mark 25, for tactical use at 350 knots launching speed, and it agreed to aid the Bureau in making immediate improvements to the Mark 13.



New planes outdated Torpedo Mark 13, but drag rings and stabilizers renewed its usefulness.

Throughout 1943 torpedo performance remained poor, but the following year witnessed a revolution in the behavior of the Mark 13. Minor changes to the propeller blades and a reduction in gyro damage helped, but the greatest improvement resulted from the stabilizing effects of two appendages—the drag ring and the shroud ring.

The first assembly, known familiarly as the pickle barrel, was readied for use by 1944. Early experiments with parachutes attached to aircraft torpedoes had demonstrated that a drag had a beneficial effect on the airflight characteristics of the weapon. While parachutes did not appear the solution to the problem, discovery of the principle involved led to the development of the drag ring. Constructed of plywood, the ring was attached to the head of a torpedo and served as a stabilizer for the period that the weapon was airborne. Oscillations were reduced and the ring effected a 40 percent deceleration in air speed, then acted as a shock absorber when the torpedo struck water. Better water entry, a byproduct of air stabilization, reduced damage so substantially that pilots were able to increase the heights and speeds at which torpedoes were released.

The drag ring went a long way toward making the Mark 13 a reliable torpedo, but underwater performance still called for improvement. By midsummer 1944, however, the shroud ring developed by the California Institute of Technology completed the torpedo revolution that had seemed so remote the year before. Almost an exact duplicate of an assembly developed by Newport in 1871, the shroud ring was made to fit over the tail blades of the torpedo. Known to pilots as the ring tail, it produced a steady water run by reducing hooks and broaches and eliminating much of the water roll which characterized the Mark 13. Speed and range were reduced but slightly. Early tests showed that ring-tailed torpedoes took too deep an initial dive, but readjustments of controls soon remedied that last obstacle. Hot, straight, and normal runs approached 100 percent, and the once critical battle reports soon became enthusiastic in praise of the Mark 13. Even psychologically the appendages contributed to success, since the external design of the torpedo equipped with a pickle barrel and ring tail and the improved appearance of its underwater travel caught the fancy of the airmen.

To speed the availability of the modified torpedo the Bureau built tail assemblies with the shroud ring attached, then sent them to the fleet as substitutes for the equipment on hand. By the fall of 1944 the revamped weapon had a wide distribution. As a

result of the new improvements, torpedo drops at altitudes up to 800 feet and at speeds up to 300 knots were authorized. Experience soon indicated that these limits could be extended even further. On one occasion in early 1945, 6 Mark 13 torpedoes were released from altitudes between 5000 and 7000 feet; 5 out of the 6 were observed to run hot, straight, and normal. Combat use increased rapidly and the new effectiveness seemed out of all proportion to the changes made. On one air strike on April 7, 1945, Mark 13's sent to the bottom the 45,000 ton battleship *Yamato*, a light cruiser, and several destroyers. Months before the end of the war the Mark 13 was universally accepted as the best aircraft torpedo owned by any nation.

Meanwhile, both the Bureau and the National Defense Research Committee were pushing projects to develop new and superior weapons for aircraft use. Before the end of the war the Mark 25 was going through extensive tests, and concurrent developments in chemical, electric, and jet propulsion promised succeeding revolutions in torpedo warfare.

The early failure of old weapons and the later promise of new ones naturally focused attention on torpedo development, but production problems were scarcely less challenging. The weapon seemed especially ill-suited to the mass production techniques demanded by wartime expenditures. During World War I torpedoes were produced by the Naval Torpedo Stations at Newport and Alexandria, and by the E. W. Bliss Co. which had figured so prominently in the early story of torpedo development in the United States. With the end of the war the Bureau contracts with the private firm were terminated, though all Navy facilities were kept in operation to supply the ships that were under construction at the time of the armistice. After the Washington Naval Conference of 1922 reduced the number of capital ships for the main navies of the world, a further reduction in torpedo production capacity was feasible. Newport was chosen as the sole site for both production and development, and the Alexandria Station was inactivated. Between 1923 and the early days of the national emergency, Newport remained the only source for torpedoes.

For a full decade budget restrictions and lack of interest in naval power kept both development and production in low gear, but 1933 brought significant changes. The Vinson Shipbuilding Program inaugurated in that year called for an increased output of torpedoes to fill the tubes on new ships as they were sent to the fleet, and required an expansion of both personnel and facilities at the Newport Station. During the next 5 years, approximately

\$750,000 was spent for new construction and over \$500,000 was allocated for new machine tools. Total annual expenditure at the Station rose to \$7,450,928 in 1936, then to \$9,305,536 in 1937. Translated into actual items, the expenditures represented a production increase to 2½ torpedoes each working day. In spite of that production, demand ran ahead of supply and by January 1938, Newport had a backlog of orders which totaled over \$29,000,000. Even those estimates which anticipated no outbreak of war in the meantime indicated that existing production rates would find Newport 2425 torpedoes short by July 1, 1942. An immediate need for new facilities was obvious.

A preliminary study of possible new production sources narrowed the range of Bureau choice to three locations—Newport, Alexandria, or San Diego. Despite pressure from a variety of New England sources, the Bureau considered a further expansion of the Newport Station inadvisable. From a military point of view a concentration at one point seemed unwise unless it could be accompanied by expensive defensive installations. Moreover, a 50 percent increase in Newport's output would require \$4,500,000 and 1½ years to achieve. San Diego, too, was ruled out. While there were advantages to be derived from the establishment of a plant on the west coast, the estimated 3 years required to start production in a new location was too great a delay in view of the critical status of the torpedo program. The Bureau decided that the most expeditious as well as the most economical way to attack the problem was to reopen the station at Alexandria. Buildings valued at \$1-745,000 were already in existence and an excellent proving ground was available at nearby Piney Point. Also, the military defense provided for the Capital would afford a high degree of security for the neighboring station.

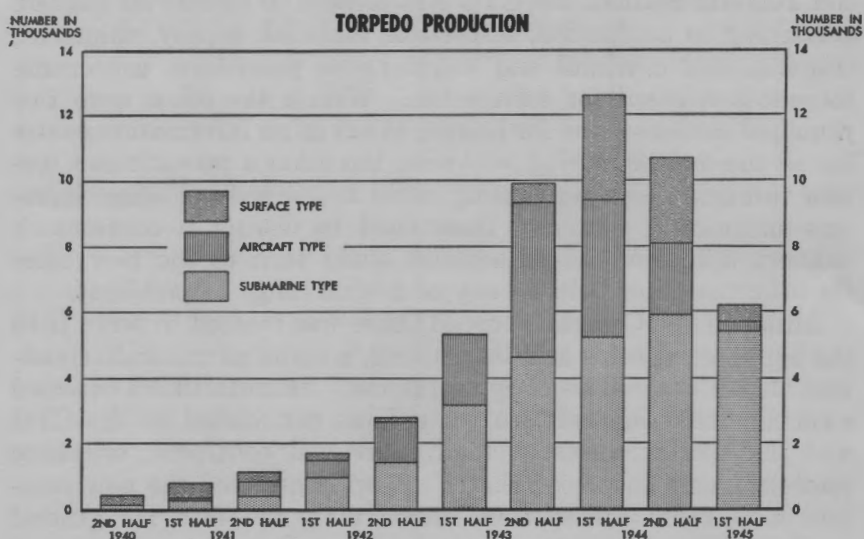
No sooner was the plan announced than the full weight of New England opposition was felt. Both political and labor leaders demanded an expansion of the Newport Station. Letters whose common inspiration was reflected in repetition of misstatements and fallacious reasoning poured into both Congress and the Bureau; opposition was so strong that there was real doubt that an appropriation could be secured for the reopening of the Alexandria Station. Fortunately for torpedo production, it was found unnecessary to get special authority for the project. Since Alexandria had been designated a part of the Naval Gun Factory in 1923, funds for its rehabilitation were simply included in the Gun Factory budget for 1939. Additional capacity was provided by an expansion of the Naval Torpedo Station at Keyport. Never used for production

since its establishment in 1914, that station nevertheless proved its value by the manufacture of spare parts, conversion of older torpedoes, and the ranging of weapons produced elsewhere. Although torpedo production was still low—3 a day—when the national emergency was proclaimed in September 1939, an investment of almost \$7,000,000 assured early improvement.

No expansion of commercial facilities for the production of complete torpedoes accompanied these first moves, but the heavy forging capacities of Bethlehem, Midvale, Crucible, and American Locomotive were soon expanded to meet increasing demands for air flasks and bulkheads. More industrial progress was made in July 1941, when the Bureau adopted the welded flask developed by the A. O. Smith Co. This production technique saved countless man and machines hours, released critical forging facilities for other essential programs, and conserved huge quantities of valuable high alloy steel. Prior to this innovation, which was unique to American torpedo manufacture, the air flask was made by one of two expensive techniques. It could be fabricated from a solid billet of steel weighing in excess of 13,000 pounds, drilled, forged on a mandrel, rough turned to 4 inches wall thickness, then machined to final dimensions; or a disc of similar weight could be cupped and drawn into a long cylinder, then machined to final dimensions. The latter represented a marked improvement over the more tedious method, but both were costly operations. The new welding process required but 5400 pounds of metal, was cheaper, and speeded the availability of this vital equipment.

Despite significant advances in delivery rates, pressure continued to build up in the torpedo program. Shipbuilding schedules were repeatedly accelerated and small torpedo craft were built faster than the weapons they were designed to carry. To meet the demands of the program the Bureau decided to adopt a new policy and consider the torpedo a production item rather than a tool-room job. The new attitude made available to the Bureau the facilities of firms whose normal peacetime business was in mass production. The first contract for the private production of torpedoes was made with the American Can Co. to construct and operate, as an agent for the Navy, a large torpedo plant at Forest Park, Ill. Requirements by this time were up to approximately 50 torpedoes per day, so while private reinforcements were on their way the 2 torpedo stations were ordered to increase their output. For Newport and Alexandria this meant installing additional machinery and recruiting personnel to man 3 full shifts on a 7-day-a-week basis. Thus strengthened, the 2 stations could between them account for about 23 torpedoes a day.

Following the declaration of war, torpedo requirements were again revised sharply upwards. Added impetus was given to torpedo production because we were at war with Japan, a strong maritime power against whom we had for a time only two weapons—aircraft bombs and torpedoes. With few aircraft carriers available early in the conflict, submarines and their torpedoes were destined to carry the burden of the war against the Empire. Moreover, the British increased their requirements and additional appeals were received from the Dutch and the United States Army Air Force. Even greater reliance had to be placed on private enterprise to meet the new demands, and contracts followed one another in rapid succession. The American Can Co. agreed to turn over a St. Louis plant which they were in the process of building in addition to the Illinois plant already covered by Bureau contract. Both NOP's were operated by the Amertorp Corp., a subsidiary of American Can. In February 1942, the Pontiac Motor and the International Harvester Cos. were asked to manufacture the British aerial torpedo for which large requisitions had been placed.



A few months later these plans were changed and contracts were placed with these two companies for the manufacture of the Mark 13 aircraft torpedo. In May 1942, Westinghouse was given a letter of intent for the production of electric torpedoes. Meanwhile, the two manufacturers with contracts for the British torpedo, E. W. Bliss Co. and the Precision Manufacturing Co., were asked to accelerate their programs. No other sources for complete tor-

pedoes were added during the course of the war. Increased demands were met by expanding facilities at the existing plants and by an extensive subcontracting program. At one period Newport was supplied by over 750 subcontractors and Alexandria was receiving parts from over 550 suppliers. One of the NOP's received machined parts and forgings from 350 subcontractors.

As necessary as the rapid expansion into the commercial field was for the success of the vital torpedo program, it introduced a whole new series of problems for Bureau solution. Centralized control was essential to assure that specifications were met by contractors new to the field of ordnance work, but this was difficult to achieve when over a hundred firms might be involved in the production of a particular item. Moreover, the ever-changing war picture required a constant review of existing contracts so that new needs could be anticipated and met. To solve the problems attendant upon a sprawling industry, the Bureau of Ordnance established the Central Torpedo Office in May 1942. Located at Newport and directed by the commanding officer of the Torpedo Station, the CTO was created to handle all matters pertaining to production, inspection, material, supply, shipment, training, and overhaul and maintenance procedures concerning torpedoes released for service use. Within the office were two principal sections—one for liaison, to act as an information center for all the manufacturing activities, the other a procurement section through which purchasing could be centralized when shortages or priority problems threatened to disrupt a contractor's delivery schedule. Manufacturers could turn to the new office for information or help on any of a wide range of problems.

Although the Central Torpedo Office was created to serve both the commercial firms and the Bureau, a series of misunderstandings almost negated its early usefulness. Manufacturers detected a certain confusion between the policies enunciated by the CTO and the specific terms of their individual contracts; ordnance establishments suspected that Newport considered the new creation a personal convenience rather than an office for general service. The agency created to keep the Bureau in close touch with a sprawling industry threatened to have the opposite effect. Early in 1944 the Bureau made some progress in clarifying the situation by a statement of policy, from which the following is quoted:

"The Central Torpedo Office, under the direction of the commanding officer, Newport, is to be the agent of the Bureau of Ordnance and channel policies of the Bureau to all activities.

Central Torpedo Office will carry out in detail Bureau directives and insure that the program and schedule as set up by the Bureau is met. This does not prevent officers in the field from going directly to the Bureau; it does not prevent officers in plants from going directly to the Bureau and asking for a change, or objecting to a decision made by Central Torpedo Office. No one in Central Torpedo Office will take any action whatsoever to prevent this direct contact with the Bureau. Bureau directives, will, however, be channeled through Central Torpedo Office in order to coordinate the whole program and to prevent conflict in the field."

Once the function of the office and its relationship to the Bureau were more clearly established, misunderstanding and bad feeling diminished. Throughout the last year and a half of war the adverse effects of decentralized production were counteracted by a coordinated control.

In the period from January 1, 1939, to June 1, 1946, the Bureau of Ordnance produced and ranged 57,653 torpedoes for United States forces. The cost of the program, including expansion of facilities, was close to \$700,000,000. Of this impressive total of torpedoes procured, Newport produced 18,751; Alexandria, 9920; Westinghouse, 8250; Forest Park, 8391; St. Louis, 6257; Keyport, 795, and Pontiac and International Harvester, 5289.

Torpedo tubes, like the weapon for which they were designed, posed a tremendous production problem for the Bureau of Ordnance. Until shortly before the outbreak of war, the Naval Gun Factory was able to supply the Navy's needs, but as the ship-building program mushroomed the capacity of the plant was outstripped. If ships were not to be delayed for lack of ordnance material, outside sources had to be tapped. Fortunately, tubes were much easier to procure through private contractors than torpedoes, which required a mechanical duplication of hand worked precision. In all, 7 prime and several times as many subcontractors joined 2 ordnance plants in producing tubes in mountings that ran from single to quintuple. The usual problems accompanying wartime production beset the program, but except for small torpedo craft, ships were not withheld from action for lack of the vital equipment. PT boats represented a special problem. Built faster than the torpedoes they were designed to carry, the small craft threatened to deplete the critical supply of 21-inch torpedoes. A solution was found by substituting a side launching rack for the single-tube mount originally built for the vessels. With the new rack, PT boats could fire either 21- or 22½-inch torpedoes. For a short while manufacturing difficulties at the

A. C. F. Brill Co. and the need to redesign the racks for bridge firing posed a bottleneck in PT schedules, but the new equipment proved itself in combat.

Throughout World War II, circumstances tended to emphasize the gloomier aspects of the torpedo story. Quantity and quality were both admittedly inadequate, and those were deficiencies which could not be corrected quickly enough to avoid the creation of an atmosphere compounded of controversy and recriminations. *The overall problem was accentuated by the fact that the Navy's first offensive torpedo warfare had to be waged against a great maritime power.* During the course of the first year and a half of war, however, almost every one of the plaguing defects was eliminated, so that efficient torpedoes contributed heavily to the eventual defeat of that enemy. For the most part, they were the same torpedoes with which the United States entered the war, though the later modifications were far more efficient and reliable weapons than those carried to sea in the first months after the attack on Pearl Harbor. Very naturally, attention was attracted primarily to those Bureau efforts which produced a happy ending to a hectic story. But a concentration on specific achievements to the exclusion of developments that could not be measured in terms of service weapons slighted an important sphere of Bureau activity. As a part of the campaign to improve or replace existing torpedoes, the Bureau sponsored a variety of research programs which, after contributing to the solution of immediate problems, pointed the way to further developments in underwater ordnance. Some were on the verge of realization when victory removed the need for haste; others merely indicated the direction that subsequent torpedo development would take. The future looked bright.

Chapter 7

DEPTH CHARGES

JAPANESE airplanes plunged us into World War II, but once the conflict was underway German submarines proved an even greater menace to the Nation. As a matter of fact, the threat antedated Pearl Harbor by some months. Regard for international law was shortlived with the Nazis, who considered neutral ships fair game for the torpedoes and shellfire of their underwater fleet. United States merchant ships thus became the Nation's first casualties. The danger grew after mid-1941, as U-boats, driven farther to sea by land-based planes from England, began operating closer and closer to American shores. By fall the situation was serious enough to demand action, and on September 15, 1941, the United States Navy entered the antisubmarine war by contributing ships for escort duty with transatlantic convoys. This was a defensive move, but it was war. That fact became obvious the very next month when two United States destroyers the *Kearny* and the *Reuben James* were torpedoed by German submarines. The nature and extent of the menace was clear.

"I will show that the U-boat alone can win this war," Admiral Doenitz boasted in 1940, and the events of the next 2 years did little to prove him wrong. Germany had some 200 fleet-type submarines when the United States entered the war. A production rate of 20 a month guaranteed a rapidly expanding armada, and the conquest of Norway, Holland, Belgium, and France afforded ample bases for the Reich Fleet. From those ports the U-boats emerged singly and in wolf packs to comb the oceans in search of prey. British shipping suffered heavily from the outset and after Pearl Harbor the United States was confronted with the full impact of Admiral Doenitz' threat. Not only were transoceanic voyages jeopardized, but the very coastal lanes of the United States were invaded by the enemy craft. Each day brought reports of tankers and freighters sent to the bottom by torpedoes. In the single month of January 1942, 14 ships were sunk along the eastern sea frontier. The war was brought home to America. Even that Navy lake, lower Chesapeake Bay, proved vulnerable to enemy submarines that broached the defenses to plant mines in an area of heavy traffic. The ports of New York, Wilmington, Charleston,

and Jacksonville were all closed at one time or another because of the presence of submarine-laid mines.

The industrial genius of the Nation performed miracles of ship-building, but it seemed a losing battle. Germany built a score of U-boats each month, and each submarine seemed capable of sinking a score of ships before its own destruction. Here was a problem of the first magnitude. The effectiveness of United States participation in the war depended on breaking the underwater barrier thrown up by Axis forces. The logistical situation was such that approximately 70 tons of supplies had to be shipped each year for every soldier maintained in Europe. That required about 6 gross tons of shipping each month for each soldier, or a fleet of 30 million gross tons continuously at sea for the maintenance of an overseas force of 5 million men. The preservation of even a small margin of safety demanded prompt relief from the heavy losses.

While the problem was mainly an Atlantic one, the threat was by no means localized. Mother submarines equipped with fuel, food, and torpedoes, were able to supply the U-boats at sea, permitting them to extend their destruction. The Caribbean and Gulf of Mexico were invaded in force. The Pacific was safe only by comparison. Within 3 weeks after Pearl Harbor the United States lost nine ships to U-boats of the new enemy. With a total of only 70 fleet submarines at sea during the war, the Nipponese threat did not match that of the Third Reich, but it concentrated its attacks on naval vessels and served as a cement for the sprawling empire of the rising sun. It was no mere accident that the destruction of the Axis undersea power coincided with the turning of the tide of battle on and above the surface of sea and land.

At the outset of the war the primary antisubmarine weapon was the depth charge. Known as ash cans because of their appearance, the charges consisted of cylindrical drums containing cast TNT. Inserted in opposite ends of a tube that extended through each case were a booster extender mechanism and a pistol. The former was designed to arm when exposed to sufficient hydrostatic pressure, while the pistol contained a percussion detonator that fired when the water pressure corresponded with the depth setting on the scale. Depth charges could be set to explode at any of seven specified depths from 50 to 300 feet.

The weapons were products of World War I, when German submarines posed their first threat. The charges were originally thrown from slings on the stern of destroyers, but the course of the war led to the development of multiple launching racks for rolling them off the stern and Y-guns for projecting them abeam.

Simple to manufacture and use, depth charges were efficient enough at a time when attack doctrines were based on the destruction of submarines that had been sighted on the surface or at periscope depth.

The first of the depth charges considered by the Bureau of Ordnance for World War I was a complicated design for a cylindrical device that divided into two sections when launched. A float remained on the surface, attached by a cable to the explosive container. The sinking motion unwound the reel of cable which measured off the depth of the charge and actuated an explosion when the cylinder reached its set depth. The design proved too complicated for service use. Depth was obviously restricted, and the 50 pounds of explosive carried by the case was too small for effective use. The war was actually fought with two hydrostatic type charges, Marks 2 and 3. The first of these carried 300 pounds of TNT to depths as great as 200 feet; the second employed an improved pistol and booster mechanism in order to detonate at controlled depths to 300 feet.

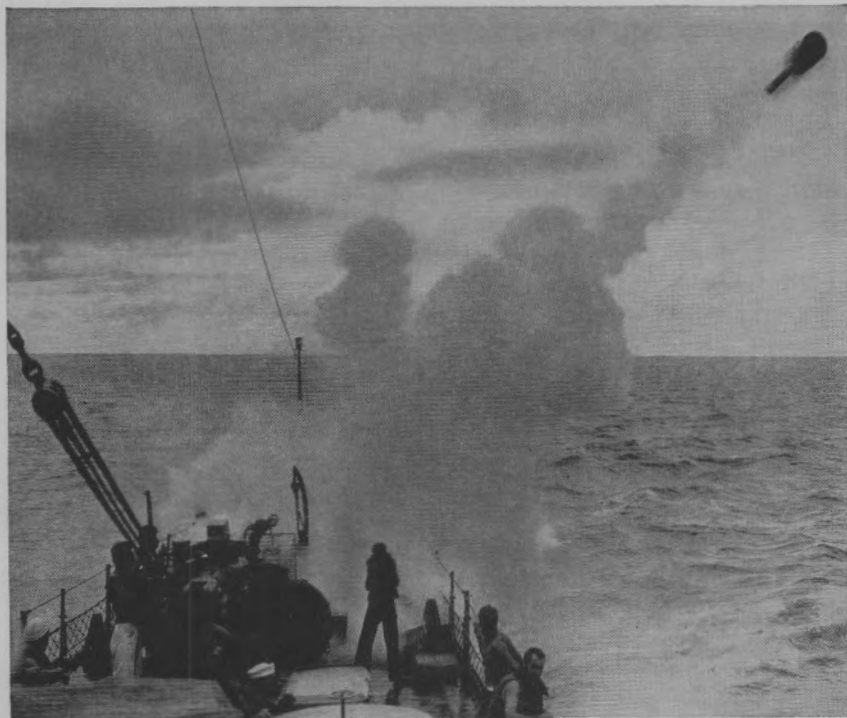
While depth charges were anything but the war's most efficient weapon, they maintained their position as primary antisubmarine armament. The experiences of World War I dictated the direction of postwar developments. Increased power rather than radically new designs seemed the logical route to improvement. In 1919 the goal was achieved with the Mark 4 depth charge, an ash can containing 600 pounds of TNT, but otherwise resembling the weapons already proven against enemy submarines.

Development deviated from the established trend in the early 1920's when the Bureau worked on a charge designed for use with a mortar that could be directed in elevation and train, but the attempt was prophetic rather than fruitful. This Mark 5 depth charge remained on paper and developmental efforts quickly returned to the more familiar pattern. Before the outbreak of World War II, two additional ash can type charges, Marks 6 and 7, were added to the Navy's arsenal. These were essentially improved versions of the Marks 3 and 4, respectively. Designed in 1937, the two weapons were of simpler construction than their predecessors, and took advantage of new production techniques perfected in the interwar years. When the renewal of war demanded large numbers of depth charges the relative ease of manufacture proved a boon to the Bureau and its contractors, but the changes added relatively little to the Navy's power to strike at submarines. The sinking rate of 8 feet per second for the lighter charge and 9

feet per second for the Mark 7 represented an improvement, but the explosive weight and maximum depth settings remained at the old figures.

More important than these minor improvements was the development of new projectors and submarine detection equipment. The Y-gun of World War I vintage was designed to straddle the centerline of ships and simultaneously throw charges to both sides, thus broadening the pattern of charges which were rolled off the stern. The disadvantage of the projector was its location, which obviously limited the number of installations that could be made on a ship. In June 1941 a new projector, the K-gun, was developed by the Bureau. This equipment, like its predecessor, took its popular name from its peculiar shape. The vertical shaft of the K-gun comprised the base and an expansion chamber. The lower bar of the K was merely a mount and support for the barrel and breech mechanism of the gun.

When used with projectors, depth charges were strapped to trays known as arbors. A stem protruding from the bottom of the cradle-



Two primitive weapons, the Y-gun and the depth charge, helped defeat Axis U-boats.

shaped tray served as a piston that fitted into the cylinder or barrel of the gun. A propellant charge loaded through the breech could be fired either electrically or by percussion to project the arbor and charge off the beam of the ship. Destroyers, destroyer escorts, submarine chasers, minesweepers, and patrol vessels were equipped with K-guns. The Cameron Iron Works, Houston, Tex., manufactured the projectors, and they quickly superseded the older Y-gun. Improved models that featured a retractable arbor operated through a gas recoil system were developed for the Bureau during the course of the war, but the new devices never saw service use.

Far more important for antisubmarine warfare was the development of detection equipment that could hunt out submerged U-boats. Underwater listening devices that could detect and indicate the bearing of a submarine were devised for use in World War I, but the system was so rudimentary that only 20 percent of the submarines destroyed during the war were actually detected beneath the surface. The origin of a better system was worked out in England as early as 1918, but the new equipment was still in an experimental stage at war's end. Originally called ASDIC after the initials of the Allied committee that developed the equipment, the new method was one of echo ranging. Sound waves were transmitted through the water. When the energy struck a submarine hull an echo bounced back to a receiver, providing both the range and bearing of the enemy craft. By 1930 both England and the United States had exploited the new techniques to provide practical detection gear. This sonar equipment, as it was called by the United States Navy, was continually improved, but it suffered from many limitations. At best, its range was from 1000 to 1500 yards, and average conditions reduced that figure to something between 600 and 800 yards. Range and depth determination were uncertain and proved weak points in attacks on submarines.

Unfortunately, the depth charges and detection gear with which the Navy entered World War II were not complementary. Sound contact with submarines was lost when an attacking ship came within approximately 300 feet of the enemy's position. Since charges were thrown abeam or dropped astern, the submarine was granted valuable evasion time between the beginning of an attack and the actual launching of weapons. The blind time was further increased by the slow sinking rate of the charges, just as accuracy was made impossible by the uncertain trajectory of the ash cans. The situation was made even more discouraging by the fact that the explosion of the charges as they reached their depth created

so much turbulence that the recovery of sound contact with the submarine was delayed. Thus an unsuccessful attack created cover conditions that handicapped succeeding attacks.

The techniques and the ordnance for antisubmarine warfare were inadequate. The Navy was aware of that before the United States joined the war against the Axis. In the fall of 1940 the Navy Department asked the National Academy of Sciences to survey the whole problem and make recommendations for the improvement of antisubmarine tactics and ordnance. The Bureau of Ordnance and Ships, the Coordinator of Navy Research and Development, and the National Defense Research Committee also initiated projects to study the whole subject of underwater warfare. The civilian reports, along with the experience of the Allied Powers, provided an outline for action.

As far as ordnance was concerned, attention was directed toward developing ahead-thrown weapons that could be launched before sound contact was lost, and toward improvements to depth charges. The model for a projector was readily available. England, faced with the submarine menace much earlier than America, had been working for several years on a multiple charge, spigot type projector known as the Hedgehog. This was a heavy equipment designed to replace a forward gun mount and throw out a pattern of 24 contact charges, each carrying 31 pounds of high explosive. The Bureau of Ordnance followed its development closely, but imitation was discouraged by the Admiralty's low estimation of its own weapon. The price of installation was the loss of a forward gun mount, and the tremendous thrust of the projector precluded its use on small vessels. On the other hand, the Hedgehog was well suited for use with existing detection gear. Its contact fuzed charges avoided turbulence on an unsuccessful attack; its range was sufficient to reduce by two-thirds the blind time encountered with conventional depth charges.

Clumsy as it was, the weapon proved of great value after the outbreak of war provided combat testing. Since British experience and United States research both indicated the desirability of ahead-thrown weapons, the Bureau determined early in 1942 to make a copy of the English equipment. The result was the A/S Projector Mark 10, which deviated from its foreign counterpart enough to gain greater strength and flexibility. The United States' version of the Hedgehog contained 24 spigots, each of which held a small impact-fuzed depth charge. In comparison with the explosive capacity of conventional ash cans, the 31 pounds of TNT carried by Hedgehog ammunition seemed insignificant, but it was

powerful enough to inflict lethal damage on contact with a submarine hull. The 24 charges, fired in pairs, produced a roughly elliptical pattern some 250 yards ahead of the attacking ship. When used in conjunction with conventional depth charges thrown abeam and dropped from the stern, a large volume of sea was made dangerous for the enemy. The A/S Projector Mark 10 offered the additional advantage of controlled fire. A target designation transmitter and a gun train indicator, both based on British models, provided a measure of control that was rare with antisubmarine ordnance.

Production of the new equipments began late in 1942; by the end of the following year the Hedgehog was the primary antisubmarine weapon in the fleet. From the beginning, its effectiveness proved to be twice that of depth charges. Training and combat experience enhanced its value still more. In mid-1944, statistics showed that eight percent of the Allied Hedgehog barrages were successful. A year later the figure had risen to nearly 10 percent. Part of the explanation was that Hedgehogs were not generally employed unless attack conditions were favorable, but much of the advantage was inherent in the weapon. The principal disadvantage of the Hedgehog was a recoil force of 40 tons. Small craft obviously could not tolerate such forces, yet the investigation that indicated the requirement for ahead-thrown weapons also pointed up the need to expand the Nation's antisubmarine fleet by bringing small craft into the fray. The two recommendations seemed mutually incompatible. The Bureau faced a dilemma familiar in ordnance work.

Fortunately, the problem had been anticipated and its solution ran concurrently with the development of an Americanized Hedgehog. The National Defense Research Committee, working under Bureau contract, tackled the assignment late in 1941. Rocket propulsion, already exploited to provide airborne antisubmarine weapons, seemed the obvious expedient. The absence of recoil circumvented the obstacle to mortar type projectors. The NDRC project thus became an attempt to combine the respective virtues of the Hedgehog and rockets. By the spring of 1942 the solution was at hand in the Mousetrap, an antisubmarine projector that launched a salvo of sixteen 7.2 rockets ahead of the attacking ship. Though never as effective as the Mark 10, the A/S Projectors Mark 20 and 22 did for small craft what the Hedgehog accomplished aboard larger vessels.

With the installation of ahead-thrown weapons in the fleet the Bureau met one of the principal requirements for the fight against



Hedgehog bombs ready for action and in the air.

Axis submarines, but a great deal remained to be done. Even when they were reduced to a secondary role, depth charges remained important. Vessels that used the new projectors still needed charges to complete an effective pattern. Moreover, hundreds of ships could use only depth charges.

The Marks 3, 4, 6, and 7 depth charges with which the fleet was equipped at the outbreak of war were obviously inadequate. The first two were products of the World War I period, and the last were but slightly improved versions of the first. Combat quickly proved their ineffectiveness. In the first few months of war only 5 percent of the carefully executed depth charge attacks proved successful. Normal combat conditions reduced that figure to 3 percent. Theoretical studies indicated an even bleaker picture. The lethal probability of a nine-charge pattern of Mark 6's—the type with the widest distribution—was estimated at 0.05 for 150 foot settings, 0.03 at 300 feet. Thirteen charges set for the same depths only raised the probability of a kill to 0.07 and 0.04, respectively. Compensation had to be found in the use of great numbers of charges set for various depths and designed to saturate a large volume of sea.

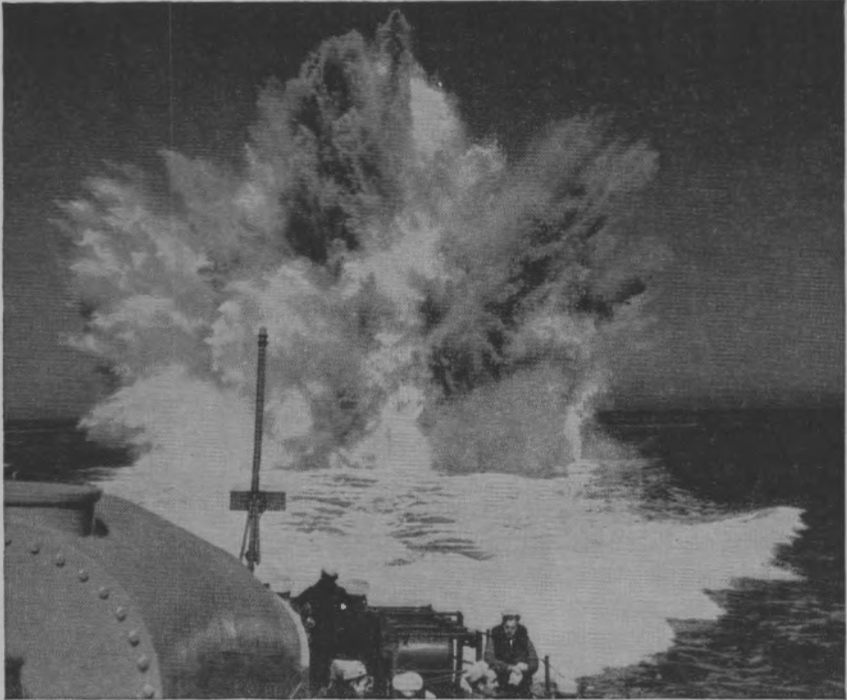
The quality of the ordnance was naturally reflected in fleet tactics. Whenever submarines were detected within a mile of a convoy, destroyer captains were instructed to make "urgent" attacks—that is, to dispense with careful sonar tracking and make a high speed charge on the enemy's probable location. The idea behind the urgent attack was simply to shake up the submarine crew and discourage any planned attack. But the tactics reflected desperation rather than a proper exploitation of depth charges. If the weapons were ineffective in their primary role, they were useless in haphazard attacks except for their psychological effect on submariners.

Extensive developmental work was urgently needed. The ideal weapon was pictured by the Commander in Chief, United States Fleet, as a proximity fuzed depth charge with a lethal range of 15 feet, a projection range of 150 yards, a terminal velocity of 50 feet per second, and a stable underwater trajectory. This was, of course, a description of an ultimate depth charge, not a statement of the minimum characteristics acceptable to the fleet. Much basic work was necessary before the Bureau could supply such a weapon.

The Bureau program to achieve this goal followed two courses: the development of improved hydrostatic charges, and the invention of satisfactory influence firing mechanisms. The two major projects were pursued concurrently, but the first naturally seemed

capable of faster solution. Existing charges bore no real similarity to the ideal pictured by the Commander in Chief, but at least they furnished a point of departure for research and development work. And until radically new ordnance could be supplied, modifications to the Marks 6 and 7 offered the surest route to getting weapons into service use. A modification of the pistols and booster extender mechanisms increased the range of depth settings on both sides of the scale. By late 1942 the charges were available for use at depths from 30 to 600 feet. The latter setting—a response to information that German submarines were able to withstand water pressure at lower than 500 feet—represented a doubling of the charges' potential.

Sinking rates, too, were considerably improved by the addition of 150 pounds of lead to each case. This technique was an expedient rather than a genuine solution to the problem, but even a slight increase of lethal probability justified the expense. This was especially true for the Mark 6, the depth charge used most frequently throughout most of the war. Even when newer charges were introduced, the improved Mark 6 remained in demand. Some



A Mark 7 charge—powerful, but limited in utility—exploding at a shallow setting.

218,922 were procured—almost twice the total for any other depth charge. No other prewar depth charge proved as adaptable to modern warfare. The Marks 2, 3, and 4 were declared obsolete as soon as the prewar inventories were exhausted; the Mark 7 fell into relative disuse because it lacked the versatility of rival weapons. Its total weight of 765 pounds precluded its use with projectors and reduced the number that ships could carry. Moreover, depth charge development moved in another direction. Weights were reduced rather than increased.

Although modifications to existing ordnance proved successful enough to stave off obsolescence for the Mark 6 depth charge, emphasis was placed on more fundamental work. The Bureau recognized that cylindrical types were near the limit of their development. Ash can and depth charge had long been synonymous terms, but the grim necessities of war freed design from conventional restrictions. At the risk of having to scrap thousands of tracks and K-guns, the Bureau proceeded with the development of a charge designed to achieve a faster sinking rate and a more stable trajectory. Late in 1942, the results were in hand with the Mark 9, a teardrop shaped weapon containing 200 pounds of TNT. A streamlined case and rotation-inducing canted fins permitted the charge to sink on a fairly straight line at a terminal velocity of 14.2 feet per second. Moreover, existing tracks could be used after relatively minor modifications. Production of a new arbor even permitted its projection from K-guns.

Tests late in 1942 indicated that the charge fired erratically at depths below 100 feet, but its promise was such that the Bureau was ordered to begin procurement in April 1943. Hopes ran high that the Mark 9 would meet the demands of the fleet once a better



A pattern of depth charges helped compensate for the low lethal probability of a single explosion.

firing mechanism was produced. The transition from development to production was troublesome, however, and optimism suffered in the process. Manufacturing techniques needed revision. Cases were made by rolling steel into cylinders, cutting orange peel segments from each end, hammering the edges in, and welding the shaped strips into a teardrop design. The steps were involved and the assembly line weapons lacked the structural strength and smooth finish of the experimental models. The differences soon proved great enough to relegate the Navy's newest depth charge to the obsolescence of World War I ash cans. In service use the Mark 9 failed to achieve the high sinking rate that justified its radical design. Even worse, structural defects impaired normal use. Nose rings and shrouds became distorted, causing the charges to jam on the release tracks. Men who had to manhandle the charges in the midst of an attack hardly considered the new ordnance proper replacement for the familiar Mark 6.

As a result of fleet complaints the Mark 9 went through a series of changes. The first modification attempted to correct structural defects by the adoption of new manufacturing techniques, but the results were not gratifying. Some weaknesses were inherent in the design, not introduced during production. Procurement was speeded through the use of new methods, but performance was only slightly improved. Early in 1944 more radical changes were made. Pistols and booster extender mechanisms were modified to provide reliable firing at greater depths. To achieve a better sinking rate the Bureau added 40 pounds of lead to the interior of the nose section and reduced the angle of the tail fins from 20 to 3 degrees. Rotation was reduced by the change, but the Mark 9 Mod 2 achieved a sinking rate of approximately 20 feet per second. Other minor changes solved most of the launching problems and resulted in a sturdy, reliable depth charge. Remaining complaints were met by further modifications. Before the end of 1944, the original Mark 9 and its first modification were obsolete. In their place the Mark 9 Mods 2, 3, and 4 gave enemy submarines a new respect for the power of depth charges. The new pear-shaped case packed less explosive than conventional cases, but a high terminal velocity and a predictable trajectory more than compensated for the loss.

The arrival of the new ordnance was reflected in a steady increase in the effectiveness of depth charge attacks. The figures never became spectacular but, measured on a barrage basis, the lethal probability of the improved Mark 9 approached 6 percent. Coupled with the accumulated experience of antisubmarine crews

and the use of better Sonar and radar for detection, the weapon represented an appreciable increase in the Nation's offensive potential. Though it was but one of several contributing factors, the introduction of the Mark 9 coincided with the period when surface craft reached their greatest effectiveness against U-boats. Some damage was then inflicted on approximately 30 percent of the enemy craft detected; kills were registered on nearly 20 percent of the attacks. While this potential would have been more valuable in 1942 and 1943, when the submarine menace was at its height, it was still desperately needed throughout the remainder of the war. During the first half of 1944 the average U-boat sank only one-half a ship before being destroyed, but in June of that year Germany had 400 submarines—twice the number the Allies faced when the United States entered the war. Less than one-third of these were kept at sea at any one time, but the threat was obvious especially when invasions of the continent were impending. New weapons were welcome.

Paradoxically, the success of the Mark 9 type charges introduced a new problem. The relatively low weight of the new weapon made it attractive armament for vessels too small to carry the 420-pound Mark 6 depth charge, yet the fast sinking rate canceled out the advantage. The Mark 9 sank so rapidly that slow craft could use it safely only with deep settings. Submarines could not be attacked at a depth of 50 feet unless the ship was making at least 14 knots. Even the more common 100 foot setting required a speed of 8 knots. The Bureau turned to the Naval Ordnance Laboratory for help in perfecting a modification designed for slow vessels. Early experiments centered around the obvious expedient of using a parachute device to reduce the sinking speed, but the ultimate solution was the use of spoiler plates attached to the case.

The history of the Mark 9 covered almost 2 years of frustration, but the design established a new trend in depth charges. With one short-lived exception, ash cans were outmoded. Even the popular Mark 6 was withdrawn from production in 1944. In two important respects, the Mark 9 fell short of the 1941 specifications for an ultimate depth charge; the sinking rate was still only half that desired by the Commander in Chief, and the new charge carried a hydrostatic firing mechanism rather than a proximity device. The first failure was the result of compromise. Streamlined though it was, the Mark 9 was nonetheless of relatively squat design. The logical extension of the teardrop shape would have been a long thin charge. The Bureau could have produced such a weapon, but only at the cost of extensive investments in new release gear. Even

when economy was no special virtue, time and materials were too critical to justify the delay such installations would have required.

The lack of a proximity fuze was another matter. At the beginning of the war the Bureau decided to follow two separate lines of depth charge development so that neither would be dependent on the other. While research progressed on influence firing mechanisms, another group worked on improved hydrostatic charges. The designers of the Mark 9 hoped to equip the case with a proximity device, but they could not withhold the charge from service simply because progress on the two programs could not move at the same pace. Experience with proximity fuzed charges vindicated the Bureau's decision to maintain separate programs for hydrostatic and influence charges, rather than to hold out for the development of a single type that could meet the requirements of both.

The first project to develop a proximity type firing mechanism for depth charges originated some months before the United States entered the antisubmarine war. Early in the spring of 1941, the Bureau received reports that the British were working on a magnetic type firing mechanism that would detonate a charge within lethal range of a submarine. While the Research Division was far from enthusiastic about the program, a project was instituted to follow the English experiments. Some American destroyers even received issues of British experimental models so that data could be acquired from actual tests. Optimism grew with the course of developments during the year. Repeated studies proved that the lethal probabilities of depth charge barrages could be considerably increased by the use of influence type pistols. Depth estimation, one of the principal problems in planning an antisubmarine attack, was eliminated. The result was, in effect, a magnification of the target and an increase in the effectiveness of existing detection gear.

No less important, magnetic actuation promised to eliminate the turbulence created by hydrostatic charges, which exploded without regard to the success of an attack. Since an influence fuzed charge would theoretically detonate only within lethal range of a submarine, sound contact could quickly be reestablished after each unsuccessful attack. This was a vital consideration. The low lethal probability of a single depth charge, or even a single barrage, could be offset by increasing the number of attacks on each submarine contact. Combat records subsequently showed that when the lethal probability of a single barrage was only 3 percent, 5 attacks could raise the chance of a kill to 10 percent. The pos-

sibility of inflicting damage improved to an even greater degree, approaching 30 percent for each contact on which 5 attacks were made.

By the end of 1941 the Chief of Naval Operations was convinced of the utility of proximity devices, and the Bureau of Ordnance was instructed to expedite production of such a mechanism. One that would fit present cases was desired, but the need was considered so urgent that CNO expressed a willingness to accept new designs. Several courses were possible, but the Bureau concluded that the best hope was for the development of a magnetic type mechanism housed in a nonmagnetic case with dimensions similar to existing charges. A proximity device that would fit all hydrostatic charges was established as a goal—but a secondary one. Until other influence type pistols were developed, the use of proximity fuzes in existing cases seemed remote. Two acoustic devices plus a magnetic type that could function in a steel case were placed under development, but they were long range programs for which the fleet could hardly wait.

The device whose advanced state of development dictated the decision to use a new ash can type depth charge was a magnetically operated mechanism. Its operating principle was based on the fact that no magnetic signal would be generated while a charge fell through the earth's field. Once it came within range of a submarine, however, a small signal would be produced. This could be amplified enough to operate a relay and complete a firing circuit. The range would naturally vary with the magnetic condition and course of the submarine, but it would usually fall somewhere between 20 and 25 feet. Since that coincided with the lethal range of the explosive charge, an actuation would theoretically result in a "kill."

The case developed for this firing mechanism was made of aluminum and built to the dimensions of the Depth Charge Mark 6. Slightly more than half the total weight of 520 pounds was in cast TNT, and a part of the remainder was made up of 150 pounds of lead packed into one end of the case. This gave the Mark 8 depth charge a sinking rate of 11.5 feet per second. In addition to the proximity device, the weapon was equipped with a hydrostatic pistol. This feature increased the versatility of the charge, since the proximity device could not be used safely in shallow water or at speeds under 14 knots. This dual feature also made the Mark 8 adaptable to the creeping attack, a prevailing doctrine in some commands. Because sonar gear sent out sound energy that struck the hull of submarines, then echoed back to the receivers, the enemy

could sometimes tell when he was being stalked and base evasive tactics on the information gained from the pinging picked up by his own listening devices. A creeping attack circumvented that handicap by employing two ships in close cooperation. One would use sonar to track the course of a submarine, then signal the positions to another ship. The second craft used this borrowed data in lieu of its detection gear and moved in on the enemy slowly. A low speed was necessary in order to reduce the noise that a submarine might detect. Shallow depth settings or proximity type fuzes would obviously have jeopardized the attacking ship. The versatility of the Mark 8 permitted ships to continue use of the creeping attack when necessary, yet enjoy the advantages of an influence charge at other times.

Theoretically, at least, those advantages were good. Mathematics indicated that in attacks on a submarine at a depth of 300 feet, the lethal probability of the Mark 8 was 14 times greater than that of the Mark 6, 7 times as great as the Mark 9 Mod 1, and $5\frac{1}{2}$ times greater than the later modifications of the pear-shaped depth charge. Unfortunately, experience gave the lie to theory.

From the very beginning of its development the Mark 8 was plagued by difficulties. The elimination of one problem merely uncovered another. Not until the spring of 1943—almost a year later than original estimates—was the charge released to production. And the problem did not end there. The aluminum cases and the electronic components of the Mark 8 presented new challenges. They were ultimately met, but not until after weary months of work by the Bureau and its contractors, and never to the satisfaction of the fleet. The depth charge that was expected in mid-1942 did not arrive in the fleet until 1944, later than the Mark 9. Even then the issue was confined almost entirely to destroyer escorts, whereas 12 types were originally slated to carry the new armament.

The ships singled out to receive the Mark 8 were not long in feeling honored for the distinction. In service use the depth charge proved subject to extensive spurious firing. The fact itself came as no surprise to the Bureau, which expected prematures to approach 20 percent, but the extent of the failures and the reaction of the fleet provided unexpected repercussions. Dissatisfaction among skippers of antisubmarine vessels grew rapidly. Complaints poured into the Commander in Chief, Atlantic Fleet, indicating that an average of 9 out of every 16 charges were defec-

tive. Experimental droppings under combat conditions seemed to bear out the reports.

Pressed by the Atlantic Fleet Commander, the Bureau ran new tests. Depth charges were withdrawn from ships in from patrol and used under controlled conditions. The results seemed to vindicate the Bureau's position. Prematures at depths shallower than 600 feet ran at 8 percent—less than half the expected rate of failure. Other defects were exposed, but most of them were the result of poor fleet maintenance rather than inherent in the Mark 8.

Bureau reassurances were small comfort to the operating forces, however, and hostility to the weapon continued. The Commander in Chief, Atlantic Fleet, even recommended removal of the suspect charges from the ships under his command. The suggestion was defeated by the Bureau. Even in the face of a high rate of spurious firings, the Mark 8 appeared the best depth charge available. If that fact was an indictment of antisubmarine ordnance, it nonetheless emphasized the need to use the best weapon available. A charge that offered influence firing down to a random depth was superior to a charge that would leave a submarine unharmed unless its position happened to coincide closely with the hydrostatic setting of the weapon's pistol. This was especially true because the condition of submarine detection left a large arbitrary element in the estimation of an enemy's depth.

Safety was not involved. The charge could not explode before it reached an arming depth of 35 feet. The crux of the problem was that the defective charges usually exploded shortly thereafter, thus reducing the effective size of the pattern laid by an attacking ship. Moreover, the shock created by the explosion activated an anticountermining device in other charges, momentarily inactivating them and further reducing the potential of the pattern. Spurious firing also created turbulence, crippling sonar and handicapping subsequent attacks on the submarine.

Innumerable causes were assigned for the failures at one time or another. No completely satisfactory explanation was ever found. Leakage through faulty closures, deformation of the relatively soft aluminum case, failure of the anticountermining mechanism, and impact with the bottom were all contributing factors. The most troublesome single cause of spurious firing was the inadequate design of the arbor used with the depth charge. Since arbors were of ferrous composition it was essential that they separate from the charge promptly. Otherwise, the magnetism of the steel device was enough to activate the firing mechanism and detonate the charge as soon as it reached its arming depth. The same require-

ment obtained for the Mark 9, since its high sinking rate could not be realized if the arbor remained attached, destroying the streamlined effect of the case. An Arbor Mark 7 was designed to assure prompt release, but the design proved inadequate. Its chain hook device, activated by tension on the charge during projection, proved susceptible to corrosion that "froze" the arbor to its charge. The arrival of the Mark 8 made a superior design mandatory, and a new equipment was invented within the Bureau. This device, designated Mark 7 Mod 3, offered two distinct advantages: A reliable release mechanism eliminated a source of spurious firing in the Mark 8; by securing both arbor and charge to the projector, it eliminated the need for the lashings ordinarily used to prevent accidental dislodgements due to gunfire. Older arbors were subsequently converted to the new design.

Unfortunately, the status of the Mark 8 was but slightly improved by the new equipment. Only those charges which were projected from Y- or K- guns were affected and the net result was simply to bring their rate of failure in line with that of the stern dropped charges. The Atlantic Fleet was unimpressed. They used the Mark 8 of necessity, but with less confidence than the Bureau felt the weapon deserved.

Meanwhile, the Bureau of Ordnance tried to improve the situation by establishing worldwide maintenance facilities to service the Mark 8. Ships would turn in unexpended charges after patrols and draw reconditioned ones in their stead. Details were carefully trained to keep the magnetic mechanism in perfect adjustment. Gaskets were checked to prevent water leakage and the batteries that amplified changes in the magnetic field were replaced frequently. The Bureau was so confident that proper maintenance would make the Mark 8 a reliable performer that late in 1944 the charges were issued in the Pacific.

Now there seemed a diabolical perversity about the weapons performance. In the new theater prematures disappeared almost completely. But this was no victory. The charges frequently refused to detonate at all. Under the tropical conditions of the Pacific the electronic components of the firing mechanism deteriorated rapidly. The anticountermining device proved especially vulnerable. Instead of functioning momentarily to prevent sympathetic explosions, the circuit simply acted like a blown fuze. The first explosion in a pattern of charges was often enough to inactivate the remainder of the charges. Maintenance groups made heroic efforts to cope with the situation, but it proved hopeless. The electronic parts were fused into a single component, requiring

a complete replacement of the unit even when only one part was actually defective. Both economical and logistical considerations ruled out a continuation of the effort. The Mark 8 was withdrawn from service use. The depth charge that was slated to give the ash can a new lease on life simply confirmed its obsolescence.

The design of the Mark 8 represented a compromise with expediency, selected not for intrinsic value but because it promised to be the fastest way to get an influence type charge into the fleet. Though reliable performance had been expected of it, the development of proximity fuzed depth charges started rather than ended with the ill-fated ash can. The real object of the Bureau was to combine the theoretical benefits of the Mark 8 with the superior case design of the pear-shaped Mark 9. This goal got top priority within the depth charge program in mid-1943, with attempts to combine a nonmagnetic streamlined case with the firing mechanism of the Mark 8.

This project materialized with two depth charges. A Mark 11 was designed for use from projectors, the pattern to be filled in with stern dropped Mark 12's. The case for the first of these was more streamlined than the pear-shaped Mark 9, and made of plastic instead of steel. A three-fin-tail assembly was attached to the body to produce rotation and a stable underwater trajectory. Two hundred and thirty pounds of TNT were included in the total weight of about 480 pounds, giving the weapon a lethal range of from 15 to 25 feet. While the firing mechanism was originally supposed to be similar to that used with the Mark 8, several improvements were incorporated in the specifications. The elimination of bottom firing, quicker arming, time and depth sterilization, and extended influence range were included to improve the rate of lethal probability.

With a sinking speed of 36 feet per second and a superior proximity mechanism, the Mark 11 appeared to combine and exceed the virtues of the Marks 8 and 9. The disadvantages were two: the high terminal velocity of the streamlined case confined its use to projectors that could throw the charges a safe distance from the ship, and special loading equipment was required to mount the weapon on the K-guns. Neither of these was great enough to cancel out the apparent advantages offered by the Mark 11. Nonetheless, the charge never saw service use. Experience with the Mark 8 proved that the type of firing mechanism employed was not a dependable performer. A substitute magnetic exploder was produced by the Bell Telephone Laboratories, but the new device

DEPTH CHARGES

was not ready until late in the war. By that time the cost of installing new and complex loading gear aboard each ship could no longer be justified.

Meanwhile, the complementary Mark 12 had been developed. This was a relatively small, torpedo shaped depth charge with an overall weight of 93 pounds. Its sinking rate was even greater than that of the Mark 11, but the explosive charge of 45 pounds of Torpex was not great enough to endanger the attacking ship. Of course the lethal range was not great against submarines, either, but the charge was designed to explode only on contact. Such a charge could have been used alone in direct attacks against submarines, but its real function was to complement the larger Mark 11 by filling in the center of the pattern created by the projected charges. Service tests proved the new weapon satisfactory, but it nonetheless joined the Mark 11 on the shelf. The failure of its partner deprived the small weapon of its special function.

Neither charge was mourned by the Bureau or the fleet. The weapons could not have contributed to the antisubmarine campaign until 1945. By that time a long range program devoted to the development of superior firing mechanisms showed such progress that enthusiasm for the magnetic exploders waned. The new type had many advantages, but the greatest was the fact that it could be used with existing depth charges. By using it in lieu of the hydrostatic mechanism, the Bureau was able to create a new depth charge that marked the fruition of the many projects devoted to meeting the Commander in Chief's early specifications for the "ultimate" depth charge. The new weapon was never credited with a kill; only pilot lots reached the fleet before the war's end.

The Hedgehog, Mousetrap, and seven depth charges represented the bulk of the Bureau's efforts to develop and produce antisubmarine armament for surface vessels, but they were not the whole story. The threat to the Nation was unprecedented. Some of the responses fell in that same category. Ideas by the hundred were channeled to the Bureau for investigation. Many were proposals for Rube Goldberg contraptions that never advanced beyond the talk stage, but developmental effort was not in direct proportion to conventionality. The Bureau worked on depth charges that could be shot from 5-inch guns, on release chutes for dropping aerial depth bombs over the side of small craft, on clusters of small charges banded together around a bursting charge that threw them into a desirable pattern, and on numerous other abortive equipments.

One of the queerest of the lot was a sort of hybrid weapon, a cross between a projectile and a depth bomb. The idea was to build a shell in two parts, placing a proximity fuze and bursting charge in the forward end and an explosive filler aft. The projectile would be fired low over the water along the suspected course of a submarine. If the path of the shell crossed that of an enemy submarine at approximately periscope depth, the proximity fuze would detonate the bursting charge, separating the two halves of the projectile. The rearward push of the charge was supposed to cancel out momentum of the shell, permitting the rejected after end to fall straight down on to the deck of the enemy submarine. The idea was abandoned for use from surface craft, but the same principle was employed in the retrobomb, an antisubmarine weapon designed for aerial use.

A good deal of attention was also given to the development of small depth charges that might be used to create more extensive patterns than was practical with the conventional weapons. The utilization of the Hedgehog and Mousetrap tended to deemphasize such projects by accomplishing the same purpose, but enemy tactics ultimately caused the development of one miniature depth charge, the Mark 10. Each of the Axis triumvirate supplemented his fleet with midget submarines, human torpedoes, or swimmers trained to plant limpet mines on ships at anchor. Each of these represented a way that the enemy could bring the war home to the United States. Small Japanese submarines participated in the strike at Pearl Harbor, and the state of our net defenses made continental ports equally vulnerable.

Existing ordnance was inadequate for the challenge. Harbor defenses had to be left in the hands of small and generally slow craft. Standard depth charges were too bulky for them to handle and too powerful for them to use safely. Even regular antisubmarine vessels were at a disadvantage against a miniature enemy that could hover too close to the surface to be destroyed by depth charges at their shallowest hydrostatic setting, yet too deep to be vulnerable to shellfire. The Bureau alleviated that situation by modifying standard firing mechanisms, but the expedient was only a partial answer to the enemy threat.

A depth charge light enough to be manhandled from small craft was an obvious solution to the problem, but the Bureau of Ordnance opposed the development of special ordnance for a transient threat. Stronger nets with a smaller mesh were being procured rapidly. The completion of that program would obviate the requirement for new depth charges. Since the development

of one weapon would have to be at the expense of another, any unnecessary program jeopardized vital projects. The Bureau proposed that its role be limited to technical advice to district commandants, who might then use available commercial products until actual requirements could be determined.

The Bureau plan was given a try. Improvised depth charges were made from 25-pound sticks of straight gelatin dynamite fitted with electric blasting caps. The new weapon was powerful enough for its function, but several hitches developed in the program. In the first place, the charges were dangerous to use. The official instruction book warned: "The cartridge must be thrown overboard within 2 seconds after the time that either of the wires has touched either pole or could possibly have touched them. The boat should be moving at a speed of not less than 7 knots." Seamen found the first requirement a disconcerting challenge; many small craft were denied to the war effort by the second. The improvised weapons furnished other problems, too. Transportation of the explosives was outside Ordnance jurisdiction, but once the dynamite reached its destination, storage became a matter of concern to the Bureau. The commercial product could not be kept with regular service explosives, yet separate facilities were not always available. Safety, a responsibility of the Bureau of Ordnance, was jeopardized by the charges procured by district commandants.

Early in 1942 the Chief of Naval Operations directed the Bureau to end the unsatisfactory situation by developing a small depth charge to replace the dynamite sticks. The result was the Depth Charge Mark 10, which first became available for issue in December 1943. The weapon was designed for easy manufacture. A standard 2-gallon paint can served as a case, rubber dental dams as hydrostatic diaphragms. Twenty-five pounds of TNT was substituted for dynamite as an explosive charge, thus eliminating the storage problem. Slow boats were protected by a special feature: the charge floated for a moment when first thrown overboard, then sank slowly. A hand grenade type firing mechanism caused some consternation, but the charge was much safer than its predecessor and was no more dangerous than the weapons infantrymen used as a matter of course.

The Mark 10 was specifically designed for use against midget targets, but the Bureau was anxious to increase the utility of the depth charge. New net designs capable of thwarting torpedoes and midget submarines were available by the time the Mark 10 was ready for service issue, so a broadening of its function was essen-

tial. The fact that no launching equipment was required simplified distribution and use, but the small explosive charge limited its applicability. The Bureau solved the problem by designing a shipping box capable of holding three of the weapons. A central hole permitted a pistol and booster charge to be placed in one of the charges without disturbing the others. Since the explosion of one charge would set off its companions, the whole box could be treated as one weapon. Against a fleet-type submarine the lethal range of even a box full of Mark 10's was low, but the weapon was valuable for its harrassing effect. The particular threat which led to its development never materialized, but 40,000 of the charges offered valuable insurance for American harbors.

In all, the depth charge program included the design of well over a dozen marks and modifications of antisubmarine weapons. Research and development work naturally bulked large. The dormancy of the field during the two prewar decades and the enormity of the submarine threat demanded a gigantic developmental effort. Production problems, by comparison, seemed small. Of course that was not actually true for any wartime procurement. Overworked plants, scarce materials, and the paucity of skilled labor were factors of general application.

Perhaps the most distinguishing characteristic of depth charge production was the virtual monopoly held by relatively small manufacturing concerns. Many ordnance equipments were so complex that the facilities and capabilities of large companies offered the Bureau the greatest assurance of satisfactory production, but depth charges were relatively simple weapons. The Marks 6 and 7, for instance, were expressly designed for ease of manufacture. Later changes introduced more challenges, but by that time the producers had enough experience to cope with the new problems. The Mark 8, bedeviled in every phase of its existence, was the most notable exception. The aluminum case was difficult to procure, and its flexibility complicated the problem of providing watertight integrity. Securing the miniature electronic components for its magnetic mechanism proved even more ticklish. Commercial products were inapplicable and the depth charge program was forced to compete for the services of the Nation's electronic industry. The result was a tardy appearance for the Mark 8, as well as a higher cost. At \$300 per unit, this was the most expensive depth charge ever issued to the fleet. Over 76,000 complete units were procured at a cost of \$22,801,200. Fifty-seven thousand were still on hand on V-J Day.

Large postwar inventories were characteristic of all depth charges. Requirements were determined by the Chief of Naval Operations in accordance with the number of tracks and projectors scheduled for shipboard installations. Since this armament had almost universal application, the requirements were established at correspondingly high levels. New ship construction created a constant upward pressure as almost \$39,000,000 worth of release track and projection equipment was purchased between Pearl Harbor and V-P Day. A total of 622,128 depth charges were bought during the same period, not counting Hedgehog or Mousetrap ammunition or the limited procurement of experimental charges which were never released for service use. This required an investment of over \$65,000,000 and raised the total cost of the depth charge procurement program to \$104,307,421.

Well over half of all the charges purchased during the war were still on hand when hostilities ended. Since there was no reduction of possible targets, the surplus seemed an indictment of the weapons' effectiveness. An evaluation was not that simple, however. Too many factors were involved to permit a simple conclusion. The fact is that U-boats were defeated before the end of 1943. The number of enemy craft afloat continued to increase, but the reduction of their effectiveness more than offset the quantitative gain. At least a half dozen factors contributed to the favorable situation. The convoy system discouraged attacks, since the U-boat could strike only by exposing its position; the construction of faster ships to replace initial losses complicated submarine tactics and decreased their opportunities to attack; sonar forced the enemy to the surface, where radar could detect his position; experience gained in the early months of uneven struggle gradually increased the effectiveness of United States forces; the loss of the German aces and the influx of green crews to man the expanding fleet robbed the enemy of the skill and daring that characterized the first 2 years of the campaign; the use of air patrols, both sea and land based, destroyed many submarines and restricted the area in which they could operate. To the list must be added the improvement of depth charges and the introduction of ahead-thrown weapons.

Mathematical studies of lethal probability painted a bleak picture of the potential of the antisubmarine armament provided surface craft, but results were never governed by theoretical statistics. Experience permitted the fleet to increase the number of attacks made on each submarine detected, and the results far exceeded the paper potential of the weapons they used. In the last

year of war some damage was inflicted on submarines in 35 percent of the Allied attacks. Thirty percent were lethal.

On the other side of the ledger was the discouraging fact that after losing 915 submarines during the course of the war, the Axis still commanded a large armada when forced to capitulate. The Third Reich alone had about 350 oceangoing U-boats at her disposal on V-E Day. Many of them were superior to those which sank the bulk of the 23,000,000 gross tons of shipping lost by the Allies during the war. Snorkels and improved propulsion plants gave the newer submarines more speed, maneuverability, and endurance than their formidable predecessors. Thus, while the tide of victory turned in favor of the Allies in 1943, the threat in 1945 was greater than it had been since the first bleak months of 1942. The introduction of a new depth charge late in the war might have helped prevent another shift of fortunes, but the outcome was no foregone conclusion. And in any event, the depth charge was no longer primary ordnance for antisubmarine warfare. Mortar type projectiles, rockets, and ironically, the submarine's own principal weapon, were all in higher esteem.

Chapter 8

MINES

THE naval mine is a weapon less intricate than the torpedo but nevertheless an instrument that has required much thought in design and production. Employed not as a competitor of the more direct forms of attack on enemy ships but as a valuable supplement, mines have failed to attract as much attention as torpedo warfare. It is a little known fact that German mines destroyed more British warships during World War I than submarine torpedoes. Likewise, it is not generally known that the North Sea Barrage, planted by the United States and the British early in 1918, contributed greatly to the Allied victory by restricting the movements of German commerce raiders, both surface and submarine.

Mine warfare emerged from relative obscurity in September 1939, with the planting of the first German magnetic types in British shipping lanes. Losses were alarmingly high until successful countermeasures were perfected. Between September 1939 and 1942, the 20,000 ground mines laid in the harbors and channels of the United Kingdom took a toll of over a million tons of Allied shipping. German mines also were used effectively in American waters; ships were sunk and several harbors were closed for short periods. On the other hand, British mines in World War II sank approximately 1050 Axis warships and merchantmen, and the American offensive mining campaign in Japanese home waters, initiated in the spring of 1945, virtually strangled the domestic and military economy of the islands.

Mine warfare is not new. The Dutch broke the Spanish blockade of Antwerp in 1585 with an "explosion vessel," which was nothing more than gunpowder piled in a boat and ignited by a clockwork-operated flintlock. The British experimented with mines, but cautiously, because they had the largest navy and would be the chief target if anything came of the weapon. Their fears proved well founded, for it was against the British Navy that the first real mine was used. David Bushnell, a lieutenant-captain of sappers and miners in the Revolutionary Army, and famous as the inventor of the submarine, resorted to mines when the submarine failed. In 1778 he attempted to break the British blockade of the Delaware

River at Philadelphia with floating kegs filled with powder and equipped with contact firing devices. His plan was to allow the mines to drift downstream, in the hope that they would be detonated by contact with the blockading ships. Detected on the ebbing tide, not one struck a target, although four sailors were killed attempting to remove a keg from the water. An observer reported that the British were so awed by the devices that "great were the exertions of officers and men, and incessant were the firings, so that not a chip or stick escaped their vigilance." Francis Hopkinson immortalized the engagement in the *Battle of the Kegs*:

Such feats did they perform that day,
Among the wicked kegs, sir,
That years to come, when they get home,
They'll make their boast and brag, sir.

Robert Fulton, whose versatility extended from steamboats to portrait painting, also worked with mines. After several false starts, he persuaded the British in 1805 to let him try an underwater charge against a ship. On reporting the results of the experiment, Fulton wrote that the vessel offered no more "resistance than a bag of feathers and went to pieces like a shattered eggshell." Prime Minister Pitt, sponsor of the experiments, was characterized by an opponent as the "greatest fool that ever existed to encourage a mode of warfare which those who command the seas do not want, and which if successful will deprive them of it."

The mine graduated from the gadget stage in the Crimean War, and by the time of the American Civil War it was a fullfledged naval weapon. Facing superior Union naval forces, Confederate engineers were hard pressed to keep their harbors inviolate. Novel types of contact and controlled mines soon attested to Confederate ingenuity. The utility of these mines is indicated by the fact that during the war 27 Union vessels were sunk by mines while only 9 were destroyed by gunfire.

Although the effectiveness of mine warfare was explosively brought home to the United States with the sinking of the *U. S. S. Maine* in 1898, no significant advances in mine design or tactics were achieved until the Russo-Japanese War of 1904 proved the mine a weapon more versatile than had been suspected. Even though the behavior of the Russian Fleet in that engagement bore all the aspects of a tragicomedy, and the "Japanese Nelson," Admiral Togo, made tactical mistakes that would have lost the war to almost any other enemy, the war had real significance for mine development. Past effectiveness had failed to win respectability

for the mine. As dangerous to friend as to foe, naval powers had since the Battle of the Kegs relegated it to purely defensive work. Such was the Russian attitude, too, and for the oversight of the dual role open to mines the Tsarist Fleet paid dearly. Japan developed the offensive use of the mine, lured part of the Russian Fleet to destruction, and opened new vistas for mine warfare. The western powers noted the change. If for the moment they persisted in underestimating the possibilities of offensive mining, the advent of World War I rapidly altered the situation.

Extensive mining activities, both defensive and offensive, were eventually carried out by the Allies and the Central Powers. The British laid some 129,000 mines, the Germans more than 43,000. In addition, over 71,000 mines, the majority of them Bureau of Ordnance products, were planted in the famous North Sea Barrage. As a result of those efforts, the Germans lost 62 war vessels, 40 submarines, and 42 auxiliaries. British losses totaled 225 auxiliaries and 44 war vessels, including 3 battleships sunk by Turkish mines in the disastrous attempt to force the Dardanelles. Finally, some 586 Allied merchant ships, totaling over 1 million gross tons were sent to the bottom.

Actual sinking of enemy vessels is only half the story of mine warfare; the indirect effects are just as important though not as spectacular. An aggressive mining campaign requires the enemy to engage in sweeping and countermeasure efforts which divert a large number of ships and men; it restricts or stops traffic until proper sweeping or countermeasures have been completed; it forces traffic from shallow coastal waters into areas where it is more vulnerable to air, surface, and submarine attack; and lastly, its continuing threat has an adverse effect on the morale of crews.

In such an offensive campaign the mine is often a long-term weapon which may not achieve its effect until weeks after it has been laid. As a strategic and tactical weapon it must be laid in accordance with a well-defined policy. From the planner's point of view, one difficulty is that in many instances considerable time must elapse before it is possible to determine whether the policy is the correct one. In addition to this time lag, mines are quite incapable of distinguishing between friend or foe. Finally, between the inception of the plan and the actual laying of the mine there is an intervening period of design, test, production, assembly, storage, distribution, and preparation, all calling for the highest degree of efficiency and coordination at every stage if the over-all scheme is to be successful.

Mine development in the period from 1918 to the declaration of the national emergency in 1939 was virtually dormant. Development of mines and depth charges was lodged in the Naval Ordnance Laboratory, following its establishment as a "Mine Building" in 1918, but for 20 years the technical staff at the Laboratory was so small that practically all of its energy was spent on the modification and perfection of the moored contact mines remaining on hand from World War I. At one time during the somnolent peace years, Bureau funds were so restricted that the Laboratory's staff was reduced to one physicist working on mines, and one engineer working on projectile fuzes and pyrotechnics. Some effort was spent on different types of mines, however. "These mines," according to an NOL scientist, "were difficult to distinguish because of confused nomenclature and the thrifty habit of borrowing major components of one to use with another. Drifting, moored, and ground mines were designed, using mechanical, chemical, galvanic, and magnetic firing mechanisms. Most of them never advanced beyond the design stage, or, if they did, like the magnetic mine, they were never released for service use. Some were manufactured in small lots and used for drill. Of historical interest only is the fact that an acoustic firing mechanism was conceived, but work never progressed beyond the stage of collecting some of the equipment necessary to build the first model."

The use by the Germans of their deadly magnetic mine in late 1939 was the signal for the expansion of the NOL in both personnel and facilities. While the Bureau realized that the first task was the study and perfection of countermeasures to the new mine, it hoped that the Laboratory would be able to develop influence mines concurrently with the necessary degaussing techniques. As it turned out, the Laboratory was so busy with countermeasure work during the first few months that it had little time for the thorough design of a magnetic mine.

By June 1940, however, the Laboratory had produced a crude magnetic mine firing mechanism. This proved so inferior to the German device, one of which was furnished by the British, that it was decided to copy the German mine, making only those changes which were necessary to fit it to American manufacturing methods and launching equipment. The mine, designated Mark 12, was a needle-type magnetic ground mine which could be planted by submarines, surface vessels, or aircraft. Prospective types included both acoustic and magnetic moored mines.

Operational groups in the Navy showed little interest in these mines; their primary concern at this early period was in defensive

mining and the existing equipment was considered entirely adequate for coast and harbor protection. Lack of general interest forced the Bureau to design the mines around its own specifications and make its own estimates of the quantities required. Under these circumstances, mine development and production could not compete with those ordnance fields of more immediate urgency.

December 7, 1941, found the Navy in a weak position for waging mine warfare, but the arsenal was not entirely bare. Thousands of Mark 6 mines, originally designed for antisubmarine operations during World War I, had been modernized. The Mark 7, a special drifting type, and the Mark 5, of the moored chemical horn variety, were available in limited quantities. In addition, the Marks 10 and 11, both of the moored contact type, were available for submarine laying, though only one submarine, the *Argonaut*, was equipped for handling the Mark 11. The only influence mine released to service use was the Mark 12, a version of the S-type magnetic mine developed by the Germans in the 1920's. The first Mark 12's were delivered to Manila just before the outbreak of hostilities but the suddenness of the Japanese attack made it necessary to dump them in deep water to prevent capture. One version of the Mark 12 was fitted with a parachute for aircraft laying, but it could be handled only from wing or torpedo racks, and few types of long range aircraft were available for minelaying.

While the Bureau had been the chief promoter of mining during 1940 and 1941, the advent of war soon quickened the interest of operational groups in this form of warfare; by the summer of 1942 there was a real demand for the development of new offensive mines. As one officer expressed it, the Bureau was then being told that it had not "quickly enough passed from the stage when nobody wanted any mines . . . to the stage where abundant mines of various special types [were] ready to plant from all possible places." Fortunately, the degaussing problems had been solved by the Naval Ordnance Laboratory leaving many of the scientists free to work on the development of more proficient mines.

American naval mines soon underwent radical change, emerging as potent, versatile, and decidedly offensive instruments of warfare, with little resemblance to their predecessors in either appearance or operational principles. In addition to those which required contact with a ship's hull, there were others which responded to the magnetic strength of a nearby ship (dip needle type), or were activated by underwater sound waves (acoustic type). Some of these were designed to be moored slightly below the surface, some to lie motionless on the bottom; others, equipped with sterilizers;

were designed to drift along at a predetermined depth. Still greater complexity was introduced through the use of novel accessory devices for delayed arming, controlled life, countermining protection, and resistance to detection and removal. The number of possible combinations of such properties was almost unlimited and illustrated the versatility of mine warfare, just as the expenditure of well over \$100,000,000 illustrated the size of the program. In all, the Bureau assigned mark and mod numbers to 65 mine designs, 39 of which were released for service use. Production emphasis, however, was confined in the main to 7 mines.

The mine production program initiated by the Bureau in January 1942, proposed a ready stockpile of thousands. While the immediate concern was with defensive types, production was to be evenly divided between defensive and offensive mines as soon as the minimum stockpile had been accumulated. Informed of this tentative program in January 1942, the Office of the Chief of Naval Operations issued a confirming directive accepting the Bureau proposals. By the summer of 1942 Naval Operations was ready to establish mine requirements and began to furnish the Bureau detailed information on the types and quantities desired for service. While an adequate supply of mines had to be on hand at all times, the volume of production had to be determined with caution. Many types were in production or under development simultaneously. To make volume of production a goal for its own sake would have resulted in congestion of storage facilities, deterioration of material, and the sacrifice of the effectiveness gained by keeping ahead of enemy countermeasures. Guided by those considerations, the Bureau and OPNAV agreed that the mine program should call for moderate production, guarded by arrangements for step-ups when required. This policy became the keystone for all future mine procurement. Its immediate effect was to revise drastically the original production program by placing emphasis on offensive mines. A further result was that periods of relative quiet were punctuated frequently by weeks of intense activity, during which production resources were taxed to the utmost.

During 1940 and 1941 the Bureau was hard pressed to locate manufacturers for the rapidly expanding program. The larger firms were swamped with orders for consumer goods and reluctant to accept government work, particularly on a competitive bid basis. As a result, the Bureau placed many of its contracts with small business. This wide distribution of production among small firms proved highly advantageous. The management and engineering staffs of the companies were well indoctrinated in the problems

peculiar to mine production and, as industry shifted to war production, these plants became in effect small ordnance establishments.

The emphasis on defensive mining in the early stages of the war led the Bureau to concentrate on the production of two new types of influence mines. Although they were still in the design and development stage, certain components were completed, and procurement was initiated for considerable quantities even though modifications might have to be made in the light of final design and test.

The general policy of the Bureau, dictated by the fact that complex mine types had not reached the production stage, was to administer the technical and fiscal aspects of procurement with little or no direct contact with the Naval Ordnance Laboratory or the selected contractor. Employing the same philosophy, the Laboratory conducted its development and design activities in relative isolation, minimizing contact with the Production Division of the Bureau and the manufacturer, and channeling all material ready for production through its own Design Section. By attempting to develop, design, produce, and test a complete assembly concurrently, the Bureau and its Laboratory hoped to push mines into service much sooner than normal procedure would have permitted. This decision, a natural one in the light of the great need for defensive mines for the east coast submarine barrier, proved unsound. Under that organizational procedure, too many phases in the evolution of a finished article were moving coincidentally to assure a satisfactory product. The result was an appalling number of radical design changes during production, the scrapping of much material, and in some cases, the delay of a project until a single component could be redesigned and made ready for production. One mine, for instance, was never released for service even though millions of dollars worth of material was procured for it. Fortunately, its components could be used in other mines.

Contract procedures, complicated by the unusual nature of the mine program, were a source of continual difficulty. The Production Division of the Bureau was responsible for initiating all the design changes recommended by the research groups of both the Bureau and the Naval Ordnance Laboratory. Moreover, manufacturers frequently requested permission to make changes in specified materials or production techniques in order to utilize available supplies or machine tools. Thus, modifications arose from several sources, preventing a crystallization of design. One mine case contract, for example, was amended well over 100 times, with each change affecting both specifications and price. The basic problem

was that too little was known at the time production was initiated about the probable operational performance of mines. Two years of interrupted procurement pinpointed the problem, and in April 1944, a new procedure to provide more operational testing before the inauguration of full scale production was adopted by the Bureau.

The original specifications and design features were revised in the light of information obtained from bench models and ideas developed from working with the design. NOL procurement was then initiated in sufficient quantities to permit the Mine Warfare Test Station, Solomons, Md., to determine the performance that could be expected from regular production units and to establish the difference between design performance and operational requirements. When the soundness of a design was proved, the Bureau initiated regular production.

Although a design could not be frozen when full scale production was ordered, the Bureau tried to restrict further changes in order to minimize delays. The policy thereafter was to accumulate recommended design changes and make substitutions only at intervals that would cause the least interference with the even flow of manufacture. When fundamental design error was exposed, however, corrective measures were applied immediately. To execute this production policy a new type contract was adopted. The document was in two parts, the first permitting adaptation of the design to the tools and equipment available to the contractor, the second providing a full and uninterrupted flow of production for service use. Design or specification changes found necessary during the first, or limited production, phase of the contract were incorporated immediately. Once limited production was completed, the contract called for the uninterrupted production of an arbitrary number before further changes were permitted. In cases where the items had a satisfactory history of commercial development, NOL procurement was omitted and full scale production started immediately.

Despite the low priority assigned to mines in the early days of the war, the Bureau of Ordnance was always able to keep abreast of the increasing fleet requirements for this weapon. In fact no mining campaign was ever delayed because of a shortage of mines. Fleet Admiral Nimitz acknowledged this accomplishment: "The fact that the Bureau of Ordnance not only met . . . original requirements, but, in some cases, anticipated them to comply with modified operational plans indicated an outstanding performance of a task which . . . contributed materially to the war effort."

Sharing this accolade with the Bureau were the scientists at NOL, the Mine Warfare Test Station, the Naval Mine Depot at Yorktown, the manufacturers, and the Ammunition Depots at Hawthorne, Hastings, and McAlester.

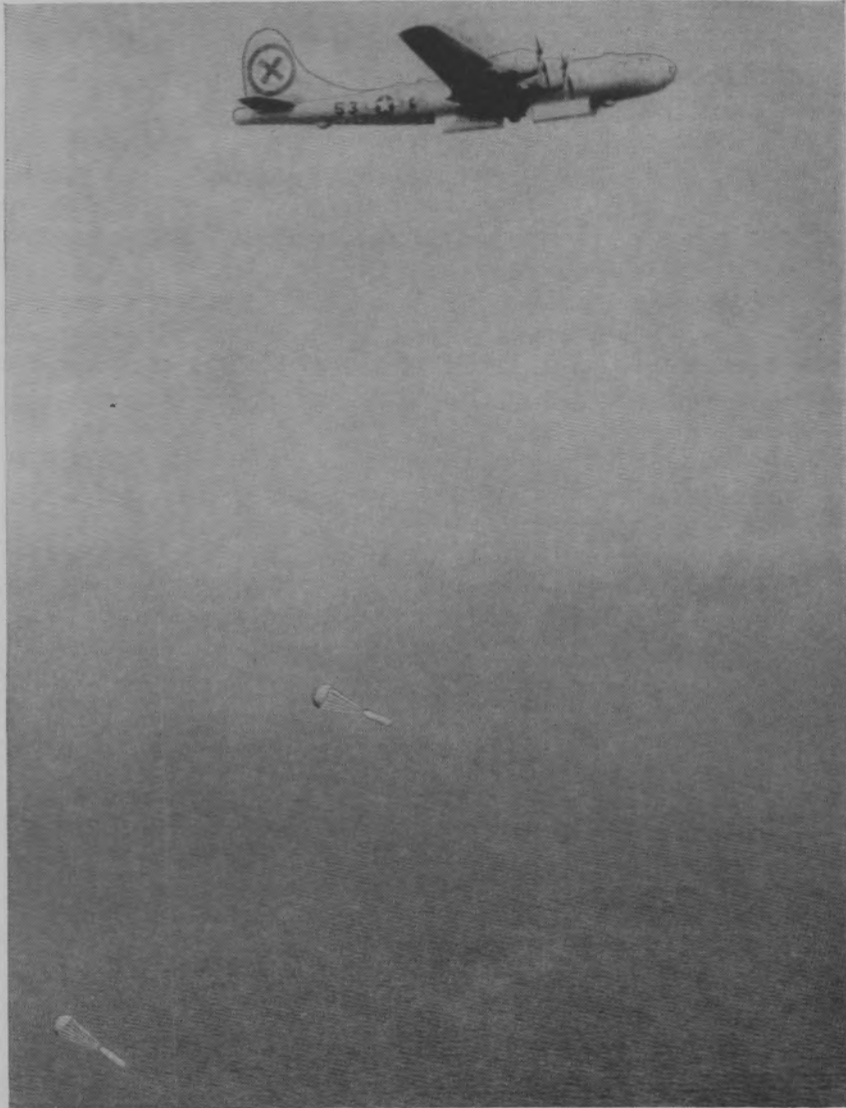
The mines developed by the Bureau were in a real sense the Cinderellas of the Pacific war. Lacking in glamor and originally slated for a purely defensive role, they emerged as a powerful offensive weapon. Through Army-Navy cooperation and inter-allied coordination they were used to form a cordon around the heart of the Japanese Empire. The minelaying campaign against the Japanese sank or damaged nearly 2,000,000 tons of shipping—approximately one-fourth of the prewar strength of the Japanese merchant marine.¹ Enemy casualties included 2 battleships, 2 escort carriers, 8 cruisers, 46 destroyers and destroyer escorts, 7 submarines, and 81 other naval vessels. Of the more than 1,000,000 tons of shipping damaged by mines, an estimated 25 percent might as well have been sunk because the facilities of repair yards were inadequate to take care of the mounting toll. The Japanese declared that a large ship damaged by mines required an average of 95 days for repairs. Even a small ship was out of action for 70 days. These results were achieved with an amazing economy of men and materials. Though 21,389 aircraft type mines were laid, only 55 airplanes, 15 of them B-29's, were lost in 4760 sorties. No submarines or surface craft were sunk while planting the remainder of the 25,000 mines used to strangle Japan.

This offensive was divided into two principal campaigns: first, a widespread attack on enemy ports and shipping routes on the fringes of Japan's new empire; and second, a large aerial mine warfare blitz concentrated on Japan itself.

The first phase or "outer zone" campaign was initiated in October 1942, and lasted until the end of the war. Employing submarines, surface vessels, and aircraft, over 13,000 mines were planted in 150 enemy harbors and shipping channels. This campaign, attritional in nature, hampered the outward flow of enemy troop supplies and restricted raw material shipments to the Japanese homeland. It delayed offensives and complicated efforts at defense. Finally, it accounted for over 700,000 tons of enemy shipping.

Operations were carried out from China, India, Australia, Ceylon, and island bases in the south and central Pacific. Rangoon and

¹The account of the mining campaign against Japan is taken from "*Pacific Cinderella*", an article prepared with the cooperation of the Bureau of Ordnance, and published in *All Hands*, June 1946.



Air Force B-29's and Bureau mines virtually strangled Japanese economy in the last months of the war.

Haiphong were rarely used by large ships after mining began. The presence of mines frequently closed Shanghai, Hong Kong, Takao, Bangkok, Singapore, Balikpapan, and Surabaya to enemy ships. Palau, Penang, and Kavieng were abandoned as key bases because of mining. At Palau, planes from the *Hornet*, *Lexington*, and

Bunker Hill "mined in" 32 merchant ships and tankers; torpedo planes and bombers from the task force then sank every one of the vessels. Nor was mining confined to strategic purposes; the amphibious operations against the Marshalls, Hollandia, the Marianas, and the Philippines all bore witness to the increasing use of mines as tactical weapons.

By late 1944 the American advance in the Pacific had virtually isolated the Japanese homeland from the east and south. The supply lines to China, Manchuria, and Korea were still open, however, and in the relatively shallow waters of the adjacent seas Japanese shipping shuttled back and forth with relative immunity. Submarines could not readily get at these protected trade routes. Aerial bombing could hamper but could not stop the traffic. Mines were available, but the Navy did not have planes for the long distance operation. Admiral Nimitz proposed that Army B-29's based in the Marianas complete the blockade with naval mines. General LeMay agreed, and "Operation Starvation" was soon underway.

The inner zone campaign covered the last 4½ months of war and marked the most concentrated mining offensive in the history of naval warfare. During this period, B-29's operating out of Tinian planted thousands of mines in the waters surrounding the Japanese Isles with such deadly results that defense against mining was assigned top priority by the enemy. The situation became so desperate that radar, anti-aircraft guns, and searchlights were moved from important industrial cities to strengthen defenses in key mining areas. Actually, the transfer proved of little value; it did, however, weaken the defense of various cities, making them easier prey of Army and Navy bombers.

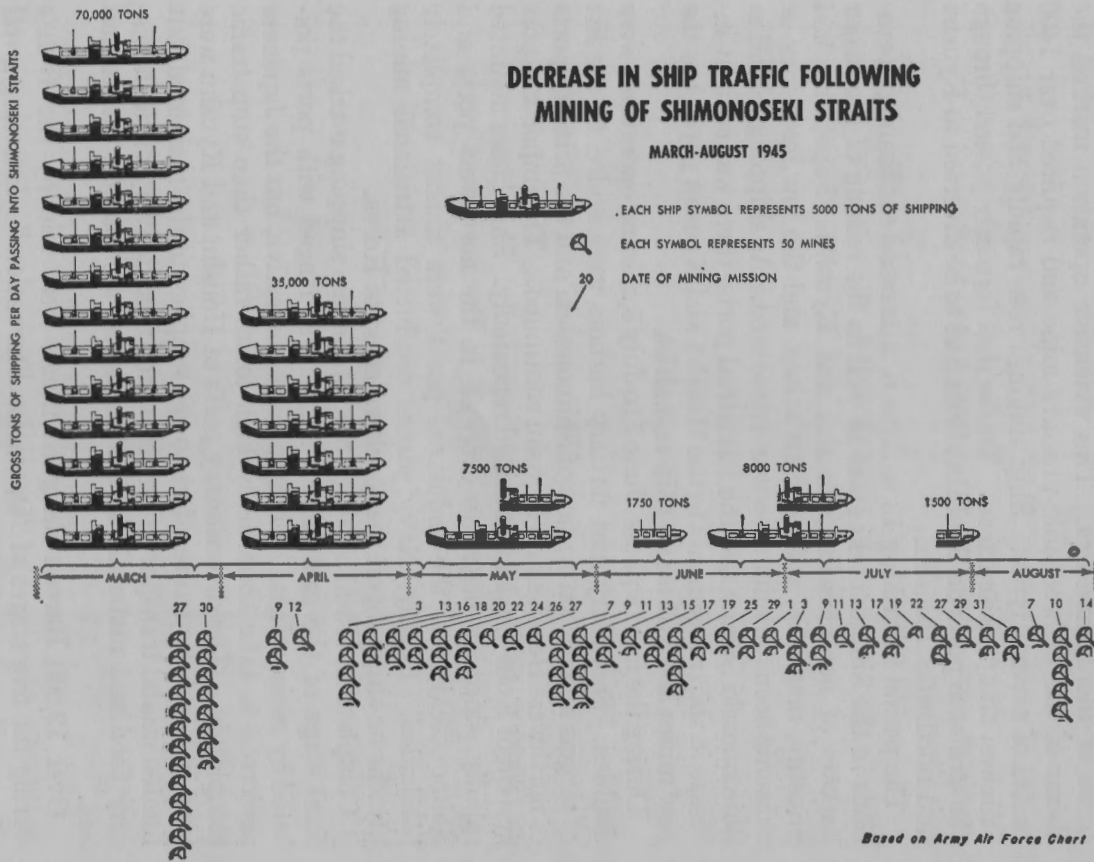
The Bureau had five principal types of mines available for this operation. These consisted of two magnetic mines which had been used previously in the "outer zone" and were believed to be known to the enemy, and three new mines. The first of the new ones was of the audiofrequency acoustic variety which, lying on the bottom, would be fired by the sounds of a passing ship. By sheer luck, the Japanese discovered that they could sweep this mine with underwater noisemakers which they had been using for training sonar operators. Magnetic sweeps also were used to defeat the mine. The Bureau then released its two "unsweepables"—the subsonic acoustic mine and the pressure mine. The subsonic device was fired by ship sounds so low in frequency that they could not be heard by the human ear. The pressure mine was exploded by the changes in water pressure caused by a passing ship.

But the various types were only part of the story. Much of the success of the campaign sprang directly from the effective work of a Mine Modification Unit. Based on a similar program operated by the British, the unit was established by the Bureau in 1944 to increase the military value of mines by employing a group of experts at the fighting front to adapt mines for immediate operational needs. The Mine Modification Unit, staffed by highly trained technicians from the Naval Ordnance Laboratory, the Mine Warfare Depot, and the Bureau, was first attached to the Mine Assembly Base on Oahu. In March 1945 the group moved to Tinian to work with the Army Air Force. During the next few months over 10,000 of the mines planted by the B-29's in Japanese waters were modified according to recommendations of the MMU.

Modification tailored an already effective weapon for a specific operation. These changes were prompted by intelligence relating to enemy target characteristics, sweeping techniques, and evaluations of previous B-29 mining missions. Mine modification was intended to accomplish two goals: First and most important, to defeat the known enemy sweeps; second, to select the largest enemy ships for sinking. By the use of Bureau designed conversion kits, arming delays were provided for mines in which they were not previously available and firing mechanisms were modified to make enemy minesweeping more difficult. Firing characteristics of some mines were altered, assuring greater effectiveness by localizing and thus intensifying the explosive effect. Other mine firing mechanisms were modified to allow sensitivity settings which would respond only to the larger ships. It has been estimated that the work of the modification unit was responsible for doubling the amount of Japanese tonnage sunk.

The Army-Navy campaign to clamp a blockade on Japan was divided into several phases. Between March 27 and May 2, 1945, B-29's parachuted mines into Shimonoseki Straits, the naval bases of Kure and Sasebo, and the port of embarkation at Hiroshima. The targets were selected to restrict Japanese naval movements during the Okinawa campaign, and the strategy worked. Much of the enemy fleet was effectively tied down by the explosive barrier; the single task force that attempted a sortie did so with disastrous results. As the group tried to slip out of the Inland Sea by way of Bungo Suida they were attacked by United States carrier aircraft. The force was turned back and the battleship *Yamato*, pride of the dwindling fleet, was sent to the bottom.

In the second phase of Operation Starvation, from May 3 to 12, mines were laid along the vital shipping routes on the southern



Based on Army Air Force Chart

coast of Honshu. The purpose of the attack was to destroy sea-borne communications between the industrial zones of Japan by supplementing the blockade of Shimonoseki with mining around the ports of Tokyo, Nagoya, Kobe, Osaka, and in the main shipping lanes of the Inland Sea. This extensive operation marked the debut of the unsweepable pressure mine and required over 1400 mines of several types. Ship sinkings rose rapidly and shipping followed an opposite curve. Traffic that formerly passed through the straits to ports on the Inland Sea had to be diverted to Kyushu and northwest Honshu.

The period from May 13 to June 6, witnessed continuing operations in the Shimonoseki areas as well as the mining of the major harbors of northwestern Honshu and Kyushu. Superforts laid pressure, magnetic, and acoustic mines, and the low frequency or subsonic acoustic mine also was introduced. As shipping fell off in Shimonoseki Straits and the industrial ports, there was a slight increase in ship movements to the Honshu and Kyushu ports, but the new mines brought many ship casualties.

During the fourth phase, June 7 to July 8, mining operations were doubled. Secondary and tertiary harbors were added to the list of targets and the saturation of Shimonoseki and the primary ports of northwest Honshu and Kyushu continued. The important port system of Kobe-Osaka was mined repeatedly. Ship losses mounted rapidly, shipping began to drop off in the northwest ports and Shimonoseki, and the industrial ports were almost completely blockaded. Finally, Navy planes conducted attritional mining attacks on shipping off the southern coast of Korea.

Complete and total blockade of all Japanese shipping marked the final stage of the campaign. Japan was ringed with ports polluted by aerial mines. Sweeping was ineffective, but the Japanese preferred to take abnormally high losses rather than stop traffic completely. The diversionary ports of Honshu and Kyushu were used in a last desperate effort to get supplies to the mainland, but limited inland transportation prevented final delivery of the necessary food and materials to the industrial sections on the Inland Sea.

Over 12,000 Bureau designed mines were laid by the B-29's during the five stages of "Operation Starvation." Exacting a toll of more than 1,200,000 tons of enemy shipping, the mining campaign virtually severed Japan's lifeline to the continent. Industry was paralyzed. Food imports from the Asiatic mainland were reduced to a trickle; at least 10 percent of the 70,000,000 inhabitants would have starved had the war continued another year.

Although the Bomber Command devoted only 5.7 percent of its efforts to mining, Prince Konoye, a former Japanese premier, estimated that the aerial mining attack had an overall economic effect comparable to the bombing and incendiary raids of the remaining 94.3 percent of the Command's work. This was indeed a tribute to a weapon that only 3½ years before had been scheduled for a minor role in the naval war. The old saying that "no admiral ever got his stars because he was a mine specialist" was up for revision.

Chapter 9

NETS AND BOOMS

NETS and booms are among the most unglamorous of the major items in the arsenal of naval ordnance. The defensive job they perform in their vigil to protect ships and harbors is unspectacular. No sensational "kills" are attributed to them. Yet, their mere presence acts to frustrate the most powerful submarine and its deadly torpedo. The reluctance on the part of large submarines to attempt to breach net and boom defenses has led to the development of new forms of attack—the midget sub, one- and two-man torpedoes, which on the whole have proved as ineffective as their larger counterparts. The success of the defense against these spectacular weapons is the story of a late start and a whirlwind finish; of new methods of defense to counter new means of attack; and above all of resourcefulness in meeting the accelerated demands of a global and amphibious war.

Defenses designed to close harbors to the penetration of enemy weapons can be traced to earliest times. While the employment of these defenses in American naval history dates back to Revolutionary days, it was not until World War I, when the effectiveness of the modern submarine was established, that the use of such obstructions assumed any importance. To meet the menace of this new weapon, the antisubmarine net developed by the British shortly before the outbreak of World War I was adopted and installations were made at the principal Atlantic ports. Judged by present day standards, this net was indeed crude but it furnished the security it was designed to give. Enemy records, examined after the war, revealed that the Germans made no attempt to penetrate the net defenses of American harbors.

The period following World War I witnessed a rapid decline of net activities in the United States Navy. No research or procurement was initiated and with the exception of the occasional netting of a harbor, primarily for training purposes, virtually no interest was shown in this type of defense. When Hitler launched his European onslaught in 1939, there was no American experience with nets which could serve as a basis for design. Five million dollars worth of antisubmarine nets of World War I vintage were in storage at various activities along the Atlantic coast, but their

excellent condition failed to save them from an obsolescence for modern war comparable to that of smooth bore cannon. Once again it was necessary to turn to the British.

The British Navy was outstanding in the development of nets and booms. From 1914 to 1918 His Majesty's Navy laid approximately 600 miles of nets in 85 harbors and bases at a cost of about £9,200,000. Engaged in rigging and maintaining these defenses were 360 officers, 4222 men, and 312 vessels. The British net, rushed into production without the usual careful consideration and service tests necessary to establish reliability, served its purpose, although the one attack launched against it by a German submarine in October 1918 suggested that the security it afforded was largely illusory. This realization spurred the British to increased activity. During the years following the war, exhaustive experimental work was initiated and designs of promise were subjected to full-scale service trials. By 1939 effective types had been developed and were in production. In the summer of that year the British offered to share their success with the United States Navy. The offer was accepted and representatives were dispatched to make a detailed study of the British net establishment. Ordnance officers spent ten weeks in England and Scotland and returned with all available publications and drawings. It is interesting to note that under British terminology "boom" describes any obstruction whose primary function is the exclusion of hostile vessels or weapons moving on or under the water. American practice distinguishes between the types of defense: Nets defeat underwater moving objects, while booms counter surface threats.

The inadequacy of World War I nets and booms to afford security for American harbors was well known to the Bureau, but not until the fiscal year 1940 brought general increases in appropriations was a program undertaken. The original plan called for the netting of 10 harbors: Coco Solo, Balboa, Guantanamo Bay, St. Thomas, Hampton Roads, Yorktown, San Juan, Newport, Rich Pass and Agate Pass, Wash. The Chief of the Bureau estimated that it would require at least 2 years and possibly 3 to procure the material and install the defenses. The tempo of the European war soon led to the expansion of this program, and early in 1941 the Chief of Naval Operations directed procurement of material for net defenses at Indian Island, San Francisco, San Pedro, San Diego, Pearl Harbor, Honolulu, Kaneohe, Midway Island, New York, New London, Boston, Portsmouth, Sasco Bay, Charleston, Argentina, Delaware Bay, and Pago Pago.

In carrying out the 1940-41 net and boom program, considerable design work had to be done. During the initial stages, ordnance engineers, though leaning heavily on the British designs, found it necessary to make many modifications in the drawings in order to meet American production practices and standards. The British "tailored" their heavy nets to the site with extreme care, and this practice was adopted for continental defenses and for a few outlying sites. Due to lack of experience, the defenses in most instances were drastically modified at the time of installation in order to overcome conditions of current, sea, and anchor-holding bottom. The problem was solved by the adoption of designs which showed the typical characteristics of the defense, and thus could be applied to any harbor with only minor modifications. The officer supervising the installation adapted the materials in a manner which would furnish the most effective defense. This policy became more significant as the war progressed, since it was demonstrated very early that it was impossible to design from a remote location the optimum installation for a given site.

Difficulty was encountered in the design of shackles, clips, clamps, wire rope fittings, and clevises. Many of these marine hardware items had never been produced by American industry, and considerable time was required in detailing the drawings of these components so that the material could be produced rapidly and at reasonable cost. The Hubbard Co. of Pittsburgh, a well-established hardware firm, cooperated with the Bureau in this project, and under a dollar a year experimental contract, developed many new items. In addition to important design work, this company furnished over 90 percent of the marine hardware required by the net program.

Late in 1940, British designs had been adapted for submarine nets, single- and double-line torpedo nets, combined submarine and torpedo nets, light indicator net, heavy indicator net, net gates, and antimotorboat booms for use in conjunction with submarine or torpedo nets.

Production problems equalled those of the drawing board. Manufacturers were unwilling to swap well-established civilian production with its known profits for the Pandora's Box of the defense program. In some instances, nationwide publicized schedules for net material failed to attract a single bidder.

The task was further complicated by the decision to use the facilities of small business as much as possible in order that the larger industrial establishments would be available for the production of more urgent ordnance material. Many of the small firms

indicating an interest in net work had such limited resources that there was little chance that they could successfully execute a Navy contract. Collectively, their potentialities were great. At the instigation of the Bureau, the facilities of many of these plants were pooled and successful contractual relationships initiated. The Texhoma Co. furnished an excellent example of this type of cooperation. Composed of 26 small oil-well-tool machine shops scattered over northern Texas and southern Oklahoma this company did an excellent job in producing over 50,000 flotation units. A salaried representative stationed in Washington acted as the prime contractor and sublet to the various shops according to their special facilities.

Small business could not qualify for the manufacture of wire rope. The tremendous requirements for this item were supplied by two well established firms—John A. Roebling's Sons Co. of Trenton, N. J., and American Chain and Cable Co., Inc., of New York City.

Chain constituted an early production bottleneck. At the end of World War I, the surplus of heavy chain of all sizes was sufficient to meet peacetime requirements for many years. As a result, artisans in heavy chain manufacture were forced to shift over to the specialty chain field and there was no further need to train apprentices. By 1939, the heavy chain industry was virtually dormant and could supply only a very small fraction of the chain required for the underwater defenses. Since the success of the whole net program depended upon an adequate supply of chain, it was imperative that apprentices be recruited for training immediately. While the nets were still on the drawing boards, the chain industry, at the urging of the Bureau, launched an ambitious recruiting campaign for trainees in the hope that there would be no appreciable time lag between design and production.

The training of chain makers was no routine process; special qualifications were required, but in spite of the careful screening of applicants, only 2 out of every 10 likely prospects successfully completed the training program. Then, too, training was relatively slow since the apprentice had to work up through the various sizes of chain. In spite of these handicaps, which caused a slight delay in meeting early schedules, the chain industry by 1941 had built up its capacity and was fulfilling all production requirements. In the revival of the industry, the McKay Co. of Pittsburgh played a leading role. This company had no heavy chain capacity in 1939, but within 2 years it had built the largest wrought iron chain making plant in the world at McKees Rocks, Pa., and was producing

more heavy chain than all other American manufacturers combined.

In spite of the tremendous expansion of net facilities, manufacturers were barely able to keep abreast of requirements. Material for 28 harbors, however, was produced and delivered in less time than was set for the original 10—1052 drawings, 56 overlays, 45 sketches, and 120 lists of drawings were required for the 150,000 tons of material that went into these defenses, and the \$20,957,000 cost represented a procurement of approximately 48 miles of net material. With the delivery of the new type nets, the old World War I antisubmarine net material was broken out for use in fixed obstructions.

Installation of the defenses was accomplished without serious complication; all material, with the exception of a few minor alterations and additions, being delivered by December 1, 1941. Before any of the nets were placed, officers trained for several months in the theoretical and practical aspects of net defenses were available in the various districts. Net vessels were under construction and some net components were undelivered, but the ingenuity and training of the officers and enlisted men resulted in adequate net defenses, although many, of necessity, deviated from the standard designs.

The efficient organization of productive capacity during 1940—41 contributed immeasurably to the smooth functioning of the net and boom procurement program in the years following Pearl Harbor. For the most part, production problems had been solved by the time of Pearl Harbor.

The experience gained at Pearl Harbor resulted in the reorientation of the net and boom program. The devastation caused by the Japanese aerial torpedoes and the potential threat of midget submarines pointed up clearly the weaknesses of the existing net defenses.

On December 7, 1941, 86 combat and service ships were berthed in Pearl Harbor—8 of the 9 battleships of the Pacific Fleet, 9 cruisers, a third of the fleet's destroyers, 5 submarines, numerous supply and repair ships, tenders, and oilers.

When the Japanese struck, their principal targets were the heavy ships, and on these vessels their bombers and torpedo planes wreaked a frightful toll. When the attack was over not one of the battleships was capable of meeting the enemy, and the light cruisers, *Helena*, *Honolulu*, and *Raleigh* were crippled. While serious damage was done by bombs, torpedoes were the principal



Midget submarines cooperated in the attack on Pearl Harbor.

cause of the immobilization of the ships. To make sure that these destructive weapons reached their targets in the relatively shallow and narrow confines of Pearl Harbor, the Japanese contrived a wooden fin which prevented deep diving. This eliminated to some degree the inherent danger that the torpedo would bury itself in the mud on its initial dive and, as a further safeguard, they employed an exploder designed to function after a very short run.

Midget submarines cooperated in the well-planned attack. At 0530, one of them completed a 60-minute reconnaissance around Ford Island and retired to report its observations to the Japanese Fleet. The two-man submarine inside the inner harbor remained to take part in the actual attack. It was discovered and sunk, but not before it had fired two torpedoes both of which missed the target.

The standard submarine net protecting Pearl Harbor was constructed of 300-foot panels of 1-inch mesh rope measuring 8 feet on each diagonal. The Japanese midget submarines were especially designed to penetrate this type of defense; they were small in size, employed extensive net cutters, and the whole tail assembly was so arranged as to offer no projection to foul a net. The fact that they entered the harbor through an open gate and made no frontal attack on the net did not obviate their potential effectiveness. A careful examination of the midget beached outside the harbor led to the belief that, by cutting one wire in the 8-foot diag-

onal, the sub could undoubtedly have penetrated the net without giving any indication of attack.

The Japanese assault raised two questions concerning nets: Could they be altered to provide protection against torpedoes fired from inside harbor entrances? Could they be altered to defeat sneak attacks? The effectiveness of the net defense system depended in no small degree upon the solution of these problems.

Sneak attacks are segregated into three distinct classes. The first comprises standard large size submarines and motorboats whose displacement and maneuvering characteristics are such that they attempt to breach defenses by frontal attack, relying upon momentum to burst the nets or booms. They have long operational ranges and employ torpedoes and mines as attack weapons. The second class embraces medium or small size submersibles, or motorboats which attempt to penetrate the defenses by evasion through openings above, below, or around the nets. The largest of this class, equipped with cutters, is capable of a direct assault. The operators, enclosed within the vessels, rely upon the excellent maneuvering characteristics of the craft to gain the position desired to launch their torpedoes or mines. The craft in this category are especially constructed for sneak raids and, therefore, incorporate all the devices which are factors in the accomplishment of a successful mission. A further characteristic is short operating range—some types must be delivered to within 20 miles of the objective. The third category includes submersibles in which the operators are exposed and may dismount and use their hands as desired. The craft in this class are used primarily to transport the operators to the scene of action, and are characterized by small size, slow speed, short range, and extreme versatility.

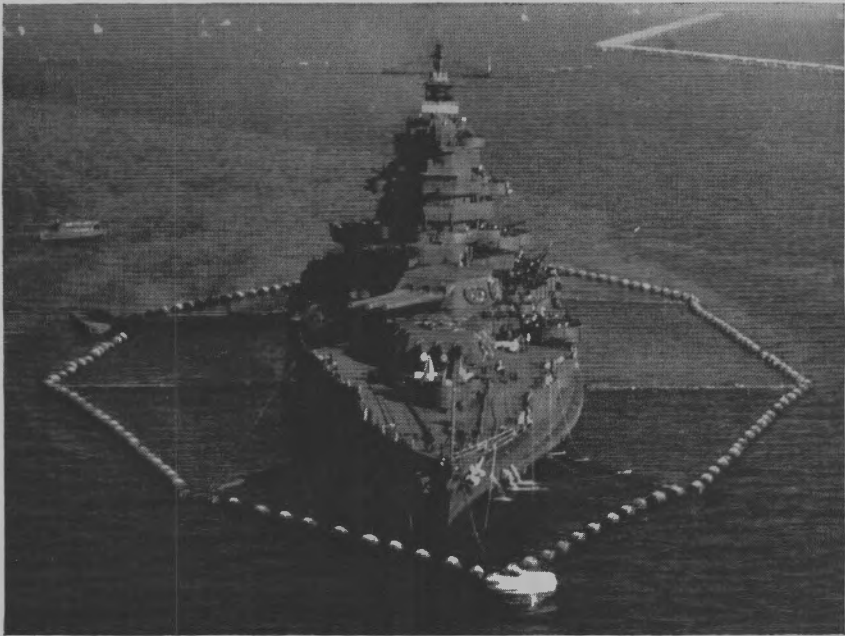
The policy of the Bureau in meeting these threats was to present the most effective barrier against the larger craft, while incorporating as many features as possible in design to defeat the other classes. The British, on the other hand, attempted to incorporate features in their basic designs to counter all three types. War experiences, however, demonstrated that combined defenses were not reliable.

Another fundamental point constantly kept in mind by designers was that no net or boom was effective in the sense of being self-sufficient. These barriers afford maximum security only when supported by alert net patrol vessels and other defenses equipped to destroy an attacking enemy—the nets and booms merely delay and provide indication of danger; other means must be used to apply the *coup de grâce*.

In the application of these principles, the Bureau, early in 1942, reduced the mesh of the submarine net. In order to conserve material and time, this was done with nets already in use by inserting a one-half inch wire rope in such a manner as to quarter each 8-foot diagonal. Appropriate clamps were developed and the design modified to support the increased weight of the net panel. Heavy indicator nets, which also employed the 8-foot diagonal, were reduced to a 4-foot diagonal and the manufacturing slabs adapted to this construction. Fortunately, the modification of the design of light indicator net was initiated before procurement deliveries were made. Designs of skirt and apron nets to be used in conjunction with torpedo and other types of standard net defenses were rushed to completion in order to furnish additional protection. In keeping with Bureau policy these modifications did not impair the efficiency of the nets against large submarines.

Nets protecting harbor entrances, while furnishing adequate security from submarine attack, offered no defense against the airplane and its torpedoes. The spectacular success of the torpedo plane at Pearl Harbor, as well as at Tulagi and Taranto, vividly illustrated the need for effective individual ship protection inside harbors. The danger was particularly great for moored ships. In early 1942, it was estimated that the normal expectation of aircraft hitting a ship at anchor was 1 torpedo out of 2; a capital ship underway, 1 torpedo out of 7; and a merchantman underway, 1 torpedo out of 3. The vulnerability of anchored ships to torpedo attacks led the Bureau to place a high priority upon design, development, and test of nets for individual ship protection.

The individual ship protection program (ISP), initiated in 1942, served a useful purpose until the rapid advance toward Japan introduced new tactical elements which forced the abandonment of the program as originally planned. While offering excellent protection against torpedoes, nets afforded no security against limpet mines, bombs, suicide planes, or other suicide devices, and as the offensive approached the Japanese mainland the intensity of these attacks increased. Maneuverability was essential and even with the most efficient release gear the nets remained an embarrassment to a capital ship in getting underway. The 300 ISP nets in use were not a loss, however, as they were employed as additional baffles supporting the primary protection of anchorages. Procurement of light ISP nets was continued primarily for use as baffles for assault stage rapid laying. This application eliminated the net



Individual ship protection.

gate and gate vessels, thus reducing the delay in passing ships through a gate. At the same time, greater maneuverability was assured inside the anchorage.

Like the Pacific war itself, the net program progressed from defense to offense. In other words, up to and through a part of 1943, nets were primarily for harbor defense. As the theatre of the Pacific war advanced eastward, it became necessary to modify nets in order to permit them to function at the maximum efficiency at advanced bases and with advance units. The problem was first brought into sharp focus with the shortage of shipping space. Materials were available and trained personnel on hand, but the tremendous weight and volume of nets precluded any but the most important shipments, and these were generally in a rear echelon. Weeks were required for the net tending vessels (AN's) to install the nets as they were assembled by advanced base details. As the tempo of war increased, there was a corresponding demand for lightweight nets which could be laid rapidly. Protection was desired on or near D-Day, not weeks or months later. A temporary net defense against submarines would aid in the success of an amphibious operation when the initial supplies were being unloaded—

when the speed of the advance was measured by the supply of critical items furnished in early echelons.

The first step in the solution of this problem was the development, in the summer of 1943, of an entirely new indicator net. In contrast to the submarine type which weighed 2200 tons per mile, occupied 173,000 cubic feet, and required special vessels 3 to 4 weeks to install, the light indicator net weighed only 8 tons per mile and could be laid at a speed of 3 knots from the smallest landing craft. In order to provide rapid laying characteristics, soluble brailing cord was employed to get the net to unbrail automatically after being in the water for 20 to 30 minutes. The net had sufficient life, 7 to 10 days under normal sea conditions, to bridge that critical period when the beachhead was being consolidated. Eighty miles of this net was procured at a cost of approximately \$1,000,000.

The short service life of this net brought a demand for a lightweight semipermanent submarine installation. British heavy indicator net was a fair solution to the problem but its use required special net laying vessels and these were not available since the originally planned AN's had been diverted to other uses. Without these vessels for stowage and laying, heavy indicator net was not desirable for semipermanent installations. While retaining the indicator features of the heavy net, a novel mooring assembly was incorporated in a new net which was designated the LSI-2. The LSI-2, designed late in 1943, furnished an effective net which could be used in tideways with relatively low maintenance. Service use brought a marked reduction of flotation in the mooring system with a corresponding decrease in the volume and shipping weight of the net. This net was the only type of submarine net in common use at advanced bases.

Torpedo nets were of such importance that special vessels (AKN's) were assigned to transport and install net material at advanced bases. The AKN's were put in operation early in 1944. Two types were used: The *Keokuk* class, converted from a train ferry, which laid thousands of feet of light but effective torpedo net in a matter of hours, and the *Indus* class, a group of specially designed Liberty ships equipped to assemble and launch a more permanent defense after the initial stage of the attack. These ships not only took care of the primary problem of transportation, but also served as the net depot and assembly area. This avoided delays in handling and, in many instances, eliminated shore depots. The AKN's were loaded to meet the demands of each specific net mission but they usually carried 10 percent light indicator, 20 per-

NETS AND BOOMS



AN's removing German torpedo nets from Cherbourg Harbor.

cent light submarine indicator, and 70 percent torpedo. Several AN vessels were assigned to each AKN to install the net as soon as it was fabricated and launched from the cargo vessel. In this way the time required to lay torpedo nets was reduced from weeks to days, and since the nets were the only cargo on the vessel they could be moved into the landing area around D-Day. The operational use of the AKN-AN vessel groups was a most significant advance in net and boom defense since the nets were furnished in sufficient quantity and at a time when the area was a potential submarine and aircraft torpedo target.

A few examples are sufficient to illustrate the effectiveness of AKN-AN operations:

At Saipan, the *Keokuk* laid 3300 yards of light indicator net in 3 hours and 35 minutes.

At Saipan, the team of the *Tuscana* (AKN) and the *Holly*, *Cinchoma*, and *Chinquapin* (AN's) installed 7373 yards of torpedo net in 19 days.

At Ulithi, the *Tuscana*, *Sagittarius*, *Zebra* (AKN's) and the *Mastic*, *Cornel*, *Veburnum*, and *Winterberry* (AN's) installed 16,000 yards of torpedo net in 28 days.

At Kossul Passage, the *Zebra* (AKN) and the *Galapa, Cliff-rose*, and *Winterberry* (AN's) installed 3160 yards of torpedo net in 6 days.

To provide protection as early as possible during an operation, the *Keokuk* developed a special technique for laying light indicator net, and at Saipan the net was actually laid before the reduction of the island and in time to protect the naval craft engaged in the assault. The nets were stowed in 1000-foot lengths and when ready for installing were run out as overlapping baffles. The baffles, being temporary, were eventually replaced by permanent nets installed by AKN-AN vessels. This use of the light indicator net found much favor with fleet planning officers and became a permanent net defense.

The importance of net defenses at advanced bases is shown in the following table:

Advanced Base Torpedo Net Installations

<i>Base</i>	<i>Yards</i>	<i>Base</i>	<i>Yards</i>
Guadalcanal	1300	Peleliu	1000
Tulagi	2700	Ulithi	23,300
Espiritu Santo	5000	Manus	9000
Kwajalein	3100	Philippine Islands	8500
Eniwetoc	8800	Okinawa	13,500
Tinian	4400	Aleutians	30,000
Saipan	9800		

The magnitude of the task of delivering the tremendous quantities of net material overseas, is illustrated by one shipment which comprised 18,000 long tons and involved the efforts of four Navy bureaus. In fact, the weight and cube of nets and allied equipment shipped overseas exceeded the volume of any other class of inert ordnance material. In order to prevent sudden and periodic overloading of rail and tidewater facilities which these shipments might necessitate, storage points in the Pacific were set up where materials were gradually accumulated. These staging points proved invaluable in enabling the net cargo vessels to keep up with the pace of operations in the Pacific.

Approximately \$120,000,000 was spent in net and boom procurement from July 1, 1940, to August 14, 1945. At all times during this period there was a sufficient supply of material to meet all requirements, though in several instances the productive capacity of the Nation was strained to the limit. These production crises arose primarily from the inability of the Office of the Chief of Naval Operations to estimate operational requirements with any degree of accuracy. Indeed, CNO's difficulty was entirely understandable in the light of rapid advances in the Pacific.



Advanced base detail assembling torpedo net.

A survey early in 1943 disclosed that more than 60 percent of the procurement of carbon steel, the principal component of net material had been for unscheduled projects about which the Bureau had no advance notice of individual directives which required immediate performance. In order to meet these unforeseen demands, the Bureau based its procurement upon the estimate that the ratio of unscheduled operational requirements to scheduled requirements would be approximately 2 to 1. Procurement on the basis of this rough and inflated estimate enabled the Bureau to meet all demands. The changing requirements in the operational characteristics of nets rendered obsolete much of this material; the excess components, however, were absorbed by the Bureau of Ships and the Bureau of Yards and Docks and the surplus was never unmanageable.

From the beginning of the European War in 1939 until mid-1941 the Bureau of Ordnance was concerned primarily in providing net designs of proven ability and in procuring sufficient materials to install the necessary defenses. As soon as the installation of the continental defenses began, the interest of the Bureau centered upon problems of fitting these designs to the conditions experienced at actual net sites. Another objective in 1941 was to

operational requirements for new designs by the rearrangement of standard net components. During 1942, the initial American designs began to appear and fundamental studies of all important phases of net and boom work were undertaken. In 1943, as service experience was gained, new methods of achieving the ultimate goal of submarine and torpedo defenses were conceived and reduced to improved designs. In the development of these new nets, the Bureau worked closely with the experimental units at the Naval Net Depots, Melville, R. I., and Tiburon, Calif. The commissioning of the AKN vessels in 1944 advanced the whole field of net and boom defenses, and the streamlining of the heavy nets plus the development of new light ones changed their entire tactical use from a harbor defense unit to a significant part of amphibious operations.

Net and boom defenses advanced tremendously from the early days of 1939 when there were no American defense designs, no modern net material, no written literature on the subject, and few trained personnel. By the end of World War II there were net designs for nearly every operational need, hundreds of trained net officers, thousands of enlisted personnel, a hundred or more special net laying vessels, adequate net material, invaluable experience in the maintenance of nets, and a thorough background of the fundamentals applicable to all types of net and boom defenses.

Chapter 10

AMMUNITION

THE value of ordnance lies in its power to destroy and the root of that power is explosives. "It is not the ship or airplane that really hurts the enemy," observed an old ordnanceman, "they are just carriers for the item that does the damage. Explosives are what really knocks out the enemy. . . ." The truth in his statement, however oversimplified, was obvious, and Bureau effort in the development and procurement of explosives was in proportion to the importance he accorded them. Representing billions of dollars, that effort was one of the major accomplishments of World War II. The explosive capacity of the country, virtually dormant at the beginning of the emergency in 1939, was built up to such an extent that its wartime output would have overflowed a freight train stretching from Boston to Los Angeles.

That feat was even more spectacular when viewed in the light of the rigid standards demanded of the product. A military explosive must be reasonably safe to manufacture, handle, and load. It must have a long service life and ability to withstand adverse conditions of stowage, combined with physical properties that permit a maximum weight to be packed in a minimum volume. The explosive must deliver enormous power for its weight, produce the proper fragmentation when that power is released, yet resist all forces that might prompt a premature detonation. Above all, the explosive must be available in quantity. Difficult as they were to achieve under normal conditions, these requirements were further complicated by the intricacies inherent in a rapid build-up of the explosive facilities of the Nation, by the shortage of raw materials, and by demands for the development of new items.

One of the most important explosives is smokeless powder. All United States naval firepower, from the small caliber machine gun firing at the rate of more than 1000 rounds a minute, to the 16-inch gun hurling 2700-pound projectiles 20 to 25 miles at speeds of 2800 feet a second, depends upon this mistitled explosive for propulsive energy. The term smokeless powder is a paradoxical misnomer, for the substance is neither smokeless nor a powder. Smokeless only by comparison with its predecessors, black and brown powders, which give off dense white smoke when fired, it is

used in the form of small flakes, strips, pellets, single and multi-perforated cylinders, and other varying geometrical shapes. Grain sizes vary from 0.05 of an inch for small machine gun ammunition to huge 60- by 5-inch sticks for the Tiny Tim rocket. Designed to meet the individual needs of each weapon, the space, dimensions, and the number and arrangement of the longitudinal perforations in each grain are determined with minute precision in order to obtain the uniform generation of propulsive power which contributes so much to the performance of projectiles. Tamed by the knowledge of the explosive chemist, the quick acting smokeless powder is under such perfect control that its action can be predicted for any type weapon. The advance in guns and gunnery in recent times is rooted in this development.

For centuries missiles were thrown toward an enemy by a propelling charge of black powder. First used in battle by the Chinese in the thirteenth century, the mixture of saltpeter, charcoal, and sulphur remained for over 600 years the standard gunpowder of belligerents. Black powder was not an ideal propellant. Only 35 percent of the charge was utilized; the remaining 65 percent vanished in a cloud of dense white smoke or remained in the bore of the gun as a sticky residue. An even more serious objection sprang from the fact that black powder burned so rapidly that 90 percent of the pressure was exerted on the breech end of the gun, a force so terrific that casualties often resulted. Ruptured guns were the trademark of black powder. The American Navy was not immune to the hazards of this material, and early naval annals are studded by ill-fated explosions. Perhaps the most disastrous of these occurred in February 1844, when a revolutionary new gun, the Peacemaker, exploded on the *U. S. S. Princeton*, killing the Secretary of the Navy, the Secretary of State, and injuring scores of congressmen, diplomats, and other high Government officials who had been invited to witness the firing. President Tyler himself narrowly escaped.

Just 6 years before the tragedy aboard the *Princeton*, the first step toward reducing such accidents by replacing the principal culprit was taken in a French laboratory when Jules Pelouze discovered the effect of combining ordinary cotton with nitric acid. This was the earliest known synthesis of guncotton or nitrocellulose. There lay the origin of smokeless powder, although 50 years passed before the discovery that the colloid possessed the remarkable property of burning progressively under pressure. In 1865, building on the work of Pelouze and his successors, Sir Frederick Abel of the British War Department, worked out a relatively

safe process for the manufacture and purification of nitrocellulose, thus permitting further progress in the development of smokeless powder. The purification methods perfected by Abel are essentially the same as those in use today.

But even after this advance, the use of nitrocellulose in weapons seemed stymied. Guncotton was too quick and violent in action and lacked a strong and satisfactory physical structure. Very much like cotton in its original state, it consisted of fine porous fibers with little mechanical coherence. Through this structure the flame traveled with great, uncontrolled rapidity, giving rise to sudden and high pressures. Extremely dangerous to use in guns, nitrocellulose was for years primarily employed as a blasting agent.

The problem of changing the physical structure of guncotton to secure controlled burning was early appreciated. Experiments were made with many different substances and compounds. But it was not until 1880 that the first notable success was achieved with the discovery that the solvent action of ether and alcohol partially gelatinized or destroyed the porous fiber structure of the guncotton, thus slowing down the burning rate. In spite of this advance, the powder still burned much too fast for effective use in large rifled guns.

In 1884, the French chemist Vieille incorporated nitrocotton into a mixture of ether and alcohol and rolled the resulting paste, a colloid, into thin sheets, which were then cut into small squares and dried. The colloid, after rolling, lost the undesirable physical properties of the original nitrocellulose and became gelatinized into a pliant, coherent mass. This plastic substance could be formed into various shapes and had good physical strength after drying. The first true smokeless powder, the new product was named Poudre B for General Boulanger, sponsor of the experiments.

Contemporaneously with Vieille's work, Nobel developed ballistite. Made in essentially the same manner as Poudre B, Nobel's guncotton was gelatinized with nitroglycerine and acetone instead of ether and alcohol. This produced a more powerful propellant because of the added energy of the nitroglycerine. These two variations of smokeless powder form the two classes known as single and double base powders. A propellant consisting essentially of nitrocellulose, such as Poudre B, is a single base powder; one containing both nitrocellulose and nitroglycerine, such as ballistite, is a double base powder. A third variation, multiple base powder, contains both nitrocellulose and nitroglycerine, plus large additions of other chemicals. All variations of smokeless powders may be classified as one of these types.

The Bureau of Ordnance did not begin research in smokeless powder until the 1890's. In his annual report to the Secretary of the Navy at the opening of the decade, the Chief of the Bureau called attention to the manufacture abroad of smokeless powder for use in rapid firing guns and to its adoption for small arms by France, "where the secret of its manufacture is guarded." The next year the Bureau began experimental work on smokeless powder at the Newport Torpedo Station, where a small plant was installed to manufacture guncotton for submarine mines and automobile torpedoes. The outlook was optimistic; an official prediction forecast that "within a short time the use of present gunpowder will be abandoned in all calibers 6 inches and below and replaced by smokeless."

In 1897 the fulfillment of that prophecy began with the introduction to service of a new powder developed at Newport. Made of a special variety of nitrocellulose, the powder was a tough colloid with a high ballistic efficiency. Since the facilities of the Torpedo Station were too small for large scale production, contracts were made with du Pont and the California Powder Co. for the manufacture of 200,000 pounds of the new powder. In October



Boiling tubs, Naval Powder Factory.

1897, the *U. S. S. Marblehead* became the first American ship to be fully equipped with smokeless powder; thereafter all new ships were similarly supplied as they entered the fleet.

The Bureau was reluctant to depend upon commercial sources alone for a supply of smokeless powder. At the Navy's request, Congress appropriated \$94,000 in 1897 for the construction of a powder factory large enough to meet the needs of the fleet. Work on the plant at Indian Head, Md., started immediately, and the first powder was made in June 1900. Thereafter, most of the propellant powder required by the United States Navy during peacetime was produced at the Naval Powder Factory. The skills and techniques of Indian Head personnel in the manufacture of smokeless powder and explosives became a proud tradition of the Ordnance establishment.

The powder grains manufactured at Indian Head are smooth, regular cylinders of an innocent looking hornlike material, varying in color from light amber to dark brown. Cotton linters, too short to be woven into cloth, are immersed in a solution of sulphuric and nitric acids and converted into nitrocellulose or pyro. Millions of gallons of water are required to purify the pyro by boiling and washing, and to transfer it safely from building to building. Long hours of boiling and poaching, while acid and water are reclaimed to repeat the process again and again, prepare the pyro for the dehydrating house. The bulk of the water is removed by centrifuges. Alcohol eliminates the remaining water. When ether is added, the pyro becomes a tough colloidal mass, which can be extruded into appropriate rope or twine sizes for cutting into tiny grains for small guns, or large cylindrical grains for the big guns. Pin sized longitudinal perforations in each grain insure complete burning of the charge by the time the projectile leaves the gun muzzle.

The service life of the powder is approximately 20 years, and even after the expiration of this period the propellant may be reworked to bring it up to service standards. For purposes of test and issue, smokeless powder is manufactured in lots varying in weight from 25,000 to 125,000 pounds, depending upon the granulation. After proof firing and acceptance, a lot or a blend of several lots is given an index number and assigned to a specified gun, with approved weights of charge for service and target practice velocities. During the war over 6000 index numbers were assigned. A prefix to the index number is always used to indicate the type of powder: among others, SPD signifies smokeless powder with a diphenylamine stabilizer—the key to long life; SPDW, reworked powder;

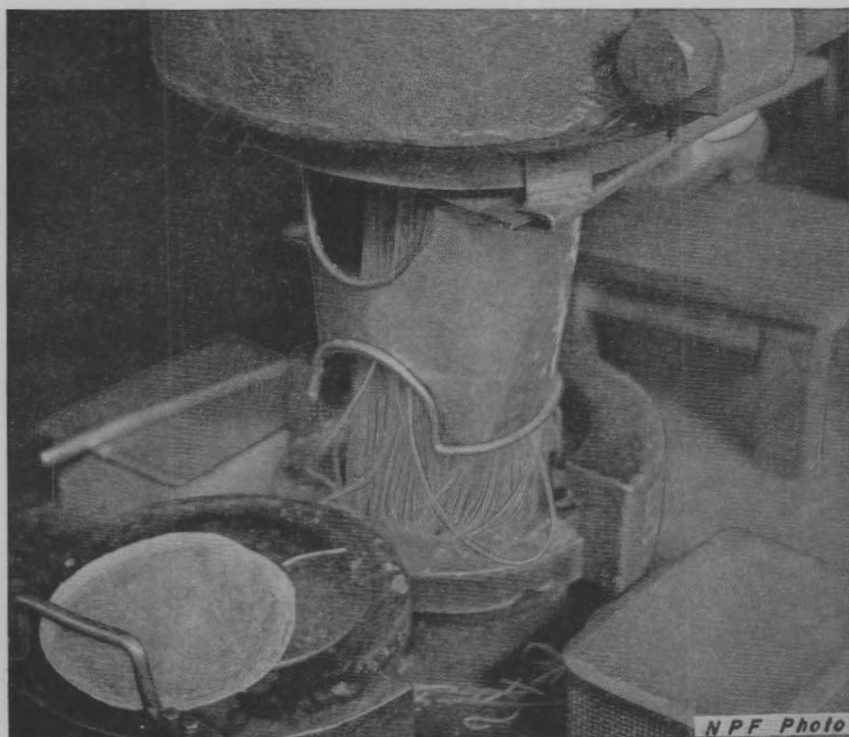
SPDX, stabilized water dried powder; SPDB, a blend of more than one index, and SPDF, a flashless type.

Indian Head became the center around which the smokeless powder and high explosive programs of the Bureau revolved. During World War I it produced over 10,000,000 pounds of new powder and reworked approximately 800,000 pounds of older powder. At the close of the conflict only three sources for the manufacture of smokeless powder existed: the Naval Powder Factory; Picatinny Arsenal, operated by the Ordnance Department of the United States Army at Dover, N. J.; and the Carney's Point, N. J., plant of the du Pont Co.

The first commercial contract for smokeless powder placed by the Bureau after the close of the war was awarded to du Pont in May 1927. From then on small contracts were placed with du Pont in order to keep alive the commercial art of smokeless powder manufacture. This policy was so vital to the Bureau that on occasions the production at Indian Head was reduced in order to keep the Carney's Point plant operating. The soundness of the decision was reflected in the substantial number of du Pont personnel who were called upon to operate the many smokeless powder plants erected to meet the needs of World War II.

Although the Naval Powder Factory and the du Pont Co. had sufficient facilities to supply the peacetime requirements of the fleet, their capacity could not begin to meet the demands of a shooting war. Following World War I, there was much criticism of ordnance procurement. In many cases both the Army and the Navy attempted to design and produce almost identical items, and they competed in the market for the same raw materials. To avoid this duplication in any future war, the Army-Navy Munitions Board divided the tasks so that one service would have the responsibility for producing the wartime supply of certain types of munitions required by both. It was established, well prior to the declaration of the emergency, that in general the expansion of production facilities for explosives would be under the cognizance of the War Department, the largest user of military explosives. In order to keep the Navy in touch with manufacturing processes, informal agreement between the services permitted the Bureau of Ordnance to place small orders for various explosives with commercial sources. In certain cases where the Bureau of Ordnance had pioneered in the use of an explosive ingredient, aluminum powder for example, the Army insisted that the Navy assume the procurement role.

The procurement of explosives was well coordinated between the Bureau of Ordnance and the Ordnance Department of the



Extrusion press, Naval Powder Factory.

Army. Approximately 80 percent of the smokeless powder, rocket propulsion powder, TNT, explosive D, and RDX compositions supplied to the Navy came from Government ordnance plants, contractor-operated under the cognizance of the War Department. The remaining 20 percent was produced in Navy-owned and operated facilities or by private contractors. The War Department furnished about half of the tetryl and lead azide required by the Navy; black powder was almost wholly supplied from commercial plants.

The establishment of production arrangements left many developmental problems confronting the Bureau of Ordnance. The firing of guns with smokeless powder was accompanied by a loud report, a large flame, and a moderate quantity of red-brown gas. The numerous night actions in the early days of the Pacific war emphasized the need for a flashless powder. Curiously enough, the demand arose not from a desire to conceal the position of the guns but from the necessity of preventing the temporary blinding of ships' crews during firing runs. According to the fleet gunnery officer, the elimination of the flash in night firing would

also improve fire control performance. With the advent of radar in World War II, smoke became less objectionable and the fleet was willing to accept considerably more smoke in order to obtain a "good reduction of flash."

The problem was not unknown to the Bureau of Ordnance. In the mid-1920's, both the Naval Powder Factory and the du Pont Co. developed flashless powders. The Powder Factory had also obtained good results by mixing flash-reducing chemicals with the conventional powder charge. Flashlessness, however, was gained only by an increase in the amount of smoke, then unacceptable to the fleet because it interfered with searchlight illumination and fire control. By 1928, the Bureau had stopped work on flash suppression.

At the time the request for flashless powder was received, the Bureau had already accumulated large inventories of smokeless powder. If this material was not to become obsolete some means of converting it into acceptable flashless charges had to be found. Recalling the 1920 experiments at the Naval Powder Factory, the Bureau turned to that activity with its problem. By the summer of 1942 the NPF had the answer in a chemical tablet made of a mixture of potassium nitrate and potassium sulphate, to which was added a small amount of graphite to facilitate pelleting. After extensive tests by the Naval Proving Ground, the complex details of manufacture, loading, and ballistic adjustments were worked out; by September 1942 production for service use was under way.

Production facilities were established at the Naval Powder Factory, where a single pelleting machine turned out between 25,000 and 50,000 pounds of material a month. From time to time these facilities were expanded until, in the latter half of 1944, the productive capacity of the Powder Factory had reached approximately 200,000 pounds a month.

Commercial production was centered in the pharmaceutical industry, whose pelleting machines were adapted to the manufacture of the aspirin-like tablets. The Parke, Davis Co. was the first of the firms to produce flashless pellets. In the 3 years it was engaged in the program the drug company turned out an average of 75,000 pounds of pellets a month. Parke, Davis was not only an outstanding producer, it was also the repository for production techniques which it made available to the 10 other pharmaceutical concerns accepting Bureau contracts. Some idea of the demands upon the industry may be gained from the fact that at the height of production in 1943-44, these firms were producing over 1.3 billion pellets a month. The National Fireworks Co. was the only non-pharmaceutical contractor participating in the program. The 12

private firms, together with the Naval Powder Factory, were able to meet the oscillating fleet demands, which varied from a low of 100,000 pounds a month to a high of eight times that amount. The margin was so close, however, that it was normally necessary to express shipments to the various depots and to handle ballistic reports by telephone.

The use of flashless pellets was limited to 3-, 4-, 5-, and 6-inch guns. Even in these calibers performance was not always perfect. Because their combustion was incomplete, the pellets at times formed a fused mass of clinkers in gun chambers, which at high angles of gun elevation resulted in casualties such as jammed breech mechanisms. To eliminate the hazard, the Research Division, working with the Naval Powder Factory, developed a flashless grain. The new material consisted of 50 to 70 percent potassium sulphate mixed with nitrocellulose, colloided as a normal smokeless powder, and extruded in the form of a powder grain. Satisfactory in both ballistic and flash suppression properties, flashless grains were in production at the Naval Powder Factory when the war ended. Meanwhile, pellets continued to serve the need for a flash suppressor. While not completely satisfactory, they provided the fleet with an essentially flashless charge long before it was possible to have true flashless powder.

The most desirable replacement for flashless pellets was, of course, flashless powder. Considering the use of depressants a temporary expedient, the Bureau instructed the Naval Powder Factory to seek a more permanent solution in the perfection of a real flashless powder. By the end of 1942, the NPF had developed satisfactory flashless granulations for both the 5"/38 and 6"/47 guns. Similar granulations for the Navy's big guns presented more complex problems. Since Indian Head was under pressure to use all its facilities for production, the Bureau placed a contract with the National Defense Research Committee in December 1942, for the development of flashless powders for the larger naval guns.

The National Defense Research Committee experiments soon demonstrated that for any powder to be satisfactorily flashless in 8" calibers and above, a composition similar to a British powder known as Cordite N would be required. The Bureau did not look with favor on the foreign powder though limited quantities had to be used until a better product could be developed. It was brittle; even worse, it contained nitroglycerine, a highly sensitive and rather volatile substance not often used in naval explosives. Escape from the impasse lay in the development of a material to replace the hazardous nitroglycerine. After testing scores of nitrated

compounds, the NDRC scientists narrowed the field to two likely candidates—DINA and Fivonite. Experimental firing at Dahlgren showed little difference between the two, but DINA was selected because of its superior physical properties.

Albanite, the name given the new flashless powder because of its white color, appeared to have all the desirable features of Cordite N and few of the objectionable one. Studies of Albanite by du Pont demonstrated the feasibility of large-scale production, and by V-J Day the Bureau had launched an ambitious procurement program which called for monthly deliveries of 4,000,000 pounds of the new propellant.

Flash elimination was but one of many developmental problems that faced the Bureau after combat experience began dictating ordnance requirements. Another important project was introduced by the increasing use of high capacity projectiles. The potent new ordnance—a direct descendant of the bombardment projectiles used by the 14-inch railway batteries in World War I—gained its lethal blast by sacrificing wall thickness for a larger explosive cavity. But the resulting thin walls changed the characteristics of the projectiles and complicated the job of propellant makers. Experimental firing demonstrated that conventional service powder, even in reduced charges, was not entirely satisfactory for HC projectiles. Gun erosion was hastened, velocity uniformity was poor, and in many cases unburned powder slivers littered the deck. A quicker powder—one that reached maximum pressure early in the projectile's travel in the gun bore—was needed. Thinner web powders were first tried, but they produced charges so small that they were difficult to handle in magazine hoists and hard to load into gun chambers. Furthermore, in order to keep the proper length to prevent unseating of the projectile, the diameter of the charge became so small that there was danger that the flame from the primer vent might miss the ignition pocket on the after end of the bag.

These difficulties were eliminated by the development of a new grain which retained the thin web but incorporated larger external dimensions. A single perforated grain, much like oversize macaroni, added 50 percent more bulk to the standard round, and was almost universally applicable for HC charges. Effecting a greater efficiency in powder combustion, and accompanied by a marked improvement in velocity uniformity as well as a halving of gun wear, reduced charges employing the new grains were exceedingly popular in the fleet.

With the advent of large-scale shore bombardment, it became increasingly evident that some method would have to be found to avoid or reduce the coppering of gun bores. Tin, a strategic metal, was the best decoppering agent, but it was not available in the large quantities required. Lead foil was selected as the most promising substitute, and throughout the war varying amounts of this material, depending upon the caliber, were introduced into all service charges. Surprisingly enough the use of lead foil as a decoppering agent was the result of a chance discovery. Fleet reports often indicated that the firing of illuminating projectiles brought a decoppering effect. Bureau investigation traced this result to the lead gaskets in the base of the projectiles. The addition of lead foil lessened the effectiveness of flashless pellets, however, and the search for a better material continued. At V-J Day, a new decoppering agent even more effective than tin was on the verge of quantity production.

Guns and propellants were, of course, the true staples of the fleet. In technological perfection and in quantity of expenditures, they represented the highest level of ordnance endeavor. Long before the war was over, however, a newcomer to naval ordnance—rockets—began to assume a major role in Bureau procurement. In range, accuracy, and general utility, rockets could not rival naval guns, but their tactical applications grew rapidly enough to push the rocket program into a position of highest priority.

The major problem connected with rockets was that of securing the powder sticks used to propel them. For small calibers the explosive material could be mixed with a solvent and molded into shape, but that method was not applicable to the sizes that came into common use. When sticks were of any appreciable diameter, the solvent failed to evaporate thoroughly and the propellant lacked the proper ballistic qualities. A method of manufacture was required whereby the powder could be left dry and forced into sticks of any desired size. Dry extrusion techniques were known and used abroad, but the hazards of production were too great for application to manufacture on a large-scale. A safe procedure applicable to American practices was needed, and the creative genius of the National Defense Research Committee soon solved the problem with the development of a dry extrusion press that could be duplicated for large-scale production.

The solution of the developmental problem left enormous hurdles ahead, however. Naval requirements mushroomed to 20,000,000 pounds a month by the summer of 1945. The gap between the output of the primitive press which began operations at the California

Institute of Technology in January 1942 and the procurement demands at war's end had to be closed by one of the many production miracles that marked the war years. As in the case of all Navy explosives, rocket powder was produced almost exclusively by the Army. Expansion of production facilities was unable to keep pace with the rapid increase in requirements. There seemed to be no limit to the utilization which the fleet proposed for rockets. Demands arose quite suddenly and it was difficult for the Bureau to anticipate requirements; in many cases it was necessary to request further expansion before previous schedules had been met. Production facilities were expanded under urgent pressure before processes for mass production were developed and perfected.

The Bureau of Ordnance, realizing the imperfection of production techniques, devoted considerable time and effort to the development of new equipment. A press employing standard hydraulic equipment was perfected to meet the mounting rocket extrusion requirements. Producing the large propellant grains used in the Holy Moses and Tiny Tim rockets, hundreds of these 15-inch presses were installed in Army plants where their efficiency increased production by as much as 40 percent. In addition, drilling and finishing equipment for use in Army facilities was developed jointly by the Naval Powder Factory and the Bureau. Concentrating rocket propulsion expansion at three contractor-operated ordnance works—Sunflower, Badger, and Indiana—the Army spent over \$85,000,000 for new facilities to keep abreast of Navy demands. By the summer of 1945, the rated capacity of the three plants exceeded 18,000,000 pounds of rocket powder a month.

The Army's mass production program was "piloted" by the modest output of the Naval Powder Factory and CIT, whose combined capacity was approximately 1,300,000 pounds a month. The NPF began extrusion operations in August 1943, with the 8-inch vertical presses obtained from CIT and three modified presses from their own smokeless powder line. During 1944, six modified 10½-inch presses, plus the original 15-inch prototype, were added, and the processing facilities were increased to keep pace with this extrusion capacity. At the end of the war, Indian Head was able to process approximately 1,000,000 pounds of finished rocket powder a month.

The relatively small capacity of the Naval Powder Factory was by no means indicative of its importance to the rocket propellant program. Developing engineering data and information extremely useful to the Army in the operation of its plants, Indian Head could

quickly adapt production to meet emergency requirements when the Army Ordnance Works were falling behind production schedules. In addition, the Bureau scheduled for the NPF those propellants which were still in the research and development stage and not readily adaptable to mass production. Thus, the 14,473,332 pounds of rocket powder produced by the station was characterized by a limited production of a wide variety of propellant grains on a "production emergency" basis.

Production was complicated by the multiplicity of types of grains required for the expanding program. Initial plans called for three types of small cylindrical grains for use in antisubmarine warfare. By the spring of 1945 there were 10 grains in production, 4 types in intermittent production, and two new grains awaiting processing. All the producers of ballistite grains encountered difficulty in manufacturing a product that could meet the specification of the prototype grains. At CIT where the process was developed, rejections averaged 20 percent; the rate was even higher at other facilities. At one period early in 1944, only one-third of the grains extruded were available for assembly in rockets. Improved production techniques as well as improved equipment soon brought the number of rejections into reasonable compass.

Fire was a constant menace. In January 1944 there were 550 fires during sheet rolling operations. The development of alternate propellant formulae reduced this danger. Achieved by the closely integrated cooperation of CIT, the War Department, the Hercules Powder Co., the NPF, and the Bureau, the improved state of the art of rocket propellant manufacture not only minimized the fire hazard but actually increased production.

The process of inhibiting the extruded powder grains proved difficult and reached alarming proportions in the spring of 1944. Designed to control the burning rate of the rocket powder, inhibiting consisted of cementing cellulose acetate strips on the surface of extruded grains in a definite pattern. Necessarily done by hand, the job was slow and laborious. With the mounting Navy requirements for rocket powder, the Army found it impossible to inhibit all extruded grains. The decision to discontinue this work at the extrusion plants threw the entire burden of inhibiting, along with its related problems of adhesive cements, ventilating, and industrial poisoning, onto the naval ammunition depots, which had neither facilities nor background for the task. Fortunately, the War Department activities continued inhibiting rocket powder as a temporary expedient until Bureau facilities were in operation.

Strenuous efforts were required to break this bottleneck. Automatic machines developed to perform the operation were not successful in securing a uniform product. Even at the end of the war inhibiting remained a critical hand operation. A solution had to come through efficient organizations and hard work—a combination which was gained through the cooperative efforts of the depots, the research groups of commercial molding manufacturers, naval powder laboratories, and Bureau contracting and loading personnel.

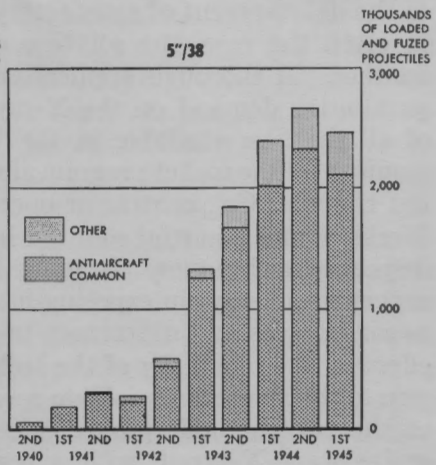
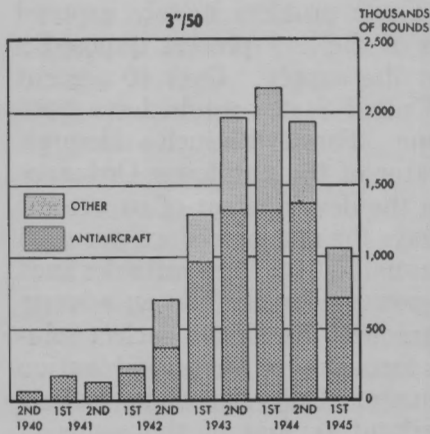
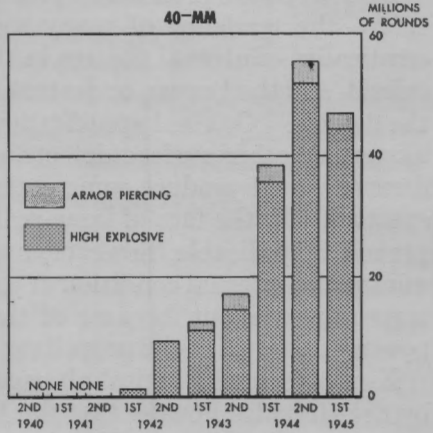
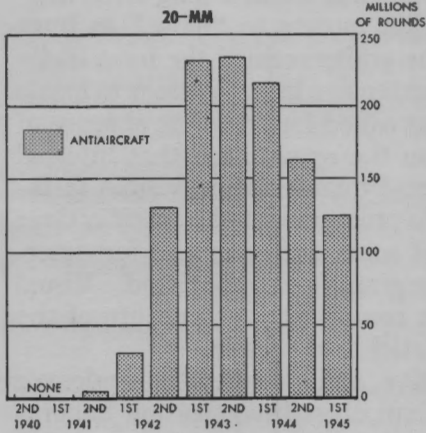
Related to the production problems was another long-lived difficulty—the tendency of many rocket motors to “blow,” or burn erratically. Internal fissures in the grains seemed the most likely culprit, and the Bureau undertook extensive investigations to locate the defects. Original specifications called for complete absence of blisters or other surface defects, on the assumption that internal fissures would produce some external manifestation visible to inspectors. In the face of large-scale procurement the specifications proved inapplicable, however, and some better means for determining the internal condition of the grains had to be found. Visual inspection was out, because of the completely dark nature of the powder from which the propellant sticks were made.

X-rays seemed a logical alternative, and a cooperative endeavor by the Hercules Powder Co., the Explosives Investigation Laboratory, the Naval Powder Factory, and the Bureau of Ordnance led to the development of satisfactory X-ray techniques. But as was so often the case, the solution of one problem merely exposed another. A thorough application of the new process imposed a prohibitive demand on the X-ray film supply. Over 40 percent of all the film available in the United States would have been required for the rocket program alone. Faced with such a dilemma, the Hercules Co., contractor-operator of the Sunflower Ordnance Works, found a partial solution in the development of supersonic inspection techniques. In some ways the new procedure was even superior to X-rays in exposing internal defects, but variables such as air bubbles and differences in powder density had an adverse effect on the reliability of the technique. No single, perfect solution to the inspection problem was forthcoming, but a combination of the two methods proved adequate. Only suspicious looking grains were X-rayed, with a resultant savings of thousands of dollars in film costs. The apparent perfection of the remaining powder sticks was put to the test of supersonic examination.

New powders and new production techniques characterized the Bureau's wartime explosives programs, but one item of ancient lineage maintained its position of importance: black powder

AMMUNITION PRODUCTION

1 JULY 1940 THROUGH 30 JUNE 1945



remained the best ingredient for prodding the new and modern propellants into action. Throughout the conflict it was used as the principal ignition charge for gun ammunition, illuminant mixtures, depth charge projectors, torpedo tubes, and rockets. Though longevity was a distinguishing characteristic of black powder, the material enjoyed an even more important distinction. In a period of material shortages, manpower problems, and overworked production lines, the powder posed almost no procurement problems. The single exception was with the spherohexagonal grains used in depth charge projectors. Longevity actually proved a detriment there. Because of the large inventory remaining on hand at the end of World War I, no production was needed between the wars. New demands for the powder, stimulated by the antisubmarine campaign that opened World War II, soon revealed that the art of production had been lost. Spherohexagonal black powder could be manufactured in sufficient quantity, but the ballistic qualities of the old stock were never regained. The quantities required to obtain a given range remained the same, but the pressures developed were considerably in excess of those which had previously prevailed.

By far the largest use of black powder was in the ignition charges of the bag type ammunition employed in the 16-inch guns of the biggest battleships, the 14-inchers of the older battlewagons, and the 8-inch and 12-inch guns of the heavy cruisers. Encased in bags of pure silk, much of it of prewar Japanese origin, the smokeless powder grains were stacked in uniform layers on top of an ignition pocket of black powder which formed the circular base of each bag. Bearing a distinctive maroon color to facilitate identification, the ignition pocket of each charge was fashioned of comparatively light weight silk for quicker burn-through. Careful weighing both preceded and followed the quilting of the bag that assured even distribution, since the slightest variation would spoil the intricate calculations on which accurate gunfire depends. Stored in and protected by tightly closed metal tanks, the loaded bags were then ready for action. When that moment came, the black powder was but one of several factors in the complex operation involved in firing a naval gun. The heat generated by an electric current ignited a small charge of guncotton and pyrocellulose, which in turn, detonated a cap containing fulminate of mercury that set off the black powder, the igniter of the smokeless powder. This sequence took only a few milliseconds, but in that instant the bags vanished in the blast of the explosion, for the silk

burned completely, leaving no smoldering embers to ignite the next charge.

The primary purpose of propellants is to deliver the high explosive charge which pays off in damage to the target. As paradoxical as it may seem, the belligerents of World War II entered the struggle still depending upon TNT, Explosive D, Amatol, and Tetryl of World War I for their principal explosive compounds. The increasing toughness of targets soon made it evident that the effectiveness of weapons, other things being equal, would diminish unless the high explosive was improved. In the Bureau of Ordnance that realization prompted a cooperative research and development effort with the NDRC and its affiliated laboratories. The programs bore fruit, but the improved explosives were not perfected overnight, and throughout the war TNT, Explosive D, and Tetryl continued to play a significant role.

At the beginning of World War II, the Navy's stock of underwater weapons and general purpose bombs were filled with TNT. Projectiles utilized Explosive D. With respect to power, there was very little difference between the two explosives. The method of loading differed, however, with TNT cast loaded and Explosive D press loaded. A cast explosive is poured into a weapon case and, upon cooling, solidifies. A pressed explosive is added in increments, each increment being pressed by means of a mechanical device.

Explosive D, or ammonium picrate, was patented by Nobel in 1888, although in mixture with saltpeter it had earlier been used as a propellant. Important as a military explosive because of insensitiveness to shock and friction, it is slightly inferior to TNT in explosive strength. The Army Ordnance Board recommended the use of Explosive D in 1901, and in 1907 the explosive was adopted by the Navy upon the recommendation of the Special Board on Naval Ordnance. For several years ammonium picrate was used mainly in conjunction with black powder in projectiles. The usual loading consisted of Explosive D in the nose section of the projectile, with black powder in the rear. In 1917 the filler for the smaller caliber projectiles, 5 to 8 inches, was changed to a mixed loading of TNT and black powder; while major caliber projectiles were completely loaded with Explosive D. The large projectiles gave trouble, mainly deflagration on impact. Such failures were attributed to low density fillings, and in 1923 the Special Board on Naval Ordnance recommended that projectiles loaded with Explosive D to a high density be supplied to the naval

services. The new loading proved so satisfactory that it remained the standard throughout World War II.

During peacetime the production of the Naval Powder Factory and the du Pont Co. was sufficient to meet naval needs. The tremendous demand for projectiles, however, called for a rapid build-up of facilities for the manufacture of this vital explosive. Indian Head was expanded, additional contracts were placed with du Pont, and a contractor-veteran of World War I, the Lansing Paint and Color Co., was brought into the program. The production of the three facilities, although large, accounted for only a minor part of the total production. Army facilities, principally the Maumelle and New York Ordnance Works, supplied over 80 percent of the Explosive D that went into Navy munitions. Rising from a requirement of 1,500,000 pounds a month early in 1942 to a high of 6,500,000 in 1944, the production of Explosive D always paced that of the weapons into which it was to be loaded.

In the last year of the war a new and more powerful explosive, composition A-3, began to replace Explosive D in smaller anti-aircraft projectiles. This substitution did not lessen the demand for the old material, however. The development of jet-assisted-take-off units, using a mixture containing 50 percent ammonium picrate, more than counterbalanced the replacement in AA missiles.

Reclaimed material helped supply the tremendous quantities needed. Since the explosive is press loaded, the fuze cavities must be drilled out after the pressing operation. The amount removed varied with the caliber and type of weapon, but at least 10 percent of the original loading was eliminated to provide space for the fuzes. The breakdown and cleaning out of loaded projectiles was also significant in increasing the supply of reclaimed Explosive D, and this source became more important as the war progressed and ammunition was returned from the fleet. Both the Naval Powder Factory and the Lansing Paint & Color Co. recovered hundreds of thousands of pounds of Explosive D, which eventually found its way back into projectiles. Considered almost equally satisfactory for loading and explosive power, the reclaimed D was produced at a cost of from one-fifth to one-fourth that of the original product.

One of the major difficulties in the processing of the reclaimed explosive was the tramp material in the boxes returned to the recrystallizing activities. These ran the gamut from pop bottle caps to wrenches, drift pins, and pieces of sheet lead, to occasional lumps of mud the size of a baseball. Screening eliminated most of the stray items, but throughout the war contaminated material poured into the recrystallization plants.

TNT was the "workhorse" explosive for bomb type ammunition and underwater ordnance items. Stable, relatively insensitive, and powerful, trinitrotoluene was the quantity explosive of World War II. Navy requirements, furnished entirely from War Department facilities, exceeded 30 million pounds a month at one point in the war. For all its virtues, TNT suffered one defect: more powerful explosives existed. They all had some disadvantages or they would have been adopted immediately, but the prospects of a greater punch from weapons made the fleet discontented with TNT. That was especially true of submariners, who became the most outspoken advocates of more powerful warheads for their torpedoes. They held and voiced many grievances against their principal weapon, but not the least of them was that the enemy got better results, hit for hit, than United States torpedoes provided.

Later statistical studies showed that the claimed superiority of enemy torpedoes was exaggerated if not completely unjustified, but comparative studies were irrelevant. The Bureau of Ordnance shared the fleet's desire to replace TNT with a more powerful explosive composition. Indeed, the search for such a product was well advanced months before the attack on Pearl Harbor lent impetus to the work. The search centered around the use of RDX, an explosive with a reputation for power dating back a half-century. Unfortunately, its superior qualities were more than offset by two notable defects; sensitivity and cost. Until those disqualifying characteristics were eliminated, RDX could not meet military requirements.

The first of the problems was removed by the British, who discovered that the addition of beeswax, plasticizing oils, or even TNT, reduced the sensitivity of RDX enough to permit its use in weapons. But cost remained prohibitive. The conventional British method of manufacture, known as the Woolwich process, consisted of combining formaldehyde and ammonia to get hexamethylene, which then reacted with nitric acid to form RDX. The procedure was wasteful: for every 100 pounds of RDX produced, approximately 1300 pounds of material was handled. A more economical means of production was imperative, and the National Defense Research Committee undertook the task of finding one. That search bore fruit in the Bachmann method, named after its discoverer at the University of Michigan. The new process removed the second barrier to an exploitation of the power in RDX. Now only 641 pounds of material were required for the production of 100 pounds of explosive. Not only was a cheaper product pos-

sible, but the less elaborate plant equipment used in the process saved the Government millions of dollars in construction costs. All of the major combatants used RDX, but only the United States developed a relatively cheap method of production that could remove the explosive from the luxury class.

In answer to the requirements for underwater ordnance, RDX was important as a principal ingredient in Torpex, an explosive made of RDX, TNT, and aluminum powder. The British began using the new ordnance in mid-1942, as a filler for depth charges. Bureau investigations at the Explosives Research Laboratory, Woods Hole, Mass., showed that Torpex was a much more powerful explosive than TNT. On a weight basis, 100 pounds of Torpex produced the same underwater damage as 150 pounds of TNT; on a volume basis, the power ratio favoring Torpex was 170 to 100. The one disadvantage of the British product was that it was more sensitive than TNT to bullets and shell fragments. The experiments convinced the Bureau that the good points of Torpex more than compensated for its deficiencies, especially since sensitivity presented little danger for most types of underwater ordnance.

When the Bureau decided early in 1942 to adopt Torpex, its initial order for 20 million pounds presented tremendous procurement problems to the Ordnance Department. Only experimental production lines for RDX existed in the United States; the newly discovered Bachmann process was not yet ready for industrial application. This meant that the expensive British technique had to be employed first, and Army Ordnance gave the initial production contract to the du Pont Co., which was already engaged in pilot line production of the explosive. Operating the Wabash Ordnance Works, the company employed the Woolwich process to manufacture three types of RDX. Designated Compositions A, B, and C, the explosives differed from one another in the proportion of TNT that was added to the RDX. By continual refinements to manufacturing techniques, du Pont was ultimately able to bring the cost of its product to within two cents a pound of the cost of RDX produced by the cheaper Bachmann process.

A second facility for the production of the explosive was installed by the Tennessee Eastman Co. at the Holston Ordnance Works, Kingsport, in 1942. Using the Bachmann process, Holston was equipped to make only Composition B or its modifications. The East Tennessee plant, erected at an initial cost of \$70,000,000, was constantly expanded until its capacity was many times that of the Wabash Ordnance Works. Improvements in manufacturing processes contributed to this large production. New methods of pour-

ing and cooling cut production time, hastening to the fleet the Holston product.

Most of the RDX production went into Torpex for use in underwater weapons. Initial loading began in November 1942. Within a few months after Torpex loaded torpedo warheads were issued to the fleet, submarine commanders agreed unanimously that it was a much more powerful explosive than TNT. Originally issued to submarines with the best record of kills, the new product was distributed throughout the submarine fleet as fast as production permitted. Ship sinkings increased, and the Bureau received reports that Torpex warheads were able to break vessels in two. Comparative tests with captured enemy munitions showed that neither the Germans nor the Japanese possessed explosives as powerful as Torpex.

The use of Torpex was next extended to aircraft depth bombs, aircraft mines, and antisubmarine depth charges. This decision was based upon the necessity for obtaining maximum explosive effect and upon the fact that these weapons ordinarily would be little exposed to the bullets or fragments to which Torpex was sensitive. Subsequently, Torpex was utilized in the warheads of aircraft and PT boat torpedoes. Though a calculated risk was involved, the Chief of Naval Operations declared that the casualty rate for torpedo planes was already extremely high, and that the added damage potential of Torpex justified the increased hazard of this bullet sensitive material.

The dangers were never accepted as permanent, however, and an ambitious research project to minimize the sensitivity of Torpex coincided with the loading program. A variety of methods, materials, and changes in the physical characteristics of the Torpex constituents were evaluated. Paraffin type waxes showed promise, but they tended to separate from the mixture when used in adequate quantities. Another lead came from the British, who informed the Bureau that a 5 percent desensitizer of paraffin wax, lacquer grade nitrocellulose, and lecithin oil proved satisfactory when used in their 12,000 pound Tallboy bombs. This British Torpex was undoubtedly less sensitive than the American counterpart, but one major defect barred its use in United States weapons: containing a low melting point wax, the British desensitizer was unsuited for use in the tropics where much of the American action was taking place. The Bureau needed a high melting point wax which could be stored in a warm climate with little danger of exudation. The NDRC, working through the Explosives Research Laboratory, uncovered five microcrystalline waxes which were

available in quantity and which, used alone or in blends, furnished a satisfactory desensitizer. The Bureau accepted the NDRC findings and created a new explosive. The desensitized Torpex, containing a 5 percent proportion of a high melting point wax, was named HBX. First manufactured in makeshift facilities at the Naval Mine Depot, Yorktown, Va., demand for the desensitizer quickly outgrew the capacity of that station. Du Pont was able to adapt equipment at the Wabash Ordnance Works to the production of the new material, and that War Department activity became the primary source for the desensitizer.

The new explosive combined the desirable features of both TNT and Torpex. The mixture of TNT, RDX, aluminum powder, and desensitizer was much less sensitive than Torpex, yet practically as powerful. The 2 percent loss in damage power was more than compensated for by the greater safety of HBX. Replacement of TNT and Torpex in underwater munitions began with depth bombs in January 1945. Within 3 months aircraft mines were loaded with HBX, and torpedo warheads and other weapons were receiving the safer explosive by May.

Like Torpex, HBX gave off a gas after loading. Sometimes the evolution of the gas, an interaction of moisture with other ingredients, generated sufficient pressure to deform the container and the exploder cavity. Even though tests conducted in this country and in England led to the conclusion that the gas did not constitute a serious explosion hazard, its accumulation was obviously undesirable. A simple remedy, the addition of anhydrous calcium chloride as a drying agent, was found to remove the moisture and prevent reactions with the other components of the explosive mixture.

Though the production of RDX reached enormous proportions in the United States, the continual threat of a shortage led to the development of two possible substitutes for Torpex and HBX. Designated DBX and UWE, the cast explosives included large amounts of aluminum and reduced quantities of RDX. Since the anticipated shortage of the critical component never materialized, neither of the standby explosives received extensive use in naval ordnance. Their development was not without value, however; late in the war the Army accepted UWE and, under another name Tritonal, used it as a filler for general purpose bombs.

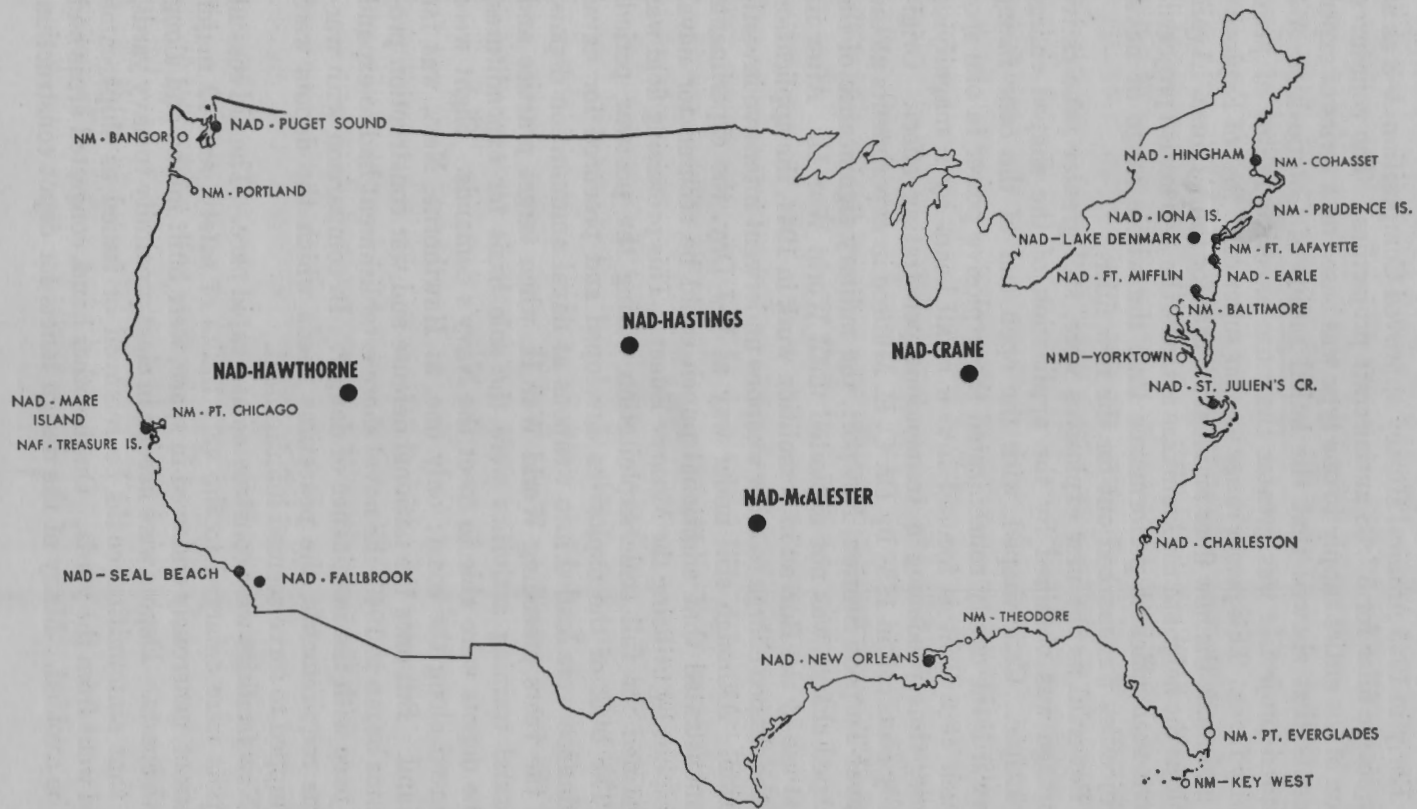
While the large quantities of aluminum used in DBX and UWE were less desirable than a higher proportion of HBX, the addition of the metal powder in its optimum ratio boosted the temperature of an explosion and increased target damage by about 20 percent.

Its use in Torpex, HBX, and DBX, each of which served as a filler for weapons with large explosive cavities, naturally created substantial requirements for the product. Requests from the British Air Commission and the United States Army eventually increased those demands tenfold.

Production was accomplished through an atomization process patented by the Metals Disintegrating Co. Aluminum ingots were first melted, then sprayed through an atomizing air nozzle. The resulting powder could then be collected and used as an explosives raw material. The process had an added virtue in that large quantities of powder could be obtained without excessive cost for facilities. Throughout the first half of the war the patent holder remained the sole Bureau contractor, but a single source was not enough to supply the increasing orders for the material. By late 1944 requirements were up to 20 million pounds a month, and the Aluminum Co. of America and the Reynolds Metals Co. were brought into the program. At the end of the war the Bureau of Ordnance was procuring over 90 percent of all the aluminum powder manufactured in the United States.

Although underwater explosives claimed the main attention of the Bureau, projectile fillers were not overlooked. Explosive D was an ideal munition, but as the war progressed the introduction of new and larger fuzes reduced the explosive cavity of small and medium caliber projectiles to such an extent that fragment velocity was lessened, reducing the damage to a target. A more powerful explosive was needed if projectiles were to keep pace with enemy targets.

A composition developed by the British at Woolwich and manufactured in Canada in limited quantities offered possibilities. Designated RDX/BWK-91/9, the English product combined 9 parts of beeswax with 91 parts RDX. Canadian experience with 40-mm ammunition demonstrated that the explosive was more powerful than TNT and Explosive D. American tests bore out this contention. But the British product could not be manufactured in the quantities required by the Bureau; there was not enough natural beeswax to meet Ordnance needs. Fortunately, an American explosive, Composition A-3, containing 91 percent RDX and 9 percent microcrystalline wax, functioned equally well. Projectile for projectile, Composition A-3 was from 60 to 100 percent more powerful than Explosive D. In addition, bore and flight safety, ignition temperature, storage, and exudation qualities were all acceptable. Moreover the equipment used in loading Explosive D could be adapted to Composition A-3.



Early in 1945 Admiral Hussey approved Composition A-3 as an explosive filler for 5"/38 anti-aircraft projectiles. The concentration of the entire supply to one type was based on a series of experiments that showed that the lethal radius of Composition A-3 loaded projectile was greater than the effective radius of proximity fuzes. This power range was far superior to that of Explosive D and made the new filler an ideal partner for the VT fuze. Available at the height of the kamikaze attacks, the A-3 loaded projectile gave such efficient performance that the whole range of naval projectiles was marked out for the new filler.

Powerful as the new explosives were, still greater penetrative damage was obtained by the application of the shaped charge principle. Cone-shaped, with the open end of the cone facing forward, the cavity concentrated the explosive power in one spot much as a light is focused into a small beam by a magnifying glass, thus producing a tremendous penetrating effect. Originally observed in 1888 by Dr. C. E. Munroe in experiments at the Naval Torpedo Station, Newport, the military significance of the shaped charge was not exploited until World War II. After its first use by the Bureau in demolition work in 1944, the application of the shaped charge to other weapons underwent intensive investigation. Although still under way at V-J Day, the experiments demonstrated that additional punch could be secured for naval weapons by utilizing the Munroe Effect. This promising field was destined for full scale exploitation during the postwar period.

The bulk of the explosives developed and procured for naval ordnance were loaded into weapons at naval ammunition depots. In the years preceding World War II, when target practice and normal training activities were the sole basis for expenditures, nine depots were able to meet the Navy's demands. Eight were located along the coast; only one, at Hawthorne, Nev., was far inland. But once the national defense and war construction programs began in 1940, the naval shore establishment had to expand in pace with the imminence of danger. In comparison with wartime requirements, the peacetime needs which the depots were equipped to serve seemed infinitesimal.

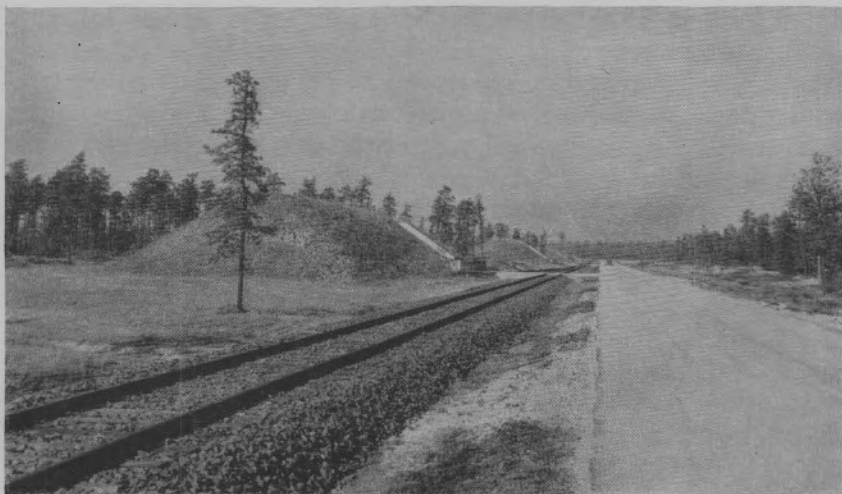
New facilities were constructed at a rapid pace. The old coastal depots were enlarged to the very limits of safety, and 12 major stations, generously endowed in space, were built inland and along both coasts. Depots were needed in close proximity to navy yards, so that ammunition could be removed or issued as ships came and went from the yards. On the other hand, congested areas had to be avoided. Many of the design tenets for depot construction

dated back to 1926, when the Navy's depot at Lake Denmark, N. J., was the scene of an especially disastrous explosion. During World War I the station's capacity had been pushed to contemporary ideas of the maximum for safety. The depot remained filled with surplus ammunition after the conflict, and in the midst of an electrical storm in 1926, a fire broke out in one of the magazines. A series of explosions racked every building on the station and the detonations were followed by a week-long fire that swept away the wreckage.

Even relatively minor ordnance mishaps are followed by investigations. The Lake Denmark disaster was studied with a zeal in direct proportion to its magnitude. Out of that research came a new set of standards, keynoted by emphasis on dispersal, that governed the Bureau in its construction of the many depots required to serve the fleet during World War II. The NAD, Hawthorne, was a direct result of the Lake Denmark explosion, and it was the first depot to be laid out in accordance with the new requirements. Even careful planning was no guarantee against accidents, however, and one of the largest explosions of World War II occurred in July 1944, at the Naval Magazine, Port Chicago, Calif. Over 500 people were killed or injured. Two ships, the main pier with all its buildings and equipment, and a Coast Guard fire barge were completely destroyed. But Port Chicago arose from the debris like the fabled Phoenix, and the disaster could not obscure the fact that with this single exception the Bureau establishments maintained a safety record out of all proportion to the dangers inherent in explosives, the inexperience of the personnel, and the millions of tons of ammunition handled as the munitions passed from production lines to the ships at sea.

Ammunition handling and loading was actually only one of the roles of the depots. Though commercial sources provided most of the components, the Navy depended upon the Bureau stations to perform many of the final production steps: loading the weapons with high explosives, completing the assembly of the ammunition, and readying the ordnance for its final move to the fleet. Moreover, the unexpended ammunition withdrawn from ships had to be reworked at periodic intervals to guarantee its safety and reliability for reissue. At some of the depots the productive activities dominated; at others, storage was the principal responsibility. But in some measure, all of the stations were equipped to perform both functions.

While safety factors and the location of navy yards helped determine the sites for Ordnance establishments, strategic considera-



Magazine area, NAD, Earle. Dispersal keynoted ammunition storage.

tions underlay the pattern of expansion. World War I naturally emphasized the Atlantic coast, with a consequent concentration of facilities in the east. Then, as the fleet was built up to treaty strength in the last decade before World War II, the increase in the Pacific Fleet brought new demands for establishments along the coast. And in both East and West, storage facilities were urgently needed.

Although the bulk of the United States Fleet was in Pacific waters when the war began in Europe, the Atlantic shore received more attention as the most likely target if the Axis became able to strike the continental United States. That threat, coupled with the acute storage problem, led to the decision to construct a giant ordnance station behind the safety of the Appalachian mountains. If seaports were bombed, the inland station would be indispensable. The Bureau received funds for such an establishment in June 1940, and within 6 months construction started on a site near Burns City, Ind. In 1942, the centenary year of the Bureau, the depot was designated NAD Crane in honor of the commodore who served as the first Chief of the Bureau of Ordnance. The wartime activity of Crane, which served the east coast in much the same manner that Hawthorne served the west, could be measured by its growth. The original site of 8 square miles was later enlarged to include 100 square miles; the initial appropriation of \$3,000,000 was supplemented until the depot ultimately represented an investment of over \$100,000,000.

By the beginning of 1942 the Bureau of Ordnance controlled a whole group of new ammunition facilities. Establishments at Indian Island and Fallbrook supplemented the west coast facilities, while a depot at Charleston and a naval magazine at Cohasset bolstered the strength of the eastern seaboard. Outside the continental limits, the fleet was served by two stations at Oahu, one at Balboa, and by a branch depot at Coco Solo. Finally, construction of a facility to serve the Gulf coast was under way at New Orleans just as the war began. Even that prodigious expansion was not sufficient to serve the demands of full scale war, however, and the Bureau soon started building two tremendous ammunition depots at Hastings, Nebr. and McAlester, Okla. Situated far inland for strategic security, and astride transcontinental transportation lines, the depots were well located to fulfill their mission of supplying Hawthorne, Crane, and the coastal depots. The two facilities were placed in commission in 1943; by V-J Day, when they were able to provide stowage for over 1 million gross tons of ammunition, the depots represented a facilities expenditure of more than \$150,000,000.

Despite their multiplication, the ammunition depots were unable to handle the huge export shipments demanded by a global war. As the inland move illustrated, they were not even primarily designed for that purpose. Consequently, commercial piers were used to supplement activity at Navy establishments until the Bureau could build new shipping facilities at Port Chicago, Calif., and Earle, N. J. Additional points, relatively small by comparison, were established at Seal Beach, Calif., and Bangor, Wash.

Port Chicago, the principal explosive shipping facility on the west coast, went into operation late in 1942. Located 32 miles northeast of the Golden Gate, it removed from the immediate vicinity of San Francisco one of the great hazards of the war—the movement of high explosives across the docks of that metropolis into the vessels making up the convoys for South Pacific bases. The disastrous explosion of July 1944 emphasized the imperativeness of the move.

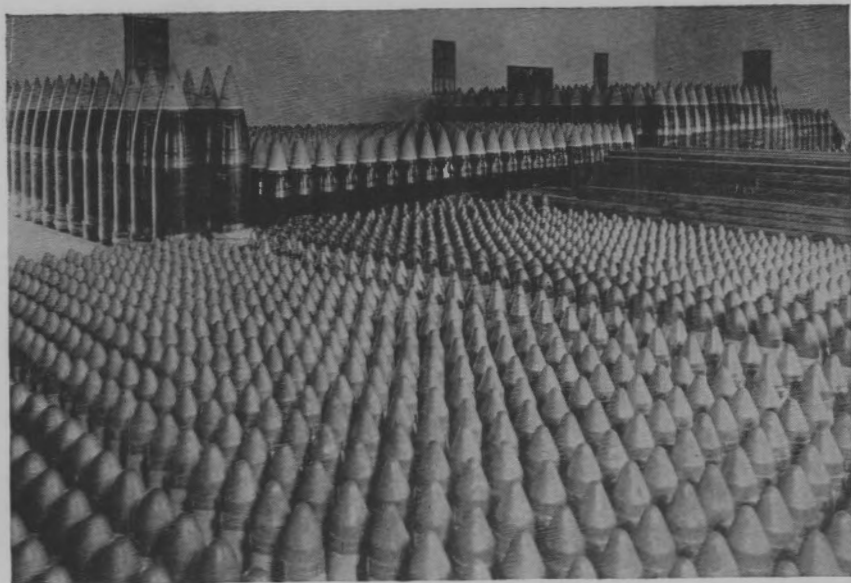
The Naval Ammunition Depot, Earle, N. J., became the eastern counterpart of Port Chicago. Covering an area of 17 square miles, it was the largest ammunition depot on the east coast and the keystone of logistic support for the ammunition required in the Atlantic area by the Army and Navy. Long before the outbreak of World War II, both services recognized the need for an explosives shipping facility somewhere in the Port of New York, a focal point for important rail lines. Each service independently established

boards to survey the harbor area and recommend a site for such a base; both selected the south shore of the harbor. Since the Army preference encompassed populated towns and areas of improved property, the War Department had to abandon the project as prohibitive in cost. The Navy carried its search further abroad, however, and by aerial reconnaissance found a large area of swamp and scrub forest 12 miles from the coast. The board recommended that the shipping facilities be located on the shore, near Leonardo, with the magazines, industrial, and administrative areas inland.

The Secretary of the Navy approved the recommendations in June 1943, and construction began immediately. The new depot, named after the World War I Chief of the Bureau, was formally commissioned 6 months later. Meanwhile, the Army had established an ammunition loading pier at Caven Point, N. J., near the scene of the Black Tom explosion of 1916. The highly industrial nature of the locality was not ideal for loading operations, and shortly after Earle was established the Army asked the Bureau to construct an additional pier and supporting facilities for their explosive shipments. Financed with Army money, a new pier with four deep water berths was ready for use in the summer of 1944. Earle was originally planned as a \$25,000,000 facility, but logistic considerations dictated expansions that pushed the final cost to nearly \$60,000,000. Over 731,000 tons of ammunition were outloaded from the depot, much of it explosives that would otherwise have passed over the docks of New York or Norfolk. An index to the capacity of the station was furnished in the two months of March and April 1944, when 225,000 tons were loaded to support the Normandy operation.

Early in 1944 the Bureau gained still another shipping facility when it acquired an Army magazine on Mobile Bay at Theodore, Ala. Although the use of the station required transit of the Panama Canal, with attendant risk, it was required to relieve the congestion of shipments to the Pacific, especially after the explosion at Port Chicago. Theodore had additional value since it was, along with the Leonardo piers at Earle, one of but two locations in the east suitable for loading ships with ammunition subject to mass detonation.

The very existence of the tremendous ammunition depots depended upon a steady supply of ammunition details—a rather simple designation for much complex and diverse material. Fuzes, tanks, primers, tracers, and cases were familiar items. The service at large knew little of the tremendous quantities of silk cloth needed for bags and beackets, of binder's board required for wads



Projectile stowage at coastal NAD.

and distance pieces to go between the top of the powder in a case and the base of the projectile, and cork plugs for cartridge cases which must be strong enough to stand power ramming yet fragile enough to burst into pieces too small to injure personnel. Other items of this category included extractors to snap on the base of cartridge cases to pull them from tanks and to protect the primers while they passed through hoists; waterproof protecting caps to insure that no moisture got into fuzes while in depots, magazines, or ready service stowages; smokeless powder packing boxes in which powder was shipped from the factory to the depots for stowage until required for assembly. These are only a few of the details—all of them useful, most of them vital—which called for a far reaching procurement effort which was largely concentrated in small business.

The mobilization of money, facilities, technical talent, and manpower were basic problems confronting the Bureau of Ordnance in almost every program it undertook during the war. In the case of ammunition—as with many other items—critical material shortages plagued Bureau planners. None of the precious metals needed for high quality ammunition was in long supply, but the most threatening situation was that involving brass. The copper and zinc alloy was essential for the cartridge cases common to fixed and semifixed ammunition through a 6-inch caliber. Several

qualities accounted for the apparent superiority of brass over any practical substitute: the alloy was easily worked, had good frictional qualities, was nonsparking, corrosive resistant, and sufficiently elastic to permit ready extraction from the gun chambers in which it had to be used. Early in the war the brass supply was marginal; every indication pointed to a really critical situation by 1944. Some relief was found through the utilization of scrap, gained in part from the recovery of expended cartridge cases, but manufacturers preferred the use of virgin materials.

Fortunately, the shortage came as no surprise to the Bureau. Months before the outbreak of war, Ordnance metallurgists were at work on the problem of finding a satisfactory substitute for brass. Before the situation became acute, the answer was in their hands, ready for exploitation. By subjecting steel to special heat treatments they succeeded in modifying its physical qualities to such an extent that it could be made equal or even superior to brass. Hardening by heat treatment guaranteed safe ejection of the cartridge case from the gun and surmounted the main obstacle anticipated in the use of steel. Minor problems remained, but their eventual solution eliminated the sparking and corrosion hazards with which the Bureau had been concerned. In some respects, steel promised to be superior to the original metal. With great tensile and yield strength, it was less apt than brass to crack under stress. A whole new avenue that might lead to the development of more powerful guns and projectiles seemed open to the Bureau scientists.

In early 1942, the Bureau inaugurated an experimental production program with real enthusiasm. Backed by months of research, the program moved rapidly. Steel cartridge cases in calibers from 20-mm to 5-inch were placed under development, and by May 1942, the first lots were ready for firing at the Naval Proving Ground. The tests were a success. Proving Ground personnel considered the cases normal in extraction, recoil, obturation, and appearance after firing. While unsolved production problems prevented the event from marking the culmination of the search for a substitute for brass, results were encouraging enough to stimulate the remaining experimental work. Manufacturing techniques and various grades of steel were tested experimentally by manufacturers, while the Bureau worked on the knotty problem of quality control over a new product.

By early 1943, steel cases were available to the Bureau in 20-mm, 40-mm, and 3-inch calibers. The 5''/38, the largest cartridge case for which a switch was envisioned, was in an early stage of development. Meanwhile, the copper situation appeared

to be deteriorating. Warned that he could expect a critical problem within a year, Admiral Blandy directed a switch to steel cartridge cases in all practical calibers and up to 100 percent whenever satisfactory results could be obtained. In the light of existing information, the step seemed necessary. Between July 1942, when the Admiral made the decision, and October, a radical change was evident, however. Brass became more plentiful and the right grades of steel proved elusive.

Confronted with a new situation, the Bureau altered its plans. The percentages of steel cases were reduced for all calibers; 60 percent was established as the limit for any program, and the idea of producing the new cases in calibers as large as the 5"/38 was abandoned. Meanwhile, the original program was subjected to other deterrents. Though Russia and Germany, pressed by necessity, were both using steel cases with some success, United States experience was not so satisfactory. The Navy hesitated to send the new cases into combat as long as orders could be filled with the more familiar brass, and Army experience in the manufacture and use of steel cases was not a happy one. Moreover, some of the anticipated advantages of production in steel failed to materialize. Rather than being cheaper and more plentiful, steel proved almost as expensive and much harder to obtain than brass. Scrap losses ran high and extra time consuming operations slowed up manufacture of the steel cases.

By the end of the war many of the problems were solved, permitting the economical production of steel cases. But wisdom dictated caution, so the Bureau lowered its steel case program to a reduced production level. Fleet demands were met with the brass, while the less popular steel cases furnished a valuable reserve. Of greater worth was the experience gained during the relatively short period of production in steel. Aside from the production problems peculiar to wartime, the new cases appeared to fulfill their promise. The vital ammunition program was rescued from the mercy of transient shortages and more powerful guns and ammunition were placed within reach.

The availability of materials, shifting from time to time, called for prodigious efforts in ammunition programs other than projectiles. One of the most important of these involved powder and cartridge tanks. Aluminum had long been used by the Bureau for these two items; it was light, strong, relatively free from corrosion, safe from sparking, and presented few problems in maintenance. Early in the war, however, the demands of the aircraft industry for virgin aluminum forced the Bureau to switch tank

production to steel. Steel presented several disadvantages, but the most important was a sparking hazard. This defect was minimized by adding thick layers of copper to the lid and top spring of all powder tanks. Although steel proved an acceptable substitute, the Bureau was never happy about the situation and in 1943, when steel became more critical than aluminum, production immediately returned to the latter.

Throughout the war much of the ammunition moved from the depots to the fleet in unit loads which were especially designed to be handled swiftly and safely by lift trucks and mobile cranes. The Naval Ordnance Materials Handling Laboratory at Hingham, Mass., worked out improved shipping methods for each type of ammunition, and accomplished great savings in time and manpower. Examples are legion, but one is sufficient to illustrate the trend: at the Naval Ammunition Depot, Hingham, one girl moved unit loads in a third of the time required by eight men using hand methods. These improvements hastened loading and unloading at every transshipping point, thus speeding ammunition to the fleet.

Even V-J Day did not end the activity of the many establishments constructed to serve the war. At the end of the conflict the naval ammunition depots contained over 3,000,000 tons of ammunition valued at some \$3½ billion. Made up of fleet returns and stocks on hand at the time of the Japanese surrender, that tremendous reserve created new problems for the Bureau of Ordnance. Money value aside, the ammunition represented a tremendous war reserve that added to the defensive strength of the Nation. That reserve was subject to deterioration, however. The investment had to be protected by an extensive Ammunition Quality Surveillance Program, which the Bureau inaugurated to maintain the value of its inventory. Inspection was backed by rework projects that kept the stockpiles ready for issue.

The value and the success of that program was proved after the Communist invasion of South Korea presented sudden new demands for naval ammunition. At a fraction of its replacement value, the Bureau then supplied the fleet with World War II ammunition which had lost none of its punch. Meanwhile, the Bureau was able to push to completion many of the research programs that marked the immediate postwar years. The promise of that emphasis is new ammunition for the whole range of naval weapons that make up the Navy's striking power.

ANTIAIRCRAFT MACHINE GUNS

AT THE END of World War II, the ships of the United States Fleet bristled with 87,919 gun assemblies, ranging in size from the lightweight .50 caliber anti-aircraft machine gun to the massive 16"/50 armored three-gun turret which weighed as much as a single destroyer. Merchant ships mounted an additional 48,446 anti-aircraft and double-purpose guns. The total firepower of the combined fleets aggregated 4500 tons per 15-second period—an elevenfold increase over the potential of the "one ocean Navy" of 1940. The most significant factor in accounting for that multiplication of firepower was the rapid increase in anti-aircraft armament.

At the beginning of the national emergency, the 1"1, .50, and .30 caliber machine guns comprised the Navy's principal protection against close flying aircraft and dive bombers. Five years later their role was insignificant. In their place the Bureau provided new guns and control equipment in such numbers that the decks of aircraft carriers, battleships, cruisers, destroyers, and other naval vessels were literally studded with protective anti-aircraft armament. Defense against planes was almost 100 times more effective than on December 7, 1941. Exceeding \$4,000,000,000 in cost, the anti-aircraft defense of the fleet represented the largest expenditure of the Bureau of Ordnance. Only 30 years before, the Chief of the Bureau had written: "The Bureau has taken up consideration of the design and manufacture of guns for defense against aircraft. . . . Whether guns of such types will ever be demanded by service conditions is still doubtful."

The spectacular increase in the effectiveness of naval anti-aircraft armament was one of the great tactical revolutions which occurred during the course of the war. In this revolution two foreign guns—the Swedish Bofors and the Swiss Oerlikon—played leading roles. The story of these guns can be understood only in terms of the critical anti-aircraft situation which existed in the Navy at time of their adoption and early manufacture. The development of the airplane as a threat to the surface ship is too well-known to warrant repetition, but the anti-aircraft activity within the Navy in 1940, and even earlier, should be recalled in order to appreciate the

pressure under which these guns became United States naval weapons.

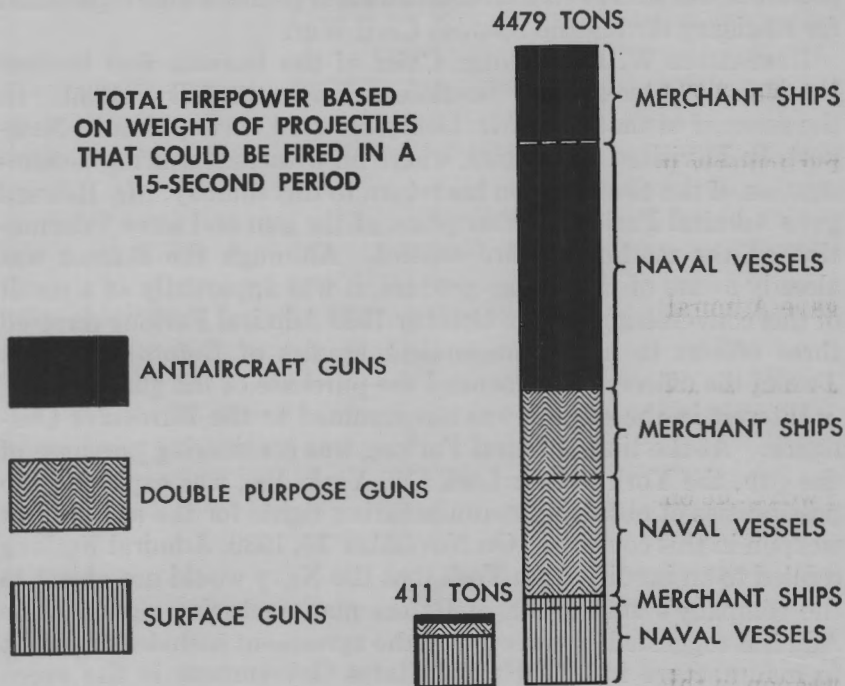
In recognition of the growing necessity for anti-aircraft fire, the more or less continuous Bureau experimentation with double-purpose guns during the 1920's finally culminated in the early 1930's in the development of the 5"/38 DP gun which fulfilled its mission throughout the war with very little criticism. While the longer range anti-aircraft gun field was taken care of, except for insufficient numbers, the situation was far from satisfactory in the short range category. Neither the .50 caliber machine gun, effective enough in plane-to-plane fire at pointblank range, nor the 1'1 which the Bureau developed in quadruple mounts in the 1930's, were competent to meet the menace of the Second World War plane. The 1'1 was too heavy to serve as a "last ditch" free mount and too light to span the gap between the small machine guns and the 5-inch guns, even had all its "bugs" been eliminated. The lack of adequate short range anti-aircraft guns together with insufficient quantities of the best guns then available created a situation which by 1940 could hardly be termed anything but critical.

In the spring of that year the Secretary of the Navy designated Rear Adm. E. J. King to make special studies for the improvement of anti-aircraft batteries, and on August 9, 1940, the Chief of Naval Operations created the Navy Department Anti-aircraft Defense Board to conduct a continuing study of anti-aircraft defense. The urgency of the situation was evident from the reports made by Admiral King and the AA Board. In a letter to the Secretary of the Navy, Admiral King stated: "It appears clear from the data available that ordnance material—armament and equipment—is the 'bottleneck' for the work in hand and, consequently, that steps toward the elimination of the 'bottleneck' are urgent and immediate." And the Anti-aircraft Defense Board declared on December 26, 1940: ". . . the lack of adequate close range anti-aircraft gun defense of existing ships of the Fleet constitutes the most serious weakness in the readiness of the Navy for war."

In the Bureau of Ordnance, a variety of vigorous steps were underway to meet the recognized deficiencies. Bureau action included stepping up the manufacture of the 1'1 until a suitable small caliber battery could be substituted in adequate quantities, efforts to improve anti-aircraft fire control, studies relating to the increase of anti-aircraft guns on board combatant and other ships, and steps to procure effective guns in both the 20-mm and 40-mm calibers.

FIREPOWER

**OF GUNS INSTALLED ON U. S. VESSELS AND MERCHANT SHIPS
JULY 1, 1940 COMPARED WITH JUNE 30, 1945**



The 40-mm Bofors machine gun has had a short but vital history in the United States Navy. First installations afloat were made in the early summer of 1942. Since that date, Bofors guns have been placed on virtually all combatant ships and on most noncombatant vessels large enough to support the weight of a 40-mm assembly. In defense against low flying enemy aircraft, the 40-mm spanned the relatively large gap between the 20-mm gun and the larger 3- and 5-inch double-purpose guns. In that role it became the very backbone of close-in antiaircraft defense.

The design of the Bofors 40-mm gun appears to have originated at the Krupp works in Germany shortly after the end of World War I. When the provisions of the Versailles Treaty required the discontinuation of the firm's operations in Germany, Otto Krupp obtained a block of stock in the Swedish Bofors Co., and Krupp equipment, along with key personnel, were moved to Stockholm. In time the Germans achieved full control of the company, only

to be eliminated by a Swedish law of 1930 which prohibited foreign ownership of munition factories. Controlling interest in the company was then purchased by Axel Wenner-Gren, a Swedish international financier. The Bofors 40-mm gun, like other Bofors products, was sold to various countries and gained a high reputation for efficiency during the Spanish Civil War.

Rear Adm. W. R. Furlong, Chief of the Bureau, first became particularly interested in the Bofors gun in the fall of 1939. In the summer of that year, Mr. Henry Howard, an engineer of Newport, R. I., visited Stockholm, where he witnessed a firing demonstration of the 40-mm. On his return to this country, Mr. Howard gave Admiral Furlong a description of the gun and some information on the methods of fire control. Although the Bureau was already aware of the Bofors product, it was apparently as a result of this conversation that in October 1939 Admiral Furlong directed three officers to make independent studies of Bofors literature. Two of the officers recommended the purchase of the gun.

Interest in the 40-mm was not confined to the Bureau of Ordnance. At the time Admiral Furlong was considering purchase of the gun, the York Safe & Lock Co., York, Pa., was exploring the possibilities of obtaining manufacturing rights for the anti-aircraft weapon in this country. On November 10, 1939, Admiral Furlong replied to an inquiry from York that the Navy would not object to the company's acquisition of Bofors manufacturing rights. The Admiral suggested, however, that the agreement included the right to manufacture for the United States Government in the event the gun should be wanted. He also expressed a desire to purchase one of the 40-mm guns for test purposes. The plan for the York Safe & Lock Co. to acquire manufacturing rights progressed to the point where a company representative, with naval authorization, started for Sweden in April 1940 to negotiate a contract. Just as the agent was ready to sail from New York, however, the Nazis seized Norway and plans for the visit were abandoned.

Negotiations for the purchase of the gun continued, however, through the Naval Attaché in Stockholm, and the purchase of an air-cooled, rather than the desired water-cooled, twin mounted gun was completed in July. The purchase also included the standard sights for the gun, spare parts, and 3000 rounds of ammunition. Eventually arrangements were made for transporting the gun and associated equipment across Finland to Petsamo, where they were shipped on the *S. S. American Legion*, arriving in New York in late August 1940. The trip of the *American Legion* was authorized to evacuate Mrs. J. Borden Harriman, United States

Minister to Norway, and other American citizens stranded in the Scandinavian and Baltic areas. Since this was the last ship to which the Germans gave safe conduct, unusual efforts were necessary to move the gun the length of Sweden by truck in order to get it aboard the vessel at Petsamo in time.

Prior to arrival of the sample Bofors gun, Captain Blandy, coordinator of the Bureau's antiaircraft program, and Comdr. A. F. France, flew to Trinidad to inspect the fire control system for the 40-mm Bofors which the Dutch had installed on HNMS *Van Kinsbergen*. Since there were no aerial targets available for testing the system, the Chief of Naval Operations ordered the cruiser *Tuscaloosa* to Trinidad, in order to have planes to tow the sleeves. Captain Blandy characterized the demonstration as an international affair: "American planes towed targets for a Dutch ship firing Swedish designed guns with a combined Dutch-German fire control system, the test taking place in the Carribean Sea off a British port." Although the American naval observers were not particularly impressed with the Dutch fire control system, they returned full of enthusiasm for the Bofors gun.

The first tests of the gun which Admiral Furlong obtained from the Bofors Co. were conducted at Dahlgren on September 28, 1940, with representatives present from the Bureau, the Army Ordnance Department, and the Naval Gun Factory. Some days later, test firings were witnessed by the Secretary of the Navy, the Chief of Naval Operations, and members of the British Admiralty Delegation. The results of these firings demonstrated the superiority of the Bofors over all similar guns available for study.

Among the machine guns under consideration were the Army's 37-mm and the British Navy's 2-pounder, more commonly known as the "pompom." The decision soon narrowed to a choice between the Bofors and the British gun. The British were anxious to have their gun adopted, and the fact that British aid would be readily available in initiating manufacture was put forward as an argument in favor of its selection. The 2-pounder, moreover, was giving a good account of itself on British ships. On the other hand, there was the distinct disadvantage that the gun was designed for cordite powder, and no manufacturing facilities for the production of this ammunition were available in the United States. Thorough study revealed that the gun could not be converted to take American powder. Another consideration was muzzle velocity: The pompom had a relatively low velocity, 2350 feet per second as compared with 2830 for the Bofors. The success of

the pompom in action was more than offset by the proved qualities of the Bofors in the hands of a number of powers who were using it, and the Bureau decided to join that group. Shortly after the Bureau's selection of the Bofors, British naval officials also decided to adopt the gun.

While the interest of the United States Army in the Bofors had no bearing upon the Navy's adoption of the gun, it should be noted that Army Ordnance officers were aware of the gun at least as early as 1937. The Army, apparently, became interested in procuring a gun for test purposes somewhat after efforts in that direction were initiated by the Navy. In November 1940, a British Army 40-mm Bofors was obtained by the Ordnance Department, and tests were witnessed by Bureau personnel, just as Army officers were witnessing the naval tests. In both negotiations for manufacturing rights and the establishment of production facilities, the Army and Navy cooperated to the advantage of both services.

The negotiations between the Navy Department and the Bofors Co. for manufacturing rights to the gun resembled transactions which commonly characterize a difficult international political compact far more than those which usually accompany a commercial agreement. Although the 40-mm gun was decidedly a "for sale" article, already in the hands of numerous powers other than Sweden, the complexities arising from European war and the United States role of "arsenal of democracy," added difficulties which might not have existed in more normal times. The two greatest obstacles were the Swedish Government's request, in return for its consent to the issuance of the manufacturing license, for certain United States airplane export and manufacturing licenses, to which the United States would not agree, and the language of the contract with respect to the eventual use of the guns. The Swedish demands were finally withdrawn, and the contract which was executed at Stockholm on June 21, 1941, provided that the items manufactured pursuant to the rights acquired under the contract were to be "for the United States use." The total price agreed upon was \$600,000, of which the Army was to pay one-half. One hundred thousand dollars of this amount was contingent upon the arrival in the United States of two Bofors production engineers. Since the men never arrived, the total payment was reduced to \$500,000.

While the basic twin gun and mechanism were obtained from the Swedish Bofors Co., the United States Navy Bofors gun and associated equipment was actually a very different final product. Bureau engineers, working with private manufacturing organiza-

tions, constantly improved the performance of the gun. The Swedish Bofors was manufactured in single and twin mountings, both manually operated. The Navy adopted twin and quadruple mounts, both operated by power, and when used with gun directors they presented quite a different picture from the parent Swedish gun.

The Bureau of Ordnance designed the quadruple mount according to a plan suggested by Mr. P. W. Burk, a Bureau engineer. In order to save the time that designing a completely new mount would require, the quad mount was composed of two twins on a single mount, with room for the loaders between the pairs of mechanisms, the whole giving the appearance of two sets of twins rather than of a single or quadruple mount.

The first design problem which had to be solved was that of converting drawings to American measurements. The conversion introduced manifold difficulties. When changed from the metric system, a great many of the measurements became troublesome decimals which added complications to the matter of tolerance. Worse still, the specifications called for in the drawings did not always agree with actual measurements taken from the gun because certain dimensions allowed for hand working. All of the first guns had to be finished by hand due to improper clearances. There were notes on the drawings which read "file to fit at assembly" or "drill to fit at assembly" which told a story of careful, expert European workmanship in producing handmade guns, but which constituted nothing but headaches for American producers faced with the necessity of setting up assembly lines for mass production.

One of the more troublesome design problems was that of interchangeability of parts between the Army and Navy guns, and even between the naval guns produced at York and those made by Chrysler. York translated in terms of decimals, whereas the Chrysler Corp., with both Army and Navy assignments, translated in terms of fractions. Something of the size of the task of converting the measurements can be seen from the fact that 8505 man-hours were required for the Chrysler transposition alone. Many additional hours of conversion were necessary before the differences were resolved and, meanwhile, the result was that approximately 200 parts were not interchangeable. In time the whole problem was solved with complete interchangeability, save for water-cooling portions of the Navy gun which were not required by the Army, and for approximately ten small items. Since Army and Navy mounts differed in both operational and design requirements, uniformity for these items was unnecessary.



40 mm and 5"/38 guns on U. S. S. Missouri. Naval vessels were literally studded with protective anti-aircraft armament.

The task of keeping drawings current and establishing Navy standards was a continual one, so the Bureau assigned the York Safe & Lock Co. responsibility for the project. The company's performance eventually proved so unsatisfactory that it seriously jeopardized the whole 40-mm program. Dimensional errors were common, drawings were not kept up-to-date, and in some instances tolerances were not specified. According to estimates, not over 20 percent of the drawings were completely dependable. Contractors

complained constantly that the drawings were a source of considerable trouble and confusion to subcontractors. This state of affairs constituted a serious handicap to the program for increasing production. In August 1943, cognizance of the drawings was transferred to the Naval Gun Factory.

Over 2200 drawing were reviewed by the Gun Factory, and priority was given to the changes required to facilitate production. Engineers from the Blaw-Knox Co. and the Naval Ordnance Plant, York, were assigned to the Gun Factory for the purpose of speeding the work. By December 1944, the revision was practically complete. Subsequently, maintenance of the drawings was transferred to the Naval Ordnance Plant, York, after the Blaw-Knox Co. had assumed operation of the facility.

Initiation of production had not waited for the solution of the innumerable problems which were the inevitable concomitant of any new program. The York Safe & Lock Co., early guardian of the transposed drawings, also was chosen as the prime contractor for the guns and mounts. The first commitment authorizing the establishment of facilities was made by letter of intent on June 25, 1941. Early plans called for the production of 500 twins and 500 quads, with deliveries of each type scheduled to start in October 1941, and increasing gradually thereafter to 25 each per month by May 1942.

Since additional guns were needed in order to meet lend-lease requirements for the British, letters of intent for establishing additional facilities were issued in June 1941 to the Blaw-Knox Co. of Pittsburgh and to the Chrysler Corp. of Detroit. These companies were selected on the recommendation of the Office of Production Management, and the plan was for Blaw-Knox to produce the mounts in a rehabilitated plant at Martins Ferry, Ohio, for which Chrysler would supply the guns. Chrysler had previously accepted proposals from the Army to produce air-cooled guns for both the United States and British Armies under lend-lease. The Navy, however, took over the administration of Chrysler production for both Army and Navy. York Safe & Lock planned from the beginning on extensive subcontracting for parts, and Chrysler proposed to spread its work through a number of its plants and to subcontractors. Barrel forgings produced by Crucible and Midvale were sent to York and to the Naval Ordnance Plant, South Charleston, W. Va., for machining. Crucible was, incidentally, already producing barrel, breech block, and breech ring forgings for Otis Fensom in Canada. Somewhat later, the National Supply Co. also began to produce forgings. The Standard

Machinery Co. and the Kaydon Engineering Corp, became the prime contractors for roller bearing assemblies.

Forty millimeter guns and equipment were produced almost entirely by commercial manufacturers, very few of whom had any previous experience with the production of ordnance materials. These producers had to run the gamut of problems which face commercial manufacturers when they attempt to meet the close tolerances and rigid specifications which must characterize the Navy's fighting equipment. In meeting schedules, the 40-mm manufacturers brought to the problem American industry's ingenuity and assembly line techniques. The number of instances of improvement in manufacturing methods, of redesign in order to produce a better part or to save man-hours in production are legion. At the Chrysler Corp., to cite one example, the redesign of 10 items saved 7,500,000 pounds of material and 1,896,750 man-hours in a year's production, and at the same time released over 30 machine tools for the production of other parts.

The general pattern of the procurement program was one of few prime contractors and relatively large numbers of subcontractors. The York Safe & Lock Co. subcontracted the major portions of its work, the proportion running as high as 90 percent on some assemblies. In 1943, York Safe & Lock listed 481 subcontractors and Blaw-Knox 200. The number of prime contractors producing components, other than for power drives and directors, never reached more than 20. In the main, the expansion was accomplished by more extensive subcontracting and by more efficient use of facilities. In the production of mounts, the prime contractors were called upon to meet schedules which demanded a twelvefold increase in the output of twins and a twofold increase in the production of quads.

Major shifts in the allocation of contracts to the principal producers were few, though several were quite significant. The York Safe & Lock Co. was gradually relieved of some of its more important functions in the program, including the transfer in July 1943, of its cognizance of 40-mm gun and mount drawings to the Naval Gun Factory, and the transfer of its prime contract for power drives to the Webster Electric Co. of Racine, Wis. Webster Electric Co. had previously produced approximately 90 percent of York's power drive equipment. In the procurement of power drives, a major change was made in May 1943, when the Ford Instrument Co., one of the original contractors, ceased to produce drives, and Vickers, Inc., of Detroit, was brought into the program.

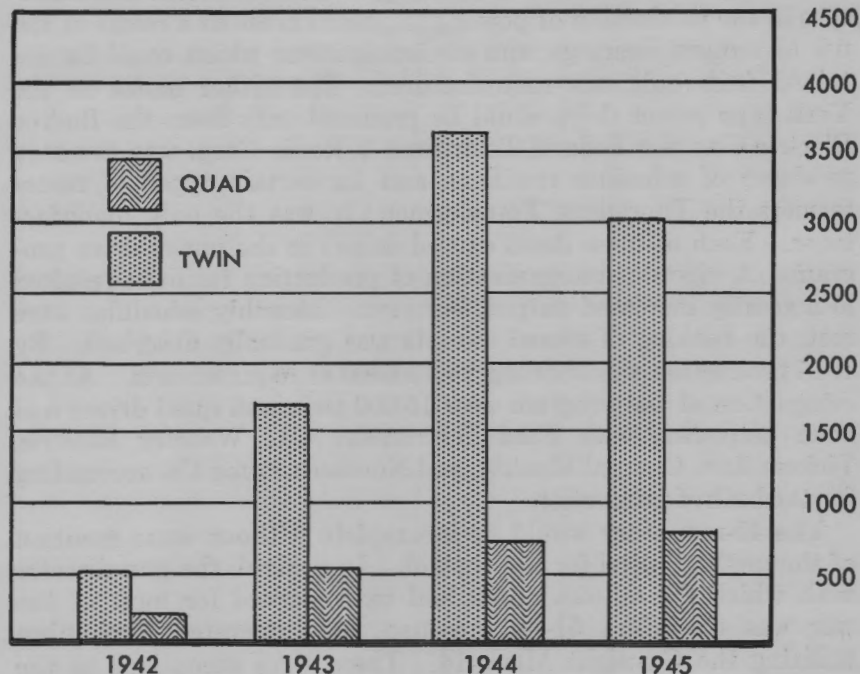
Forty millimeter procurement throughout the war was one of

the major ordnance programs. From the original contracts in June 1941, which called for an ultimate total of 500 twins and 500 quads for naval use plus an additional 500 twins and 300 quads for lend-lease, the programs expanded until more than 2300 quads, almost 10,000 twins, and over 10,000 single mounts came off the production lines during the war. Increasing production effected a considerable reduction in the price of 40-mm assemblies. By 1945, the cost of a quad mount had dropped from a high of \$86,000 to \$67,520, the 40-mm twin from \$62,300 to \$43,640.

Throughout the war, demands for 40-mm guns increased constantly. The introduction of new tactics and weapons inevitably forced alterations to many ordnance programs. In some cases they necessitated abandoning items; they did nothing, however, but increase the demands for 40-mm guns. While these facts constitute a remarkable tribute to the gun, they also point up the vital character of the program for procuring it.

In order to avoid delay in distributing 40-mm equipment to the fleet it was necessary to adapt or modify power drives that had

40-MM ASSEMBLIES



been developed for other gun mounts. The electromechanical Power Drive Mark 2 developed by the Ford Instrument Co. for twin mounts was a modification of the 1'1 Drive Mark 1; the General Electric Co.'s amplidyne drive, also for twin mounts, was an adaptation of the 1'1 Mark 2; and the Mark 5 developed by the Sperry Co. for the quad was a direct outgrowth of the drive that had been designed for the Army's 90-mm AA gun mount.

The 40-mm single mount, for installation on landing craft and other light vessels, was procured in large numbers from the Army. The Army power drive was inadequate for control of the mount aboard ship where roll was encountered, and to overcome this difficulty the Massachusetts Institute of Technology developed a new drive. Its procurement was facilitated by the fact that the prime contractors, Westinghouse Electric, Williams Oil-O-Matic Heating Corp., and the Gilbert & Barker Co., had all produced the Army type drive.

Despite this background of experience, the production of power drives was one of the major bottlenecks early in the 40-mm program. A slowly rising rate of production, adequate for the first months of the war, gradually fell behind a rapidly climbing demand until, by the summer of 1943, guns and mounts were going into storage for lack of drives. Many of the bottlenecks and shortages in the production of power equipment arose as a result of the use of motors, bearings, and electronic items which could be obtained from only one manufacturer. The dither motor in the York type power drive could be procured only from the Bodine Electric Co.; the Federal Telephone & Radio Corp. was the only producer of selenium rectifiers, and for certain types of transformers the Thoradson Transformer Co. was the only manufacturer. Each of these items caused delays in the power drive program. A vigorous reorganization of production facilities resulted in a greatly increased output, however. Monthly schedules were met, the backlog of stored mounts was gradually absorbed. By 1945 production was running well ahead of requirements. At the completion of the program over 15,000 twin and quad drives had been delivered, with Ford Instrument Co., Webster Electric, Vickers, Inc., General Electric, and Northern Pump Co. accounting for the bulk of production.

The 40-mm story would be incomplete without some mention of the methods used for fire control. In general, the gun director with which the 40-mm quads and twins served for most of the war was the Mark 51—a one-man, hand-operated mechanism utilizing the Gunsight Mark 14. There were exceptions to the

generalization, as attempts were made to use the 40-mm guns with mechanisms which were not primarily machine gun directors, and with the early blind firing directors. During the early period the attempts to adapt such a director to the 40-mm were unsuccessful, and the first models had to be abandoned. The need for blind firing was pressing, however, and early failures merely stimulated the Bureau's search. The continuous efforts to make blind firing machine gun directors available to the fleet began to bear fruit in 1945. Gun Fire Control Systems Marks 57 and 63 were placed in production early in the year and a third director, the Mark 60, was nearing the production stage at the end of the war.

Quad and twin 40-mm mounts also were equipped with sights Mark 3 and 4, respectively, for use in the event that power failures necessitated manual operations. Single mounts which were not equipped with power drives were initially supplied by the Army with cartwheel and fence type sights, though a ring sight was developed for this mount and modifications made for antipersonnel firing. Single mounts for use on submarines were also provided with panoramic telescopes.

Excellent ammunition contributed to the outstanding performance of the Bofors. Beset by numerous difficulties in the early production stages, which for a time threatened the entire program, the quality of the 40-mm round was constantly improved until it became a standard of excellence. The 4.8 pound cartridge, loaded into clips with a capacity of 4 rounds, carried a projectile which weighed slightly less than 2 pounds. In the course of the war, over \$700,000,000 was spent for 40-mm ammunition.

At the very outset of the program for the development and production of ammunition components for the Bofors gun, the Army and Navy established the cardinal principle that the ammunition must be interchangeable. The British round was adopted with the understanding that both services would be free to substitute components of proven reliability which would speed production. The round developed by the Bofors Co. was rejected on the ground that its fuze was too sensitive, was not bore safe, and was not adaptable to mass production. The British round in many ways did not lend itself to quantity production, but the urgent need for this ammunition did not permit the usual careful research and development that generally preceded service issue.

The early days of development were hectic. Forty millimeter guns and mounts were rolling off the production line, but no safe ammunition was available. Of the several components, the original British fuze caused the most concern. The foreign fuze did

not meet all Bureau requirements for safety and functioning. Further, it had so many parts and those parts were so complicated that they offered great production difficulties at a time when machine tools and assembly facilities were almost nonexistent. Procurement would be most difficult and expensive. The answer, of course, was a simpler fuze—but there was little time to work on a design. It was a matter of days; not weeks or months, and in the meantime the Bureau initiated procurement of the British fuze.

At this point, Mr. R. L. Graumann of the Naval Ordnance Laboratory presented a sketch of a new fuze. The fuze was simple in design, ideally suited to mass production, and appeared to fulfill all functional requirements. Admiral Blandy was so impressed with the advantages of the design that he stopped procurement of the British fuze. There was a prompt mobilization of the facilities of the NOL to perfect the design almost overnight. The new fuze, designated the Mark 27, was 99.9 percent efficient in ballistic acceptance tests, a record not equalled by any other fuze. Where the British design used 13 threads, the Bureau's fuze used 3. It was simpler to make, it did not tie up critical machine tools, and it cost much less. It is estimated that the savings effected by the adoption of the Mark 27 totaled approximately \$250,000,000 during the war. No significant change in the original design was ever made and the United States Army and British Navy adopted the fuze for use in their 40-mm ammunition. Both Army and Navy action reports bore witness to the inestimable value of the fuze.

Early in 1942 the overall requirements for 40-mm. ammunition were established at 5,250,000 rounds per month. From this beginning, requirements were gradually increased to a maximum of 12,000,000 rounds per month in the winter of 1943. Later developments permitted a reduction to 4,500,000 rounds a month, which proved of material benefit to the rocket and high capacity ammunition programs.

Until December 1942, all 40-mm projectiles were loaded by Triumph Explosives, Inc. One contractor could not meet the demands of the program and the Bureau, shortly after Pearl Harbor, began the construction of a model 40-mm loading plant at Charlotte, N. C. A contract was negotiated with the United States Rubber Co. to manage the new activity, and on December 21, 1942, the plant was officially opened. Within a year after operations began the rated capacity of Charlotte was exceeded with no increase in the original facilities. Also in December 1942, 40-mm lines were added to the facilities already under construction at the Naval Ammunition Depots at Hastings, Nebr., and McAlester,

Oklahoma. In 1943, when requirements were greatly increased, a supply contract was placed with National Fireworks, Inc.

Increasing estimates of requirements for twin assemblies were fairly constant while estimates for quad assemblies saw a certain amount of fluctuation. The problem which the Bureau faced was one not only of increasing production but of meeting demands which varied tremendously over relatively short periods of time. Indeed there is some truth in the statement that the schedules were ahead of production, rather than that production was behind the schedules.

In any procurement system based upon the work of numerous contractors the matter of balancing production becomes of paramount importance. This was particularly true in the case of the 40-mm because of the large number of parts involved. The advantages, not to say necessities, which made the 40-mm program one of many participating manufacturers are obvious. But equally obvious is the fact that the 3-year effort to keep pace with schedules was primarily a matter of balancing the production of the numerous components. Perhaps the best statement of the situation was made by the Bureau officer who wrote, "It still takes *all* the parts to make a complete assembly."

The balance was always more or less precarious. As one report pictured the program in late 1944: "Any unforeseen difficulties, such as casting defects, strikes, delay in rolling schedules at steel mills, or . . . the failure of a single sub or sub-subcontractor can at any time threaten the entire program and cause a serious backlog which may or may not be made up." But the report concluded: ". . . such exigencies are being and will continue to be overcome."

The 40-mm production program depended heavily for its success on the York Safe & Lock Co., and this company can with justice claim credit for a number of valuable contributions to the program. As requirements mounted, however, it became increasingly clear that the company could not be counted on to carry the responsibilities which were essential to the continuation of its major role in the program. Previous mention has been made of steps taken to relieve York of its prime contract for power drives and to transfer the administration of 40-mm drawings to the Naval Gun Factory. On January 23, 1944, the Navy Department took over certain portions of the York Safe & Lock Co., consisting principally of the facilities for 40-mm. production known as the Special Ordnance Plant which had been constructed at Government expense of approximately \$8,000,000. On June 19, 1944, these activities

were designated the Naval Ordnance Plant, York, and the Blaw-Knox Co. engaged as the contractor-operator. With these changes performance improved steadily—overhead was decreased, scheduled production was balanced, and rejections were decreased.

The original Swedish gun contained a variety of high alloy steels, medium alloy steels, straight carbon steels, and nonferrous alloys. The rigid formulas specified ruled out their use in the American 40-mm gun because sufficient quantities for mass production could not be furnished. The substitution of one steel for another was carried as far as possible without adversely affecting the quality of parts. Considerable savings were made in the conservation of critical and strategic materials other than in steels. When necessary to conserve tin, silicon bronzes were used in both castings and bar stock. A further attempt was made to save copper and tin by the substitution of malleable iron castings, but the experiment was not successful because of slow deliveries and the excessive machining operations required on the castings.

The continued demands which came from the fleet for more and more 40-mm guns constituted perhaps the best evidence of their value. There can hardly be any argument with general statements regarding the excellence of the guns, their effectiveness within range, their ruggedness, their simplicity of operation and maintenance, and the dependence placed upon them by the fleet for close-in AA defense. The value of the gun changed as the tactics of the enemy changed. For example, the emphasis by the Japanese on suicide attacks placed an increasing dependence upon close-in AA guns, as opposed to the longer range defense of DP guns. Of the kills made in the period October 1, 1944, to March 1, 1945, approximately 50 percent were credited to the 40-mm. In an earlier period when attacking planes tended to keep at a greater distance, dependence upon DP guns with special ammunition was more marked.

Although the 40-mm was employed primarily as an AA gun, it became increasingly effective as a weapon for use against certain types of shore and surface targets. This was especially true of 40-mm guns mounted on submarines and amphibious fire support vessels. Action reports late in the war stressed the value of the gun as an antipersonnel weapon.

The inseparable companion of the 40-mm gun for close-in defense was the 20-mm Oerlikon. Like the Bofors, the Swiss Oerlikon replaced an American gun that failed to provide adequate defense against planes. In the mid-1930's the .50 caliber machine gun was one of the Navy's primary weapons against the airplane. This ac-

ceptance, however, was short-lived. Reports of naval operations in the European war, and the rapid increase in the speed and armor of aircraft illustrated the relative weakness of the gun. By the summer of 1940 it was apparent that the .50 caliber was not an effective weapon against diving or low flying planes. Firing tests showed that a large number of .50 caliber hits were necessary to disable a plane, and that only a very small number of hits on a diving airplane were attainable from any one ship mounted gun. Further, there were not enough favorable gun positions aboard ship to permit the installation of the number of .50 caliber mounts that would be required for a reasonably adequate defense. Discarding the work of 20 years, the Bureau turned to the 20-mm Swiss Oerlikon—a gun which fired an explosive bullet about two and one-half times the weight of the .50 caliber at a rate of 450 rounds per minute. Bureau officers estimated that the Oerlikon, which proved its worth in the Spanish Civil War and in the European war which followed, was from 8 to 10 times as effective as the .50 caliber gun.

The Bureau had long known Oerlikon guns. In its search for weapons capable of protecting the capital ship against air attack, the Bureau had in 1935 purchased two heavy 20-mm aircraft



The 20-mm gun took a heavy toll of Japanese planes.



Antiaircraft fire repulses Japanese attack.

machine guns from the Oerlikon Machine Tool Works of Zurich, Switzerland. These guns, 1934 models, were low velocity weapons with a rate of fire of only 265 rounds a minute. Following thorough tests at the Naval Proving Ground, Dahlgren, and at the Army's Aberdeen Proving Ground, the guns were rejected. The Japanese adopted this model and at the time of Pearl Harbor it was their standard aircraft and antiaircraft gun. How ironic that the licensing agreement with Japan furnished the Oerlikon Works with money to perfect the 20-mm gun which we later secured as an antiaircraft weapon—a weapon which was to be used so devastatingly against Nipponese air power by both the United States and Great Britain! The Navy's adoption of the Oerlikon was so intimately connected with British experience that a review of these events is necessary for an understanding of the Bureau's action.

In 1937 the British Navy initiated tests to find a suitable weapon for the defense of merchant ships, trawlers, mine sweepers, and similar vessels, against dive bombers and close range air attack. One of the principal requirements for the gun was that it could be operated and maintained for long periods at sea by nonspecialist personnel, such as merchant seamen and fishermen. The tests demonstrated the superiority of the Oerlikon and orders were placed with the Swiss company for large numbers of the guns. In addition,

a license gave the Admiralty the right to manufacture the gun and its ammunition in any part of the British Empire.

Shortly before the fall of France in the spring of 1940, and as the war situation was growing steadily worse for European neutrals, the British decided that an additional source of supply for the guns should be set up in the United States. Meantime, Mr. Antoine Gazda, "Export Manager, Oerlikon Works," arrived in the United States late in May. In preliminary negotiations with the British, Gazda proposed to produce Oerlikon guns at an annual rate of 2000, beginning five months after receipt of an order. He interested American capital in organizing a firm to produce the Oerlikon, and on October 16, 1940, the corporation was chartered by the State of Delaware under the name of the American Oerlikon Gazda Corp. The company, located in Providence, R. I., was 75 percent American owned.

The British plans for the new corporation, however, received a severe jolt when it was discovered that the 20-mm could not be manufactured in the United States because American authorities were forbidden to give clearance for complete guns which were not standard to those used by the armed forces of the United States. At this point the British began a campaign to have the United States Navy adopt the gun. On October 31, 1940, the Admiralty cabled the British Purchasing Commission in Washington:

"... greatly concerned to learn . . . that the United States Government has withdrawn permission to manufacture Oerlikon gun equipments and that this may be withheld altogether unless the United States Navy decides to accept this weapon.

"The Admiralty would regard such a decision, if final, as a staggering blow to their preparation for anti-aircraft arming of small ships and mosquito craft. The selection of the Oerlikon was the result of exhaustive tests and experience under war conditions, and on the cessation in May last of supplies just begun from Switzerland they turned to project for Oerlikon production in the United States of America as the only means of satisfying their vital needs. In June last, they informed the British Supply Board that requirements existed for 2000 guns and mountings and 10,000,000 rounds. Loss of time would be irreparable if it is now rendered nugatory. Request you will make every endeavor . . . to contact Morgenthau and the Secretary of the Navy and earnestly urge immediate consideration of permission for Oerlikon production. . . ."

In the meantime Captain Blandy had witnessed tests of the gun at Dahlgren and come to the conclusion that the Oerlikon was an

excellent weapon. His recommendation of November 9 that the Navy use the 20-mm was approved by Admiral Furlong. It was the Bureau's hope that with this clearance the British would place contracts for the production of 20-mm guns in sufficient number to take care of both their own and the United States Navy's needs.

At the time the Bureau selected the Oerlikon it already had a powerful 20-mm machine gun in the Hispano-Suiza which was used in both Navy and Army aircraft. The Hispano had a much higher rate of fire than the new Oerlikon and it offered the further advantage of a common gun and ammunition for both services. In comparison with the Oerlikon, however, these advantages were more than offset by the excellent features of the Swiss gun for anti-aircraft work.

One of the greatest advantages of the Oerlikon over the Hispano was the fact that it had a barrel that could be replaced in a matter of seconds. Cooling was no problem in an airborne gun, but at sea against multiplane dive bombing attacks, prolonged firing was necessary and the ability to change barrels quickly was of great importance.

The magazine employed with the Oerlikon was superior to the Hispano's. In the first place, the Oerlikon magazine could be kept fully loaded without any tension on the springs, while in the Hispano the spring was compressed as long as the magazine was loaded, a condition which brought occasional spring collapse. Secondly, the magazine had a greater reserve because of the easier task of feeding at 450 rounds per minute as against the higher rate of the Hispano's 620. Thirdly, the Oerlikon magazine had a straight tangential lead through its mouthpiece, whereas the Hispano had a 90° bend. Another deciding factor in the selection of the Oerlikon was the fact that it had a single mount for anti-aircraft use, while a satisfactory mount for the Hispano did not exist.

Lastly, British sea experience with the Oerlikon proved its superiority over the Hispano-Suiza. After the fall of France supplies of Oerlikons from Switzerland were cut off, and as a stopgap Hispano guns were installed on several escort vessels. The results were uniformly bad. Ships reported frequent stoppages from the unsatisfactory design of the cradle, salt water corrosion around the breech block, unlocked tappets, and the collapse of the magazine springs. The guns were so unreliable that one vessel reported that she preferred not to open fire with the Hispanos in the hope that the Germans would think she was not a warship! Opposed to this, the British experience with the 100 Oerlikon guns at sea in November of 1940 was excellent.

The decision of the Bureau to use the 20-mm Oerlikon made it possible for the British Purchasing Commission to press plans for the manufacture of the gun in the United States. From November 1940 through February 1941, the BPC endeavored to conclude a licensing agreement with the Oerlikon works through its agent Gazda. The proposed contract, finally signed on March 8, 1941, provide for an adequate technical staff of at least five Swiss experts to aid in setting up production in this country and for payments as follows: \$300 each on the first 2000 equipments, \$200 each on the second 2000, and \$100 each on the next 6000. No further fees were required for a period of 5 years. The agreement, however, was subject to the approval of the Swiss Government which had, on August 30, 1940, prohibited the granting of rights of any kind relating to the use of inventions, secret processes, and industrial experience concerning the manufacture of war material. The Swiss Government refused to sanction the license and the British soon cancelled the proposed contract.

The refusal of the Swiss Government to approve the licensing agreement did not deter the British, and the American Oerlikon Gazda Corp. continued to operate under a letter of intent from the British for the production of 2000 guns. A formal contract was never executed between the British Purchasing Commission and the Corporation. A proposed cost plus fixed fee contract, dated June 23, 1941, called for the production of 2000 guns, 16,000 magazines, and the necessary spare parts. The British, however, turned the contract over to the United States under the Lend-Lease Act, in accordance with the policy that foreign governments qualified to receive aid would request this Government to supply their needs. Initially, all procurement of the Oerlikon was designed to fulfill lend-lease obligations. As the tempo of the war increased in Europe and as our relations with Japan deteriorated, increasingly large quantities of the gun were ordered from American manufacturers by the Navy for its own use.

On August 9, 1941, the Bureau negotiated a contract with the American Oerlikon Gazda Corp. for the production of 2500 Oerlikon assemblies, 2000 of which were to go to the British. Deliveries were to begin in August and were to attain a maximum rate of 200 per month by October 1941. Incidentally, the first gun produced by the American Oerlikon Gazda Co. was fired on June 8, 1941—2 months before the execution of the formal contract. The contract was subject to Section 11 of the act approved June 28, 1940 (Public Law 671, 76th Cong.), which forbade access of aliens to the plans or specifications of work under secret, confidential, or

restricted contracts. Gazda therefore was replaced as a director and the name of the company was changed to the AOG Corp.

During the negotiations between the British and the American Oerlikon Gazda Corp., the Bureau was attempting to secure another source of supply for the vitally needed gun. The Pontiac Motors Division of the General Motors Corp. was finally interested in the program, and on April 3, 1941, a contract was negotiated which called for the delivery of 2000 equipments to the British under lend-lease. Deliveries were scheduled to begin 30 days after the installation of facilities—a rather indefinite date. Before production began, however, an option for the manufacture of 4000 additional equipments was taken up, and deliveries were advanced from 200 to 400 a month.

The Hudson Motor Car Co. of Detroit was brought into the program on May 22, 1941, when a contract was signed for the production of 2000 complete equipments at a delivery rate of 200 units a month. Hudson also was given a contract for the preparation of drawings, pamphlets, and design work. The new Naval Ordnance Plant at Center Line, Mich., constructed for the manufacture of light ordnance items and including a special building for the production of 20-mm guns, was turned over to Hudson as the contractor-operator. Hudson operated the NOP until October 1943, at which time it was replaced by Westinghouse.

Pontiac completed its first equipment in September 1941, but it was not until after Pearl Harbor that Hudson was able to make delivery of a 20-mm gun and mount. Deliveries during the pre-war months were disappointing. Of course, the three prime contractors were setting up facilities, taking deliveries on tooling, revising drawings, and adapting the Swiss watch like mechanism to American mass production. At the time of the Japanese attack on Pearl Harbor only 379 equipments had been delivered—264 from AOG and 115 from Pontiac.

Early in December 1941, production rates were established which called for the three prime contractors to deliver 1850 complete equipments a month. Of this total, the Naval Ordnance Plant, Center Line, was to supply 750, Pontiac 600, and the AOG 500. The rates were constantly increased, peak production being reached in September 1943, when 4693 mounts and 5630 mechanisms came off the assembly lines. From June 1941 through December 1945, a total of 146,956 mechanisms and 133,149 mounts were produced. The three prime contractors were the only source for mechanisms, and they also furnished 122,735 of the mounts. The Cameron Iron Works, the Continental Gin Co., the Eleo Boat Co., and the

Modern Welding Co. supplied 10,414 mounts—7000 coming from the Continental Gin Co. of Birmingham, Ala. The 124,735 complete assemblies plus an adequate supply of spare mechanisms and mounts, represented an expenditure of approximately \$450,000,000. An additional \$35,000,000 went for the procurement of a 20-mm twin gun mount designed and developed by Pontiac. Deliveries began in January 1945 and at the end of the war, 5760 equipments had been produced.

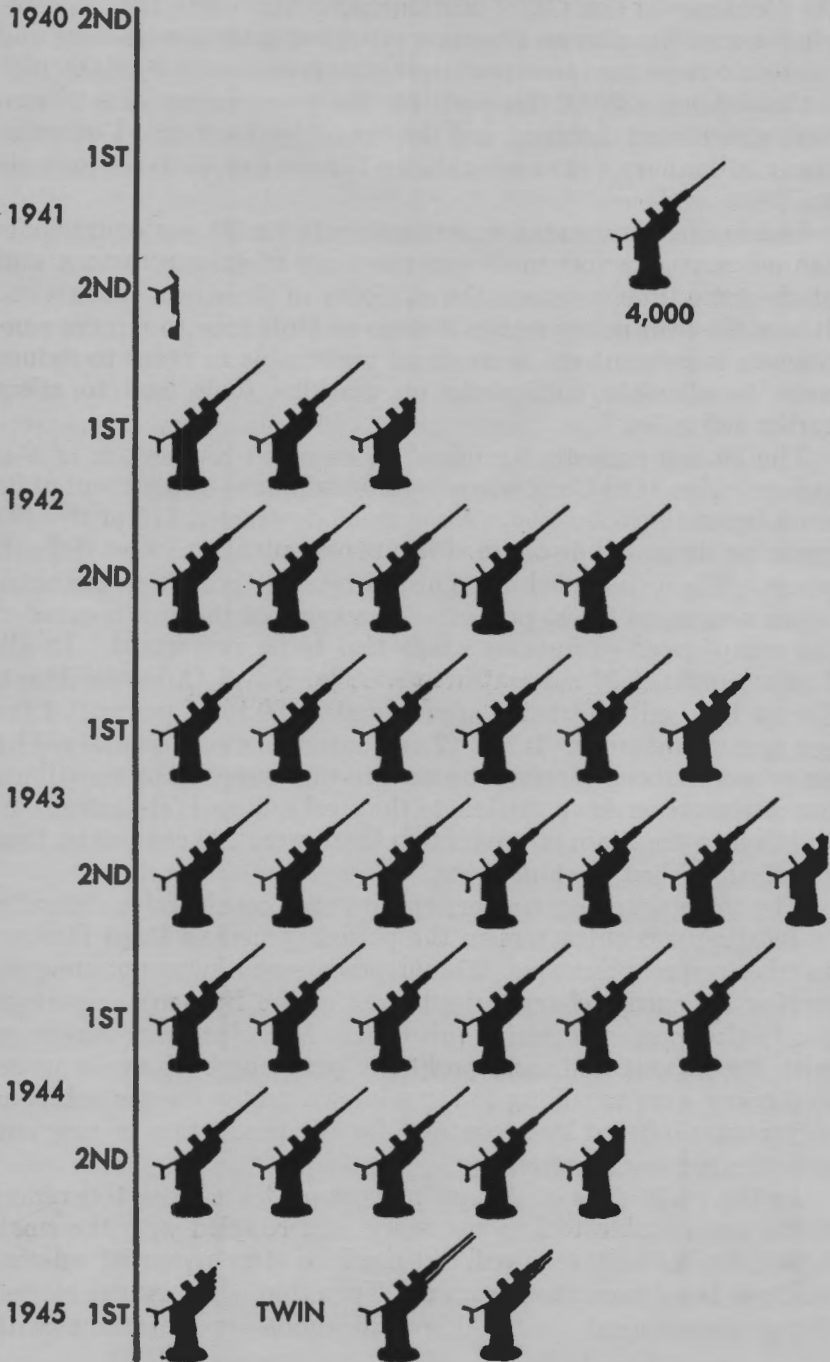
In meeting the increasing requirements for 20-mm equipments the prime contractors made extensive use of subcontractors, and at the same time increased the efficiency of their own production. It was the firm policy of the Bureau of Ordnance to require contractors to subcontract as much as practicable in order to reduce costs, to alleviate bottlenecks on machine tools, and to effect earlier deliveries.

The 20-mm program furnished an excellent illustration of this policy. The AOG Corp. was an assembly plant—100 percent of its work being subcontracted. Pontiac subcontracted 175 of the 195 parts for the gun, but retained for its own plant the most difficult pieces. These included the gun barrel and breech mechanism, which accounted for 45 percent of the value of the gun because of the complicated operations which had to be performed. In all, Pontiac utilized 94 subcontractors. The Naval Ordnance Plant, Center Line, subcontracted approximately 60 to 65 percent of the gun and mount order. It had 17 subcontractors, each was served by six or more subcontractors who were in turn supplied by contributing producers on down the line to the steel mill and fabricator. In addition to the chain of production there were 126 companies that supplied finished machine parts.

The three prime contractors encountered considerable difficulty in locating subcontractors in the period preceding Pearl Harbor. In this respect, however, 20-mm procurement was not unique; similar difficulties characterized most of the Bureau's important production programs during this time. Manufacturers were busy with the biggest and most profitable peacetime business in years, and many were unwilling to swap known profits for the nebulous advantages offered by a contract for the production of new and complicated war material.

In the early days of 20-mm procurement the close tolerances made considerable tooling necessary, and coupled with the small quantities initially required, did much to steer potential subcontractors away from the program. Then, too, all drawings carried Navy Department material specifications—specifications with

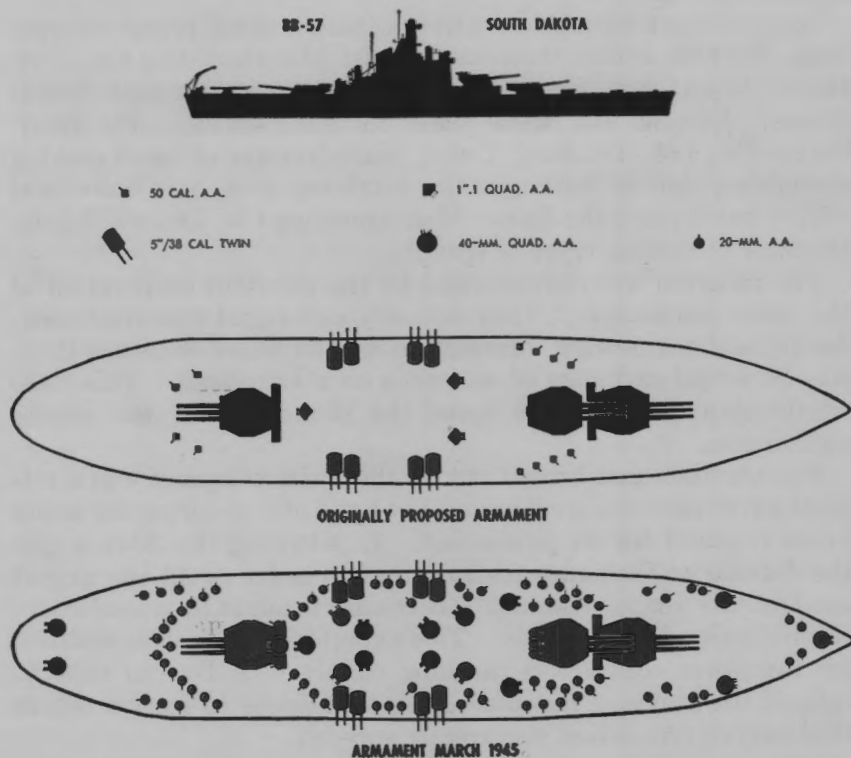
20-MM ASSEMBLIES



which civilian firms were not fully acquainted. Further, most of the parts required steel of special sizes and analyses which was not available in warehouses, and the mills, extremely busy, were not interested in making short runs. In spite of these drawbacks, and with much effort on the part of prime contractors, satisfactory subcontractors were located. Perhaps the greatest trouble was experienced in locating subcontractors for miscellaneous machine gun parts. On these pieces it was necessary, in a great many cases, to resort to jobbing machine shops as well as tool sources, and often limited quantities had to be made by toolroom methods at prices much higher than normally expected.

As the program progressed under wartime impetus, relief was given to a great extent by modification of tolerances, and in some cases by simplification in design. Also, guns and mounts were authorized in increased quantities which enabled the prime contractors to offer greater volume of production to subcontractors, thus bringing in new sources of supply.

INCREASE IN ANTI-AIRCRAFT BATTERY



The prime contractors endeavored to subcontract entire assemblies. In many instances the magazine, mount, shoulder rest, and sight were all subcontracted as entire assemblies. The more or less standard or near standard items, such as springs, were procured by purchase order. Accessories—pliers, wrenches, spanners—were also purchased items. Purchase orders for the procurement of the more standardized articles were placed with manufacturers whose products were closely allied to the items required by the prime contractors. In general, where the prime contractors could relieve themselves of added administrative responsibilities by depending on the “know-how” and experience of the manufacturer, they did so.

Attention was also given to the size and capacity of the plant of the prospective subcontractor. The prime contractors desired that the subcontractor be in a position to accept the order and still have the capacity and flexibility to meet increases in rates occasioned by an accelerated production program. If the manufacturer was able to accept only a limited contract due to other obligations, or an otherwise limited capacity, it was thought best to look elsewhere.

Some of the subcontractors were common to all prime contractors. Notable among these were Greist Manufacturing Co., New Haven, Conn., suppliers of breech face pieces, striker pins, breech cotters, plungers, and catch plates for hand cocking; the Bard-Parker Co., Inc., Danbury, Conn., manufacturer of hand cocking assemblies, double loading stops, retaining pins, axis bolts, and trigger pawls; and the Raton Manufacturing Co., Detroit, Mich., producer of various types of springs.

The program was characterized by the excellent cooperation of the prime contractors. They not only exchanged manufacturing, design, and engineering information, but on many occasions there was an actual exchange of materials on a loan basis. This close relationship did much to speed the production of the vitally needed gun.

The Oerlikon gun turned out by the Swiss company was a tailored job requiring a great amount of hand fitting during the many hours required for its production. In adopting the 20-mm gun the Bureau of Ordnance realized that in order to fill the urgent need for this weapon it would be necessary to adapt its manufacture to production line methods. This expectation was soon realized, for the prime contractors, working closely with Bureau experts, refined the gun and manufacturing techniques to such a degree that overall production was greatly speeded.

The list of these improvements is too long to give in detail; one illustrative case will be sufficient to show the trend. The barrel spring casing, initially a 56-pound solid alloy steel forging from which it was necessary to machine 50 pounds, was redesigned to consist of a hollow forged base to which a tubular steel extension was welded, thus reducing the weight to 14 pounds and effecting a corresponding savings in man-hours, machine tools, and cost.

Some typical examples of time savings are illustrated by the reductions at Pontiac:

<i>Part</i>	<i>Original (hours)</i>	<i>1 Sept. 1944 (hours)</i>	<i>Total reduction (hours)</i>
Breech casing-----	190.00	29.76	160.24
Barrel-----	37.07	5.42	31.65
Miscellaneous small parts and gun assembly-----	147.40	33.97	113.43
Spare parts-----	53.92	7.57	46.35
Total-----	428.39	76.72	351.67

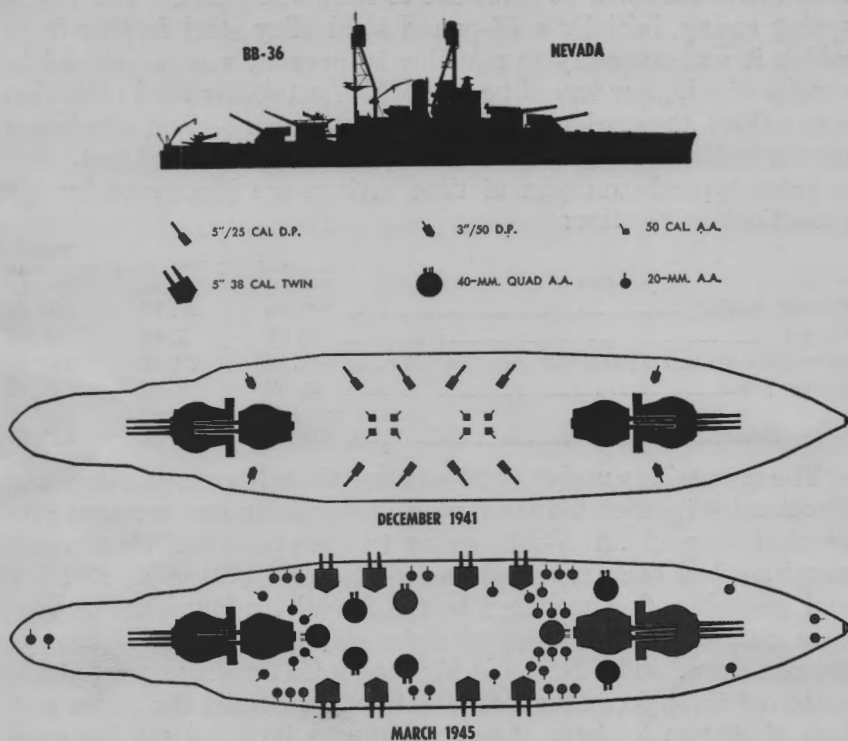
The increasing number of 20-mm antiaircraft guns on Navy and merchant ships dictated the largest ammunition procurement program of the war. At V-J Day over 1 billion rounds of 20-mm ammunition had been procured at a cost of \$786,791,000. Loading and assembly, first centered in the Naval Ammunition Depots, soon outgrew the facilities of these stations and was shifted to private firms. The National Fireworks Co., operating 10 plants scattered throughout the East and South, assumed the major portion of 20-mm loading. Lesser producers included the National Munitions Co., Victory Ordnance, and the Bermite Co. The excellent work of these companies kept the fleet supplied with five different rounds—high explosive, high explosive incendiary, high explosive tracer, armor piercing, and training.

An analysis of antiaircraft action compiled by the Commander in Chief, United States Fleet, showed that the Navy made good use of this ammunition. From December 7, 1941, to September 1944, the 20-mm was the most effective of all antiaircraft weapons. During that period 32 percent of identifiable "kills" were credited to this caliber. This supremacy was not retained. Shift of emphasis to night operations, increase in 40-mm batteries, and extensive improvements in performance of 5-inch guns reduced the 20's score to 25 percent.

Although the trend to larger calibers was pronounced and there was even some advocacy for the complete removal of the Oerlikon, a wide field of action remained for the gun in countering surprise attacks, discouraging strafing, and as a defense against flying

ANTI-AIRCRAFT GUNS

TYPICAL ANTI-AIRCRAFT MODERNIZATION



bombs. Each of these functions demanded characteristics of reliability, high degree of mobility, and large volume of fire—characteristics possessed in high degree by the 20-mm.

While the 20-mm proved very successful as a free swinging machine gun, its value was limited because of the short ranges within which it was effective. By the summer of 1945 the policy of installing 40-mm at the expense of the 20-mm had progressed to the point where the 20-mm batteries were rather weak. To the fleet the 40-mm gun appeared to be the minimum caliber weapon capable of destroying a plane in a suicide attack. Changing enemy tactics and the increased volume and accuracy of 40-mm fire continued to reduce the comparative effectiveness of the smaller gun to the point where a large battery of them was neither necessary nor desirable. However, there were two major reasons for retention of a minimum battery of 20-mm guns: First, lack of dependence on a power source of operation, and second, the fact that

it could be put into action faster than the larger power-driven calibers. Nevertheless, at the end of the war the demand for the 20-mm was confined to those locations where space or weight limitations did not permit the installation of 40-mm batteries.

Chapter 12

DOUBLE-PURPOSE, INTERMEDIATE, AND MAJOR CALIBER GUNS

A GUN according to ordnance vocabulary is "a tube closed at one end, holding a propellant charge so confined that it will drive out a projectile at high velocity in a direction determined by the aiming of the tube." This simple definition contains no hint of the difficulties involved in gun construction. Yet of all ordnance equipment the making of high powered naval guns and mounts is the most time consuming and requires the most preliminary preparation. To obtain the accuracy characteristic of naval firepower the massive components of guns and mounts must be manufactured to tolerances generally found in small precision pieces. Meticulous manufacture characterizes the production of all guns, but the picture is further complicated by variations in the construction methods used with the different calibers found in the fleet.

Large naval guns are either built up or radially expanded. Guns above 8 inches are of the built-up type, while those ranging from the 3-inch through the 8-inch may be manufactured by either process. Built-up guns are constructed of layers of metal—liner, tube, jacket, and hoops. The cylindrical forgings used for these guns are supplied by steel companies who determine the composition of each piece with meticulous care. To eliminate blowholes and gas bubbles, the steel is processed in acid open hearth or electric furnaces rather than in the basic open-hearth type. Pieces of small interior dimensions are forged solid; larger pieces are bored before being forged. In the annealing furnace the steel is heated to a point above the critical temperature range, held there for a time, and then cooled slowly. This process fosters grain refinement, removes stress and strain, and guarantees maximum softness and ductility.

The forgings, which must pass a minute examination, are bored to a tolerance of a few thousandths of an inch. To make sure that the hole is true, frequent inspections are necessary. From time to time the bit is withdrawn and the hole indicated and star-gaged; the indicator shows whether the bore has been turned true, and the star gage, registering to the nearest thousandth of an inch, accurately measures the inner diameter. Frequent bore-searching

by means of an ingenious device of mirrors and electric lights attached to a long pole reveals cracks or flaws in the interior of the bore.

The next step is shrinking the jacket on the inner tube. The assembly is accomplished in a deep electrically heated pit. First the jacket is heated to cause expansion. The tube is then placed in the pit, breech end down, with a centering mandril extending up into the bore for support. Cold circulating water cools the tube and prevents it from expanding. The jacket, which has expanded in diameter, is then slipped on over the tube. Cooled, the jacket contracts and grips the tube firmly and evenly, imparting extra strength. The addition of the hoops completes the gun. Thus assembled, the gun is ready for the conical boring of the tube which precedes the insertion of the liner. In the meantime the liner has been turned, bored, measured, and inspected. The same process used in building up the gun is employed in inserting the liner. The tube with its jacket is placed in the pit, muzzle end down, and expanded under high temperatures. The liner, filled with water and suspended above the gun, is slowly lowered into place. The gun gradually cools and contracts about the liner. With this process completed, the built-up mass is finished.

Other important operations remain to be performed, however. One is the machining of the bore of the liner to final diameter, and another is the chambering of the breech end of the bore for the powder chamber which must exceed the bore in diameter. After



16-inch guns are constructed of layers on metal—liner, tube, jacket, and hoops.

chambering, great lathes machine the outer surface of the gun to final dimensions.

The final process, time consuming and difficult, is the rifling of the liner. For this purpose a rifling head consisting of numerous cutters, the number depending upon the caliber of the gun, is used. The cutting tools on the head number half the total cuts to be made. When one set of grooves is made, the cutter is reset in exactly the right position to commence the second half of the rifling process. The rifling head literally shaves the grooves into the hard steel, the adjustable cutters digging a little deeper with each stroke down the barrel. Some 750 cuts by the rifling head, each cut removing a half-thousandth of an inch of metal, are required for the spiral grooves of a 16-inch gun. The spinning motion imparted to the projectile by the rifling steadies the missile in flight and improves its accuracy. A generous plating of chromium, resistant to the terrific heat and pressure of the propelling charge, increases the life of the barrel. The addition of the yoke and breech complete the assembly. Incidentally, the design of breech mechanisms which will open and close freely and yet hold against bore pressures of 20 tons per square inch constitutes one of the most important problems in gun design and poses a great challenge to ingenuity.

In a radially expanded or self-hooped gun the inner circumference of the steel forging is bored slightly smaller than that of the finished gun. Subjected to intense hydraulic pressure, much higher than that developed during firing, the bore is expanded uniformly. The metal at the bore is the first to be stretched beyond the elastic limit. The process is continued until the metal at the outer surface just reaches its elastic limit. At this point the increase of hydraulic pressure in the bore stops, and soon afterward the pressure is reduced to zero. Since the metal at the bore has received a certain amount of plastic deformation, it would, if left free to do so, retain all of this "set." But since the metal at the outer surface has received no permanent set, but only a strain within the elastic limit, it attempts to return to its original diameter. The metal between the bore and the outer surface has received some plastic deformation, decreasing outward. The final result is that the bore is forced back to a diameter somewhere between the original dimension and that which was attained under the maximum hydraulic pressure. Thus the bore has received a certain amount of tangential tension, exactly as in the case of the built-up gun. The difference is that the built-up gun has a very limited number of actual "layers" of metal, each shrunk upon the next inner layer, with definite contact surfaces, while in the "radially expanded" or self-hooped gun, the

layers are actually all parts of the same tube, indefinite in number, infinitesimal in thickness, and having varying stresses to produce the maximum possible strength in the finished gun. The French call such a gun the "pièce de résistance égale," meaning that every bit of metal throughout the wall of the gun reaches its new elastic limit at exactly the same instant under full bore pressure.

Originally, radial expansion was limited to naval guns of intermediate caliber, but in the 8"/55 a combination of processes was achieved by radially expanding the inner tube and then shrinking a jacket over it by the built-up process. This gun, much lighter and stronger than its built-up counterpart, also effects great savings in labor and machining. The monoblock gun is not normally relined when worn out. In the built-up type, the liner can be drawn and replaced as often as necessary simply by reversing the installation process. The gun is heated to cause expansion, while the chilled liner contracts. When sufficiently loose, it is withdrawn. Steel companies were interested in the radial expansion of 3-, 5-, and 6-inch barrels as early as 1937, and contracts in 1940 with Bethlehem, Midvale, Crucible, and the National Forge & Ordnance Co. hastened the production of this vital equipment.

The built-up and radially expanded guns produced by the Bureau were among the brightest stars in the Ordnance firmament. And fortunately so, since the development of better ordnance is triggered by the results achieved in gunnery. Vice Adm. A. G. Noble, summarizing the prewar gunnery of the fleet, commented: "By the early 1930's battleships were demonstrating their ability to fire effectively 14- and 16-inch projectiles at unseen, maneuvering targets at ranges greater than 15 miles, in salvos of from 8 to 12, remotely controlled and fired from a single firing key. . . . The late thirties saw improvements in accuracy, smaller pattern sizes, better rangefinding, increased rates of fire, and many fire control refinements which tended generally to solve more varied ballistic problems by more fully automatic processes. Automatic, remotely controlled train and elevation systems for intermediate caliber guns reached the fleet. By 1941, even officers who had been closely associated with ordnance and gunnery for years were awed by the Navy's surface gunnery. Gunnery officers of the newer destroyers stated quite seriously that their 'point blank' ranges extended to 5 miles. . . ."

At the time of Pearl Harbor the larger guns of the fleet ranged from the 16"/45 caliber turrets of the *North Carolina* to the 3"/50 caliber double-purpose guns for escort destroyers and merchant ships. Between these two guns lay the 6- and 8-inch rifles of the

light and heavy cruisers which were unequalled for fast, accurate firing; the dependable 14- and 16-inch guns of the older battleships; and the 5"/38 caliber double-purpose guns which served so effectively in antiaircraft defense that the Japanese described them as "giant machine guns." Of historical interest only is the fact that the Bureau developed an 18-inch gun. Lined down to 16 inches after the 1922 disarmament treaty, the 16"/57 fired the longest shots ever ranged at Dahlgren. So tremendous was the gun that a ship of about 70,000 tons would be required to use it profitably. No production was ever planned for this weapon.

In days of peace the Naval Gun Factory was the chief source of the Navy's guns, mounts, and related equipment. Although the NGF was expected to bear the major portion of gun work in case of conflict, no single facility could meet the wartime demands of an expanding fleet. Since guns are one of the first staples required by a fighting Navy, the expansion of gun producing facilities was of paramount importance to the Bureau of Ordnance. A survey of the potentialities of American industry for gun work, initiated in 1937, marked the first step in this program. Although very little could be done at the time because of limited funds, the survey furnished the basis for the planning which enabled the Bureau to move immediately when increased appropriations became available in 1940.

The first expenditures went into facilities at the Naval Gun Factory; new buildings, machine tools, and additional personnel absorbed millions of dollars. Three of the five new naval ordnance plants were designated "extension gun factories" to supplement the output of the NGF in Washington. The plants at Canton, Ohio, and Center Line, Mich., produced finished gun parts for assembly at the NOP, Louisville; Center Line specialized in miscellaneous light ordnance parts, and Canton in the heavier equipment. In addition to the assembly of guns and mounts, Louisville machined gun barrels from 5-inch to the 16-inchers of the biggest battleships. A proving ground near the Fort Knox reservation, close to Louisville, was established to test the hundreds of guns assembled by the NOP. Representing an expenditure of approximately \$70,000,000, the 3 plants were in operation several months before the attack on Pearl Harbor, and at the height of the war their monthly production exceeded \$16,000,000. The Army arsenal at Watervliet was also utilized for the machining of heavy guns.

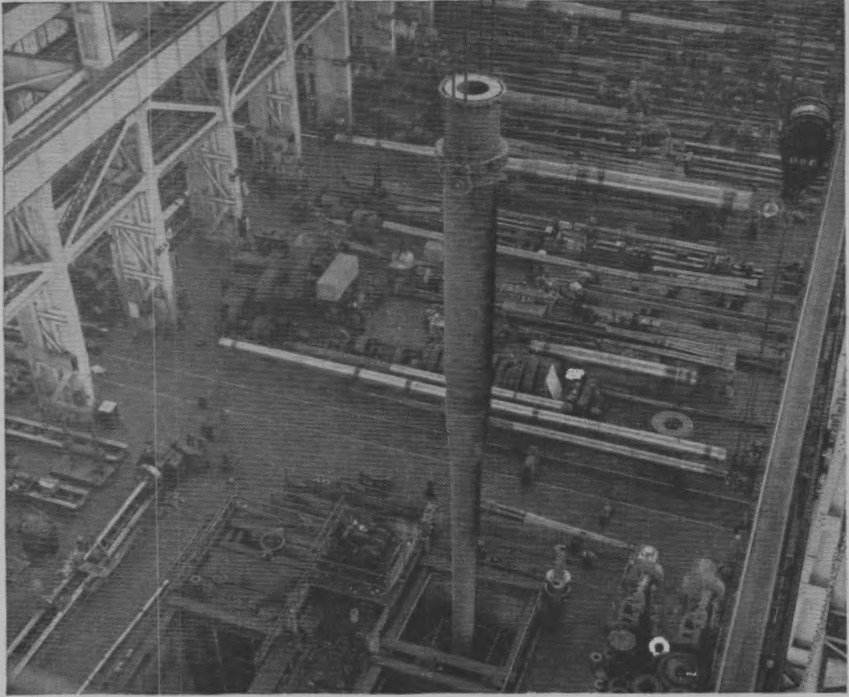
The rehabilitation of the Naval Ordnance Plant, South Charleston, W. Va., idle since 1922, furnished a further source for the

manufacture of 3-, 5-, and 6-inch guns. The North Unit at South Charleston was activated at a cost of \$4,770,000, and the General Machinery Ordnance Corp. accepted a contract to operate the facility. Subject to the usual difficulties common to new ordnance producers, the GMOC, by intensive development of special methods, soon reached a production rate that exceeded all expectations.

Although the establishment of the Naval Ordnance Plants filled a void in gun production, the Naval Gun Factory remained the only facility capable of producing and servicing major caliber guns. The Japanese threat in the Pacific emphasized the need of a second gun factory near the west coast. Security also demanded it. The Bureau's expansion plans therefore included an NOP at Pocatello, Idaho. Originally designed as a relining plant to avoid the long cross-country shipment of Pacific Fleet guns, the NOP was soon enlarged to include the manufacture and repair of all types of guns. A 270 square mile proving ground at Arco, some 70 miles from Pocatello, furnished adequate facilities for standard proof tests. Opened in the summer of 1943, the plant was slow to reach its capacity; as one officer expressed it, "the making of a gun machinist from a shepherd is not an easy process." In spite of difficulties, the NOP was taking a considerable load of relining work and manufacture from the Naval Gun Factory by early 1944.

Obviously, the procurement of guns could not wait for the construction of the Naval Ordnance Plants, and while the work of erecting the Government-owned facilities was underway, the Bureau was expanding private companies for the production of ordnance equipment. The shortage of heavy forgings threatened an early bottleneck in the gun program and a whole series of expansions had to be made in 1940-41. The forging capacity of the Midvale Co., Bethlehem Steel Co., Erie Forge Co., Struthers Wells-Titusville Corp., American Locomotive Co., Camden Forge Co., Penn Forge Co., and the Allis Chalmers Manufacturing Co. were all enlarged with Bureau money. Because of experience in this field, the Bureau was given the responsibility of taking care of the forging requirements of both the Bureau of Ships and the Maritime Commission. By 1941 the expansions were well underway to meet schedules in forgings for guns, ship shaftings, and turbine rotors.

For turret equipment and broadside mounts the Bureau had depended entirely upon the Naval Gun Factory, except for electric-hydraulic equipment which was manufactured by the Waterbury Tool Co., Vickers Inc., and the Northern Pump Co. These firms



Lowering 16-inch gun into electric furnace at Naval Gun Factory preparatory to relining.

expanded their capacities by 200 to 300 percent in 1940. The procurement program for hydraulic equipment for major and medium caliber guns was thus started on a sound footing. Throughout the war the NGF continued to produce the bulk of the turret equipment, but the major procurement program devoted to double-purpose gun mounts was based primarily on commercial sources.

Gun and mount production required great precision in manufacture. This feature called for the highest grade of materials and machine tools, excellent engineering in the design and manufacture of jigs, fixtures, and special tools, and the services of highly skilled workers. No small part of the problem was the recruiting and training required to provide this labor force. The private companies accepting Bureau contracts were primarily big concerns whose peacetime products included printing presses, locomotives, pumps, safes, cotton gins, automobiles, electrical equipment, and flour milling machinery. Numerous small manufacturers examined drawings and specifications and decided to seek something easier. But others ventured, persevered, and succeeded.



Liner covered with graphite ready to be lowered into hot gun.

The program was characterized by relatively few prime contractors. However, in the interest of expediting schedules and in order to take advantage of available facilities, the prime contractors utilized numerous subcontractors. For example, the breech housing of the 5-inch double-purpose gun consists of a hundred different parts. One contractor working on this piece utilized 65 subcontractors, retaining only 15 percent of the dollar value for production in his own shop. Northern Ordnance, Inc., once let 877 subcontracts with 230 different suppliers.

The activities of the private plants, the Naval Ordnance Plants, and the Gun Factory were necessarily interlocked, with the output of one depending upon the successful functioning of the others.

In spite of the close coordination required to maintain the flow of parts from plant to plant, no major bottleneck developed and the equipments moved to the fleet on schedule.

The early days of the program belied this accomplishment, for matters did not go too smoothly at first. It is a rare contract that anticipates every dispute, and the gun program proved no exception to the rule. One complaint regarded inspection. Several of the producers charged that some of the inspectors were lacking in self-confidence; afraid to make important decisions themselves, they held up production through interminable appeals to the Bureau and the Gun Factory for aid and service. Apparently there was foundation for this complaint. One remedy was to detach inspectors who lacked experience, and fill their places with seasoned naval officers from the retired list. Another was to iron out difficulties by means of repeated visits to the trouble spots, as well as by having manufacturers come to Washington. A third remedy only time could produce; namely, to let both inspectors and producers gain greater knowledge by experience. In practice, all three were employed and eventually most of the difficulties were eliminated.

Blueprints were another source of trouble. While the objections seemed well-founded, the difficulty was really inevitable; it was the ceaseless tangle between the drafting office and the workshop. Bureau contractors found, time after time, that blueprints were out of date and did not incorporate the latest inspection requirements. These drawings were prepared at the Gun Factory for use in its own shops. Even so, a new model rarely emerged from the shop exactly as designed. Inspecting officers and master mechanics often made changes and modified tolerances which they incorporated as they went along, reporting them back to the draftsmen. By this time the draftsmen were engaged in other work and the changes were not immediately reflected in the drawing. This was the situation that confronted the mechanics new to ordnance work at NOP's and private plants. The Gun Factory master mechanics and foremen with their proficiency and long experience, had learned to be critical of drawings and leaned as much upon their own vast fund of knowledge and savoir-faire as upon the blueprints. It was not so at the plants attempting to produce guns for the first time. They expected, and rightly so, to be able to follow a blueprint to the letter, and complained when their products failed to pass inspection. Again the only remedy was interminable visits in an effort to smooth out the rough spots. The situation gradually improved as the producers gained experience,

but blueprints remained a source of friction throughout the war.

The difficulties of this early period led the Naval Gun Factory to concentrate more and more work in its own shops. At the time of Pearl Harbor the Gun Factory was crowded with urgent production jobs while the capabilities of the NOP's and private plants remained only partially utilized. The Gun Factory was rapidly becoming a bottleneck because of unwillingness to farm out work which other agencies could perform. Admiral Blandy broke the stalemate early in January 1942, when he ordered the NGF to lighten its production load through a more thorough exploitation of outside facilities. The Admiral also suggested that "consideration . . . be given to the temporary loan of necessary personnel to expedite efficient manufacture."

Under this program the Gun Factory threw most of the production burdens upon the NOP's and private contractors. In effect the NGF became the center of a nationwide production system. Figuratively, its capacity became executive. As would any good manager, the Gun Factory delegated the routine work, retaining the most difficult jobs for its own experts. The repair of battle damage, the development of new models, troubleshooting at other plants, and the production of urgently needed equipments under short lead time requirements became the dominant activities within the Naval Gun Factory. As both a prototype and production establishment, the Naval Gun Factory made valuable contributions throughout the whole field of gun and mount production; in fact the success of the Bureau in arming the fleet with the best guns afloat was in no small measure due to the splendid work of this plant.

The demands for guns of all types to arm combatant and merchant ships were so pressing that the primary concern of the Bureau centered in the rapid production of existing types of weapons. For this reason most of the design changes incorporated during the early days of the war were intended to speed production and not to improve performance. Fortunately, two of the weapons most urgently needed, the 3"/50 and the 5"/38 double-purpose guns, were already proven naval armament and could be rushed into production with a minimum of delay. Involving an expenditure of well over a billion dollars, the procurement of these two guns represented one of the Bureau's major programs.

The 3"/50 was an effective weapon in World War I and, with slight modifications, proved most useful in World War II. Employed as the main battery on smaller combatant ships, patrol craft, other auxiliary vessels, and merchantmen, over 14,000 of

these guns were mounted on 26 types of naval craft. Described as a "good all-around gun," the 3"/50 fired approximately 20 rounds a minute and hurled a 13 pound projectile to a maximum range of slightly over 5 miles. Although overshadowed by the exploits of the big batteries, this double-purpose gun added a deadly sting to hundreds of triple-purpose ships—"the ships that fought planes and subs and surface enemies while doing vital war errands."

The Bureau awarded the first contracts for increasing 3"/50 production early in 1940, and by the end of 1942 approximately 3000 assemblies had been manufactured. The high water mark was reached in 1943, when 6488 gun assemblies came off the production lines. As supply gradually caught up with demand in 1944, the total dropped to 4562, and by 1945 the 3"/50 program was virtually dormant. This production record represented the cooperative efforts of the Bureau, the Naval Gun Factory, the Naval Ordnance plants, and the prime contractors, principally, Miehle Printing Press Co., Baldwin Locomotive Co., Blaw-Knox Co., Northern Ordnance, Inc., Fisher Body Co., and the Cameron Iron Works.

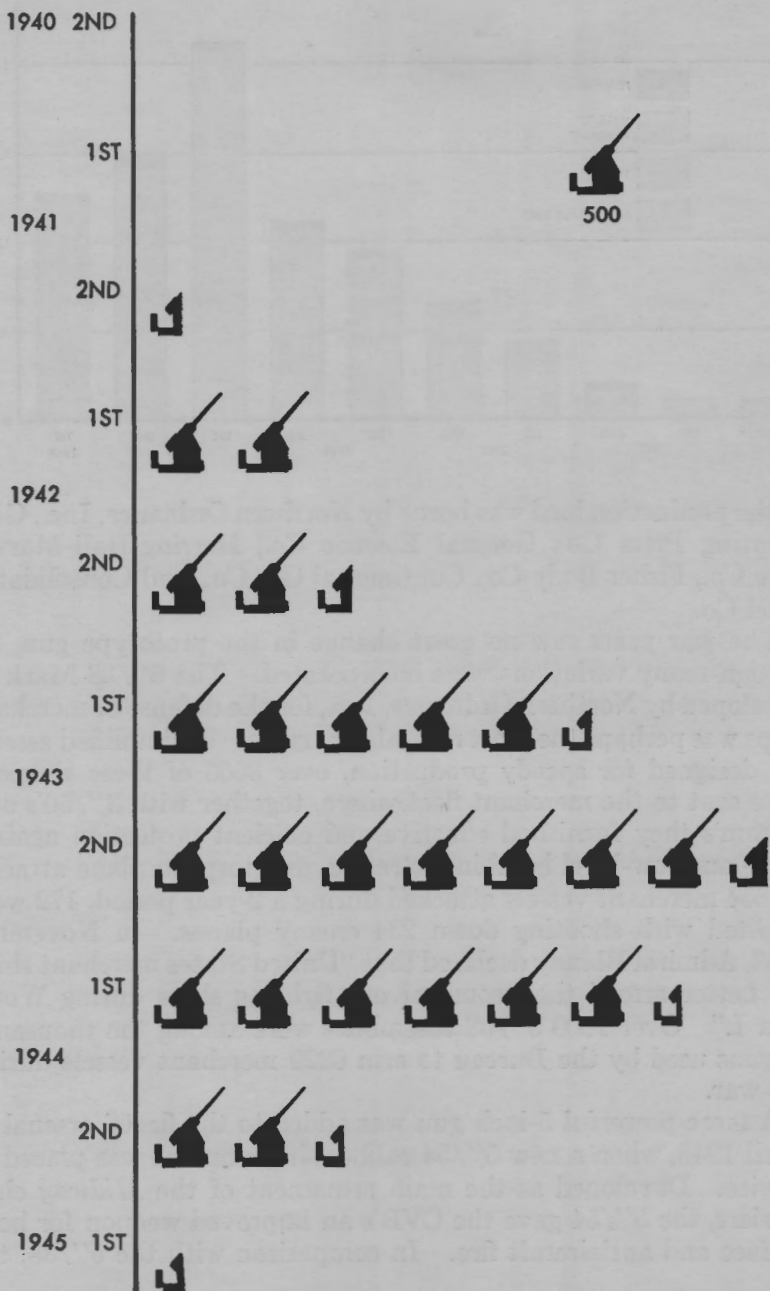
The Navy's largest and most powerful double-purpose weapon to see service in World War II was the 5-inch gun employed as the main armament on aircraft carriers, destroyers, submarines, and larger type merchant vessels, and as the principal secondary battery weapon on battleships and cruisers. Developed by the Bureau in the early 1930's with money siphoned from the funds appropriated to relieve unemployment, the 5"/38 single open type mount was first installed in the *Farragut* class destroyers in 1934. A closed or turreted mount was added 3 years later. Work on the 5"/38 twin was initiated in 1936, and in 1940 production for battleships, cruisers, and carriers was under way.

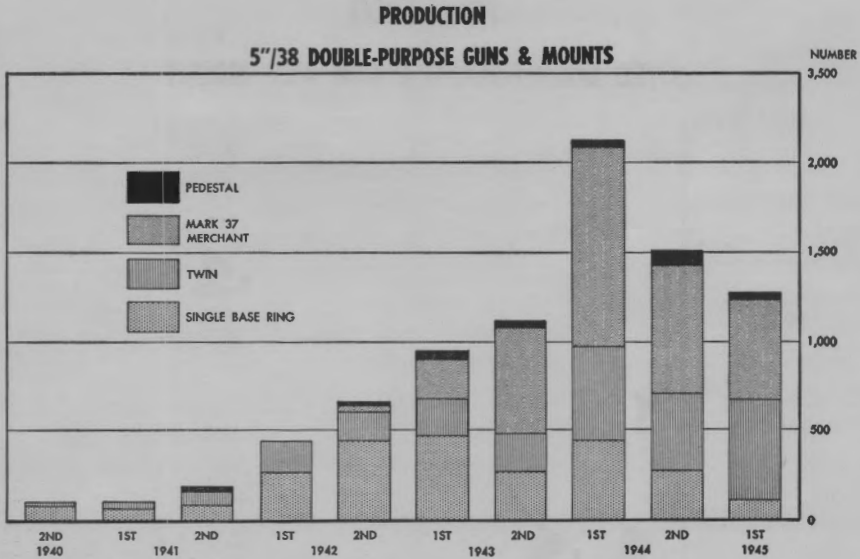
The gun, which Navy men said "could do anything but shoot straight down," had a range of 10 miles, a ceiling of 6, and could be fired at a rate of from 12 to 15 rounds a minute. In this gun the United States Fleet possessed the best long range anti-aircraft weapon in existence. What was more important, according to Admiral Hussey, "we had it years before . . . actual hostilities . . . when there was ample time to prove its potentialities, to eliminate any bugs that might show up, to incorporate new techniques of fire control, and to prepare tooling facilities for manufacture. . . ."

During the 5 years preceding V-J Day, the Bureau procured over 8000 5"/38 assemblies at a cost of \$800,000,000. The ammunition for these guns added another half billion to that total. The brunt

PRODUCTION

3"/50 DOUBLE-PURPOSE GUN AND MOUNT





of the production load was borne by Northern Ordnance, Inc., Goss Printing Press Co., General Electric Co., Herring-Hall-Marvin Safe Co., Fisher Body Co., Continental Gin Co., and Consolidated Steel Co.

The war years saw no great change in the prototype gun, although many variations were incorporated. The 5"/38 Mark 37 developed by Northern Ordnance, Inc., for the defense of merchant ships was perhaps the most radical departure. A simplified assembly designed for speedy production, over 3600 of these weapons were sent to the merchant fleet where, together with 3"/50's and 20-mm's they furnished effective and efficient protection against high- and low-level bombing, strafing, and torpedo plane attacks. Of 654 merchant vessels attacked during a 2-year period, 172 were credited with shooting down 234 enemy planes. In November 1943, Admiral Blandy declared that "United States merchant ships are better armed than some of our fighting ships during World War I." Over 1600 5"/38 assemblies were among the thousands of guns used by the Bureau to arm 6229 merchant vessels during the war.

A more powerful 5-inch gun was added to the fleets' arsenal in April 1945, when a new 5"/54 caliber single mount was placed in service. Developed as the main armament of the *Midway* class carriers, the 5"/54 gave the CVB's an improved weapon for both surface and antiaircraft fire. In comparison with the 5"/38, the

new gun had several thousand yards additional range, much greater altitude, and its heavier projectile carried a more lethal payload. Although these guns saw little action, they were slated for an increasingly important role in Bureau programs to improve the anti-aircraft defense of the fleet.



5"/25 guns gave submarines an additional sting.

The versatility of the 5-inch gun was also extended to submarines. Early in the war the principal battery of the underwater craft consisted of either a 3"/50 or a 4"/50 gun assembly. Submariners considered this armament inadequate and needed the Bureau for a "gun larger than a peashooter." Although the gun was a minor adjunct to the submarine's main weapon, the torpedo, there was nevertheless a wide field of action for surface fire. Hundreds of small Japanese craft, many of them radio-equipped for patrol purposes, were not worth a torpedo, but were fair game for a surface attack. Originally concentrated about the Japanese homeland, many of these ships soon dotted the expanding periphery of Nipponese conquest.

Submarine doctrine did not look with favor on the sub versus plane battle, but the element of surprise often made a crash dive

impossible, and under such circumstances the gun was the submarine's only means of defense. According to one submarine historian, the value of a gun "was psychological as well as military, and on several occasions . . . the deck gun used in desperation . . . saved the submarine."

Even before the request for a bigger gun arrived, the Bureau was at work on a 5"/25 for submarines. Early in 1942 the Naval Gun Factory was assigned the task of perfecting the new weapon. The development of a wet type mount was not a simple problem: The assembly had to retain the refinements of its surface counterpart, and at the same time be relatively light and compact. Scores of moving parts had to function easily and quickly after long periods of submersion in corrosive salt water. Excellent design had to be matched by the highest noncorrosive materials. Hundreds of revisions were necessary before the weapon moved to the fleet early in 1944.

The outstanding features of the new gun included long range, light weight, manual operation, and improved corrosion resistant parts. Designed to use minimum installation space and offer a low silhouette, the assembly was slightly less than 12 feet long, 7 feet wide, 4 feet high, and the working circle had a radius of only 8 feet. To speed fire, muzzle and breech covers were eliminated. Mounted on new submarines and on older subs as availabilities permitted, the 5"/25 won the immediate approval of underwater skippers. Deck guns gave a good account of themselves during the war. Nineteen large ships aggregating 86,000 tons and hundreds of smaller craft, which more than equaled this total, were sunk by accurate shellfire. This was indeed an excellent return from a modest investment which did not exceed \$12,000,000. The excellent reputation of the gun was still further enhanced when, late in the war, VT-fuzed ammunition made it possible for submarine gunners to annihilate gun crews and bridge personnel on the small boats defending the Japanese mainland.

Guns larger than the 5-inch are installed in huge turrets of thick steel. Extending down into the very vitals of cruisers and battleships, the turret protects the gun and mount as well as the supply line from the ammunition rooms to the breech. A single turret of a modern battleship weighs as much as a destroyer, yet the tremendous structure rotates so smoothly and effortlessly that the guns may be brought to bear on a target in a matter of seconds. Each gun can be elevated separately as well as in unison with the others of the turret, and they can be fired singly or in salvos.

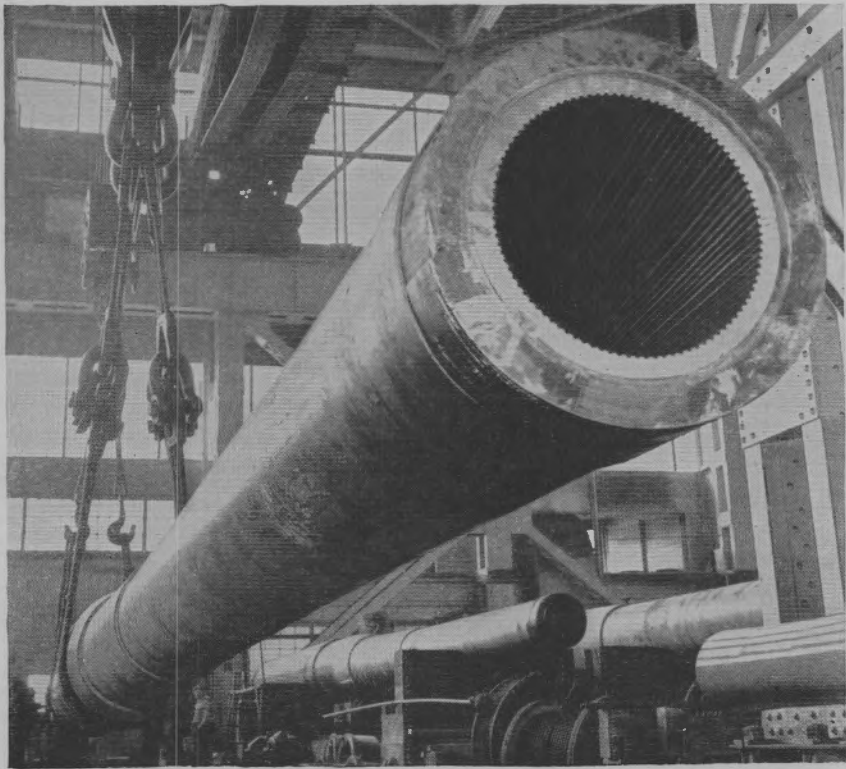
The turrets of the *North Carolina* and the *Iowa* class battleships were in the process of construction long before Pearl Harbor. Work on the 16"/45 equipment for BB's 55-60 began in 1937, and the turrets were placed in service in 1941. Development of the 16"/50 turrets for the *Iowa* class followed in 1939, and the turrets were installed in 1943. Despite the complexity of the equipment, production ran well ahead of scheduled delivery dates. Incorporating the most modern advances in firepower, the ships of the two classes were among the most powerful afloat. Three 16-inch three gun turrets, two forward and one aft, commanded the entire circle of sea around the ship. Maximum gun elevation of 45° permitted the delivery of 2700 pound projectiles to targets well over 20 miles away. Behind 1 minute of fire, according to a statistician, lay 3600 man-hours of labor required for the production of the "100,000 pounds of alloy steel . . . the 1300 pounds of carbon steel . . . and the more than two-thirds of a ton of copper and brass expended."

The turrets of the new battleships represented a major improvement over those of the *Maryland*, *Colorado*, and *West Virginia*, the only prewar battleships which mounted such big guns. The main features of the design included welded structure, heavier armor, lower silhouette, higher rate of fire, heavier projectiles, fully automatic control, and hydraulic operation of cradle and spanning trays. More thorough compartmentation, plus an electric hydraulic interlock system between the gun and the powder handling room, guaranteed increased safety. Reversible projectile hoists eliminated the lowering devices which were characteristic of earlier turrets, thus effecting significant space savings in an area that was always crowded. Further consolidations increased the capacity for projectile storage. The General Electric system of remote control drove elevating and training mechanisms with motors six times more powerful than those of the prewar *West Virginia* class. And these motors controlled the 4,000,000 pounds of rotating structure resting on the roller path carriage with a precision that was uncanny. The ships of neither ally nor enemy mounted turrets of comparable efficiency.

Throughout the war an ambitious turret modification program gradually brought to the old dreadnaughts a degree of effectiveness vouchsafed battleships of the *North Carolina* and *Iowa* class. Heavier turret armor, an increase in gun elevation to secure greater range, the installation of automatic remote control, and the addition of the most recent fire control instruments were all significant in bridging the gap between old and new. The *West Virginia*, is

a typical example. Sunk at Pearl Harbor on December 7, the "Weevee" was later modernized at Bremerton and joined the fleet in time to take part in the battle for the Philippines. At Surigao Strait the *West Virginia* teamed with the *Pennsylvania*, *California*, *Tennessee*, and *Maryland*—all of which had been damaged at Pearl Harbor and later received extensive turret modification—to cross the enemy's T and annihilate the southern prong of the Japanese Fleet which was sweeping down upon the newly won beachhead and its hundreds of landing craft, transports, supply ships, and oilers.

Turret modification was not confined to battleships and as availabilities permitted the older cruisers were brought up to date. Improvement in elevating and training equipment, the simplification of powder hoists, plus the addition of remote control greatly increased the firepower of the prewar cruiser. Further, for the first time in the history of the Navy, complete 6- and 8-inch spare turrets were built and used as replacements in damaged ships.



16-inch gun barrel.



Staggered 16-inch guns on U. S. S. Missouri.

Another gun to join the fleet during the war was the 12"/50. Twelve-inch fifties were not unknown to the Navy; the first of this type had been developed by the Bureau in 1907 and installed in the *Arkansas* and *Wyoming* 5 years later. Six two-gun turrets comprised the main battery of these battleships. Hurling an 870 pound projectile for a distance of over 7 miles, the *Arkansas* and *Wyoming* lacked the punch of the *Texas*, *Nevada*, *New York*, and 7 of the later warships which mounted 14-inch guns and fired projectiles that weighed 1400 pounds. The Navy showed very little interest in an intermediate caliber gun and no new developments were undertaken in the 12-inch field until the late 1930's, when preliminary planning was initiated on a new class of large cruisers. The *Alaska*, the prototype of this class, was in reality a battle cruiser, the first to be built by any Navy since the Washington Conference. A super 30,000-ton vessel, 808 feet in length, heavily armored and armed, and faster than battleships and cruisers, the *Alaska* was the answer to the prewar challenge of the German pocket battleship and Japan's armored cruisers. Plans called for the building of 6 ships of this type, but the number was later reduced to 3. Actually only the *Alaska* and *Guam* were finished in time to join the fleet. The *Hawaii* was approximately 85 per-

Turrets and mounts installed on Navy combatant ships

Type of turret or mount	Number of installations		Percentage distribution by type of ship, 30 June 1945							
	1 July 1940	30 June 1945	Battleships BB	Carriers CVB, CVL, CVE	Large and heavy cruisers CB, CA	Light cruisers CL	Destroyers DD	Destroyer escorts DE	Submarines SS	Mine craft CM, CMC, DM, DMS
	Number	Number	Percent	Percent	Percent	Percent	Percent	Percent	Percent	
<i>Surface</i>										
16"/50 3-gun turrets	0	12	100							
16"/45 3-gun turrets	0	18	100							
16"/45 2-gun turrets	12	12	100							
14"/50 3-gun turrets	20	20	100							
14"/45 3-gun turrets	12	6	100							
14"/45 2-gun turrets	14	12	100							
12"/50 3-gun turrets	0	6		100						
12"/50 2-gun turrets	6	6	100							
8"/55 3-gun turrets	52	82			100					
8"/55 2-gun turrets	12	4			100					
6"/53 twin mounts	20	18				100				
6"/53 single mounts (wet and dry)	66	54				96		4		
6"/47 3-gun turrets	15	152				100				
5"/51 single mounts (wet and dry)	218	33	97	3						
5"/38 SP twin mounts	52	15					100			
5"/25 SP wet mounts	0	225						100		
4"/50 single mounts (wet and dry)	723	60					30		70	
3"/50 SP mounts (wet type)	39	13							100	
<i>Double purpose</i>										
5"/54 DP single mounts	0	36		100						
5"/38 DP twin mounts	8	958	15	10	7	26	37			5
5"/38 DP single base ring mounts	315	1455	1	1			76	16		6
5"/38 DP single pedestal mounts	0	162		47	2		51			
5"/38 DP Mk 37 merchant type mounts	0	97		100						
5"/25 DP single mounts	288	160	20		55	25				
3"/50 DP single mounts (wet and dry)	95	938	3	1		6	2	84	2	2
3"/23 AA mounts (wet and dry)	181	0								
<i>Antiaircraft</i>										
40-mm. AA quadruple mounts	0	1585	24	24	13	10	21	6		2
40-mm. AA twin mounts	0	3045		27	1	9	43	17		3
40-mm. AA single mounts	0	510						52	48	
1.1 AA quadruple mounts	38	97						100		
20-mm. AA twin mounts	0	2381	15	14	9	6	50	1	5	
20-mm. AA single mounts	0	10180	9	23	3	4	20	35	3	3
Caliber .50 AAMG (singles)	916	433	2				2	2	85	9
Caliber .50 AAMG (twins)	0	8					25	75		

cent complete when hostilities ended, but was scheduled to be finished and placed in the inactive fleet.

The main battery of the new battle cruiser, described in the fleet organization as "Cruisers, large," consisted of 9 12"/50 guns. Exhaustive studies preceded the selection of this battery; 10-, 11-, and 12-inch guns mounted in 1-, 2-, and 3-gun turrets were all investigated. The original design called for two 2-gun and two 3-gun turrets, but this was soon changed to three 12-inch 3-gun turrets in order to simplify manufacture and procurement of equipment.

The new gun, the pilot model of which was completed by the Gun Factory in January 1942, had little in common with the original genre on the *Arkansas*; it was much lighter, yet fired a heavier and deadlier projectile for a longer range. Improved turret equipment upped the rate of fire, and increased the elevation of the guns to 45°, some 30° greater than the older vessels carrying the same size weapon.

The Bureau procured 10 complete turrets—1 was a spare—at a price of \$1,550,000 each. Exceeding in cost by some \$150,000 the 16"/50 3-gun turret assembly on the *Iowa*, the 12"/50 was the most expensive turret procured by the Bureau.

Even before the war was over the Bureau was preparing to meet the challenge of faster and more elusive targets. In the last year of the war, the Japanese suicide attacks pointed up the weaknesses in the close-in anti-aircraft fire, and the development of guided missiles and supersonic planes, already under way at that time, gave further warnings that the anti-aircraft defense of the fleet could not remain static. Defensively, anti-aircraft guns remained a major weapon, but they had to be improved. To attain greater effectiveness per gun barrel, investigations were launched to reduce the time of flight of the projectile, to improve the damage power of the missile once it reached the target, and to increase the rate of fire. Progress marked all three programs, but the most significant advance was made in improving the rate of fire of double-purpose guns. Although these guns did not see service use, development was so far advanced at the time of the Japanese surrender that their future was guaranteed even under the economy-dictated budgets of peacetime.

The 3"/50 was the first of the rapid fire DP guns to join the fleet. Development was under way early in 1944. The Japanese *Bakas* and kamikazes hastened the program, and the first prototype was ready for test by September 1, 1945. Designed to fire 50 rounds per gun per minute, the 3"/50 throws a heavy, fast,

VT-fuzed stream of shot into speeding aircraft and missiles. The heart of the system is a mechanical loader which is perfectly synchronized with the opening and closing operations and counter recoil mechanism of the gun. The mounts—singles and twins—are installed on aircraft carriers, cruisers, and destroyers.

The vital statistics of the weapon furnish a clew to the complexities of gun construction. The twin mount weighs 32,000 pounds and incorporates 28,000 separate parts, many of which are machined to a tolerance of 0.0002 of an inch. Approximately 30,000 machine operations are required on the 125 metals used in the mount. The manufacturing process calls for 9000 different standard tools and 16,000 special tools, fixtures, and gages. And the ordinary gages must be accurate to a few hundred thousandths of an inch, the master gages to a few millionths.

Although the 3"/50 rapid fire gun was an excellent weapon, it was not perfect. Considerable training was required before a crew could attain the designated rate of fire, and even then the rate could be sustained for only a few minutes. The mechanical and electrical complexity of the loader made excellent servicing mandatory; in fact, it had to be in almost perfect condition to function at all. Breakage was another problem. Due to the nature of the firing operation many of the loader parts are light in construction, and under the stress of heavy firing breakage was common.

Deficiencies notwithstanding, the 3"/50 rapid fire gun proved vastly superior to the 40 mm. Test firing against Nakajima-type planes showed that one 3"/50 was as effective as two 40-mm quads, and against the Baka bomb the advantage was even more pronounced—five 40's were required to do the work of a single 3"/50. And these results were accomplished at ranges far beyond the reach of the Swedish gun. Although there still remained a demand for the Bofors, particularly on small ships, the gun was no longer considered a major anti-aircraft weapon. It should not be forgotten, however, that this gun contributed as much as any other one weapon to saving the warship from the oblivion which was so freely predicted for it by air power experts during the early days of the war. The decline of the Bofors was but another reminder that ordnance cannot remain static; "today's weapons are tomorrow's museum pieces."

Improvements in 3-inch guns were matched by progress with larger anti-aircraft rifles. The 5"/38 double-purpose mount was surpassed by 5"/54 rapid fire mounts designed for the main batteries of several new ships. An automatic loading system enables this gun to produce a rate of fire approached by no other gun of similar caliber.

The 8"/55 three-gun turrets of the heavy cruisers *Des Moines*, *Salem* and *Newport News* represented another step in the Bureau's program of adapting automatic features to big guns. Although these ships were not commissioned until after the war, work on the turrets had been under way at high priority since May 1943. The new 8-inch gun, primarily a surface weapon but also effective against aircraft, fires several times faster than similar World War II guns.

Extensive mechanization was largely responsible for this spectacular accomplishment. Completely automatic from ammunition handling rooms to the gun muzzles, the projectiles and cartridge cases are untouched once they are loaded into the lower sections of the hoist deep in the ship. Unlike the old guns which had to be returned to a loading position, the new turrets incorporate ingenious devices which permit loading at any angle up to the maximum elevation of 41°. The substitution of case type ammunition was also significant in increasing the rate of fire, since it has eliminated the elaborate safety precautions necessitated by bag type ammunition.

The gun has several other unique features. In addition to being the biggest case gun in the Navy, it was the first to use a loose liner. This development represented a significant advance in gun construction; no longer will it be necessary to return the whole gun assembly to the continental United States for regunning, since a worn liner may be withdrawn and a new one substituted by repair ships. Rotating rings on each level move the projectiles to the handlers, and special gear pushes the ammunition from the ring into the hoist. In comparison with older turrets, such labor-saving devices have brought a reduction in personnel from 66 to 44 for each turret. Automatic fuze setting may be accomplished a split second before the projectile is rammed into the gun, thus insuring a small, uniform dead time. Other novel features include empty case ejection through the front of the turret, and a control and trouble indicator panel for each gun, showing the position of the ammunition from magazine to breech as well as the exact location of any type of electrical failure in the system. The whole circuit is so well interlocked that there is little chance of a casualty causing any damage. Ordnance engineers may well be proud of this revolutionary turret.

The 8-inch turrets were soon joined by the 6-inch 2-gun rapid fire turrets of the *Worcester* class of light cruisers. Mounting twelve 6-inch double-purpose guns in 6 turrets, plus 3-inch anti-aircraft guns, the *Worcester* was the first Navy ship of her type on

which all guns could be used for both antiaircraft and surface fire. Commissioned in 1948, the main battery of the ship marked the culmination of 11 years of intermittent effort.

Preliminary plans for a 6"/47 double-purpose twin mount were submitted in September 1937. Representing the first attempt at automatic loading of a major caliber gun, the design attracted considerable interest in ordnance circles. Pressure of more urgent programs slowed the work and in 1941 the project was abandoned, only to be resurrected in August 1943, when Admiral King recommended the construction of an antiaircraft cruiser. Ordnance characteristics specified by the General Board included "twelve 6"/47 caliber double-purpose guns mounted in 6 turrets on the centerline, 3 forward and 3 aft, as completely mechanized as possible, arranged with special attention to volume of high angles of fire in all directions."

The progress of the ordnance equipment paced the building of the cruiser. Although the gun turret was not as fully automatic as the 8-inch, the rate of fire was considerably higher. Incorporating both a fast moving turret and a high degree of gun elevation, the defense of the *Worcester* approached the ultimate in antiaircraft fire.

Before shipboard installation, the strength, materials, and functional reliability of all United States naval guns is thoroughly tested by repeated test firings. During the war the Bureau utilized 17 firing ranges to check the performance of the thousands of weapons which were sent to the fleet. Test of the larger guns, 3-inch through 16-inch, was confined to the proving grounds at Arco, Fort Knox, and Dahlgren. Of the three, the Naval Proving Ground at Dahlgren, Va., was the biggest and most important. Located 60 water miles down the Potomac from the Naval Gun Factory, Dahlgren had long been the center of acceptance and experimental testing. At the height of the war this facility could prove 20 major caliber rifles, 100 intermediate guns, and about 400 3-inch guns monthly. And each of these guns had to pass a test that was more severe than any likely to be encountered in battle; for example, test firing included at least one round at a pressure approximately 15 percent above that of the normal service round. Dahlgren, it was said, "fired more rounds . . . than all the battle-ships of the fleet." Certainly, the average monthly expenditure of over 110,000 intermediate and major caliber projectiles proclaimed the Bureau's aim that "If anything goes wrong it will happen at the Proving Ground, not in battle."

Chapter 13

THE VT FUZE

VICTORY through air power was a popular concept with both military and armchair strategists in the years between the two world wars. The traditional American reverence for sea power suffered from the competition, and extremists even saw in the airplane the doom of capital ships. Some of the new prophets occupied high places. Perhaps the most vocal of them all was Maj. Gen. William Mitchell, who informed the House Naval Affairs Committee as early as 1921 that he was convinced planes could sink or disable the mightiest battleship. Of course, there were diehards on the other side too. Rear Adm. C. B. McVay, Jr., Chief of the Bureau of Ordnance, countered the Mitchell argument with the assertion that "airplane development has not yet reached the stage . . . where there is a serious menace to the modern fighting vessel."

The weight of opinion and existing evidence was stacked against the Admiral, however. Something of a showdown was scheduled for the summer of 1921, when several captured German ships were towed to sea as targets for aircraft bombs. Dead in the water, incapable of maneuvering, and denied even a modicum of damage control, most of the vessels were quickly sunk. The popular press took up the clamor started by the advocates of the Mitchell view. The Navy could find some comfort in the fact that the single battleship involved in the test taxed the power of the planes and their bombs before sinking, but that was a relatively small consolation. At best it merely restored a measure of doubt. The Navy was left on the defensive. The truth lay between the extreme views of General Mitchell and Admiral McVay, but, whatever its exact location, its implications were threatening for the Navy. Carrier based planes made air power an integral part of sea power, but left unaffected the antithesis between the two types of fire power. Since nothing short of combat could provide a final answer, the role of traditional sea power in modern warfare remained in question throughout the uneasy peace of the 1930's.

In the fall of 1939, Adolf Hitler furnished a giant testing ground from which a final answer might emerge. From a purely academic point of view, the antagonists were perfectly chosen:

Europe's greatest land based air power was pitted against the world's mightiest sea power. The first returns were discouraging for naval observers everywhere. The Luftwaffe seemed more than a match for His Majesty's Navy. The invasion of Norway emphasized the disparity by imposing heavy losses on the British Fleet, and Pearl Harbor demonstrated American vulnerability to the same kind of attack. The sinking of HMS *Repulse* and *Prince of Wales* by Japanese naval planes off Malaya in the opening days of the war furnished additional evidence that if capital ships were to retain a place of importance, their defensive power had to be enormously increased. Fortunately for the Navy, important steps were made in that direction before the outbreak of war.

Two promising anti-aircraft guns were developed during the decade that ended in a national emergency. One of these was the 5"/38 caliber double-purpose gun that eventually proved itself the best naval armament afloat; the other was the 1"1, a rapid fire gun slated for close-in defense against enemy planes. The lighter mount proved a disappointment, but between the invasion of Poland and the attack on Pearl Harbor the Bureau of Ordnance secured two new guns, the 20-mm Oerlikon and the 40-mm Bofors, that were admirably suited to take over the role of the 1"1. The decks of the fleet were soon literally crowded with the new defensive armament.

Directed by radar equipped fire control instruments, the anti-aircraft and double-purpose batteries were a substantial part of the solution to the problems posed by air power. But one important innovation was needed. The fuzes with which 5-inch projectiles were equipped were inadequate. Until fuze development caught up with that of guns and projectiles the full potential of the 5-inch guns could not be realized.

According to their intended function, fuzes were mechanical or powder train devices designed to detonate or ignite the charges carried in projectiles. While largely a modern development, fuzes of some sort were as old as explosive ammunition. The Middle Ages knew them, though their primitive state at the time was illustrated by a sixteenth century definition of the devices as "curiosities specially adapted to hurry those who meddled with them into the next world." Early models were ordinarily simple affairs, consisting of a powder train leading to the main bursting charge of the shell. Ignited just before firing, this served as a timing device to detonate the projectile when it reached the enemy. Later developments included percussion fuzes that fired only on impact, when the force of inertia drove a firing pin into a detonator



Extremists saw in airplanes the doom of capital ships.

powerful enough to explode the main charge. Combinations of the two types followed, permitting delay fuzes that allowed shells to pass through armor before exploding.

Modern science introduced a host of refinements and many safety features, but the basic types remained essentially the same. The United States Navy entered World War II with but two classes of fuzes, those that functioned on impact and those that employed some timing mechanism to initiate detonation. Within the two broad categories were four variations or combinations, classified as auxiliary detonating, base detonating, mechanical time, and point detonating. Each was designed for some special function, and they varied in characteristics from supersensitive point detonating fuzes that might operate on impact with raindrops to base devices that could withstand the penetration of heavy armor or concrete before setting off an explosion. Within those categories, the marks and mods multiplied during the war.

At the outset, the Bureau procured ten types—6 for projectiles and 4 for bombs. By V-J Day, over 90 fuzes had been developed. A number of them were designed for the rockets introduced during the war, others were in answer to new tactical requirements, and the remainder were replacements for earlier models that proved inadequate or defective in service use. For the most part the history of this development was a story of gradual improvement and modification rather than of spectacular advances in design, but the nature of the progress was simply in answer to unfolding military requirements. Evolutionary change was sufficient because even at the beginning of the war almost every target the fleet might encounter was vulnerable to one or more of the fuzes provided by the Bureau of Ordnance. The exception was the airplane, and the exception to the normal pattern of development was the fuze devised to counter that threat.

A fast flying plane at long range was obviously a small and difficult target in a vast sky. A direct hit, even with excellent fire control, was extremely difficult. Close-in defense with the rapid fire Oerlikon and Bofors guns presented less of a fuzing problem, but the safety of ships demanded that the 5-inch dual-purpose guns reduce the number of planes that might come within range of the smaller guns. The number of direct hits might be increased with better fire control equipment, but no spectacular improvement could be expected in that direction. Nor was that necessary. The lethal burst of a 5-inch projectile was great enough to make near misses as effective as hits, so long as the explosion occurred at the proper instant. In effect, the situation placed ultimate responsibility for successful defense on the fuzes used with AA projectiles. Here was the weak link in the defensive chain made up of guns, crews, radar, directors, and ammunition.

The fuze commonly used was a mechanical time device that operated rather like an alarm clock. Weak link or not, it was a remarkable engineering accomplishment. Despite an acceleration 20,000 times greater than gravity, the mechanism was generally accurate to within a few hundredths of a second for a period ranging from 2 to 40 seconds. Mounted in the nose of projectiles, the fuze was designed for easy setting of the time interval between firing and detonation. This requirement imposed a severe handicap, however, since it depended upon an accurate appraisal of the target's range. United States naval fire control was probably the best in the world, but its weakest point prior to the utilization of radar was the determination of range. Moreover, three sources of error remained even when the distance to the enemy was properly

estimated: Slight variations during manufacture affected the accuracy of the fuzes, the manual operation involved in setting the time scale invited error; and the estimation of dead time, the lag between setting and firing, might be incorrect. These variables enormously complicated the fire control problem and introduced barriers to the precision needed for adequate antiaircraft fire. Even when radar revolutionized fire control and provided range data of spectacular accuracy, the problems inherent in time fuzes remained as imposing as ever.

The desirable solution was obvious to all imaginative people who had ever watched antiaircraft guns in action. What was needed was a fuze that would automatically detonate a projectile when it came within destructive range of a target. A device with a self-contained source of intelligence could eliminate most of the variables involved in antiaircraft fire control.

Ideas for proximity fuzes occurred to many people all over the world. Patent offices here and abroad listed many possibilities, and the Bureau of Ordnance was literally bombarded with suggestions for such devices by inventive individuals—most of them with more imagination than knowledge of ordnance needs. During the 1930's the Bureau studied the possibility of developing an infrared fuze that could be triggered by the heat of an aeroplane engine, and such a project, though dormant, was still under consideration in 1940. Work on the fuze, as on other ideas and patents for proximity fuzes, was stalled by the formidable engineering obstacles that stood between the concept and its crystallization. The contribution of the Bureau of Ordnance was that it joined forces with the OSRD to translate one of those germinal ideas into a design capable of mass production. This accomplishment represented one of the outstanding achievements of that alliance between the military, science, and industry that characterized the American war effort.

The cooperation which finally led to success started in the summer of 1940. In July of that year the Bureau revived its dormant project to develop an infrared influence device. During that same month, the possibility of producing some sort of proximity fuze was also discussed during meetings of a group made up of members of the National Defense Research Committee and the Navy Department Council for Research. Though no definite plan crystallized during the sessions, the members reached what they called a "meeting of the minds" on the practicality of such a project. An infusion of optimism was received later in the month when it was learned that the Western Electric Co. and the Radio

Corp. of America were manufacturing thousands of electronic tubes and photoelectric cells for the British Army. Since two of the most promising possibilities for a proximity fuze were based on the use of radio waves or photoelectric devices for activation, the information suggested that projects might already be under way abroad. The determination to pursue a similar course was strengthened. Further impetus was lent the project in August 1940, when the Bureau of Ordnance placed influence fuzes at the top of the list of projects on which NDRC work was desired.

One month later, the suspicion that England was already engaged in such a project was confirmed when the technical mission led by Sir Henry Tizard gave the NDRC a summary of British progress on proximity fuzes. Both photoelectric and radar types were then under development, but the prospects of perfecting a fuze for use in anti-aircraft projectiles seemed remote. The fuzes were dependent upon electronic tubes—components with a reputation for fragility. The requirements for rocket and bomb use were not too demanding, but projectiles were a greater challenge. The terrific shock involved in gunfire, coupled with the rotation of the shells in flight, imposed strains so severe that many scientists and engineers shook their heads gloomily over the prospects of building a sufficiently rugged electronic tube. Nonetheless, the Bureau of Ordnance was anxious to sponsor an attempt, and on August 12, 1940, an informal request for the development of a proximity fuze was presented to the NDRC. No single approach to the problem was stipulated. On the contrary, infrared, acoustic, magnetic, optical, and radio techniques were all mentioned as possibilities worth investigating.

Administrative machinery and research facilities were established rapidly. On August 17, 1940, a new section was created in the NDRC to supervise the project. One week later, Dr. M. A. Tuve of the Carnegie Institution was named chairman of the new group. Since the organization, named section T for its chairman, had no research facilities of its own, arrangements were made for the actual work to be conducted at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. The scope of activity was extended 3 months later when the Bureau of Standards joined its metropolitan neighbor on the project. For a time, the two activities conducted parallel research on the broad subject of proximity fuzes, each working on devices that might be applicable to a wide range of weapons. The project was soon split, however. The Navy was interested in all possibilities, but the Bureau assigned special urgency to the development of a fuze

for antiaircraft projectiles. Urgency was translated into priority, and a concentration of effort resulted. Starting in July 1941, Dr. Tuve's section, operating in the Department of Terrestrial Magnetism, and various other NDRC contractors focused their attention on projectile fuzes, while the Bureau of Standards applied its facilities to nonrotating applications of influence devices.

Meanwhile, the sense of urgency grew. Less than 1 month before the attack on Pearl Harbor, the Bureau broadened the base of fuze development by introducing the Crosley Corp. to the project. Though under technical supervision of the NDRC, the company was to pursue independent research. This relatively isolated work was not expected to solve basic developmental problems, but the participation of an industrial concern was expected to assure realistic design from an engineering standpoint. This extension of activity was a continual process. By the end of 1941, a host of companies and universities were working on the fuze as contractors for the NDRC, the Bureau of Standards, or the Bureau of Ordnance. Even so, the pace of development rapidly outstripped the facilities available for research.

These growing pains dictated a new administrative alignment and, in March 1942, the fuze section was removed from the NDRC and placed under the Director of the Office of Scientific Research and Development. A few days later, the Johns Hopkins University received a contract to take over the administration of the secret project. Since the Washington area seemed a logical site, the University established an Applied Physics Laboratory at nearby Silver Spring, Md. An automobile salesroom and garage served as a start, but new buildings soon had to be erected to house the expanding laboratory. The APL became the coordinating hub for work done by contractors over the Nation. When the Bureau of Ordnance relieved the OSRD of all responsibility for the program on December 1, 1944, this policy was maintained. The Silver Spring activity remained the central laboratory, directing and coordinating the development and production of proximity fuzes. The changes were purely administrative. Most of the scientists and engineers engaged in research were unaware of the shifting responsibilities that characterized the project from its inception by the Bureau in 1940 until its return to complete Bureau cognizance at the end of 1944.

At the time of the shift to OSRD cognizance, the Bureau selected Comdr. W. S. Parsons, later Rear Admiral and Deputy Chief of the Bureau, as special assistant to Dr. Vannevar Bush for the activities of Section T. It was soon apparent that this interlocking of func-

tions and personnel of the Navy and OSRD was close to optimum for solution of the specific problem at hand which was to get an important new weapon developed, and into combat in the shortest possible time.

Unaffected by the twists and turns of administrative control and stimulated by the steady growth of facilities, actual developmental work alternately stumbled and spurted from September 1940 until the end of 1942. Many possibilities had to be considered before a process of elimination permitted concentration on the most hopeful techniques. Acoustic, thermal, electrostatic, and magnetic types were all studied, then abandoned early in the program. For the first few months, the greatest emphasis was placed on the use of photoelectric cells. This project was never entirely abandoned, but Bureau interest in the device was short-lived. The cells were promising for nonrotating applications like those carried out by the Bureau of Standards, but Bureau enthusiasm at that time was dampened by two restrictions: The cells could not withstand the centrifugal force of projectiles, and they required daylight for operation. Further research removed the first complaint, but the tactical limitations imposed by the second dimmed Bureau enthusiasm. Though a photoelectric fuze was virtually completed by the late spring of 1941, the Bureau's contractors left its development to the Army and concentrated on experiments with radio waves.

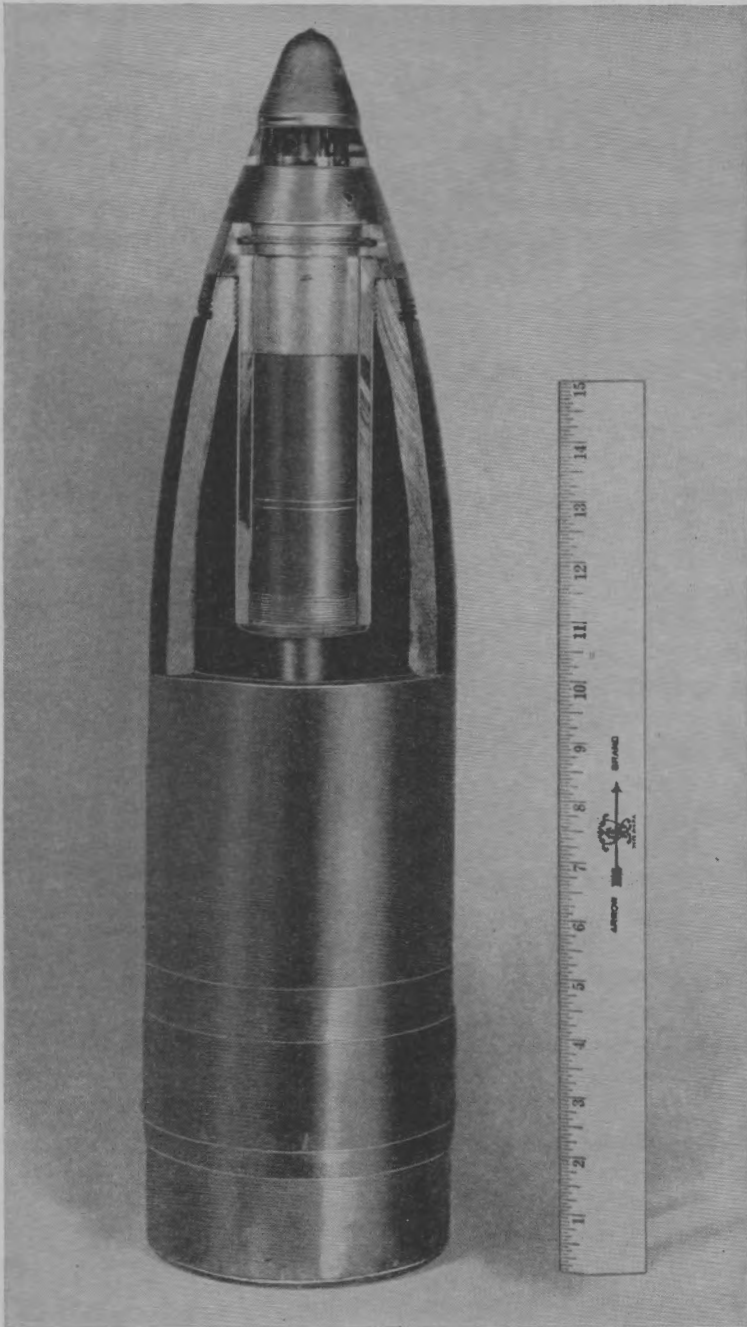
Several applications seemed possible, including one in which radio waves transmitted from the ground were reflected from the target to activate the fuze, a "pulse" type triggered by radio pulses from a ground transmitter, and a "ripple" type in which the transmitter and receiver were both located on the projectile. This latter self-contained unit functions by transmitting a continuous pattern of waves in space. These signals are reflected back to the oscillator by any target that gives a radio reflection. At first the projectile is so far from the enemy that the signals are not returned with any strength. As the projectile nears the target, however, the reflected waves picked up by the oscillator grow stronger. The outgoing and incoming signals then interact to create a "ripple" signal which is amplified by vacuum tubes. When the projectile comes within a radius of about 70 feet from the target, the ripple pattern becomes strong enough to trigger the thyatron tube that serves as a switch. That action releases the electrical energy in a charged condenser, and the current, in turn, initiates an explosion in the electrical detonator, or squib. That blast activates the standard electrical detonating fuze which sets off the main explosive charge

in the projectile. If the triggering pattern of the fuze coincided with the fragmentation pattern of the shell, a "kill" was probable.

This type was finally selected as the most promising for anti-aircraft use. It ultimately received the name VT, or variable time, for no particular reason except that some designation was necessary and Capt. S. R. Shumaker, Director of the Bureau's Research and Development Division, hit on the term as one that indicated the special nature of the fuze without violating the strict secrecy surrounding its operation. In completed form, the VT fuze consisted of four principal parts: A radio frequency oscillator and receiver, an amplifier and thyratron tubes, a battery, and an explosive train incorporating vital safety features.

All the electronic components represented unparalled challenges to both developers and producers. A householder generally treats a radio set with extreme care; except for an occasional exasperated slap when it falters, he moves it about gingerly out of respect for the fragility associated with electronic equipment. The VT fuze, on the other hand, was a five tube sending and receiving set that had to withstand an accelerative force of 20,000g when fired, then the centrifugal force caused by almost 500 rotations a second during flight. A problem under any circumstances, the difficulty was compounded by rigid limitations on size. Fuzes had to be designed for projectiles, not vice versa, and the maximum space allowed was about the size of a pint milk bottle. Extreme ruggedness thus had to be combined with a scaling down of dimensions that introduced a pretentious new word, miniaturization, to the Nation's vocabulary. In addition, the fuze had to be light, relatively inexpensive, adaptable to mass production techniques, immune to counter-measures, safe in use, and operable regardless of weather conditions. Most important of all, the fuze had to detonate the projectile at a moment when the shell fragments could embrace the target. If that coincidence of triggering and fragmentation were not achieved, the results would be, in the words of Captain Schuyler, "the world's most complicated form of self-destroying ammunition."

Under normal circumstances, the perfection of such a device might have been a credit to a whole generation of scientists and engineers; but, the circumstances were not normal and the project was operated as a war program, not a scientific one. Routine experimental procedures were abandoned in favor of techniques apt to produce the first rather than the best fuze. Time and utility were at a premium, economy and perfection were expendable. The spirit of the program was expressed by one of the informal

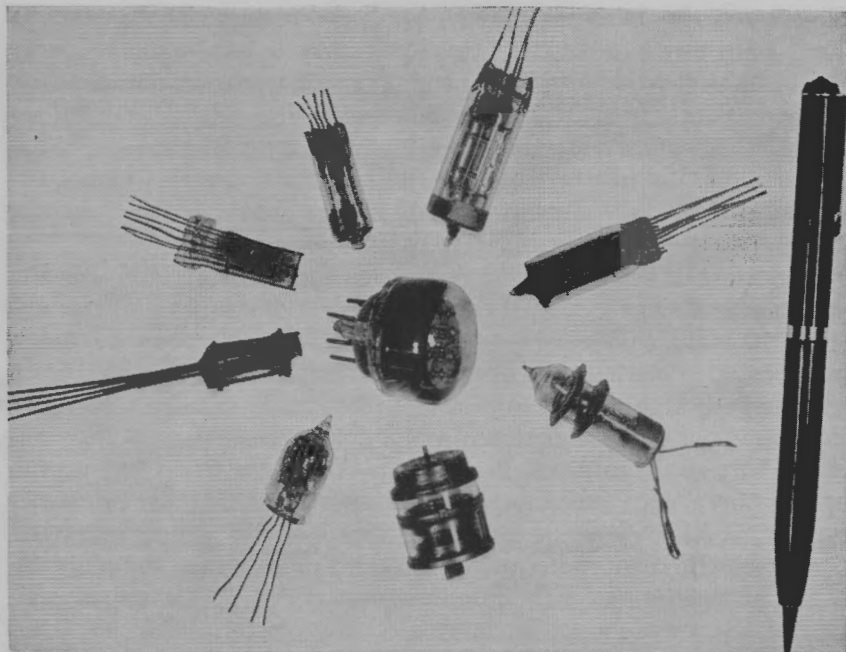


Fuzes had to be designed for projectiles with maximum space about the size of a pint milk bottle.

dictates of the Director of the Applied Physics Laboratory: "I don't want any damn fool in this laboratory to save money, I only want him to save time." The need for speed was so urgent that the Bureau of Ordnance established 50 percent dependability as an acceptance criterion. By normal ordnance standards, that was ridiculously low, but a workable proximity fuze offered so many advantages that a 50 percent rate of failure would leave them far superior to the time fuzes they were to replace.

The most difficult problem confronting the researchers was the design of sufficiently rugged vacuum tubes. Beginning in September 1940, samples of existing miniature radio and hearing aid tubes were tested in centrifuges, dropped on concrete, and test fired from a homemade smoothbore gun or from 37-mm howitzers. Early in the following year, experimental models were mounted in parachute flare shells and test fired at the Aberdeen Proving Ground, while others were subjected to accelerations of 20,000*g* in centrifuges. Vertical firing techniques developed by young scientists permitted the recovery of projectiles and proved invaluable in the study of the fuze and its components. Most of the tubes were special handmade samples fabricated by Western Electric, Raytheon, Hytron, Erwood, and Parker-Majestic engineers. Quality proved uneven, but the test results were hopeful. Complete collapse of the structure sometimes resulted, but a major portion or all of a mount often survived, indicating that standard small tubes could be made suitable by redesigning and strengthening the structures. This was an industrial problem of the first magnitude, but one that proved capable of solution.

Scarcely less of a challenge was the development of a satisfactory battery to energize the fuzes. The research program was originally in the hands of three private contractors, but work was ultimately concentrated with the National Carbon Co., Cleveland, Ohio. As early as 1941, the contractor was able to initiate pilot production of dry batteries that appeared capable of withstanding the rigors of gunfire. But while this adaptation of a commercial product met the operational requirements for an energizer, logistical considerations ruled against its continued use. The dry energizer had a short shelf life, ranging from 12 months under favorable conditions to 3 months in the South Pacific. An extensive program of battery replacement could keep the fuzes operable, but even such an uneconomical procedure could not remove the shadow of unreliability cast by a short-lived component. Thus, a research program for a substitute battery ran concurrently with the experimental production of dry cells. The need for long shelf life suggested the



Rigid limitations on the size of components complicated procurement of the VT fuze.

general approach—a separation of the electrolyte from the electrode until the moment energy was actually needed to activate the fuze. This was accomplished by the design of a wet, reserve type battery in which the electrolyte was contained in an ampule at the center of a cylindrical cell of thin plates. The shock of firing was enough to break the glass ampule, releasing the electrolyte. Centrifugal force then pushed the free liquid outward, where it flowed between the plates and made the battery an active electrical unit. Separation of the electrolyte gave the battery an indefinite shelf life, while its design permitted activation of the unit by the time a projectile traveled four or five hundred yards. The new type was ready for experimental use by February 1942, and ultimately replaced the dry batteries which energized the first VT fuzes.

Meanwhile, fuze development had been making good progress. Assembled models were tested intermittently throughout 1941. Prematures and duds emphasized the need for more intensive laboratory work, but enough of the models worked to lend encouragement to the project. Then, on January 29, 1942, the long awaited day arrived. A group of VT fuzes, made on a pilot assembly line,

were fired in standard 5-inch projectiles; 52 percent operated successfully by proximity to water at the end of a 5-mile trajectory. The feasibility of the devices was at last clearly demonstrated, and the Bureau of Ordnance instructed the Crosley Corp. to start pilot production of VT fuzes at once.

The inauguration of pilot production by no means ended the developmental work on proximity fuzes. The two phases of the program simply proceeded concurrently thereafter. The worst problems were behind, however, and subsequent tests reflected a steady increase in the quality of mass produced fuzes. The first trials against a real target, a Taylor cub suspended from a barrage balloon, proved successful in April 1942. A few months later, following the perfection of safety devices, a group of factory produced fuzes scored 70 percent, and on August 12, 1942, the climax of the precombat testing was reached in Chesapeake Bay aboard the *U. S. S. Cleveland*. Radio controlled planes were on hand as targets for the cruisers 5-inch guns, and several days of target practice under simulated battle conditions were planned. However, all available drones (three) were destroyed on the first day of firing by four proximity bursts.

This success permitted the crystallization of specifications for a real battle fuze and, after a short period of high priority debugging, production shifted from the pilot line stage to mass manufacture. The first VT fuzes were all channeled toward the Ammunition Depot at Mare Island, Calif., for assembly into projectiles. While the stock was accumulating, daily samples were flown 3000 miles to the Naval Proving Ground, where constant tests verified the quality of the fuzes. By mid-November 1942, 5000 rounds were on hand at Mare Island. This was the goal for the first shipment overseas, so the projectiles were rushed to Pearl Harbor, then to Noumea for distribution to ships slated for early battle action. Among this group was the *U. S. S. Helena*, and her guns introduced the new weapons to the enemy on January 5, 1943. The engagement was not the kind that normally made news. Four Japanese bombers attacked a United States Task Force, registering only one hit for their efforts. The pilot of one of the planes, probably estimating effective antiaircraft range on the basis of past experience, leveled off on a straight course too quickly for the new set of circumstances. The *Helena* got a good setup with a 5-inch battery and opened fire with VT-fuzed ammunition. A proximity burst occurred on the second salvo and the Japanese dive bomber, like the drones downed by the *Cleveland*, plunged into the sea in flames. The action itself was not spectacular, but it constituted

a landmark in the history of ammunition. From this time on, according to Admiral Blandy, enemy pilots computed our fuze settings and did "a damned accurate job of it."

The transition of the VT fuze from a laboratory model to a service committed weapon transferred the main burden of the program from the NDRC to the Bureau of Ordnance. Development was by no means ended, but procurement became the main concern. Fortunately, the origins of the program preceded the *Helena's* historic "first" by many months. Starting with the contract awarded Crosley in February 1942, the production base was broadened rapidly. Facilities contracts were placed to make manufacture possible, and production contracts followed in quick succession. Sylvania, Raytheon, and Hytron made tubes, the National Carbon Co. furnished batteries, the Hoover Co. rear fittings, and the Hercules Powder Co. supplied the electric squibs. The procurement program shattered precedent. Over \$50,000,000 were obligated for the proximity devices before a single test had been conducted against a real target and at a time when acceptance standards were five times lower than normal for ordnance products. This foresight and faith prepared the industrial base that began producing tubes in large numbers in September 1942. Expansion became even more rapid after combat proved the VT fuze a success, and by the end of 1944, 87 companies were operating 110 plants on prime contracts with the Bureau of Ordnance.

The procurement structure was a complicated one. The Chief of the Bureau made every attempt to free the program from routine procedures by giving production officers carte blanche to shear away any red tape that threatened to slow production, but the extraordinary nature of the program introduced more problems than the elimination of red tape could remove. Development continued long after production was under way, with the result that design remained fluid. This required continual changes during manufacture and the maintenance of pilot lines alongside assembly lines in plants holding both production contracts with the Bureau and developmental contracts with OSRD. The two phases could not be kept entirely separate. OSRD supervisors often felt impelled to give advice to company engineers, and friction between the two groups was common. Experience soon permitted the evolution of a functional procedure, however, whereby research, quality control, testing, and engineering guidance were carried on by OSRD personnel, assembly lines were run by company engineers, design changes were approved by the Bureau's Research and Development Division, and general supervision of production was the

responsibility of eight officers within the Production Division. A more centralized procedure would have saved many an administrative headache, but the apparently sprawling organization proved efficient. Within a month after assembly began, in October 1942, an average of 500 fuzes a day were being delivered.

Original plans envisioned the United States and British navies as the first users of the VT fuzes developed for and procured by the Bureau of Ordnance. Their effectiveness made them attractive for land use, however, and late in 1943 the Army requested the production of proximity fuzes for United States and British projectiles. This doubling of the Bureau's customers more than doubled the demand for VT fuzes. The two armies eventually proved to be greater consumers than the navies, and the Bureau was forced to push procurement to higher and higher levels. By the end of 1943, almost 2 million fuzes had been delivered; a year later the factories were turning them out at a rate in excess of 40,000 a day. The value of procurement contracts climbed from \$60,000,000 in 1942 to \$200,000,000 in the following year. Expenditures increased by another \$100,000,000 in 1944, then reached a high of \$450,000,000 in the last year of the war. Deliveries rose more rapidly than dollar expenditures indicated, since the cost of a VT fuze dropped from \$732 during the experimental stage to \$18 in 1945. This constant decline in price permitted the purchase of over 22,000,000 fuzes for little more than \$1 billion.

A great number of industrial firms contributed to this achievement. Assembly was concentrated in five companies—Crosley, Sylvania, R. C. A., Eastman Kodak, and McQuay-Norris—but the production of components was carried on by nearly 100 contractors. Each part of a VT fuze presented its producers with a real challenge, since peacetime products are not normally manufactured from such fluid designs or subjected to the stresses that characterized the short operational life of a VT fuze. As in development, however, electronic tubes proved the greatest problem. The difficulties that plagued experts when they were assembling handmade models in laboratories were naturally multiplied when the tubes had to be turned out by the millions on assembly lines staffed with women making their debut in the industrial world. Five companies attempted to mass produce tubes for the Bureau, but only one, Sylvania Electric Products, Inc., proved capable of combining quality with the quantities demanded by delivery schedules. As that became obvious during 1943 and 1944, contracts with the other firms were canceled, leaving Sylvania the sole tube manufacturer. By adopting new techniques and spreading pro-

duction of tubes or parts of tubes over 23 different plants, this contractor was able to achieve a delivery rate of nearly a half million tubes a day by the end of the war. The extent of that achievement can be judged by the fact that the peacetime production rate of the entire vacuum tube industry was only 600,000 units a day. As with complete fuzes, the cost of tubes declined as production rose. Sylvania's original unit price was \$5.50; at the end of the war the Bureau paid less than \$0.40 for each tube.

Despite the services rendered by the firms participating in the manufacture of proximity fuzes, the program was conspicuous for the absence of publicity. No Army-Navy E pennants flew over the plants. Workers were not entitled to wear the coveted lapel buttons indicating excellence in production, nor were they inspired or bored by visiting dignitaries. Strict security surrounded every phase of the VT fuze program. Workers were generally unaware of the importance of the item they assembled, and many of their bosses were hardly more informed. Some of the precautions were simply designed to prevent the enemy duplicating the fuze, but secrecy was intensified by the fear that effective countermeasures, based on "jamming" the radio waves, might be possible. Thus, the number of people familiar with the project was kept at a bare minimum. Instructions were verbal wherever possible, to avoid committing vital information to paper. Even the words influence and proximity were classified, and the fuze was simply referred to by mark number or by the familiar VT designation. Fuzes were kept under lock, key, and armed guard during shipment. Even operations were restricted by the security precautions surrounding VT fuzes. For the first 2 years of their existence, proximity fuzes were used only over water, where the chance of enemy recovery was slight. Secrecy paid dividends, however, for the Axis was never able to countermeasure the weapon or produce an equivalent fuze.

The VT fuze in battle was everything its developers hoped for and more than the Bureau of Ordnance demanded when it first established acceptance standards. Starting with the *Helena's* bomber in January 1943, enemy planes began to fall in increasing numbers, testifying to the effectiveness of the new weapon. The VT fuzes proved far superior to the time devices they replaced. In 1943, for instance, 36,370 5-inch rounds were fired. Although 75 percent carried time fuzes rather than VT's, 51 percent of the kills were credited to the approximately 9100 proximity fuzed shells. Subsequent improvements to the devices ran their advantage ratio up to about 4 to 1. This meant that 1 gun firing

VT-fuzed ammunition was as valuable as 3 or 4 guns supplied with time-fuzed projectiles.

The advantage ratio over contact fuzes was even more favorable. While a comparison of 5-inch projectiles with 40-mm ammunition is complicated by functional as well as size and weight differences, their relative effectiveness illustrates, in part, the superiority of influence fuzes. The burst area of a 40-mm projectile against approaching aircraft is small, about 60 square feet, because the shell must actually strike the target to detonate. The burst area of a VT-fuzed 5-inch round is, on the other hand, about 3000 square feet, since it will explode if it passes within 60 or 70 feet of the target. In other words, aircraft look 50 times larger to proximity fuzed shells than to contact ammunition. The faster firing rate of the 40-mm cancels out some of that advantage, of course, but even allowing for that differential and assuming that only 70 percent of the VT fuzes would operate satisfactorily, the advantage ratio of a 5"/38 to a 40-mm was still 8.1/3. Tactical situations reserved many targets for the smaller guns and their contact ammunition, but the value of 5-inch guns as anti-aircraft armament climbed rapidly once VT fuzes reached the fleet in sufficient numbers.

Testimonials that would have gladdened the heart of any huckster reached the Bureau in great numbers. In a combat account telling how two German planes were shot down in the Mediterranean a skipper reported: "Destroyed a German bomber and a Messerschmidt 110. Only 15 rounds were expended." Shortly thereafter came a report from Task Group 50.3, paying tribute to the VT fuze after 91 out of an attacking force of approximately 130 Japanese planes were destroyed. The gloomy prophecy of Gen. Billy Mitchell, apparently so close to fulfillment in 1940 and 1941, was, if not destroyed, at least pushed back into the future. Many factors helped contribute to the effectiveness of fleet defense against air attack, but the most significant of them all was the proximity fuze. Here was anathema for Herman Goering and his Japanese counterparts. In summing up the contribution of the new weapon, Admiral Blandy wrote: "The story of the VT fuze is a romance of science. For three reasons, it is a romance with a happy ending: First, secrecy has been effectively maintained; second, the fuze was perfected by the time it was most needed; third, the fuze actually did the job it was designed to do."

As efficient as the VT fuze proved to be, two other improvements were helpful in keeping Navy ships afloat; damage control and new techniques in preventing and fighting fires. It is difficult to untangle the statistics but American ships were still being damaged

by air attack right up to the end of the war. There is no telling how many more ships would have been damaged if it had not been for the VT fuze but it is equally clear that effective damage control and fire fighting deserve much credit for keeping our ships in action.

As invaluable as the VT fuze proved to the Navy, it was destined for even greater service with the American and British Armies. Late in 1943, the Bureau of Ordnance began procuring extra fuzes for the Army to use with howitzer shells against ground forces, but their employment was prohibited by the ban against use over land, where duds might be recovered and studied by the enemy. This restriction was not completely lifted until the fall of 1944, but the rule was excepted earlier when buzz bombs were released on Britain. The first of the V-1's fell in London on June 12, 1944, and that was but the prelude to a long nightmare for the English people. Defense became a matter of such overriding priority that the ban on the VT fuze was lifted. Several factors delayed their commitment, however, and main reliance was first placed on the Royal Air Force. All across the channel, fighter planes attacked the bombs, but they had more than met their match. Moreover, the presence of friendly planes hampered the work of the anti-aircraft batteries protecting London. By the middle of July the toll of death and property damage dictated a change in defensive tactics. Approximately 500 heavy anti-aircraft guns were moved to the channel coast where they could engage the bombs before they reached the shores of the island kingdom. The results of the change were spectacular, and the results improved as the percentage of VT-fuzed projectiles rose. The last month of the fearful 80 days of V-1 attacks constituted a special testimony to VT fuzes, for during that period the percentage of kills arose from 24 percent of all targets engaged during the first week to 79 percent in the last. On the final day of large scale attacks, only 4 of 104 bombs succeeded in reaching the capital. A few fell in the channel and some were brought down by the RAF and barrage balloons, but the heaviest toll was taken by proximity fuzed anti-aircraft projectiles.

Shortly after giving up the buzz bomb barrage of England, Germany turned the hated weapons against Antwerp. With the battle of Western Germany raging, this port was vital to the Allied cause; great quantities of supplies for English and American troops poured across its docks. V-1's dropping day after day in the late months of 1944, threatened to close the port, but again the VT fuze became the margin of Allied victory. Anti-aircraft batteries doubled, then tripled the records established with the earlier time

fuzed ammunition. The port was saved and the gunners were able to trade their defensive role for an offensive one by moving up with the troops advancing on central Germany.

Meanwhile, the Nazi infantry had been introduced to the weapon that was already the bane of its air force. This acquaintance started in December 1944, when von Rundstedt's counterof-



British fighter plane pursuing buzz bomb.



Buzz bomb over London.

fensive launched the Battle of the Bulge and threatened to prolong the war just when victory seemed so near. Since the Combined Chiefs of Staff had recently approved the use of VT fuzes over land, the time was opportune to try the new device against ground forces. The results were far better than expected. With ammunition exploding some feet above the earth and showering the area with a hail of high velocity fragments, the army's field artillery put new fear in the hearts of German soldiers. Prisoners of war were almost unanimous in damning, and thus praising, the veritable rain of death that accompanied proximity fuzed artillery fire. The soldier's sanctuary, the foxhole, was almost valueless as protection against overhead bursts. As if on a seesaw, the morale of American troops rose as that of the enemy fell. Here was a secret weapon for the Allied side that seemed as terrible as any the German scientists had developed to aid the Nazi cause. In expressing gratitude for the new weapon, General Patton wrote: "The new shell with the funny fuze is devastating. . . . I think that when all armies get this shell we will have to devise some new method of warfare." Gen. Ben Lear, commander of the Army Ground Forces, described the VT fuze as "the most important new development in the ammunition field since the introduction of high-explosive projectiles." The Bureau of Ordnance acknowledged the compliments with record breaking procurement for four services, the United States and British Armies and Navies.

Chapter 14

ROCKETS

“FOR every action, there is an equal and opposite reaction.” That third of Newton’s laws of motion states the general principle upon which rockets operate. The popular conception has long been that the gases drove the rockets by pushing against the atmosphere, but that is to overlook the physical truth stated by Sir Isaac Newton. Propulsion results because the rearward push of the gases is matched by an equal reaction that pushes against the rocket head and forces it forward.

The instrument itself is a simple device—little more than a metal tube closed at one end and open at the other. The cylinder contains the fuel, usually a powder grain, which produces the gases as it burns. Attached to this motor is the damaging body—a solid structure or head containing fuzed explosives or chemicals, according to the desired function. A nozzle at the end of the motor, an electrical ignition system, and stabilizing fins completed the assembly of a typical rocket.

Unfortunately for the lives of medieval combatants, rockets antedated the formal statement of their operational principles. “The rockets’ red glare” in the United States national anthem serves as reminder that they are no recent invention, but they might, in fact, have been so immortalized in Mongol anthems a half millenium ago. Early in the thirteenth century those dreaded warriors met a weapon for which their ponies and swords were barely a match when the Chinese unleashed the first known military rockets against the invading hordes.

While they could not stem that onslaught, rockets caught the imagination of a fighting age and followed the trade routes westward. Before 1300 Europe added the weapon to its growing arsenal, but the inclusion was short-lived. Gradual improvements to the cumbersome medieval cannon served to cancel out the popularity of the new weapon. Cannon and other firearms showed such promise that rockets declined in popularity until they almost disappeared from military arsenals.

Not again until late in the eighteenth century did rockets reappear as a military weapon. And again it was the Orient that forced the weapon on the European consciousness when Indian

insurgents employed crude but effective rockets against English troops. Appreciating the potentialities of the Indian weapons, the British decided to produce rockets of their own. Development stumbled along without real promise for some years, but at the opening of the nineteenth century the project attracted the attention of Sir William Congreve, the man whose name subsequently became a popular prefix to military rockets. Within 5 years he had developed usable rounds, and between 1805 and 1813 the British launched the weapons against several European cities and, closer home, against Baltimore and the defenders of Washington. Congreve's rockets proved erratic but effective, and the weapon enjoyed one of those spurts of popularity that have marked its development over some seven centuries.

Rocket units became an accepted part of most European armies, and the United States investigated the possibilities of the weapon used against it in the War of 1812. An important innovation resulted from this attention when an American, William Hale, developed the first spinning rocket by attaching curved vanes to the base of the weapon. The pressure of the gases against the vanes produced a constant rotation that helped stabilize the flight of the missile. The new invention was followed by preparations for its use, and before the outbreak of the Mexican War there were 11 rocket batteries in the American Army. Two thousand spin-stabilized rockets were produced for the conflict, and in at least two engagements the new weapons were turned against the enemy.

Rocket development lost its stimulus shortly after the Mexican War, lapsing into one of the several lulls that characterized its history. Further progress seemed stymied just as other weapons offered greater promise. Propelled exclusively by powder, the efficiency of all the early rockets was governed by the progress in the field of powder manufacture. Until an improved propellant was available, further work was stalled. Necessity might have overcome that obstacle—the truth in the old saw about the mother of invention has never been better demonstrated than in the field of ordnance—but the need passed during the interlude between the Mexican and Civil Wars. Just at the middle of the nineteenth century the inventions of rifling and breech loading came into common usage and provided better artillery which, in turn, provided more power and stability for projectiles. Rockets, notorious for instability in flight, could not compete with conventional missiles. Military interest dissipated accordingly. Rocket development suffered just such a lag when cannon were first introduced.

Even though gun development was such that rockets appeared

unable to compete with projectiles, some experimentation continued by scientists with other than military interests. Before the United States entered World War I, for instance, a research project to develop high altitude rockets for meteorological purposes was already in progress under a grant from the Smithsonian Institution.

After the United States entered the conflict the Smithsonian, recognizing the military possibilities inherent in the rocket, interested the Government in the project. Under the supervision of Dr. Robert H. Goddard, an American pioneer in modern rocket development, a secret project was instituted in California. A number of promising military instruments, including a long ranged bombardment rocket with an intermittently operated motor, were developed, but emphasis was placed on the application of the rocket principle to a bazookalike infantry weapon. Out of the work came an ancestor of the now familiar ordnance, but the Armistice put an end to the project within a matter of hours after the first successful tests at the Aberdeen Proving Ground.

In the postwar years military interests turned back to more familiar channels, but private rocket societies in various countries continued to work with the problems of their field. Germany was in the forefront of this development, but a combination of individual zeal and luck kept work alive in the United States. Working first at the Naval Proving Ground, then on a Massachusetts farm, Dr. Goddard continued his experiments. On a summer day in 1929, still intrigued by the idea of high altitude exploration, the physics professor tested a liquid fuel rocket not far removed in principle from the later German V-2 rockets. The results of the test were spectacular in an unexpected way. Acoustic conditions were such that the noise of the rocket traveled far across the countryside, arousing a minor panic. Ambulances and search planes were dispatched in the belief that a terrible crash had occurred. When the truth was discovered, Dr. Goddard was called in for an accounting by the state fire marshal.

Here was grist for the press mills, and the incident gained wide publicity. Partly as a result, Col. Charles A. Lindbergh communicated with the professor, then interested Daniel Guggenheim in the possibilities of Goddard's work. Out of those interviews came the arrangements that furnished the financial support that sustained a large part of America's rocket research between the two wars. Dr. Goddard's main interest continued to follow the liquid fuel lines which were more thoroughly exploited by Germany than

by the United States, but his activities were of great importance in adding to the stock of basic knowledge available within the Nation. Even in the military field a little progress was made during the 1930's by a young Army lieutenant, Leslie A. Skinner, who experimented with rocket applications. The officer received no official support, however, and found his work blocked by the lack of a suitable propellant.

The low rate of rocket development in the United States did not continue for long. In June 1940, with the war already under way in Europe, a colleague and former student of Goddard, Dr. C. N. Hickman, realized that rockets might constitute an important new weapon for the arsenal the Nation was just beginning to assemble. Especially because their absence of recoil made large caliber installations feasible on light craft, tanks, and planes, the scientist envisioned a wide variety of tactical applications for rockets. Accordingly, Hickman cleared his ideas with his former professor, then presented them to the newly created National Defense Research Committee.¹

Scientists there saw the potentials of a rocket revival, and the NDRC promptly relayed Hickman's suggestions to representatives of the services. Their reception was not generally enthusiastic. By modern standards the performance of rockets looked inadequate. The promise of the weapons was obscured by the primitive nature of their past applications. But there was one exception to the official coolness: The Bureau of Ordnance expressed an interest in applying rocket propulsion to aircraft bombs. The theory behind the Bureau's interest was that the extra velocity given to falling bombs would impart greater accuracy and penetration to the weapons. "Bombproof" was a common expression in 1940, and the Bureau was anticipating tactical and strategic requirements.

With Bureau interest as a stimulant, the NDRC organized for action in the field. Rocket research was formally under way again. The beginnings were small but the program gained acceleration with the approach of war. The project that started out as a stepchild of ordnance ultimately gained the highest priority. Although rockets did not even prove valuable in the only application originally contemplated by the Bureau, their versatility won them a place in almost every phase of warfare. Only 4 years after the inauguration of United States rocket development, the program was nearing the \$100,000,000 a month mark—a gigantic amount even in an age accustomed to astronomical expenditures.

¹ The story of rocket development for the Bureau by NDRC is based largely on *Rockets, Guns and Targets* edited by John E. Burchard (Boston: Little, Brown & Co., 1948).

The scene of the early work was the Naval Proving Ground at Dahlgren, Va., but facilities expanded with the unfolding of rockets' promise. Before the year was out the small rocket group outgrew the restricted quarters at Dahlgren and moved to the Naval Powder Factory at Indian Head, Md. While the early experiments were largely confined to rocket propelled bombs, service interest rapidly broadened to include other applications of rocket propulsion. The new enthusiasm stemmed in large part from British example. Faced with the realities of war much earlier than the United States, England was at least 4 years ahead of this country in rocket work. The benefit of their experience and some of their optimism was available to the United States, and technical information that saved American scientists weary months of work was coupled with suggestions for tactical uses that caught the imagination of ordnance planners in both the Army and Navy. In addition to lending velocity to bombs, rockets soon appeared attractive for ground-to-ground, air-to-air, antisubmarine, antiaircraft, and target use. Rockets offered no substitute for conventional guns, but they promised to be an effective complement to traditional armament. Simplicity of design, ease of manufacture, and the absence of recoil suggested a multitude of applications for the weapons. Such versatility could help compensate for the inaccuracy of rockets, as compared with guns.

Just as the original group outgrew the restricted space at Dahlgren, the gradually expanded section soon had more interests than could be pursued at the Navy quarters at Indian Head. The result was a considerable expansion of rocket facilities and activity by the services and the NDRC. Several private corporations were contracted to supply engineering talent and materials, and headquarters were established at George Washington University and the California Institute of Technology. The Indian Head operations already under way were administered from the neighboring university, while a new and broader rocket program was inaugurated at the Institute on the west coast.

After the reorganization, the Bureau of Ordnance shifted its attention from the east to the west coast. The research group which had started Navy work at the Powder Factory turned to projects of more interest to Army Ordnance, such as the famed bazooka. By 1944 even the geographical link with the Navy expired, and the NDRC moved to more spacious quarters elsewhere. On the other hand, the unit in California, established in September 1941, became almost exclusively a Navy-associated group. Later on, the west coast facilities were expanded by the construction of

the giant Naval Ordnance Test Station at Inyokern. Construction started in the fall of 1943, and the desert station expanded until it included an area about the size of Rhode Island.

While not designed exclusively for rocket work, the NOTS did concentrate on rocket testing. Moreover, the Bureau regarded the station as the logical site for a research and development program that could ultimately assume the CIT projects and extend them into the postwar period. Geographical proximity, common purpose, and an exchange of personnel established growing links between the two California organizations and aided Bureau direction of a rocket program whose private origins made it an adjunct to rather than an integral part of Ordnance organization. The final accomplishment of this goal came only at war's end, but the relationship between the California Institute and the NOTS was extremely close; between them, they accounted for the bulk of the Bureau's rocket developmental effort.

The agencies under NDRC fulfilled several related functions: They carried out the fundamental research which proved the military applicability of rocket propulsion, and they worked on the specific applications of the rocket principle requested by the services. Even in the final problems of getting the new weapons into production and use they made significant contributions. Once the power of rockets was appreciated, the military requirements multiplied rapidly. The need for haste meant that production often had to run concurrently with the final development—a situation that precluded finished drawings at the outset of manufacture. That, coupled with the critical facilities picture, complicated the Bureau's procurement problem and threatened a time lag incompatible with service demands and operational deadlines. The solution to this dilemma came with the inauguration of crash production procedures at the Institute. As soon as a new weapon was approved for military use, the Bureau could request initial deliveries from CIT, then make arrangements for regular manufacture while the NDRC group was both turning out weapons and crystallizing design. The fleet, the Bureau, and its contractors were all beneficiaries of the system.

For the most part the developmental problems were confined to work on rocket motors. The bombs and projectiles developed as independent weapons ordinarily served as a basis for warheads, leaving designers free to concentrate on the task of developing a motor capable of giving each particular head the required velocity and range. But as simple as rocket motors were in principle, the design problems were numerous. As was so often the case with

ordnance developments, many of the desired characteristics seemed contradictory or mutually incompatible. Examples were legion throughout the rocket program, but a few illustrate the kind of situation that faced rocket workers: Strength was needed, but so was lightness; stability was requisite for accuracy, but the demand for compactness ruled out elaborate fin structures; a heavy load was natural for ordnance, yet was governed by the rocket motors available; a careful regulation of gas pressure offered control over rocket behavior, but could not be divorced from concern over temperature ranges. And basic to the whole range of problems was the task of finding a fuel that combined the proper characteristics with availability.

As events proved, the solution of that fuel problem was the only really significant contribution that came out of the first rocket project sponsored by the Bureau of Ordnance—the attempt to develop a rocket-propelled bomb. The bomb itself was no problem. Standard 14-inch armor piercers were supplied for the attachment of motors that would give them added velocity just before they hit the target. The powder desired to propel such a weapon was, however, another matter. The only available explosive with the required characteristics posed prohibitive production problems. The debut of rockets was thus delayed until the developmental talents of the National Defense Research Committee, the know-how of the Naval Powder Factory, and the adaptability of the powder industry could be combined to devise extrusion presses that could shape powder into sticks required for rocket motors, then convert laboratory techniques into equipments for mass production. The problem was never completely solved in that the propellant supply was always critical, but that was due to the phenomenal expansion of the rocket program and its insatiable demands on propellant manufacturers. The remarkable fact was that suitable powder was being extruded on a small scale before the end of 1941. Four years later, the Bureau was about to begin operations with an extrusion press capable of turning out powder sticks with a diameter of 18 inches.

Meanwhile, the direction of rocket progress shifted twice. The jet-propelled bomb proved of only indirect value, even though a tactical need for such a weapon did develop during the war. A bomb's ability to pierce armor was dependent upon its velocity, which was the function of the distance it fell before striking a ship. As high altitude bombing proved poorly suited for naval warfare, with its relatively small and maneuvering targets, jet propulsion offered a substitute for distance of fall in lending veloc-

ity to bombs. But armor-piercing bombs, despite their promise, proved less valuable than those types which compensated for their lack of penetrative ability with a greater volume of high explosive. Success with general-purpose bombs and new attack techniques made large-scale procurement of rocket assisted bombs unjustified late in the war. Earlier in the conflict, the project to develop such bombs lost priority when it was forced to compete for attention with far more pressing requirements.

Even before December 7, 1941, submarines appeared the greatest menace to the United States, and the development of new weapons for antisubmarine warfare became an urgent problem for the Bureau of Ordnance. The time-honored weapon was the depth charge, an "ash can" filled with explosives and fuzed to detonate at predetermined depths. In use, the charges were usually projected over the side or rolled from the stern of ships in such a manner that a pattern of underwater explosions was created. Lacking adequate fire control, a saturation effect had to be produced. Accuracy was impossible because sound contact was lost as ships approached the submarines' position. The turbulence caused by the series of exploding depth charges disrupted all sound impulses and made the reestablishment of contact difficult after attacks. Thus, antisubmarine warfare tended to be haphazard and created cover conditions ideal for the escape of the enemy.

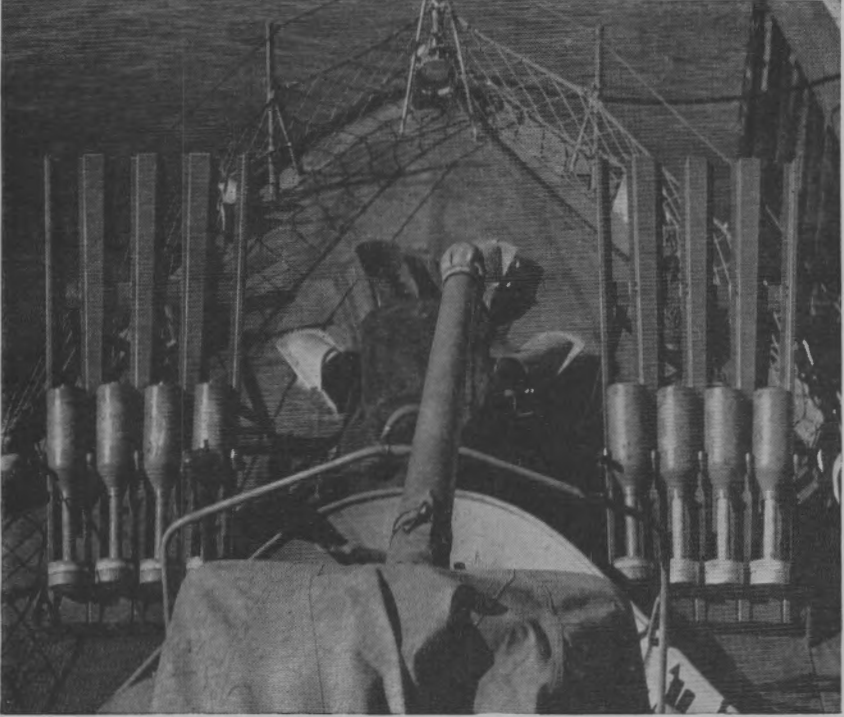
A better weapon was mandatory. The limitations of sonar suggested two desirable characteristics: The weapon should be projected ahead of the attacking ship, and it should explode only upon contact with a submarine. Faced with similar problems, the British had developed the so-called "Hedgehog," a group of launchers which projected 7"2 bombs ahead of the attacking ship. In the face of urgency, the United States adopted the English device shortly after Pearl Harbor, but it was an imperfect solution to the problem. Propelled by electrically detonated impulse charges, the bombs' recoil forces were such that use of the Hedgehog was limited to vessels of at least destroyer size. The widespread nature of the submarine menace demanded the use of smaller vessels, such as PC's, SC's, and various Coast Guard craft. Their utilization, in turn, required a modification of the Hedgehog principle. Rocket propulsion seemed the perfect answer, since the absence of recoil constituted one of the main advantages of rockets' use.

The NDRC group at CIT undertook the job of combining the respective virtues of the Hedgehog and rockets for the Bureau. Early in 1942 the development received a stimulus when the completion of the first large extrusion press eased the propellant prob-

lem and permitted the development of rocket motors capable of projecting the 7"2 bomb already in use as an ahead thrown weapon. In essence the motors were copies of those used with British 2-inch rockets, but they proved capable of throwing the bombs some 220 yards ahead of the craft. A launcher was designed to project 4 bombs at a time, giving them a transverse spread of 17 feet.

In early spring 1942, the first models were ready for testing and some 20 rounds were fired in sea trials off the west coast. The tests were not an unqualified success, but the potential of the weapon justified its immediate acceptance. Theoretically, at least, the use of the ahead thrown contact bombs made small surface ships 25 times more effective than they would be carrying the same weight in conventional depth charges. After minor improvements, the weapons were demonstrated for key officials in new tests at Key West barely 1 month after the first sea trials. Acceptance was enthusiastic; within 4 days the Chief of Naval Operations directed installations on many patrol craft and certain Coast Guard vessels. Before the end of April 1942, the Bureau began arranging for procurement of the new equipments. Officially designated Rocket Launcher Mark 20, the projector was immediately dubbed "Mouse-trap," because of its appearance on deck. While rounding up contractors to supply the vital equipments, the Bureau arranged with the Office of Scientific Research and Development for interim production at the California Institute. Though early procurement was on a small scale, installations began within 1 month of Bureau authorization to proceed with the project.

The original Mark 20 equipment was far from perfect, but improvements by the Bureau had to be gradual enough to accomplish without stopping production. The most significant change in the projector was the introduction of a double-decked launcher designated the Rocket Launcher Mark 22. By the spring of 1943 production shifted to the new model, permitting salvos of 16 rockets. Improvements to the ammunition paralleled the development of superior projectors. Original procurement was devoted to the Hedgehog bombs already available, but the Bureau was satisfied with neither the air nor the underwater velocity of the projectile. Moreover, the fleet desired a projectile versatile enough for use from either air or surface against both submerged and surfaced submarines. The requirements demanded a redesign of the original British projectile, but by early 1943 the Bureau was able to offer the 7"2 Shipboard Rocket Body Mark 4, a light bomb carrying 30 pounds of TNT.



Officially designated Rocket Launcher Mark 20, the projector was dubbed "Mousetrap" because of its appearance on deck.

Rocket production was held at 30,000 assemblies per month throughout the years' extensive antisubmarine campaign, then dropped to a level of 10,000 projectiles a month. The Mousetrap and its ammunition proved to be useful weapons. The 16 projectiles fired from the Mark 22 formed a pattern approximately 80 yards wide on an axis perpendicular to the course of the attacking vessel. The range of about 300 yards was sufficient for firing while still in sound contact with the enemy, and the lack of explosions on unsatisfactory runs permitted immediate reattacks. Extensive training was necessary before crews mastered the new devices, but the development of a subcaliber practice rocket, the Minnie Mouse, permitted practice firing with a minimum drain on the Nation's critical propellant supply.

The "crash" production of the launchers had the Mousetrap at sea long before the Bureau of Ordnance completed its production and design plans. One hundred installations were in service by November 1942, and vessels equipped with the new weapons were soon on patrol in the Atlantic, Caribbean, and Pacific. While no

spectacular statistics on kills were amassed, the Mousetrap proved a valuable supplement to the conventional depth charge attacks. The 30 pounds of explosive in the body of the rocket was not always enough to sink the submarine on impact, but a hit at least caused the enemy to surface and face a conventional attack at a disadvantage.

With but slight modification, the projectile designed for use with the Hedgehog and Mousetrap proved applicable for still a third antisubmarine weapon—the retrobomb. This was a queer missile that fired backward from a speeding plane, then fell like a plummet toward the target. The idea for this, as for most rocket weapons, came from within the NDRC, but responsibility for the retrobomb ultimately lay with the Bureau of Ordnance.

The need for the weapon stemmed from the invention of a device known as the Magnetic Airborne Detector. The MAD, developed in 1942 at the height of the German submarine campaign, was an instrument that indicated the presence of submerged submarines. With it, airplanes could stalk U-boats, but there was one major hitch to its exploitation: The MAD worked only when the plane was directly above the submarine. This posed severe bomb control problems, since falling bombs or depth charges, far from dropping straight into the sea, had an extended trajectory in the direction of the planes' flight. If a bomb were released at the moment the MAD registered the presence of an enemy, the miss was sure to be so great that the submarine could escape unharmed. Anticipatory bombing required frequent passes and was at best a haphazard way to utilize the potential of the MAD.

The obvious requirement was a bomb that would fall straight toward the target once it was released. Rocket propulsion enjoyed two characteristics which commended it for the job. Firing backward, it could cancel out the motion of the plane; lacking recoil, it could permit the firing of fairly large missiles without undue strain on a plane's structure. CIT accepted the job of designing such a weapon and by mid-1942 was able to demonstrate experimental models. Speedy development was possible because of the rapid accumulation of knowledge concerning rocket propulsion and because the Mousetrap rockets were already available. A larger motor was needed to increase the velocity, but the body could be used after minor modifications.

Torpex was substituted for the less powerful TNT, and launcher rails were developed for the patrol planes and bombers slated to carry the unorthodox weapon against the enemy. By mid-1943

the inevitable experimentation was over, and the Bureau was able to procure the ordnance for service issue. Late in the year the retrobomb was issued to the squadrons selected to use the Magnetic Airborne Detector.

In operation the combination had only short-lived usefulness. As the antisubmarine campaign gained momentum, the craft began to change their defensive tactics. Instead of staying below to sit out the attacks of Hedgehogs, Mousetraps, depth charges, and retrobombs, the submarines began to carry increased armament and surfaced to fight it out with persistent stalkers. Surface vessels could cope with the new tactics, but retrobombing planes were in a vulnerable position. To attack they had to fly directly over the submarine at altitudes between 100 and 300 feet. Unless they caught the submarine while it was submerged, the planes were no match for the anti-aircraft fire of the enemy. The tactical change spelled an end to the retrobombs. Later in the war the U-boats went back to their old practice of seeking safety below the surface, but the retrobomb was never returned to the fray in any significant number. Pilots were not interested in abandoning proved ordnance and tactics for a queer weapon whose service life was too brief to instill confidence. The retrobomb, a product of the desperate days when any antisubmarine armament was worth a try, became a limbo partner of the jet accelerated aircraft bomb.

Though both weapons fell short of the Bureau's hopes for them, the field of aircraft applications that they introduced proved a



The retrobomb, a product of the desperate days when any antisubmarine armament was worth a try.

fruitful one for rocket researchers. Planes and rockets were almost perfect partners. Aircraft, by adding their own speed to that of their weapons, gave rockets an initial velocity that lent them a stability and accuracy not possible when they were fired from the ground. On the other hand, the combination of high power and low recoil afforded by rockets could give planes a firepower out of all proportion to their structural strength.

Moreover, fire control was relatively simple. Rockets were simply attached to the underside of planes by rigidly mounted launching rails. Once launchers and sights were boresighted and adjusted to the planes' line of flight, rockets were aimed in much the same way as fixed machine guns. Torpedo directors and gun sights served as sighting mechanisms. The main problem stemmed from the gravity drop of rockets. Their lower velocity naturally permitted a greater drop than that experienced by conventional projectiles, and the trajectory was dependent upon the dive angle, range, aircraft speed, temperature, and rocket type. Under extreme conditions, the gravity drop was as great as 90 mils. To help pilots compensate for such variables, the Bureau of Ordnance distributed sight tables for use with aircraft rockets. The length of the launching rails that guided the rockets at the moment of release proved to have little influence on the accuracy of rocket fire. In fact, experiments eventually proved that the launching assemblies could be reduced to "zero-length"—that is, rockets could simply be released without the benefit of any guiding rods. All that was needed were devices to hold the rockets securely under the



Planes and rockets were almost perfect partners.

wings until the moment of release, then supply the electrical energy needed to arm the fuzes and fire the rockets.

The first two attempts to capitalize on the mutual advantages of the plane-rocket partnership were abortive, but real success came when the military and their scientist allies turned their attention to developing forward firing aircraft rockets. The first application of the new technique was, like so many new devices of the early war period, of English ancestry. And like many another ordnance innovation, it was born of the extreme urgency of countermeasuring the Nazi submarines that brought the war to the shores of England and the United States.

Late in 1942, the British modified a 3-inch fin stabilized rocket designed for anti-aircraft use and adapted it to antisubmarine warfare. The conventional head was replaced by a solid steel shot, and the converted rockets were fired from rails under the wings of bombers. During early 1943 the English used their rockets with enough success to justify emulation, and in June of that year the Bureau of Ordnance and Aeronautics were ordered to start high priority development of a forward firing aircraft rocket. Once again the NDRC unit at CIT undertook the project. The work did not have to start from scratch. A great deal of basic knowledge had been accumulated by mid-1943, and the Institute group was able to proceed as soon as the Bureau requested the work. Within 3 months, air tests of prototype rockets were under way.

The Bureau did not wait for the experiments to run their normal course. Even before the first flight test the Bureau requested production at the rate of 10,000 rounds per month. Admiral Blandy's purpose was to provide extensive service testing for the weapon before the Bureau made its own arrangements for production, but the action also had collateral benefits. Development was speeded and the order gave an impetus to the expansion of the production facilities at CIT. As rocket types multiplied and the urgency of the program grew, the ability of the Institute to proceed with immediate production of new weapons proved of immense value to the Bureau. In the case of the 3'5 rocket, for instance, the Bureau was not ready to assume complete responsibility for procurement until March 1944, yet faced urgent requirements for the weapon a half-year earlier.

Because it came late in the emergency period at a time when the manufacturing facilities of the Nation were already absorbed in vital production, the establishment of an adequate capacity for rocket production was attended by the same problems and urgency that earlier beset the programs for the production of the weapons

with which the United States entered the war. Plants, tools, and labor were all in short supply. The mushrooming rocket program had to be superimposed on a strained economy, yet outstrip the older, established programs. The inauguration of production for each new type meant a time consuming search for facilities, and the ability of the Institute to provide an interim supply of the weapons was often all that made it possible for the Bureau to meet an operational deadline.

The first of the forward firing aircraft rockets designed for the Bureau utilized 3"25 motors and a 3"5 solid head weighing 20 pounds. Motor and body together had a total weight of 55 pounds and a velocity of about 1175 feet per second above the speed imparted by the plane. The submerged range of the rocket varied with velocity and angle of water entry, but the head was usually capable of rupturing the pressure hull of a submarine after about 60 feet of underwater travel. Subsequent work in modifying the shape of the head doubled the lethal underwater range; still later, high explosive heads were developed for use against surface targets.

The order that led to the development of the 3"5 was followed on August 10, 1943, by instructions to manufacture 200 launcher installations for TBF planes, the type commonly used from escort carriers on convoy duty. The first models followed the British system of using slotted rails to suspend the rockets. One set of 4 rails under each wing provided 8 rockets which could be electrically fired in salvo, pairs, or singly. The modification of the British installations worked well enough, but it was not acceptable to the Bureau. The rockets were antisubmarine weapons, but the planes were combat aircraft whose versatility had to be maintained. The 72-inch rails reduced air speed appreciably and hindered the maneuverability of the planes. The problem was attacked by the obvious expedient of making successive reductions to the length of the launching rails. Accuracy seemed undisturbed, and these experiments led to the discovery that "zero-length" launchers were suitable for planes. Out of the discovery came the Mark 5 launchers—two streamlined posts to support the rocket until the moment of firing. Travel of the round on the launcher was limited to less than 1 inch, but the effect of the airstream at speeds over 200 knots was to "weathervane" the rocket into the line of flight without loss of accuracy. The airplane-rocket partnership took a great step forward with that development. When the Bureau of Aeronautics assumed cognizance over launcher development late in 1943, the large scale procurement of the post launcher

was initiated, and the rail type already in service use was replaced as soon as practicable.

The 3"5 proved a valuable antisubmarine weapon, but it was perhaps more important as an introduction to a more thorough exploitation of the air-to-surface potentialities of rockets. Of course the retrobomb fitted into that category, but its unorthodox and limited use failed to expose the possibilities inherent in the type. The 3"5, on the other hand, was a versatile weapon. The high explosive head developed for the rocket motor proved destructive against light armor, shipping, and personnel. The way was clear to a better utilization of the plane-rocket partnership, and Bureau interest turned toward bigger and better aircraft rockets. Out of that interest and the developmental genius of the NDRC came a series of new air-to-surface weapons.

The first step was simply a matter of devising a larger head for the existing motor. No special design problems were involved. Five-inch thirty-eight caliber antiaircraft projectiles were merely modified and equipped with an instantaneous air-arming and impact firing nose fuze like that used with the 3"5 high explosive head, plus a delay base fuze. The 3"25 motor screwed into the base of the projectile to make an 80 pound rocket about 65 inches long. Use of the standard motors permitted the new rockets to be fired from existing launchers and pushed into service use before the end of 1943. The convenience was gained at the expense of performance, however. With the new 5-inch head, the velocity of the aircraft rocket dropped from 1175 to 710 feet per second.

The reduced speed limited the rockets' usefulness. Accuracy and range suffered and pilots found themselves faced with new tactical problems. The increased payload was an answer to their requests, but use of that power was limited by the range of the weapon and the personal hazards involved in a close attack. A new and larger motor was needed to combine the velocity of the 3"5 and the destructive power of the 5"0 head. The Bureau urged the NDRC to pursue such a project and procured the thousands of feet of metal tubing necessary to speed experimental work at CIT. Work was under way on a new, more powerful motor before the end of 1943. Interim production started in the spring of 1944, and the new weapon was in combat use by August.

With greater velocity than the 3"5 and all the power of the 5"0 aircraft rocket, the new ordnance represented the coming of age of air-to-ground rocket warfare. The weapon gained the semi-official designation of HVAR (high velocity aircraft rocket), but airmen knew it as the Holy Moses. The overall length of the

rocket was 69 inches, its weight, 134 pounds. Like its predecessor, the HVAR used a modified 5"/38 AA common projectile for a payload. A combination of nose and base fuzing permitted a wide range of tactical applications—a fact demonstrated by widespread Army use of the Bureau of Ordnance weapon. Use of the HVAR posed few special problems. With slight modifications and reinforcements, the launcher assemblies already in use could carry the new rocket. Fire control was simplified because the added velocity reduced the gravity drop of the missile. Pinpoint targets actually seemed made to order for the aircraft rockets.

With their new ordnance, each plane equipped with the standard installation of eight launchers packed the power of a destroyer's salvo and possessed whatever range its fuel tanks could give. Their potency was not long in being proved. Though production did not start until the spring of 1944, the 5"0 HVAR saw almost immediate action with both Army and Navy planes. The need was so critical in Europe that some 100 rounds a day were manufactured at CIT, then flown to England for the immediate training of pilots. Requirements mushroomed almost immediately. Once a superior rocket was available, pilots disdained the use of the 3"5 and its immediate successor, the 5"0 AR. Productive capacity could not keep pace with the popularity of the HVAR, so throughout the remainder of 1944 the supply had to be rationed to the various service units.

With supply so critical the Bureau of Ordnance was anxious to find some substitute that would provide adequate training for pilots. At the suggestion of the Chief of Naval Operations, the Bureau initiated a project late in 1943 to develop .50-caliber tracer ammunition that could approximate the velocity and trajectory of the 3"5 and 5"0 aircraft rockets. Many experiments were made with reduced charge bullets, but the outcome was failure. A true rocket was needed to do for aircraft training what the Minnie Mouse had done for antisubmarine practice. The NDRC was ready to take on a new project, so the Bureau turned again to CIT and its own design unit at Pasadena, Calif. The specifications were general. The new rounds were to use a motor already in production, dip into the critical ballistite supply as lightly as possible, be adaptable to the launchers already in service, and match the trajectories of service rounds at battle ranges.

The necessity of matching the characteristics of both 3"5 and 5"0 rockets obviously complicated the design problem. Some work was done to develop two different heads for one 2"5 rocket motor, but effort soon turned to a project to use one head but to provide

two different propellant grains for the motor. With crystallization of design impossible under the circumstances, the whole program remained in a state of flux throughout the spring and summer of 1944. Drawings were available by July, but production naturally remained on an experimental and unsatisfactory basis. The result was a lowering of sights. Instead of attempting to develop satisfactory practice rounds to match the velocities of both 3"5 and 5"0 rockets, the Bureau accepted NDRC and CNO suggestions that production be standardized on the faster of the two rounds. The purposes of training could be served well enough, since the principles of rocket fire remained the same whatever the velocity of the weapon. About January 1, 1945, the program for practice rockets was standardized on one round, the 2"25 SCAR (subcaliber aircraft rocket). Designed for easy manufacture, the rounds were soon available in large numbers. Before the end of the war the rate of production exceeded one-half million rounds a month. With the SCAR the proficiency of pilots rose rapidly, adding to the effectiveness of the three service rounds already available to the fleet.

Meanwhile, work was in progress to carry air-to-ground rocket warfare to its logical conclusion—the development of the largest practicable rocket that could be manufactured rapidly and carried by carrier based aircraft. The Chief of Naval Operations, convinced that "the main strength and offensive striking power of naval aviation lies in the carrier based aircraft squadrons," directed a high priority for such a project. A large caliber rocket was also attractive as a supplement to aerial torpedoes, which were difficult and expensive to manufacture and placed limitations on the release speed of launching planes.

In determining the desired specifications the Bureau was guided by practical considerations. A 1000-pound weight limit was suggested by the capacity of the bomb installations already in use on the planes slated to carry a large rocket. A diameter of 11"75 was suggested by two factors: steel tubing of that size was commercially available and coincided with the diameter of 500 pound semiarmor-piercing bombs which could serve as rocket heads.

Experiments with such a missile indicated success, so the project was put on an emergency basis in June 1944. The CIT group initiated production of the motors, using as a propellant 4 grains of a powder that could be extruded on the presses developed for the 5-inch rockets. While the motors were being made in California, the Naval Gun Factory began making the heads from modified

bombs. Launchers appeared the greatest initial problem, the large missile had to be displaced enough to miss the propellers' arc and to protect the plane from the blast of hot gases. To cope with those problems a displacement type launcher designed to swing the rocket forward and down on two sets of arms was conceived. The solution was not a happy one, but limited production was inaugurated because of the urgency of the problem. Neither the launchers nor rockets were considered perfect, but production was necessary to provide missiles for operational tests. The assembled rocket, known as Tiny Tim, had an overall length of about 123 inches and weighed approximately 1290 pounds. At normal temperatures, the 11"75 rocket reached a velocity of 820 feet per second.

Tests throughout the summer of 1944 indicated that the new rocket was unsatisfactory. Use of the displacement type launcher was limited to F4U aircraft, and release of the weapon proved hazardous. Manufacture could not continue under the circumstances, so the Bureau shifted the emphasis of the program back to a high priority developmental project. By the end of 1944 the results were in hand. An improved propellant and better motor design made the rocket a reliable performer. Perhaps even more important, a better launching procedure was worked out. The displacement launcher with its plane type limitations and excessive air drag was abandoned for a procedure that closely approximated the Bureau's original suggestions. The rockets were simply carried in bomb racks and dropped as free missiles. Attached to the rocket was a lanyard that unwound from a reel on the plane. The unwinding of the reel measured the rocket's distance from the plane and, after a safe number of rotations, electrically fired the motor. Released in free flight and equipped with a superior propellant, the rocket was accurate at ranges up to 4000 yards. The modifications to bomb racks necessary for the drop firing of rockets were so slight that planes could alternate between the two weapons at will.

The power of the rocket was enormous. It proved capable of penetrating up to 4 feet of reinforced concrete—a common enemy defense—and was valuable against both land and sea targets. Some minor changes still had to be made, but the rocket was ready for production early in 1945. By March it was actually in action, giving relatively small planes the firepower of a 12-inch gun for one brief but important moment. Few of the massive rockets were ever fired in action, however, partly because the *U. S. S.*

Franklin, 1 of the 2 carriers whose planes were supplied with the new weapon for service tests, was inactivated by a kamikaze before any of its Tiny Tims had been expended.

The aircraft rocket program that terminated with Tiny Tim had its origin in the antisubmarine campaign that predated the United States' entry into World War II. Running parallel with it was an equally important development of rocket weapons for surface use. In fact, the two types shared a common origin in the Mousetrap ammunition with which the Bureau of Ordnance introduced the fleet to rocket potentialities. The first weapons were naturally designed primarily for defensive purposes. The needs that inspired them continued, of course, but the very first year of war also introduced requirements for offensive ordnance. In particular, amphibious warfare—obviously slated for an important role by geographical necessity—imposed new demands on the Navy, whose function it was to “soften” the beaches, get the troops on shore, then support them with firepower as long as necessary.

Conventional weapons, especially aircraft bombs and bombardment projectiles, were a partial answer to the problem of destroying the enemy's installations, or forcing him to take cover, but their use left a considerable gap in ordnance needs. Bombing had to cease entirely before troops could be put ashore, and even shore bombardment was restricted during the critical landing phase of invasions. The interval between the end of ship and plane cover and the landing of sufficient supplies for a protected beachhead was a dangerous one, yet one on which the very success of an invasion hinged. Some weapon was needed that could duplicate the firepower, if not the accuracy of naval bombardment, and continue an effective cover as the first invasion waves moved to the beach.

The solution that barrage rockets offered for the problem is now familiar but it barely came in time to meet the deadline imposed by the Allied invasion of North Africa. Their application came as the result of a suggestion by Vice Adm. Wilson Brown, whose interest in rocketry was stimulated by its early application to anti-submarine weapons. Recognizing the potentialities of rocket propulsion, Admiral Brown suggested the development of a barrage rocket suitable for use on or with landing craft.

The suggestion was picked up immediately by the NDRC unit at CIT—a group of enthusiasts who were always anxious to propagate their own faith in rockets. Drawing on the stockpile of ideas and materials accumulated during the development of anti-submarine weapons, they effected a quick marriage of convenience

between the 2"25 Mousetrap motor and a 20-pound general purpose bomb. The composite weapon that resulted filled the first tentative requirements for amphibious support. The motor provided a range of about 1100 yards, while the 20-pound projectile carried slightly over 6 pounds of TNT. The Bureau was never completely pleased with the fragmentation characteristics of the projectile, but the demand for the weapons was too great to permit a search for perfection. If rockets were to be supplied while the requirement still existed, limitations had to be accepted. A more important problem connected with the development of the rocket concerned fuzing. The original models made by CIT carried a base type, but nose fuzing was obviously more satisfactory for barrage purposes. At the request of the Bureau of Ordnance, the California group then designed another fuze which, when modified and improved by the Naval Ordnance Laboratory, became the Fuze Mark 137. This propeller arming, impact firing, non-delay, nose fuze proved satisfactory enough to become the standard fuze for the 4"5 Barrage Rocket.

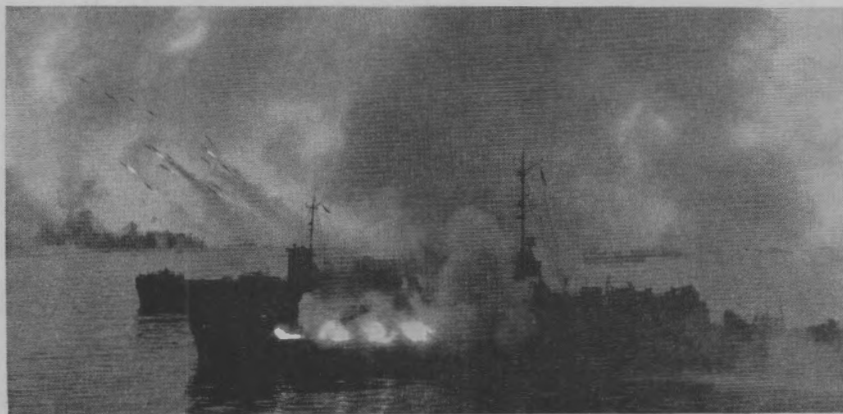
Once the characteristics of the rocket and its components had been determined, the development of suitable launchers was inaugurated. Size and weight had to be kept at a minimum if small craft were to serve as launching sites, so experiments settled on a simple installation consisting of launcher rails welded together to form a 4 layer frame. Each layer held 3 rockets, for a total of 12 rounds per installation. No train was possible. As with airplane rockets, the craft rather than the launchers had to be aimed. These first launchers, designated Mark 1 by the Bureau, could be elevated, however, and provided some control over the range of the rockets.

By August 1942 both the Mark 1 launcher and the 4"5 Barrage Rocket were ready for tests. Crews were hastily trained, and on August 25 a demonstration was staged on Chesapeake Bay. Reception was enthusiastic. Only 4 days later the Bureau asked the California Institute to supply it with 50 launchers and 3000 rockets. Faced with the deadline of the forthcoming African invasion, the Bureau requested crash production. Scarcely 2 months later the new rockets were fired at Casablanca, beginning a combat record that subsequently included the series of invasions making up the history of the war.

Of course, between Casablanca and Okinawa many changes were made in rockets, launchers, and their tactical applications. One of the first innovations was the design of a new launcher, the Mark 8, to succeed the earlier model developed by CIT. The new

Bureau installation was similar in appearance to the Mark 1, but eliminated the elevation feature. Best results were obtained when rockets were fired at their maximum range, so the adjustable frames simply added to production and installation problems without providing a compensatory gain in efficiency. The Mark 8 was also superior to its predecessor in that an improved electrical firing system permitted panel control of the fire from a large number of launchers.

While by no means the ultimate in barrage rocket launchers, the two "egg crate" types were satisfactory enough to permit a new trend in rocket warfare—the development of rocket ships. The original plan was to use the barrage rockets from the landing craft that took troops to the beach, or from small support craft that went in with or just ahead of the personnel carriers. Both tactics were employed, but of more significance was the development of larger rocket ships. The British inaugurated the practice by relieving some of their LCT's of tank carrying duties and loading the well decks with rocket launchers. Twice as large as American craft with the same designation, these converted vessels represented an enormous accumulation of firepower. While that power could not be utilized with the accuracy of conventional gunfire, the shallow draft ship could move in close to the beach and saturate enemy positions. Even after troops were landed they were valuable for area bombardment. The enemy was introduced to this new application of rocket power during the invasion of Sicily. Later in 1943 the United States Navy received some of these craft by transfer from the British Navy. Though they continued in United States service through the invasion of Normandy, American crews found the



LCI rocket ships could move in close to the beach and saturate enemy positions.

craft generally unsatisfactory. The idea, on the other hand, proved popular, and American variations on the theme soon appeared in the Mediterranean and the Pacific.

Early in 1943 the first indigenous United States rocket ships made their appearance when the operating forces mounted Mark 1 and Mark 8 launchers on the decks of LCI(L)'s. Each of these 350-ton troop carriers could carry 40 launchers, and without reloading, throw 480 projectiles against an enemy beach. This firepower permitted a real umbrella of support for initial invasion waves. The trend toward conversion was stimulated later in 1943 by the development of still another launcher assembly for beach barrage rockets, the Mark 7. This new device, developed by CIT and rushed into production by the Bureau of Ordnance, was a single guide automatic launcher that combined the capacity of the crate type frame with important savings in deck space. The Mark 7 contained only one launching rail, but beside and above it was a magazine that employed gravity to feed a continuous stream of rounds to the firing rack. As each round was fired, another fell into position; in 4 seconds 12 rounds could be fired from each installation.

The new launcher was available in record time after its development and, before the end of 1943, began to replace the earlier types on converted LCI(L)'s and smaller amphibious craft. Though the Mark 7 was definitely superior to its predecessors, it had one principal disadvantage: if a rocket failed to fire and remained in the launching rack, the whole installation was inactivated until the defective round could be removed. Improvements in rocket motors and firing circuits tended to minimize that handicap, but meanwhile the Bureau developed still a fourth launcher for the 4'5 beach barrage rockets. This was the Mark 11, an automatic firing, continuously reloadable launcher that featured a device for jettisoning misfired rounds. While the Mark 11 eliminated the main defect of the Mark 7, the development of more dependable rounds obviated the necessity for replacement. By the end of the war more Rocket Launchers Mark 7 had been procured than the total of all other Navy launchers.

The amphibious problems that stimulated the development of new rocket weapons were by no means all met by applications of the beach barrage rocket. While fuze variations gave the 4'5 BBR a considerable versatility, it was primarily an antipersonnel weapon. Left largely unsolved was the problem of coping with mines and other obstacles often encountered in the shallow water adjacent to invasion beaches, as well as the land mines and fortifi-

cations at the water's edge. Underwater demolition teams were trained to destroy such obstructions, but the work was hazardous and slow. The 4'5 rocket lacked the power required for the work, while heavy caliber gunfire created craters that were often as much of a problem as the original obstruction.

In the spring of 1943 both the Army and Navy initiated experiments to find a solution to the tactical problem. Joint tests proved that, with a few minor modifications, the 7'2 rockets used as Mousetrap ammunition were effective for demolition work if enough of them were concentrated on the area under attack. Launcher development proceeded posthaste. The first result came in mid-1943, with the production of a 32-guide launcher dubbed the Porcupine and designed for use from an LCM. The Bureau was not satisfied with the firepower of the launcher and continued its own experiments. Later in the year, a second demolition launcher was submitted by the California Institute. This was a 21-guide launcher which the Bureau designated the Mark 25, but no production was undertaken. Designed for use in pairs from DUKW's, the equipment was not an answer to the demolition problem. Of the two early developments, the Porcupine more nearly fitted the requirements, so the Bureau contracted with the American Laundry Machinery Co. for the development of a larger



The "Woofus", or Rocket Launcher Mark 24, installed in the well of an LCM.

but similar launcher that might be used from LCM's. Early in 1944 the project yielded results with production of the "Woofus," or Rocket Launcher Mark 24. This unit consisted of 120 rails so arranged as to fill the entire well of an LCM, yet capable of quick installation and removal. When carrying the 18,000-pound assembly, the craft could fire the 7"2 demolition heads from 840 to 1260 feet, depending upon whether 2"25 or 3"25 motors were used. The first units were on their way to the Mediterranean by early April 1944, and later in the year were used in the invasion of Southern France.

Another approach to the same tactical problem was the use of rocket propulsion to project grapnels and a steel cable over the obstructions, then drag them away by retraction. Research in this project began in September 1944, and resulted 7 months later in service issue of Grapnel (propelled) Mark 1 and the Rocket Launcher Mark 26. Known in the fleet as the Cutteroo, the device was never used against enemy installations, though its production was justified by its use in collecting earth samples after atomic bomb tests.

While the Cutteroo and the Woofus had important special applications, the 4"5 rockets remained the principal amphibious rocket weapon. As invasions followed one another in rapid succession in both the Mediterranean and Pacific theaters, the beach barrage rounds became increasingly important. Both numbers and types multiplied. Procurement jumped from scarcely more than 5000 rounds in 1942 to 107,564 in 1943 and 687,132 in 1944. And in addition to the instantaneously fuzed high explosive round first produced, the Bureau furnished the fleet with a variety of other rounds. Soon their application spread to the point where they not only provided cover for landings, but actually went ashore with the invading troops. Several portable launchers were provided to enable individual marines to manhandle launchers whose firepower duplicated that of heavy artillery. Still other launchers permitted true amphibious vehicles to accompany invading craft to the beach, then clamber ashore to continue supporting fire.

Each success caught the imagination of the fighting forces and suggested new applications for the weapon. Late in 1943, the 4"5 Barrage Rocket received its most unorthodox application and gained its greatest mobility through installations aboard Pacific theater PT boats. The idea for this, as for LCI(L) rocket ships, originated in the fleet, then received endorsement and support from the Bureau. Earlier attempts to increase torpedo boat firepower through the use of rockets had centered around attempts to

group bazooka barrels into a cluster that could throw the familiar army projectiles. That attempt had been given up as impractical. At first glance, barrage rockets seemed even less practical for ship to ship use because of their wide dispersion, but experimental installations in the Pacific proved otherwise. The first boats were armed with borrowed egg crate type launching frames, but once their use was justified the Bureau adapted the gravity feed Mark 8 for PT use. Special blast shields were designed to protect both vessel and crew and the installations became widespread in the Seventh Fleet. As torpedo targets declined in number the importance of the rocket installations grew, emphasizing both the potential of the rockets and the need for weapons tailored more specifically for the torpedo craft. This was the same general situation that existed with regard to the converted LCI(L)'s in the fleet. Both developments soon progressed far beyond their jerry-built origins.

In May 1943, the Bureau of Ordnance indicated the future envisioned for such craft by requesting the development of a long-range rocket for firing from shipboard against shore targets. Ten thousand yards—nine times the reach of the 4'5 BBR—was suggested for the range, and specifications called for a 3'25 motor using solventless extruded ballistite. That proved a large order, and one that opened a new field for military rockets. Long range was only one of several characteristics that existing rockets lacked to fill the new requirements. Accuracy was a major problem. The dispersion of the 4'5 beach barrage rocket was acceptable because of its tactical application to create a blanket bombardment, but the possibilities suggested by rocket ships could be exploited only if greater accuracy were possible. Moreover, the long, fin stabilized barrage rockets governed and restricted launcher development and reduced the capacity of ships. Rocket workers realized that the Bureau requirements demanded the development of a new-type weapon and, in the fall of 1943, the NDRC group launched a project to design spin stabilized rockets. With that program the United States rocket development completed a cycle and reentered a field familiar before the Mexican War.

The use of spin to stabilize rocket's flight offered a way to cancel out the forces that caused deviation. With dispersion thus reduced, rockets could be relatively accurate at ranges that would have scattered beach barrage rockets over an unacceptably wide area. And with reduced length and no protruding fins, spin stabilized rockets opened the way to compact and faster firing launchers. The spin itself was easily achieved by canting the

nozzles that closed the motor tube, but development of the new type was not nearly so simple as the principle implied. The centrifugal force imparted by rotation imposed new stresses that demanded a redesign of motors. Moreover, the ballistics of such rockets was an unexplored field in which little progress was possible until new techniques for measurement were devised.

Throughout the year from the fall of 1943 to that of 1944, the development of spin stabilized rockets ran concurrently with the accelerated procurement of beach barrage and aircraft types. In August 1944, the first of the drawings of the new type reached the Bureau, where immediate steps were taken to shorten the interval between development and production. Orders were placed for both 3:5 and 5:0 SSR, with initial deliveries requested for October. While contractors tooled up for such jobs, CIT was expected to meet immediate production requirements for motors and propellant grains which could be loaded in ordnance plants.

The variety of spinner rockets developed was about as extensive as the types of fin stabilized rounds already in production. The 3:5 proved of relatively minor importance, though two light and portable single shot launchers were developed to permit use of the weapons by partisans behind enemy lines. Five-inch rounds were produced for PT boats, amphibious barrage work, and aircraft. The rockets developed for PT boats were high velocity rounds with high capacity heads suitable for shore bombardment and attacks on light shipping. With a range of approximately 10,000 yards, they gave PT boats new usefulness just when the disappearance of suitable enemy targets tended to neutralize the effectiveness of their torpedo armament. In recognition of the changed requirements, the Bureau began procurement of launchers in September 1944 to replace the forward torpedo racks. CIT and the Bureau worked together to design the installations, which turned out to be reminiscent of the discarded cluster of bazooka barrels. Eight tubes were arranged in 2 tiers and designed for bow mounting. Each PT boat could carry 2 of these Mark 50 installations. Placed on the edge of the decks, the launchers swung outboard for firing, but could be folded in for loading and clearance.

Early in December the launchers began to move from the Bureau contractors to the Philippine area in which the PT's were active. The first installations proved the value of such armament, but emphasized the need for extensive training if the potential was to be realized. The supply of rockets was marginal, at best, and remained critical well into 1945. Their use as a training aid was out of the question, so some special device was necessary for

the success of the program. The answer was found in the mounting of a fixed 20-mm on the bow of each PT, wired for electrical firing in such a way that the gun fired on the signal that ordinarily activated the rocket tubes. Properly mounted, the fire control problem was the same for both weapons, so that the unusual substitute served as an adequate training aid. In fact, the 20-mm so duplicated the performance of the Rocket Launcher Mark 50 that the training device evolved into a combat weapon. Crews simply wired both gun and tubes to the same firing key, then fired all three simultaneously.

The second and most important application of spin stabilized rockets was to the beach barrage problem. Within that category were developed common, general-purpose, and high capacity rockets with combination of nose, auxiliary detonating, and base type fuzes. Though these rounds lacked the velocity of the 10,000-yard PT rockets, their range of 5000 yards gave them almost 5 times the reach of the 4'5 BBR. The design of launchers for beach bombardment purposes posed no immediate problem. The automatic gravity feed Mark 7 served as a model for a similar installation designated Rocket Launcher Mark 51. In contrast to the wide dispersion of the 4'5 barrage rockets fired from the Mark 7 launcher, the spin stabilized rounds traveled five times as far and still tended to fall within an area of 500 by 500 yards. Late in 1944, the first of the new launchers was installed aboard LCI(L)'s. Sixteen of the ships were supplied with 6 launchers each in time for the invasion of Iwo Jima, where they laid down an initial beach barrage, then stood off shore to deliver firepower at the call of forces on shore.

Meanwhile, plans were progressing for even more powerful rocket ships. In October 1944, the Bureau was notified that the Commander in Chief, United States Fleet, desired 12 support ships able to deliver a heavy concentration of fire on beachheads during the normal period for rocket barrages, then back up the invading forces with direct fire support of troops beyond the beach areas to approximately 4000 yards. Other projected uses for the ships included call fire missions, high trajectory fire against reverse slopes, laying smoke screens, and even total fire support for small landings when larger ships were not available or necessary.

Draft and maneuverability requirements led to the selection of the LSM as the logical ship for conversion, but armament was difficult to determine. The gap between design and production had not yet been closed in the spin stabilized rocket program, yet the 4'5 BBR was obviously not capable of delivering the required

range. A January 1, 1945, deadline precluded extensive experimentation; materials readily available had to be used if the dozen ships were to reach the fleet in time for planned operations. The immediate solution came with the decision to use 5-inch aircraft rockets and simple rail type launchers on the first of the ships, then supply the last few with the spin stabilized rockets just getting into production. Though there was no real alternative, the decision was hesitantly accepted in the Bureau. Designed for high-speed release, the aircraft rockets had many disadvantages for shipboard use. The large fins could exert only part of their stabilizing function during the low velocity flight of static fired rockets, yet a slight bend in the fins would certainly cause erratic flight. But in this case urgency outweighed hazards, and the required installations were rushed to the waiting hulls. Eight of the vessels were equipped with the fin stabilized rockets and launchers that permitted them to fire 480 rounds in 30 seconds. Subsequent attacks required considerable delay, however, since the first reloading required 2½ hours and subsequent ones took almost twice as long.

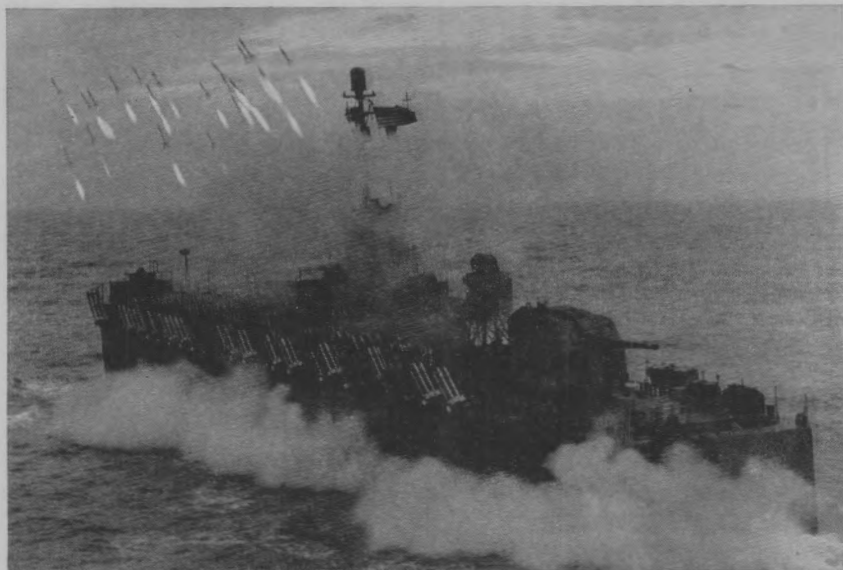
While the first ships were outfitted and sent off to Pearl Harbor, the Bureau pressed to provide better armament for the remaining 4 vessels. The rocket program, always a high priority affair, assumed even greater urgency as rockets were pushed through production faster than changes could be completed in their drawings. The Mark 51 launcher and the 5"0 SSR both made the deadlines for the last 4 LSMR's, permitting them to have a firepower that matched the total of the 8 ships equipped with aircraft rockets. Those with spinners could fire 1020 rounds in 1 minute, then reload and repeat that performance in 45 minutes. Even a third loading could be accomplished in less time than the earlier ships required for their second. The LSMR's arrived in the Pacific too late to see action in the Iwo Jima invasion, but they performed yeoman service during the action at Okinawa.

Though the LSMR represented a real improvement over the LCI(L)'s that had earlier been converted into rocket ships, they were considered of only interim design. The ultimate plans of the Commander in Chief called for 48 LSMR's that could fire 500 rounds during the first minute of action and sustain a rate of fire of 300 rockets per minute thereafter. The launchers were to be continuously reloadable and capable of train and elevation by remote control. The June 1 deadline permitted the use of spin stabilized barrage rockets, but it meant a race to develop a launcher that could meet the stiff requirements. As was so often the case,

the urgency precluded any project to develop new ordnance designed just for the specific requirements at hand. Some combination of materials on hand had to be used.

The requirements for remote control of the mounts in train and elevation demanded the use of a power mount. The Gun Mount Mark 1 Mod 2 designed for twin 40-mm installations was selected as the base. With that start, the Bureau initiated development of two separate launcher assemblies, the Marks 101 and 102. The latter was to be of more advanced design, but in case it was not ready in time for the deadline, the Mark 101 would provide a safety margin. This was essentially eight Mark 51 launchers welded to girders on a 40-mm twin mount. Only two such equipments were ever prepared, however, because the superior Mark 102 was readied in time for installation aboard the "ultimate" LSMR's. The development of the Mark 102 broke all existing records for the design of a successful, ultramodern, major piece of ordnance. Only 2 weeks elapsed between the preparation of a free-hand sketch in the Research Division and the delivery of general arrangement plans, ready for detailing, to the Naval Gun Factory.

This launcher assembly was an automatic type for firing 5"0 SSR. The 40-mm AA gun mount, modified to eliminate unnecessary parts and accommodate the rocket launcher and hoist, served as the carriage. A dummy gun on the mount was controlled by a Gun Director Mark 51, thus furnishing fire control for rocket firing. Two tubes were mounted beside the dummy gun. Operating simultaneously, they alternately moved down to connect with the ammunition hoist installed below the mount, then, when rockets had been raised into the tubes, lined up with the dummy gun to become firing tubes. The two rockets were fired a split second apart, then the operation was repeated automatically. With this mount, a rate of about 30 rounds per minute could be maintained. Ten assemblies on each ship, the usual rocket armament, permitted a sustained rate of fire reaching approximately 300 rounds per minute. The addition of a 5"/38 DP gun, 20-mm and 40-mm AA guns, plus four 4"2 mortar assemblies gave these rocket ships an accumulation of firepower previously undreamed of for hulls of that size. Some veteran officers felt that the bulk and variety of armament was greatly out of proportion to the technical talent apt to be available aboard ships with such small crews, but that question remained open. The new craft did not arrive in combat zones soon enough to contribute to Japan's defeat. In any event, they represented the logical extension of wartime rocket development and provided an imposing climax to the Bureau's program.



LSMR's represented an accumulation of fire power previously undreamed of for hulls of that size.

By the middle of the last year of war 10 basic rocket weapons and many times as many variations of them had been produced for the fleet by the Bureau of Ordnance. From a start devoted to antisubmarine weapons, rockets ultimately gained important applications in air-to-surface, surface-to-surface, and in a more limited way, air-to-air warfare. There were in addition, however, a variety of miscellaneous projects which applied rocket propulsion to specific problems that arose during the war. One of the first of these was the development of target rockets that could simulate the flight of hostile aircraft. As planes became faster and more maneuverable, towed sleeves became more and more inadequate for training purposes. Relatively fast and large rockets proved an invaluable training aid, as efficient as drones and far less expensive. Erratic flight, an often bemoaned characteristic of rockets, was turned into a premium when gunners learned by tracking them the problems of hitting evasive aircraft.

Other rockets were produced as a countermeasure against enemy radar. While the Allies had a head start in radio detection equipment, the enemy installations became a threat late in the war. One of the most effective defenses proved to be the release of clouds of aluminum strips that confused radar signals and created a screen for operations. And one of the most effective ways of projecting

that metal screen was by rocket propulsion, which offered the short range and high trajectory that proved desirable. Rocket Launchers Mark 31 and 32 were built for shipboard installation and equipped with so-called "Window Rockets"—rounds that contained strips of varying lengths and a bursting charge to spew them into the desired cloud. Using these weapons, a handful of men operating in limited space could fire rockets fast enough to prevent dissipation of the defensive screen.

An even greater threat than enemy radar was posed by the advent of Japanese suicide attacks late in 1944. The security of the fleet was seriously jeopardized by the relentless kamikaze, against which new defenses had to be constructed. The program to devise better anti-aircraft protection merged with the rocket program on December 6, 1944, when the Bureau of Ordnance initiated project COSO, a program designed to determine the comparative effectiveness of 40-mm quad mounts and VT-fuzed spin stabilized rockets against suicide aircraft attacks. Since comparisons could hardly be made before anti-aircraft rockets even existed, the project was in effect devoted to the conversion of rocket installations to new purposes. Experiments centered around the 5"0 SSR and the Marks 101 and 102 launchers, but they were invariably stalled by a failure to achieve satisfactory proximity fuzing for the rounds. Even after modified motors were built, the VT fuzes proved inapplicable.

Early in 1945, COSO Jr., was inaugurated to parallel, then succeed the original project. In this new program hope was based on the use of Rocket Launcher Mark 101 in conjunction with VT-fuzed 2"5 SSR, but the Army rounds proved no more adaptable than the Navy's own. Other attempts were made to develop closed breech rocket launchers and discover some optimum rocket and fuze combination, but at war's end rockets still did not appear likely to rival conventional guns as an anti-aircraft defense. While investigations proceeded, however, the LSMR's were pressed into service as picket ships, where they were effective enough to become themselves the target for suicide bombers. Thus, by V-J Day a weapon that had not even existed a year before the outbreak of war had become one of the most important types in the Navy's arsenal. Ten separate kinds of rocket propelled projectiles or bombs and 27 types of launchers saw service against submarines, ships, shore installations, and planes.

So many new weapons and devices could not have been furnished the fleet so quickly through familiar or routine channels. A sense of urgency characterized the entire rocket program, and a variety

of factors distinguished it from other parts of the Bureau mission. To a considerable extent the rocket program was an appendage, rather than an integral part of the Bureau organization. Design and development were necessarily performed under NDRC contracts rather than directly by the Bureau's scientists. The cost of that system was that the program could never be really "channeled," as one frustrated administrator put it, but the compensations were obvious. The group of men assembled on the campus of the California Institute of Technology were dedicated citizens who represented the greatest accumulation of rocket knowledge available in the Nation. Often they worked on the compulsion of their own imagination until they could offer the services a weapon they thought might be of value; more generally, they developed rockets to fulfill particular functions specified by the services themselves. In either event, the scientists set the pace for the rocket program. Independent and zealous, that developmental pace was often more than could be implemented by the productive facilities available to the Bureau.

The rocket program introduced, in late 1942, a whole series of problems that were reminiscent of the hectic days that followed the declaration of national emergency in 1939. The earlier period required the conversion of a peacetime economy to the needs of war—a gigantic problem involving tremendous expansion in the machine tool industry, the diffusion of the know-how requisite for the production of ordnance material, and the creation of facilities capable of meeting the demands of a nation preparing for war. While many aspects of that problem still remained in late 1942, the outlines for its solution had been established and progress was spectacular. Manufacturers who lifted eyebrows at the President's early pronouncements on what the Nation would produce were already approaching those prophetic figures. The whole Nation was brought into the production picture. Ordnance procurement, once largely restricted to Government plants, spread out to involve the large industries of the east, then the west, and finally reached down to include even small plants all over the country. Indicative of that new trend was the fact that a one-man shop actually received the Army-Navy E for its contribution to the ordnance program.

Rocket manufacture, however, had not been included in the plans that directed the initial expansion of ordnance facilities. A relatively late arrival, it had to be superimposed on a crowded economy, just as all war production first had to be superimposed upon a peacetime economy. Neither rockets nor launchers were compli-

cated articles, but that relative simplicity was more than offset by the dearth of unobligated facilities. The more experienced contractors were already assured of all the business they could assume; even the "war babies," those plants that owed their very existence to the emergency, were usually swamped with military orders. The machine tool industry, upon which the speed of initial manufacture was necessarily predicated, had experienced a great revival during the period of industrial expansion, but was subsequently diverted in large part to the manufacture of components for B-29's. And finally, the rocket program made its debut at the same time that the Army was seeking out any surplus capacity that the Nation might have for an acceleration of its artillery production, and when the Bureau was straining its own contractors with demands for high capacity ammunition. Both these programs were in direct competition with rockets for facilities and materials, since rocket heads were made of modified projectiles that had to be met from the Navy's overtaxed lines, or fabricated from tubing that the Army coveted for its artillery ammunition. Materials were so short that rocket motors were actually manufactured from oil well casings ripped out of abandoned wells. Others were made from defective projectiles, rejected for their intended use but suitable for the attachment of rocket motors.

Initiating production was further complicated by the problem of establishing requirements. In the case of familiar articles like gun ammunition, the Bureau was capable of reliable estimates. On the basis of experience, the guns and torpedo tubes installed in the fleet could be multiplied by the probable expenditure to give a figure for requirements. No such arithmetic could furnish an answer for the rocket planners. There was no experience to serve as a guide; types multiplied month by month, extending the applications and the popularity of the weapons. Launchers were light and so easy to install that the fleet could easily fire more rockets than the Bureau could procure. Moreover, the scientists at CIT were as talented at salesmanship as they were with development and were prone to sell the fleet on a new weapon before its predecessor was through the throes of labor pains. The effect of such promotion was often to dry up requests for an available weapon and to create requirements for a rocket for which even drawings were not available.

The result was that requirements were always uncertain, frequently fluctuated, and were usually higher than could be met. Acting on CNO directives, the Bureau simply procured to the limit of available industrial capacity. Since that supply almost invari-

ably fell short of demand, the rockets were allocated to various commands on the basis of quotas established by the Chief of Naval Operations. In many cases the Bureau anticipated outside directives and paved the way for the manufacture of a particular rocket even before CIT completed experiments, but rocket requirements jumped by such astonishing percentages that even imaginative anticipation could not guarantee adequate production.

To some extent the Bureau of Ordnance was remiss in preparing a proper place for rockets in its own organization. Since rockets were newer than the organization of the Bureau there was no type assistant to provide overall direction, as there was for more familiar items of ordnance. Moreover, the role of the NDRC in research and of the Chief of Naval Operations in planning tended to decentralize rocket work. Finally, the distinctive problems raised by the various components required to complete a rocket demanded separate sections with cognizance over propellants, motors, and launchers. The problem of combining specialization with coordination was certainly not new to the Bureau, but nowhere was it more acute than in the rocket program. Until the various projects could be stabilized—a golden age that did not arrive until late 1944—special procedures were needed for the rocket program. Their institution was delayed, partly because the Bureau tended to follow the fleet in becoming “rocket minded.” Guns seemed more important than a complementary weapon. Rockets became a major ordnance item before they gained a place of corresponding importance in the organizational structure of the Bureau of Ordnance. As late as April 1944, Captain Snackenber, ammunition coordinator for the Bureau, complained that “when the Army wants rockets they get generals while the Bureau of Ordnance gets lieutenants.”

The unique character of the rocket program complicated the problem of meshing it into normal Bureau procedures, but early in 1944 the Bureau made new provisions for the direction of rocket procurement. A special expediter was appointed and monthly conferences were instituted. Rear Admiral Kitts, Deputy Chief of the Bureau, served as chairman of the meetings and assumed full responsibility for the program under the unofficial title of “Rocket Czar.” Officers were sent into the field to visit contractors and serve as general expediters. The new organization helped “graft the rocket offshoot on the main stem of the Bureau,” but Ordnance remained in the uncomfortable position of being pushed rather than pushing.

By December 1944, the program had grown too large to be handled by the Bureau alone, and reinforcements came from the Naval Material Inspection Service. Procedures were established whereby each inspector was made responsible for following all rocket program orders in his district and for exerting every possible effort to insure delivery on schedule. All correspondence concerning the projects bore a special stamp, "Navy Rocket Program," that insured special treatment all along the line. This comprehensive supervision of every phase of the program from planning to actual delivery produced results. Although Bureau production on any real scale did not start until the spring of 1943, procurement accelerated at such a pace that purchases were slated to reach \$100,000,000 per month during the last quarter of 1945. While the war's end precluded such an achievement, the actual results were impressive. The value of rocket production climbed from a cumulative total of \$10.2 million at the end of 1943, to \$86.3 million during 1944, and to \$196.2 million for the first 7 months of 1945. Launchers and various accessories cost a total of \$12,248,034, raising the value of the entire wartime rocket procurement to \$304,948,034—a figure that did not include the millions spent for industrial expansion.

The construction of new facilities involved several lines of approach. Facilities contracts were placed with major steel companies to increase the Nation's forging capacity; draw benches were purchased and installed in several plants to produce the steel tubing needed for rocket motors; naval ammunition depots, especially those at Crane and Hawthorne, were provided with loading facilities; the propellant capacity of the Nation was multiplied to provide the dry extruded powder which remained the Damocles sword over the rocket program. In addition, brand new facilities were constructed. The largest of these was the Naval Ordnance Test Station at Inyokern, but its relationship to the rocket program was through development, rather than procurement.

More important for production was the Naval Ordnance Plant, Shumaker, near Camden, Ark. Built during the last year of the war at a cost exceeding \$60,000,000, the plant was destined to become the principal rocket loading, assembly, and storage plant for the entire Nation. Finally, testing ranges were constructed at key spots over the country. Since rocket and launcher production was new to all manufacturers, was partly in the hands of contractors who had no previous ordnance experience, and suffered from fluctuating specifications, a relatively large percentage of all pro-

duction had to be subjected to firing tests. Neither old-fashioned calipers nor new fangled quality control offered substitutes for the delaying procedure. Use of established test ranges involved time lost in transportation, so the Bureau erected special rocket ranges near each of the loading facilities. The test rounds moved straight from the assembly lines to the proof sites. Where rejections were necessary, the cause could usually be uncovered soon enough to eliminate the trouble from all subsequent lots.

The process of building plants and finding contractors was still in progress when the war ended, but the most critical phase of the facilities problem passed early in 1944. Prior to that, the Bureau depended on CIT to supply the weapons they developed until responsible contractors could be provided. Surprising amounts of equipment could be procured from the university group, despite their lack of practical experience with production problems. Their technique was to round up a large number of subcontractors in the Los Angeles area, then farm out the manufacture of the various rocket components. Each night, trucks made the rounds of the plants, picking up the day's output. This daily contact provided ample supervision, while the relatively small scale of production permitted selective assembly and the maximum utilization of parts.

Unfortunately, the same techniques were not applicable on the scale needed for Bureau procurement from its own contractors. The same degree of supervision was obviously impossible and manufacturers found themselves faced with problems which the CIT scientists largely escaped. Perhaps the greatest of these was the instability of the whole program. Rocket development was a continual thing, usually running concurrently with production. The result was that design changes were frequent and specifications uncertain. Faced with such a dilemma, the Bureau found reliable drawings difficult to obtain—a situation further complicated by the 3000 miles that separated the Bureau from the source of rocket development. A private contractor was established at Pasadena to provide current drawings, but the unit proved unable to cope with the situation. In February 1944, the Bureau sent an experienced officer to supervise the contractor's work. When results were rewarding, others followed, until the Bureau practically inundated its own contractor. The logical extension of the trend came with the establishment of an official Bureau design unit at Pasadena in May 1944. Thus, part of the Bureau was on the site of rocket development, while the bulk of the cognizant sections were located near the center of the Nation's industrial capacity. True stability was never possible in the rocket program,

but the readjustment did provide the earliest possible crystallization of each design. Manufacturers were relieved of one of their greatest sources of exasperation.

While the overall picture of rocket procurement was a discouraging composite of soaring requirements, inexperienced manufacturers, frustrating design changes, and shortages of skilled labor, tools, and critical materials, the ultimate results were a credit to the Bureau and its contractors. That requirements could seldom be met in full was less significant than the fact that well over 8 million rockets and thousands of launchers were procured from an industrial capacity that seemed strained before the first round was even placed on order. The files of the Bureau bulge with examples of spectacular procurement in the face of unprecedented difficulties, but none better illustrates the tempo of the rocket program than the story of the debut of Rocket Launcher Mark 7. At the beginning of November 1943, no such equipment existed; at the end of the month it was still no more than a Bureau designation for an unproved launcher developed at the California Institute of Technology. Yet only 1 month later, 252 launchers and the necessary accessories were on their way to service in Pacific combat.

The decision to place the launcher in production was made on the basis of limited experiments with a few handmade models. Only preliminary sketches existed. When first introduced to the new item, the Research Division estimated that 2½ months would be required just to complete drawings for the launcher. Even more important, the preproduction testing of the Mark 7 was so meager that there was no assurance that the average crew of a landing craft could duplicate the performance of a few scientists. On December 16, 1943, while the status of the Mark 7 was in this undefined state and little more than an idea, the Bureau was requested to ship 252 launchers and accessories to the Pacific by December 23, 1943.

Normal procurement methods were obviously inadequate for such an emergency order. A producer had to be hand-picked for the job from an area where transportation, materials, and skilled labor were all abundant or prompt delivery could hardly be expected. Scanning its lists, the Bureau selected the Joshua Hendy Iron Works, Sunnysvale, Calif., for the contract. In addition to meeting the usual requirements, the company had several things to recommend it for selection: a location close to the shipping point, a creditable ordnance production record, and proximity to CIT—the only place in the world where even a vague definition of the desired product existed.

On the same Thursday that the Bureau was asked to procure the launcher, Joshua Hendy agreed to accept the job, a truck was sent to Pasadena to pick up the model launcher, and lists of needed materials were compiled. The next day was spent purchasing supplies, securing blue prints, and ferreting out competent subcontractors. By Saturday, detailed drawings were completed and tool design and fabrication were well underway. Within another day pilot models were completed and newly established assembly lines were ready for operation.

Monday morning, December 20, 1943, marked the beginning of actual production, as skilled laborers borrowed from shipyards and nearby factories began working on unfamiliar items in a strange plant. One day later the first production unit was completed, fired, and labeled "satisfactory." Subsequent launchers moved from the assembly lines to waiting trucks that whisked them to the Naval Ammunition Depot, Fallbrook, Calif., for electrical fittings and shipment overseas. Production continued through December 23, when the required launchers and a safety margin of a dozen extra had been produced. The deadline was met, allowing operations to proceed as planned. During the war this particular production story was perhaps overglamorized and even embellished, but the ingredients for drama were certainly abundant.

While by no means typical, the debut of the Rocket Launcher Mark 7 was not merely an isolated and uncommon incident. Urgency was normal throughout the rocket program. Each of the 10 rocket types and the 27 varieties of launchers introduced its own series of problems to plague the Bureau. By the end of the war, however, production had climbed to the point that even in the face of multiplying types the requirements were becoming less critical. Spin stabilized rockets were an exception, but even those new weapons were moving to the fleet in large numbers when the Japanese capitulated. With their great range and relative accuracy, they represented the apex of the rocket program. Rockets never did—and were not supposed to—replace conventional guns, but before the end of the war they had outgrown the restricted role for which the Bureau originally had them slated. Even more important, the military application of rocket propulsion rapidly extended beyond the limits of ordinary bombs and projectiles to open up a new field of ordnance.

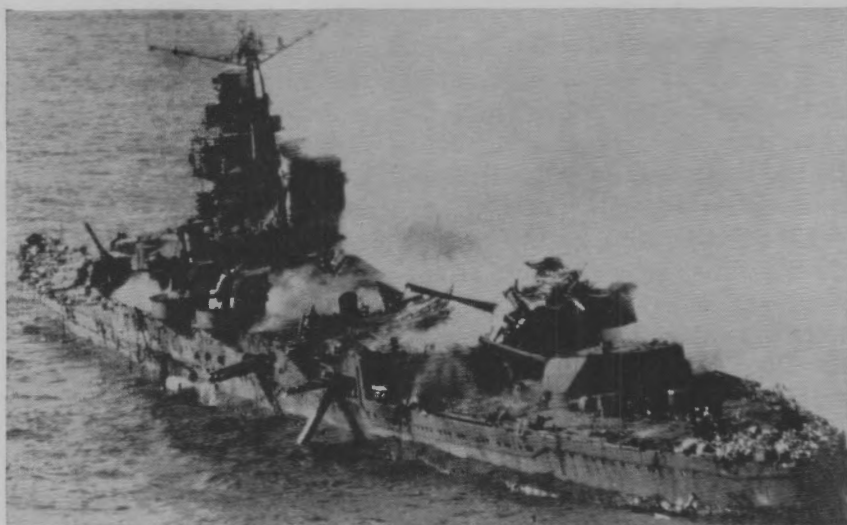
Chapter 15

AVIATION ORDNANCE

ONE of the most outstanding features of World War II was the spectacular growth of air power and its integration with sea power. When the Japanese employed their own air arm to strike at Pearl Harbor the United States Navy had only eight aircraft carriers in commission. The total number of planes available was less than 5500. Even that figure indicated too optimistic a picture, since it included obsolete, obsolescent, and experimental planes, as well as those that were ready for service use. Scarcely more than 2 years later, however, Rear Adm. A. W. Radford, a leader in naval aviation, was able to assert that "today the Navy is capable of striking with 1000 carrier-based planes—and more than 1000 planes if necessary—at almost any spot in the Pacific." Still later, at V-J Day, the United States Fleet included over 41,000 planes and 101 aircraft carriers.

The role that the air arm would play in the war became obvious in the first 6 months of combat. In May 1942, at the Battle of Coral Sea, the Navy defeated and turned back an enemy force that was never once seen by the surface ships or brought within range of their guns. Planes, once considered by the Navy to be nothing more than superior spotting platforms for the direction of gunfire, carried the victorious attack to the Japanese Fleet. When the same tactics were employed a month later at the Battle of Midway, naval aviation had clearly entered a new era. In the next 4 years the role of air power grew with the rapid pace of plane production, which climbed from 25 craft a month in 1940 to 2500 a month in 1945. Over half the submarines sunk by the Navy were victims of air attack; Navy and Marine pilots destroyed nearly 21,000 Japanese planes; finally, bomb and rocket damage to enemy ship and shore installations, though difficult to reduce to figures, was an important part of the mission of the carrier and shore based planes which the Navy threw against the Axis powers.

The speed with which aircraft multiplied in number and in types presented the Bureau of Ordnance with a host of developmental and production problems. Fortunately, the administrative basis for their solution was prepared during the last months of peace, when the complete reorganization of the Bureau changed the status



A Japanese victim of the Battle of Midway, where the new role of naval air power became evident.

of aviation ordnance. Instead of being concentrated in a single section which had complete responsibility for the whole range of aircraft weapons, it was represented in the various divisions in much the same manner as the ordnance for any particular type surface vessel. This was the administrative counterpart to the operational integration that made sea power and air power a part of the same force. A new armament policy was adopted during that same period, whereby it was decided to keep guns installed in planes at all times, transferring them with the aircraft as a part of its regular equipment. This meant that planes were to be kept in fighting trim in much the manner of warships.

The organization of aviation ordnance and the establishment of policies for the arming of planes helped prepare the Bureau for the war that followed, but administrative problems naturally ran concurrently with the vastly more important tasks of developing new armament and procuring it in the quantities dictated by the expansion of aircraft production. The division of cognizance between the Bureaus of Ordnance and Aeronautics proved a hazy question throughout most of the war—one which until 1945 was coped with through personal cooperation rather than solved through definite administrative decisions. In much the same manner, agreements with Army Ordnance had to be worked out as circumstances required. The arrangements were satisfactory, however, for standardization of aircraft weapons exceeded that in any other field of

ordnance; joint procurement was a reality years before unification was accomplished through legal action.

Even in the face of common efforts, the situation was critical at the start of the war. There were more gun positions in planes than there were guns to fill them. Fleet requests for armament had to be turned down until supply could catch up with demand. Spare parts were practically nonexistent and no adequate machinery for the distribution of spares and equipment was in operation. By the time these initial problems were solved, new ones arose to succeed them. At the height of the building program jeep carriers were coming off the ways at the rate of three every 2 weeks—an accomplishment in shipbuilding that had to be matched in weapon procurement for both the carriers and their planes. Aviation equipment was generally of light weight and small dimensions, but close tolerances created production headaches that more than offset those advantages. That naturally complicated the problem of finding and equipping the commercial manufacturers who ultimately met the demands for familiar ordnance, then supplied the fleet with weapons unknown at the start of the war.

Though aircraft used a variety of weapons that were adaptations of ordnance developed for surface use, such as torpedoes, mines, depth charges, and rockets, the primary armament for planes consisted of guns and bombs. Both were veterans of the primitive air warfare employed in World War I, and they naturally received much of the emphasis that was placed on aviation ordnance during the decades between the two global conflicts. In the case of guns, that attention resulted in the perfection of the .30 caliber type used exclusively in World War I, and in the development of the .50 caliber machine gun that became the most important aircraft gun in World War II. Both were Browning products procured entirely from the Army, but the Bureau of Ordnance contributed materially to the inter-war development of the weapons.

By 1935, the two guns were both excellent performers. The .30 caliber offered a cyclic rate of 1000 rounds per minute with a muzzle velocity of 2900 feet per second; the heavier gun was capable of firing 600 rounds a minute at an only slightly lower initial velocity. In the following half decade the Navy concentrated on further improvements to the power of the guns, as well as on better mountings, more efficient controls, and lighter equipments. The result was that by Pearl Harbor the cyclic rate and striking power of the two guns had been substantially increased.

Improvements to the lighter armament were of little avail, however. Even though its performance was improved, it was outdated

by parallel advances in aircraft design. The advent of light armor and the invention of self-sealing gasoline tanks combined to out-date the .30 caliber machine gun. Lacking the punch needed to destroy modern planes, the light weapon gave way rapidly to the .50 caliber Browning. Drawing on Army procurement, the Navy installed the gun in the wings, cowls, turrets, waists, and tunnels of its planes.

As the primary aircraft weapon, the .50 caliber machine gun naturally remained the object of concentrated developmental effort by both services. The years of research were crystallized during 1943 and 1944 in the production of guns that offered still higher rates of fire, durability, and dependability. Shortly thereafter, one of the main weaknesses of the gun was eliminated by the introduction of new "Stellite" barrel linings—an innovation that extended barrel life and permitted sustained bursts of fire during strafing runs that would have burned up earlier models of the weapon. At the war's end the latest production types of the .50 caliber machine gun were firing at a cyclic rate as high as 1200 rounds a minute, holding that rate for relatively long periods, and accomplishing the feat with no loss in reliability or increase in weight or size. That accomplishment multiplied the firepower of aircraft. And not only was each gun striking harder and more often, but newer planes were able to carry a greater number of installations.

Though the .50 caliber machine gun remained the most widely used aircraft weapon in World War II, the Bureau of Ordnance was far from convinced that the weapon approached the ideal aircraft armament. The trend in plane design and construction that made a casualty of the .30 caliber seemed to consign the .50 caliber to the same ultimate fate. Heavier planes were harder to knock out of the skies, and both Army Ordnance and the Bureau worked on guns whose striking power could negate the effectiveness of armored targets. One result of that search was the development of a promising .60 caliber machine gun, but the weapon was not completed in time to receive real service use. An even more powerful gun was added to aircraft armament during the war, however, and long before the end of the conflict the Navy was relying heavily on a 20-mm "cannon" that seemed destined to replace the .50 caliber gun as the primary weapon on naval aircraft.

The development of the 20-mm machine gun actually started in 1936 with the purchase of a foreign design, the Hispano-Suiza. Fully automatic, and operated by a combination of gas and blow-back principles, the muzzle velocity and cyclic rate of the gun com-

pared favorably with the performance of the .50 caliber Browning. Larger, heavier mounts had obvious disadvantages for use on aircraft, but the 20-mm offered a major advantage: its larger rounds could carry an explosive charge that increased the damage area considerably. Whether a large number of .50 caliber or a smaller number of more powerful 20-mm rounds had the most chance of inflicting lethal hits remained a disputed point, but the Bureau of Ordnance was anxious to put the Hispano-Suiza to a real service test.

Production of the gun was in Army hands, and many kinks had to be removed before it could be mass produced as a dependable weapon. By 1942, however, the first of the new guns were available for installation; within another year development had reached the point where large-scale procurement could begin. The first Navy installations were made on dive bombers. When the guns became available in larger numbers, their use was extended to other types of aircraft. Some trouble was experienced in finding a satisfactory feed mechanism, and the gun was never the dependable performer that surface units had in the Oerlikon 20-mm mount, but the trend toward its use was accelerated as the war progressed. Improvements to the .50 caliber gun added to its cyclic advantages over the heavier armament, but in the last year of war even that gap was being closed by the production of a new, lighter 20-mm cannon that made it adaptable to a greater number of planes. When V-J Day ended the combat tests of all aviation guns, there were still many ordnance veterans who preferred the .50 caliber, pound for pound, but the Navy was satisfied that the striking power of the larger rounds was worth the slight sacrifice in the number of installations that could be made on aircraft.

Meanwhile, the Bureau of Ordnance developed a means for increasing the number of guns that a plane could carry on a mission. Containers, complete with guns, ammunition, chargers, and firing mechanisms, were designed for suspension from the bomb racks of fighters, bombers, torpedo, and patrol planes. Whenever an aircraft went on a mission with empty bomb racks, the containers could be added to increase firepower. Single and twin gun containers were developed for each of the calibers used on planes, but only the Marks 1 and 2, carrying one and two .50 caliber machine guns, respectively, were ever released for regular service use.

Although containers were produced under Navy contracts, the Bureau's role in gun procurement as a whole was slight. The weapons and their ammunition were all provided by deliveries from Army Ordnance; only certain accessories and target material were

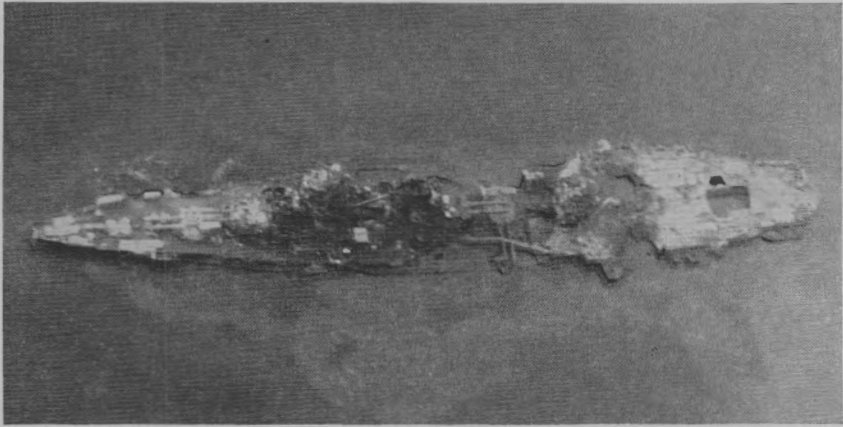
purchased directly by the Bureau of Ordnance. The same arrangement was even used for the Hispano-Suiza 20-mm cannon, even though the Navy received the bulk of the Nation's production. In return, the Bureau assumed complete responsibility for the procurement of the 20-mm and 40-mm antiaircraft machine guns.

A similar cooperative arrangement was worked out for the design and supply of bombs. Each service worked independently during the prewar years, but early in 1941 plans for standardization and a division of cognizance were laid down. Under the terms of the agreements that followed, the Bureau of Ordnance accepted responsibility for the development of two general types—armor-piercing and depth bombs. The division was logical, since they seemed the types most apt to be used against naval targets.

In the case of AP bombs, logic was not borne out by experience. Though theoretical considerations made armor-piercing bombs second only to torpedoes as the most effective aircraft weapon for use against heavily armored ships, tactical considerations made them seem far less attractive. The ability to penetrate several inches of steel before exploding could be achieved only by designing thick cases for the bombs. That meant that for a given bomb weight the percentage of explosive filler was low. Thus, the bombs had no significant mining effect if they fell into the water beside a ship. Anything less than a direct hit was almost valueless. And effective hits were harder to achieve with AP bombs than with any other type. Part of the capacity to penetrate armor depended upon the velocity gained in falling toward the target. Dive bombing failed to lend that velocity, so AP bombs had to be released from high altitudes. That requirement decreased accuracy at the same time that it made attacks dependent upon favorable weather conditions. In the face of such tactical problems, enthusiasm for the weapons was never high.

Because of such considerations, the Bureau of Ordnance did relatively little design work on AP bombs prior to the national emergency. When the war began, the only ones available were made by converting armor-piercing projectiles into aircraft bombs. The expedient was not satisfactory, however. The low percentage of filler inherent in AP bomb design was exaggerated in the make-shift ordnance, since the projectiles were designed with even thicker case walls than AP bombs required.

Early in the war the Bureau coped with the problem by designing new AP bombs in 1000- and 1600-pound weights. Despite a thinner case than the converted projectiles, the bombs were capable of piercing 8 inches of armor on ships or fortified land targets.



Destroyed by aerial bombs, the Japanese battleship Nyuga rests on the bottom of the Inland Sea.

Procurement of the two types totaled almost 19,000 units and cost approximately \$14 million, but in a period of vast expenditures the picture was not an impressive one. Semi-armor-piercing and demolition bombs were more popular, even against heavily armored targets. Their penetration was poor, but the blast effect produced by a high percentage of explosive filler was able to inflict heavy damage. Moreover, the trend in tactics was toward dive, toss, and masthead bombing. As high altitude attacks lost favor, the opportunities to use AP bombs declined accordingly. The Bureau of Ordnance, hoping to devise means for using the weapons within the framework of accepted tactics, developed rocket assisted armor-piercing bombs that could reach a high velocity during a short fall. Sticks of rocket propellant were added to the standard 1000-pound AP bombs, increasing the rate of drop as much as 480 feet per second, but the new weapons never became service items. Their development came late in the war when enthusiasm for AP bombs in the fleet and the Air Force was so low that a high priority effort to introduce new types was not justified.

Depth bombs, the second Bureau responsibility in the field, furnished a quite different picture. While tactical developments militated against the widespread use of AP bombs, the antisubmarine campaign depended to an increasing extent upon air attacks. Ordinary bombs naturally had but slight value for such attacks, since submarines could usually submerge in time to avoid being hit on the surface. The tactics required bombs with a high percentage of filler and hydrostatic fuzes that could be set to detonate the charge far enough below the surface to destroy a submerged

U-boat. No such bombs existed when the United States first joined the war against the Axis. The need had been anticipated by the Bureau, and designs were drawn up during the 1930's, but the initiation of mass production on a new weapon inevitably required a process of redesign and debugging. While that was accomplished at the Naval Gun Factory, the Bureau met the immediate problem by adapting depth charges for use by aircraft.

The expedient was short-lived. In the early spring of 1942 the makeshift weapons began to give way to the first of a group of new depth bombs, the Mark 17. Loaded with TNT, the 325-pound bomb was designed for low altitude release. Approximately 3 months later a second depth bomb, the Mark 29, was also released for service. This was a 650-pound weapon developed for use when the relationship between fuel load and payload was not critical enough to preclude a gain in explosive power at the cost of a disproportionate increase in weight.

Depth bombs arrived on the scene at a time of real need, but enthusiasm quickly gave way to suspicion on the part of the pilots. Reports reached the Bureau that the bombs were prone to explode on impact with the water, subjecting the releasing planes to a dangerous shock. Since attacks were made at low speeds and altitudes, this was a serious threat. When the Depth Bomb Mark 29 was used, the danger was compounded by the extremely large explosive charge. In reply to the pilots' charges, the Bureau launched an immediate investigation. The fears proved unjustified. A very definite shock did follow the release of a depth bomb, but it was neither dangerous nor the result of malfunction. What happened was that the bombs reached their preset depth so rapidly that explosion occurred before the water could close in around the column of air dragged down by the weapons. Then, when detonation took place, the air shaft provided an avenue of escape for the shock waves that were projected upward. Aircraft felt the effects of the blast, but the Bureau concluded that danger existed only if the plane turned and flew back over the target immediately after making the attack. Fortunately, none of the planes in service were maneuverable enough to invite their own destruction!

Depth bombs emerged from the first round of criticism unscathed, but the bugaboo was soon replaced by problems that had to be solved rather than explained away. The first of these to be exposed was that of ricochet. This was a problem that applied to all the depth charges in service use, and one that got worse as pilots tended to increase the speed at which they attacked. The combination of high speed and low altitude resulted in an unfavorable

entrance angle for the round nosed bombs. In some cases, the ricochet was serious enough to destroy completely the effectiveness of an attack. A redesign was necessary to eliminate the problem, but meanwhile the Bureau developed flat nose attachments that could be added to existing bombs. The blunt ends were able to dig into the water even when they struck at low entrance angles. Using the modified ordnance, pilots were able to increase the speed of their attacks with no loss in accuracy.

The redesign that incorporated flat noses into production line bombs was followed by a succession of other improvements. Tail assemblies were strengthened to avoid the distortion that sometimes gave the older bombs an unpredictable underwater trajectory; Torpex, then HBX, was substituted for TNT, increasing the explosive power of the bombs without altering the dimensions; new fuzes were developed to lend flexibility to the application of depth bombs. The changes led to a gradual multiplication of mark numbers as new weapons were produced to incorporate one or more of the several alterations.

Some of the new ordnance was not satisfactory. Torpex often proved too sensitive to withstand water impact. That, plus persistent fuze troubles, led to restrictions on the use of the heavier bombs. Even the lighter weapons proved dangerous until HBX was introduced as a replacement for Torpex. But, problems notwithstanding, the depth bombs proved extremely effective weapons. Nearly 400,000 were loaded during the war years at a cost of approximately \$31 million—an expense easily justified in the light of the damage they inflicted. No other antisubmarine weapon proved as lethal to U-boats.

In addition to fulfilling its responsibilities under the Army-Navy agreements, the Bureau of Ordnance worked on two other bomb types—antiaircraft and napalm. The development of the first was based on the tactical concept that fighters should be able to fly above bomber formations and drop large numbers of small bombs. The weapon designed for that purpose was the AA Bomb Mark 34, which consisted of a light case containing 2 pounds of TNT. While the explosive load was small, it was capable of blowing a 5- to 6-foot hole in the wings or fuselage of a bomber. To compensate for the fact that the bombs were effective only with direct hits, the Bureau designed bomb containers that provided for the release of 20 at a time, creating an explosive pattern about 150 yards long and 50 yards wide.

Although antiaircraft bombs gained a group of staunch advocates, their admirers were more numerous on the higher level of

planning than on the lower one of actual combat. The weapon, like the AP bomb, became a victim of changing tactics. Large bomber formations were far more common to the allies than to the enemy, especially in the Pacific area to which the AA bombs were consigned. Moreover, since a direct hit was required in either case, aviators preferred to attack with guns rather than bombs. In such attacks they had greater maneuverability to evade the bombers' fighter escorts, and they were able to fire far more projectiles than they could have dropped bombs. The lethal effects of the hits were not comparable, but the increasing use of explosive 20-mm rounds reduced the disparity. Two hundred thousand AA bombs were procured by the Bureau, but few of them were actually dropped on enemy bombers. Fortunately, they were found useful for other applications, mainly as a supplement to strafing runs against exposed personnel and grounded aircraft.

Napalm bombs were an innovation that came late in the war. The Army produced some oil and gasoline bombs for both services, but they were incendiary bombs, not similar to the napalm filled tanks that later captured the imagination of the press and struck terror into enemy troops. Incendiary bombs were designed to start a series of fires that could merge into a pattern and destroy an inflammable target. Their damage was thus subsequent to the bombing itself; its extent depended on the nature of the target, which had to provide the fuel. Napalm bombs, on the other hand, were designed to carry the fuel needed to sustain the flames required for a tactical objective. The fires started by the bombs were simply an extra bounty.

The first naval attempt to use such a weapon originated aboard one of the carriers in the Pacific when some of the men dreamed up a piece of ordnance which they dubbed the *Zacharias Zombie*. This was made by securing a practice bomb to a standard 100-pound general-purpose bomb and dropping the two together. The practice bomb, instead of carrying the customary water filler, was loaded with gasoline. The blast was sufficient to ignite the fuel and spread it over a wide area. The weapon was obviously primitive, but the aviators who used them in attacks on the Marshall Islands reported good results.

Searching for new weapons, the Bureau of Ordnance conducted a series of tests with the *Zombie* to determine whether or not it was suitable for procurement. The results of the experiments were a setback to progress with fire bombs. When the fleet device was duplicated by the Bureau and dropped into fields at Dahlgren, it

failed to give the kind of results that pilots had reported from the Pacific. In fact, it failed to inflict any more damage than the 100-pound general-purpose bomb used alone. The tests dampened enthusiasm for a gasoline bomb, but they did not stifle developmental efforts in that direction. Later in the war, the efforts received a needed stimulus with the popularity of napalm, a gelatin thickener which could be added to gasoline to produce a gel that would cling to almost any surface and burn with terrific intensity. The treated fuel, used widely in flame throwers and incendiary bombs, offered a means of overcoming many of the defects encountered with the *Zacharias* Zombie.

The use of two bombs in conjunction was given up. Instead, old jettisonable fuel tanks were filled with gelled gasoline and equipped with igniters. Each then became a bomb that could spread a devastating sheet of flame over an area of 20,000 to 30,000 square feet. The flames roared with intensity for almost a minute, then lingered over the area for another 5 to 10 minutes. The tactical advantages of such a blanketing weapon were obvious. Even the typical Japanese bunkers afforded no real protection against the intense heat and flames. Procurement advantages were obvious, too, since the materials needed for fabrication were in relatively abundant supply throughout the operating forces. When provided with igniters and napalm, the fleet could make up the weapons as they were needed.

Unfortunately, the simplicity of the bombs was overrated. Mixing the napalm, storing the bombs, and providing adequate safety during handling presented a variety of problems. Even in operation, the bombs proved a disappointment. The unstabilized tanks tumbled badly, making accurate drops difficult, and many failed to ignite after hitting the ground. In large scale tests conducted in the spring of 1945, well over 25 percent of the bombs proved to be duds. The defects were not technically significant since they were easily corrected by the addition of fins and additional igniters, but they were psychologically significant. Pilots became distrustful of the new ordnance. Even when the defects were removed, they were reluctant to carry a suspect weapon. The feeling was dissipated during the last months of the war, however, and napalm bombs proved a valuable addition to the arsenal of aircraft weapons.

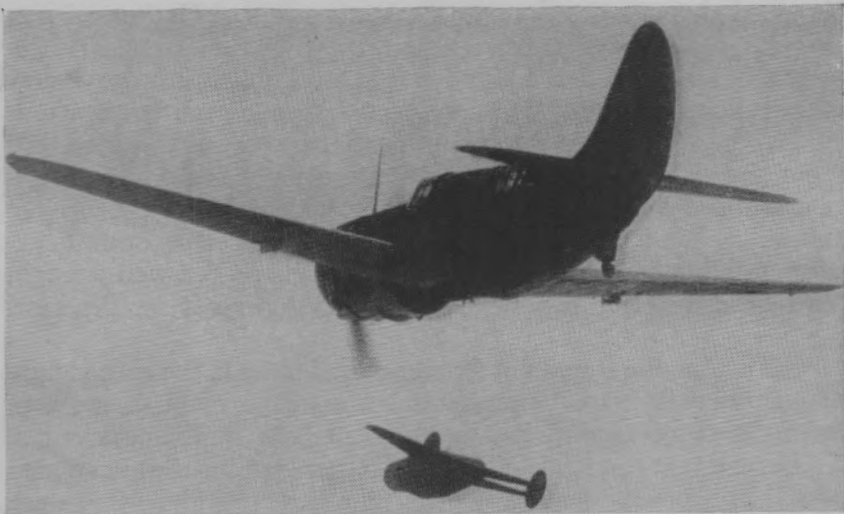
The last months of the war also witnessed the introduction of an even more spectacular weapon, a guided missile dubbed the Bat. Though its arrival was late, the weapon was the result of projects

launched almost a year before the attack on Pearl Harbor. Planning for guided missiles started within the National Defense Research Committee in 1940, and actual work got under way early in the following year. Several projects ran concurrently as various guidance systems and tactical applications were investigated, but the first naval application to receive attention was a project to develop a television-equipped, radio-controlled missile. This project materialized in a missile, but the weapon never got beyond the experimental stages. Though the mechanism worked well enough, the margin of error exposed in tests was too great for practical use.

Meanwhile, the Bureau of Ordnance had entered the guided missile picture in its search for antisubmarine weapons. U-boats were the greatest menace the Nation faced in 1942, and it occurred to the Bureau that the model air frame constructed for the abandoned missile project might be valuable. The Bureau's idea was to use the air frame as the vehicle for a depth charge which could be guided against submarines that were caught on the surface at night. The projected missile was to use radar rather than television as a source of guidance. The Bureau preference was based partly on the problem of visibility, partly on the feeling that accuracy would be much greater. No applicable radar equipment even existed then, but the Massachusetts Institute of Technology was already at work on the problem.

Three methods of radar control were investigated. One was to use an enemy transmitter as a source of energy on which a missile could "home." Another was to have a transmitter on a friendly plane that stayed close enough to the missile to provide guidance to the target. Finally, a missile could carry its own transmitting and receiving equipment, thus gaining complete independence once it was released from a plane. Each of the three systems was used in at least one weapon, but the last was favored by the Bureau of Ordnance.

In support of its interest in missile development, the Bureau established two ordnance units to explore the new field. The working relationship between the Bureau, its activities, and the National Defense Research Committee were extremely close. The coordination permitted steady progress toward the goal of a serviceable missile, even though particular projects often ended in failure. The result was that when success was finally achieved, the service missile represented 1000 man-years of reasearch and developmental effort.



The Bat represented 1000 man-years of research and developmental effort.

One of the many projects that contributed knowledge and experience rather than a combat weapon was the original search for an antisubmarine missile. Before its development reached the point where a production weapon could be envisioned, the U-boat menace had subsided. Surface ships then seemed more important targets, and the Bureau turned its interest to a missile that could carry a larger bomb as its payload. Two such projects were launched—one to produce an enlarged version of the depth charge carrying Pelican, the other to develop the Bat. Each used somewhat similar air-frames, gliders with a 10-foot wingspan designed for suspension beneath aircraft. The main differences lay in their payloads and methods of control. Pelican, loaded with a 500-pound bomb, depended on the launching plane for its guidance, while the Bat was equipped with a complete radar set that could guide it and its 1000-pound payload toward a target.

The first of the weapons to pass from development to limited production was the Pelican. By the end of 1943 the missile was in production engineering; 6 months later production models were available for tests. The hulk of a liberty ship was procured for a target and six Pelicans were assembled for the occasion. Then came one of the great disappointments of the war; every missile missed its mark. The defects that caused the inaccuracy were not great ones, but they were sufficient to end the career of the Pelican. The NDRC still considered the missile promising, but the Bureau

of Ordnance preferred to bank on the Bat, the development of which had been running concurrently with Pelican.

Though the two missiles were aerodynamically similar, the Bat possessed several advantages, even aside from its heavier payload. Its homing system, developed for the Bureau by the Bell Telephone Laboratories, was entirely self-sufficient. Each missile contained a radar transmitter for target illumination. The reflected energy was then picked up by a receiver which kept the weapon homed on the source of the echoes. That feature permitted the attacking plane to release the missile well outside the range of enemy anti-aircraft fire. Once the weapon's radar set was locked on the selected target, the aircraft could return to safety or seek out another enemy target. The range of the Bat was not comparable to that of the Pelican, but the necessity for positive identification of enemy targets tended to negate the advantages of long range.

Once the Bat was released, it glided toward the target with the speed of a fighter plane. Evasive maneuvers were of small value to the enemy ship, for the missile followed its movements ruthlessly. There were serious control problems to be overcome, however, before the Bat could be considered a service weapon. In pursuit of its target, the missile "hunted," going back and forth through the true course in a manner familiar to conning officers. When it got off its proper heading in one direction, the course was altered, but it would then turn through the course before steady-ing. Accuracy thus depended on what stage of the cycle the missile happened to be in when it reached the enemy vessel. The ship's company of a vessel inadvertently mistaken for a target had reason to be grateful for the missile's eccentricity, but tests against the liberty ship that had already survived six Pelican attacks proved that the success of an expensive weapon like the Bat could not be left to coincidence. Before the Bureau could release it for service use, intricate servomechanisms had to be designed to minimize the deviations of the hunt cycle and keep the Bat on a nearly true course to its target.

Though other refinements were still required, the missile was considered ready for combat in the spring of 1945. Crews were already trained to handle the new ordnance, and a squadron of Privateers equipped to carry a Bat under each wing soon introduced the Japanese to the weapon that ranked with the atom bomb and the proximity fuze as one of the few entirely new weapons in World War II. Because of its late arrival there were few first class naval targets left for the Bat to destroy, but smaller ships

merely offered a more severe test for the missile. One destroyer was sent to the bottom, followed by many tons of cargo shipping.

The Bat was only one of many guided missiles that were worked on during the war years by the services or the NDRC. They varied from Rube Goldberg devices steered by a pigeon pecking at the image of a target on a glass screen, to simple wing attachments for standard bombs. Some were rocket propelled, some designed for turbo-jet or ram-jet engines; others, like the Bat, merely glided or fell toward their target. But the Bat was distinctive in that it was the first fully automatic guided missile produced by any of the combatants.

Guided missiles, along with guns, bombs, rockets, and torpedoes, offered air commands a wide variety of ways in which the striking force of air power could be expressed, but the development of the weapons was but one aspect of the Bureau's responsibility in aviation ordnance. The power of a weapon was no less a derivative of its accuracy than of its explosive force. For each piece of ordnance, the Bureau had to furnish fire control equipment that could permit the pilots to utilize the potential of their firepower. Nor was accuracy the only challenge faced by the designers. Normal restrictions on size and weight were magnified for aviation equipment. Reliability had to meet even higher standards, since a plane could carry no maintenance crew for emergency repairs. Simplicity, too, was more significant when one man—often a pilot already overburdened with a multitude of concerns—had to operate both the fire control equipment and the weapons. Finally, the speed of the solution to the fire control problem had to be almost instantaneous, else it was valueless. The speed of air attacks was such that there was no time for the old-fashioned "bracket." If the original aim was not correct, there was precious little time for adjustments.

Long before the outbreak of World War II the Bureau of Ordnance was in possession of the world's finest bombsight, the Norden produced Mark 15, but the situation with gun control was far from satisfactory. The standard fire control equipment in the years just preceding the national emergency consisted of a simple ring and post sight combination with which the gunner established a line of sight to the target by bringing the ring, post, and enemy into coincidence. A multiple ring arrangement permitted a rough estimation of deflection or lead, but the sight was primitive, at best. Recognizing the need for a more precise instrument, the Bureau started procuring telescopic sights in 1941 as replacements for the older installations. Almost 15,000 were ultimately delivered

to the services by Bureau contractors, but the telescopic sights rapidly followed their predecessors into obsolescence. They were far more accurate than the ring and post sights, but the telescopes imposed a severe limitation on eye freedom. The price was too high, especially for aircraft in which the pilot was also the gunner. What was needed was a sight that could combine the freedom of vision offered by the ring and post with the accuracy made possible by optical sights.

This goal was realized in a series of reflector type sights, starting with the Illuminated Sight Mark 7, which was procured during 1941. The mark 7 and its successors were optical sights, but instead of peering through an eyepiece, the pilot or gunner merely looked through a plate of clear glass that was tilted in his line of view much like a small windshield. At the base of this reflector plate the optical system of the sight and a lamp were contained in a small box. The light bulb at the bottom of the unit furnished illumination that passed upward through a reticle and projected its pattern on the lens of the sight unit. The light that was permitted to pass through the reticle was formed into parallel lines by the lenses, then reflected back to the pilot's eyes from the clear glass before him. The image he saw was much like a ring and post sight, but it had the virtue of keeping itself aligned with his eyes as long as his head movements did not cover an area greater than the aperture in the sight unit. This reticle pattern appeared to be superimposed upon any target at which the plane and gun were aimed; it was as if, looking through a windshield, the pilot or gunner saw a gunsight always hanging in the sky before him and always bore-sighted with the guns he was firing.

The Mark 7 that first employed these features was a great improvement over the existing installations, but it suffered the defects common to the initial design of a new type of ordnance. The British had meanwhile developed a similar unit, and a handmade model of their illuminated sight was given to the Bureau for study in 1941. Its defects were as numerous as those of the Mark 7, but it also offered advantages that merited adoption. The result was that the Naval Gun Factory redesigned the British model, improved its optical qualities, and adapted it for American manufacture. In this form the equipment, designated the Illuminated Sight Mark 8, was placed in production as the successor to the Mark 7.

The new equipment stood the test of years of combat use and became the standard sight for fixed guns, but its history was one of almost continual change. During the first year of production

there were innumerable problems that had to be solved by re-design or through the painful process of gaining experience in the manufacture of an optical system that seemed to defy the techniques of mass production. In the first units the reticle image was not bright enough, and new lamps had to be designed to furnish a pattern brilliant enough to be readily visible against either sky or ground. A few months experience with the sight then showed that the reflector plate and internal optics constituted a burning glass that destroyed the reticle by focussing sunlight on the silvered glass that established the pattern. That problem was solved by the use of copper reticles, but not until new production techniques were developed for the precise metal work involved. Later in the war the Illuminated Sight Mark 8 was further modified to fit new fire control needs. It was adapted for use in low level bombing and rocket firing, and even became the basis for a torpedo director.

The Mark 8, versatile as it was, was designed only for fixed guns like those controlled by the pilot. Free guns, those which could be aimed independently of the aircraft, were controlled by a similar sight, the Illuminated Sight Mark 9. This equipment, too, was based on the redesign of a British model secured by the Bureau in 1941. Though the principle of operation was like that used with the fixed gun sight, the Mark 9 was a smaller unit. Eye freedom was less vital for a gunner than for a pilot, so a smaller reflector was acceptable. The Mark 9 ultimately became the standard sight for free guns, but early in the war there was considerable hesitancy about placing entire faith in its performance. The reticle pattern that provided the rings and center dot used in aiming was dependent upon artificial illumination. Gunners feared that the lamp might fail at a vital moment, leaving them with no way of aiming their guns. Experience with the Illuminated Sights Mark 8 and 9 proved the concern unjustified, but the Bureau did not leave that to chance.

Early installations of the Mark 9 included an auxiliary sight attachment developed and manufactured for the Bureau by the Polaroid Corp. This instrument was an optical ring sight that required no lamp for illumination. Natural light, entering an optical element made of a laminated combination of polarized glass, plain glass, and calcite, was broken up into concentric rings of alternating light and darkness. The rings could be used in much the same manner as the reticle pattern projected by an illuminated sight. Approximately 26,000 of the standby sights were procured, but their manufacture was abandoned long before the end of the war. A similar unit designed for use with the Mark

8 fixed gun sight never even went into production. The supply of calcite was always critical enough to jeopardize the entire program, and the illuminated sights proved too reliable to require a program whose only justification was an expectation of their failure.

The two illuminated sights filled a vital need in aviation ordnance, but they were never considered a final solution to the fire control problem. They freed the eyes of pilots and gunners from the captivity of a fixed eyepiece and they bestowed the benefits of an optical system on the method of aiming used with ring and post sights. They did not, however, solve the fire control problem involved in hitting a target, often an evasive one, from a fast moving, maneuvering plane. Sights were indispensable, but their value depended on the experience and skill of the men that used them. Their deficiencies had to be overcome by increasing the volume of fire in an effort to compensate for inaccuracy. Aircraft gunfire could not match the accuracy of shipboard armament until it, too, was provided with instruments that could automatically compute the lead needed to insure that the flight paths of its ammunition and target would collide.

The Bureau of Ordnance began the search for a lead computing aircraft sight in 1937. Three years later the Mark 1, employing gyroscopic stabilization and control, was designed. The new ordnance did not meet requirements, however, and the Mark 1 was rejected as too bulky for aviation use. Shortly after Pearl Harbor the British supplied the Bureau with a lead computing sight for tests, but it too was rejected. The instrument could not be used at night and it provided no means for range determination. Without a rangefinder of some sort, a gunner simply traded the job of calculating lead for the equally ticklish one of estimating the ever changing distance to a target. The Bureau was still working with this problem when the British submitted a new version of their lead computing sight. The redesign met the main objections to the earlier model. Modifications were necessary before it could be adapted to American manufacture, but the problems did not appear insoluble. In October 1942, the Bureau decided to accept the British equipment and use it as the basis for a turret gun sight designated the Mark 18.

Unfortunately, the problems of adaptation were greater than they first appeared. Several hundred changes were required before the design was considered static. Ironically, an attempt to accelerate the work by dividing it between two companies actually retarded completion of the sight, and led to an abnormal number

of modifications after production was under way. Manufacture was begun in the fall of 1943, yet production drawings were considered only 90 percent complete in February 1944. Not for another year was real mass production possible. The troublesome procurement picture was further complicated by large orders from the Air Force—an unexpected development since the Army had shown a singular lack of interest in the British sight upon which the Mark 18 was based.

The history of the sight had its cheerful side, however. Its best results were impressive. The firepower of aircraft turret guns went up, ammunition expenditures dropped. Fewer rounds were needed when more of them found their mark. The gunner's role in this accuracy was relatively limited. The proper lead was computed by an electromagnetically controlled gyroscope which was deflected from its normal axis by an amount determined by the angular rate and range of the target, the altitude and airspeed of the plane, and the position of the turret in which the gun was mounted. The altitude and speed of the craft could be set into the computing mechanism by dials; turret position was an automatic input, changing as the mount was elevated or rotated. Range was derived when the gunner spanned his target with a circle of dots which he saw as he looked through the sight mechanism. Angular rate was introduced automatically as the gunner tracked his target. Training was required before a man could simultaneously keep the sight on a target and control the circle of dots which outlined the wingspan of the enemy plane, but once the knack was acquired, the coordination of the two functions became automatic. As the gun moved in tracking the target, the gyro deflected in response to the forces exerted on it. The amount of that deflection, a measure of lead, was indicated to the gunner by a moving reticle that employed a reflection from a mirror on the gyro surface. When the reticle was on the target the gunner could fire with no need for the mental calculations upon which accuracy had previously depended.

The success of the Gun Sight Mark 18 encouraged imitation. Pilots needed a lead computing sight as urgently as turret gunners, and the Bureau started intensive work to convert it for use with fixed guns. The first result of that endeavor was the Gun Sight Mark 21. Though considered only an interim equipment, the sight went into large scale production at the request of the Army Air Force, which felt an urgent need for such an instrument in its fighters over Europe. Meanwhile, the Bureau worked on a second modification for use with naval forces. This newer equip-

ment became the Gun Sight Mark 23, which went into service use in 1945. Naval pilots received the sight with something less than enthusiasm. The illuminated sight already in use had the virtue of being familiar, and the need for a lead computing sight was less urgent than it had been earlier in the war. Moreover, the task of performing both sighting and ranging operations was more difficult for pilots than for gunners, who could devote their entire attention to the enemy aircraft.

The preference of operating forces for a familiar equipment over a strange though more efficient substitute was a familiar dilemma, and one that was almost always resolved in favor of the better ordnance. V-J Day came before the pattern was completed in the case of the Gun Sight Mark 23, but not before lead computing sights demonstrated their general superiority for the control of aircraft guns. Though their application was still incompleated at war's end, they represented the most outstanding wartime achievement in the field of aviation fire control.

For a while, when gyroscopic sights were still under development, the Bureau of Ordnance and its Army counterpart pursued a phantom that promised to lead to an easier solution to the lead computing problem, at least for the turret guns of bombers. Defense against an attacking fighter, the sole mission of such guns, followed such a fixed pattern that the variables handled by gyro computing sights seemed an unnecessary distraction. A fighter, because of the fixed position of its guns, enjoyed only a limited flexibility in attack tactics. To keep his guns aimed where the bomber would be when the bullets crossed its flight path, the pilot had to follow a pursuit curve that tended to move in toward the tail of the attacked plane. To the turret gunner, the fighter always appeared to be coming almost head-on. The most essential element in such a fire control problem seemed to be the speed of the bomber, since the ammunition fired from its guns carried the plane's own forward momentum through space.

This theory, known as the own speed sighting principle, underwent extensive tests and evaluation during 1944. As a result of this study two gun sights, the Marks 17 and 25, were developed for turret use in case the completion of experiments indicated a requirement for such equipments. The success of gyroscopic sights deprived them of service use, but the investigation proved valuable even if the sights did not. The study of the tactics involved in an attack on a bomber provided gunners with aiming techniques that stood them in good stead until lead computing sights could be

installed. The recognition that an attacking fighter would fly a curve of pursuit that would bring it in toward the tail of the bomber produced the doctrine of position firing.

Gunners were taught to aim between the fighter and the tail of their own plane. The simple technique corrected a widespread misunderstanding about the nature of a gun lead. Frequently taught to lead their target by hours of skeet shooting, gunners assumed that the oft repeated axiom to "lead the buzzards" necessarily meant to fire in front of them. The opposite was often the case. When a fighter appeared to be coming head-on in a pursuit curve, but was actually sliding in toward the tail of the bomber, the lead was negative. The path of the ammunition moved forward in space at the speed of the attacked plane. If the gunner added a forward lead, the miss was obviously of wide proportions. The technique of position firing got the idea across effectively and improved aerial gunnery in the months before a lead computing sight was available. After the Mark 18 became a service device the problem practically disappeared. Providing a gunner tracked smoothly, the sight indicated the correct point of aim, whether the required lead was negative or positive.

Gyroscopic sights did not mark the end of the Bureau's search for better methods of gunfire control. The development of air-borne radar sets opened a whole new field of investigation. In particular, it promised to overcome the principal handicap to the lead computing gyroscopic sights—the necessity for performing ranging and tracking operations simultaneously. Later, electronic advances extended the goal to include fire control equipments that could not only eliminate optical rangefinding, but could acquire and track targets with a minimum of attention from gunners. Despite the real progress in that direction, the gyroscopic sights for fixed and free guns were the most advanced equipments that became standard service items during the war years. Meanwhile, the Bureau devoted equal efforts to providing equipments that could help pilots solve the fire control problems presented by the other weapons carried by naval aircraft.

As the most powerful ordnance carried by planes, bombs naturally received a large share of the Bureau emphasis. Since that had been true from the birth of naval aviation, bomb control was already at a high level of precision when the attack on Pearl Harbor plunged the Nation into war. The Norden Bombsight, America's "secret weapon," and soon to become a national byword for accuracy, was the best evidence of the Bureau's prewar concern over the problems of aviation fire control. The evolution of the instru-

ment started at the end of the First World War, when bombing was itself a controversial new tactic. The Bureau of Ordnance already possessed a bombsight, the Mark 3, but a better equipment was needed to capitalize on the advantages of aerial bombing. Stabilization seemed the first requirement, so the Bureau turned to one of its consulting engineers, Mr. Carl L. Norden, an authority on gyroscopes. Mr. Norden quickly solved the first element of the bomb control problem by devising a gyro stabilized base for the existing Mark 3 sight.

Even when improved, however, the equipment could not meet the tactical problems of naval bombing, where the typical target would be a maneuvering ship. It assumed a nearly stationary target, the sort of windfall Navy pilots could not count on finding. Norden was confident that he could develop a computing bombsight that would solve the control problem posed by a maneuvering target, however, and the Bureau awarded him a contract in June 1922. Assisted by a Bureau officer, Lt. Comdr. F. I. Entwistle, and Theodore H. Barth, an engineer with a genius for translating his partner's ideas into working equipments, Norden then developed the Bombsight Mark 11, a gyroscopic instrument that used a timing device to determine the correct moment for dropping the bombs. The first of the equipments was delivered in 1924, but five more years of redesigning and testing were required before the bombsight was ready for release as a service weapon.

By 1929, the year of its acceptance, the Bombsight Mark 11 was half again more accurate than the Mark 3. The Bureau was not satisfied, however. Though the sight's accuracy was good, it had two important disadvantages: The mechanism was extremely complicated, and the timing method it utilized placed pilots and bombardiers under severe tactical limitations. The closing speed of the attack had to be definitely established in advance and adhered to during a long period of approach. Aside from the plane control problem involved in the procedure, it increased the element of danger that was already high in horizontal bombing.

With a new contract from the Bureau, Norden went back to work. Experience with the Mark 11 speeded the project, and an experimental model of the new Bombsight Mark 15 was ready for extensive tests in 1931. Complexity was not eliminated, but the objectionable timing requirements were at least alleviated. The closing speed of the attack could be established at any time during the bombing approach. An extremely steady—and thus vulnerable—course had to be held during the final bombing run, but fifteen or twenty seconds at a fixed speed and altitude were enough



The maneuverability of the typical naval target intensified the problem of bomb control.

for a highly skilled bombardier. The accuracy of the mechanism was proved in 1931 tests against the *U. S. S. Pittsburgh*, and the experimental sight then became a production item. The vulnerability of the old heavy cruiser impressed the Army as well as the Navy, and the first procurement contract included an order for the Air Force.

Analyses of the bombing results obtained with the Mark 15 indicated that further development of the bombsight could offer but small improvements in accuracy, yet the horizontal bombing problem was far from solved by the new equipment. Fleet pilots were not able to match the precision of their specialist colleagues at the proving ground. Deflection errors were common and the benefits of practice were negated by improved anti-aircraft guns that forced bombers to operate at higher and higher altitudes. Once again Norden, working with the Bureau, was able to devise an equipment to meet the situation. This was the Stabilized Bombing Approach Equipment, a sort of automatic pilot that took over control of the plane during the actual bombing run. It used gyroscopic stabilization of the aircraft to eliminate the roughness of

manual flying. Though it was often regarded and used in the fleet as a navigational device, the SBAE was a precise fire control equipment, an integral part of the Norden bombsight. Two gyros were used for stabilization. Directive forces from them actuated motors that afforded rigid control of the plane. While the aircraft was controlled by the SBAE, the corrections and adjustments put into the bombsight made simultaneous changes in the directive forces at the power unit of the automatic pilot. The course and altitude of the plane automatically corresponded with the data used by the computing unit of the sight. The combination of the Mark 15 Sight and the gyropilot made ordinary bombing teams close rivals of the specialists who operated at the Naval Proving Ground.

Though the bombsight was a complicated apparatus of over 2000 parts, its operation was relatively simple. The bombardier got from tables the time of fall, based on the speed and altitude of the plane, and the trail, or the distance behind the bomber that the missiles would actually strike. These values, plus the speed of the plane, were then set into the computer of the sight. The gyroscope was adjusted to spin with its axis perpendicular to the ground, and the telescopic sighting unit was lined up with the true course of the bomber. Once the settings were made, the bombardier tracked his target for a few seconds by holding it in the cross hairs of the telescope. At that point, the bombsight could take over. The computer, using the data set into it beforehand or received by the tracking motion, generated answers to the bomb control problem, held the plane on the right course, and released the bombs at the proper moment. The effects of wind were also taken into account, and in the case of a cross wind, the drift of the plane was increased enough to compensate for the cross trail of the bombs.

The Norden Bombsight and its accessory equipment were available well before the outbreak of World War II, offering the United States an unrivaled superiority in the field of horizontal bombing. The developmental advantages had to be reflected in production figures, however, and bombsight procurement became one of the major programs of the Bureau. Starting with the German invasion of Poland, the Bureau began pressing for a higher rate of manufacture, hoping that the Nation could capitalize on the initial advantages the sight offered if it became involved in the European war. The first expansion merely increased production at the Norden plant in New York City, but the Bureau soon broadened the base of procurement. President Roosevelt's decision in June

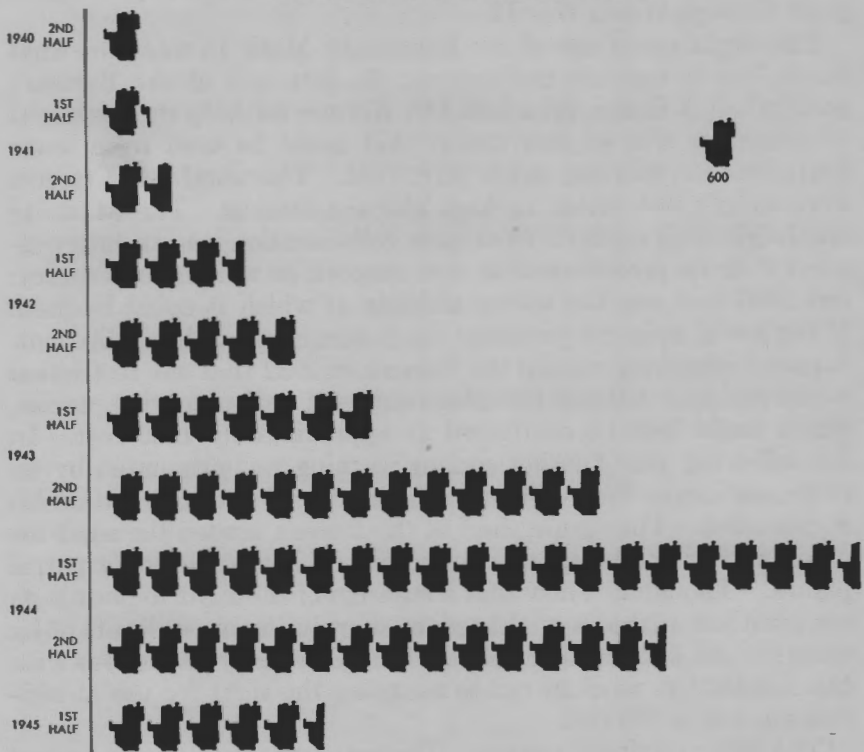
1940 to build up an Army and Navy air force of 50,000 planes called for a production rate that demanded new facilities. The result was the expenditure of over \$13½ million on a Naval Ordnance Plant at Indianapolis, Ind. Management was provided by the Norden Co. through a new subsidiary, the Lukas-Harold Corp.

The two facilities provided a production potential of approximately 800 bombsights and SBAE's per month, but Pearl Harbor tended to make these once imposing figures seem insignificant. The goal for aircraft production moved to 60,000 planes in 1942; by the end of the following year plans called for a combined air arm of 125,000 craft. Since the Bureau of Ordnance supplied both Army and Navy, the prewar plans for bombsight production no longer appeared realistic. There followed a rapid search for new sources. The Navy added a plant to be operated by Remington-Rand under Norden guidance, and agreed to an arrangement whereby the Air Force found and equipped three commercial sources to provide part of its own requirements.

The creation of a broad base for bombsight manufacture solved but one of the many problems involved in procuring the Norden equipment. Even when the new plants were in operation, deliveries continued to lag behind the stated requirements of the two services. A lack of precision ball bearings constituted the main bottleneck, but other obstacles contributed to the difficulties. The assembly of the many components in the precision instruments was an art, requiring skill and patience. Even those attributes were no guarantee of perfection. Stringent inspection standards caused many of the sights to be rejected even after they passed the earlier hurdles. The situation was further complicated by the competition for orders and materials between the Army and Navy producers. Neither service was satisfied with the situation. The Air Force, even after it found three sources of its own, was unable to meet its requirements without a large quota of the bombsights procured by the Bureau of Ordnance. Moreover, requirement predictions fluctuated so much that planning was difficult, even when the facilities and materials problems were overcome.

Harmony ultimately came as a result of tactical rather than procurement factors. The Navy found that its own requirements for the sight were inflated. Naval missions were not suited for the use of high altitude horizontal bombing techniques—the only type of attack for which the Norden Bombsight was useful. Even the development of a glide bomb attachment that removed the restricting requirements of level flight altered the situation but

PRODUCTION OF BOMBSIGHT MARK 15



slightly. The ever-changing operational conditions of the war forced the Navy to adopt a conservative policy in regard to revising requirements, but a series of reductions began in mid-1944. Each cutback in Navy orders permitted a larger allocation of equipments to the Air Force. Before the end of 1944 the situation had changed so radically that the services were able to reduce the number of their production sources, looking toward a gradual termination of contracts with all of the commercial plants except Norden. A sudden upward revision of Air Force requirements in early 1945 jeopardized the plans, but the crisis was met by transferring unused Navy sights to the Army.

By V-J Day the Army was almost the sole user of the famed sight. Of the 43,292 equipments produced between July 1939 and September 1945, the Army ultimately received all but 6434. The monopolization was so nearly complete that the American public thought of the sight as an Army achievement—a natural irritant to the service which had fostered its development since the end of

World War I, then guided the half-billion dollar procurement program through World War II.

The slight naval use of the Bombsight Mark 15 was somewhat ironic, but it was not unforeseen. In fact, one of the Bureau's goals when it first approached Mr. Norden for help in bombsight development was an instrument that could be used from lower altitudes than existing sights permitted. The usual naval targets were simply not suited to high altitude attacks. The Mark 15 bombsight that resulted from their collaboration was an improvement over its predecessors in that respect, as well as in accuracy, but 1800 feet was the lowest altitude at which it could be used. Many naval aviators predicted the inadequacy of the equipment. A patrol squadron warned the Bureau in 1932 that the restriction would seriously hamper the effectiveness of antisubmarine patrols, which could best be conducted at approximately 1000 feet. In the following year another serious warning was originated by an Ordnance officer then serving with the fleet, Lt. Comdr. Malcolm F. Schoeffel. The future chief of the Bureau lauded the sight for use in carrier bombers, but pointed out its inadequacies for patrol planes. Though he knew that a redesign of the sight to permit its use from low altitudes might reduce sharply the upper limits of its effectiveness, Commander Schoeffel suggested new discussions with the Norden Co. with an eye to adapting the sight for use at altitudes as low as 800 feet.

The latter produced results. The entire problem was presented to the Norden Co. for comment. Technical difficulties prevented any significant lowering of the minimum altitude for which the sight could compute the solution to bomb control problems, but Mr. Barth suggested an attachment to the Norden sight that would permit bombing from heights as low as 500 feet. Approximately a year later the idea was crystallized in a low altitude bombing attachment that started on a long career as a controversial test item. Proving ground reports were optimistic, if not enthusiastic. Early service tests showed less accuracy, but were encouraging enough to keep the Bureau interested in the attachment. In 1938 that interest was translated into a production contract, though procurement was kept at a relatively low level.

The decision to buy a limited number of the attachments did not end the controversy over their utility. Within a few months the squadron testing the equipment informed the Bureau that "the attachment is merely additional gear and serves no useful purposes." The disparity between proving ground and service reports was less a reflection on the accuracy of the sight than on the

training problems connected with a new piece of ordnance, but those problems were sufficient to abort the career of the attachment. Production continued for the lack of a substitute, but developmental efforts were turned to the invention of a simple, hand-held instrument that could be used from extremely low altitudes.

The attack on Pearl Harbor naturally intensified these efforts. The antisubmarine campaign that followed made low altitude sights an urgent requirement. Combat experience bolstered that fact by proving that the "seaman's eye" method of bomb control, a technique previously considered satisfactory by many pilots, was even worse than its critics had been contending. Gun sights could be and were used for low altitude bombing by adjusting the line of sight to compensate for the gravity drop of bombs, but the technique was never considered more than a temporary expedient. Bombing called for bombsights, not substitutes—as welcome as they were in the interim.

A new project was soon under way. A naval officer, Comdr. A. B. Vosseller, suggested that a simple sight might be devised to indicate the proper moment to drop bombs or depth charges on the basis of the estimated course and speed of a submarine at the moment it dived to escape attack. By sighting on the swirl made by the U-boat's dive and using the estimates for computation, the officer thought the bomb control problem could be solved with the use of an uncomplicated, portable equipment. This idea was presented to the National Defense Research Committee for development under a Bureau contract. The actual work was done at the Franklin Institute in Philadelphia, where several models of a low altitude bombsight were devised. As soon as one of them gave good test results, the Bureau designated it the Bombsight Mark 20 and started a procurement program. The Institute assembled 60 of the equipments on a crash basis, while a production contract for 1000 sights was awarded a private contractor.

From the first, the instrument ran into both production and tactical difficulties. Complete drawings were not available for the manufacturer, who was forced to start work with nothing to guide him but a developer's model and the Bureau specifications. That situation naturally delayed procurement until a redesign could be accomplished. When early models of the sight began to reach operational use, tactical problems were exposed. In some planes the equipment could be used as a hand held sight by the pilot or copilot, but on others visibility restrictions required the use of a bombardier in the nose of the plane. Even worse, proper

use of the sight placed unacceptable restrictions on a plane's maneuverability. Although sound in principle, the sight did not meet the requirements of the combat forces. A process of improvement and modification ultimately produced an acceptable bombsight for use in blimps, but the low altitude bombsight problems for planes remained unsolved. Late in 1943 the contract for 1000 sights was cutback to 250 units. Fortunately, the submarine menace subsided just as the sight proved a failure, but U-boats were by no means the only target for low altitude bombing.

The end of the Mark 20 program left the Bureau with nothing to offer the service except the low altitude bombing attachment for the Norden bombsight, but two new sights were already under development before the end of 1943. The first of these, the Bomb-sight Mark 21, originated with a Pacific Fleet unit which designed the equipment and initiated production at the Naval Air Station, San Diego. It consisted of an Illuminated Sight Mark 9 mounted in such a manner that the sight could be set at any predetermined depression angle. This "San Diego Sight" was far from an ultimate answer to the bombing problem, but it was just as far superior to the "seaman's eye" method for which it seemed the alternative. Thus, when the Mark 20 proved a failure, the Bureau began procuring the simple, fleet-designed equipment.

Meanwhile, work was pressed on the development of a new sight that could better exploit the advantages inherent to low level bombing. The idea for such a sight came from within the NDRC, where concern with submarine countermeasures had already produced the Bombsight Mark 20. When that simple instrument proved inadequate, the scientists turned their attention to the design of a gyro controlled unit that would provide a fairly automatic solution to the low altitude bomb control problem. The answer was found by exploiting the so-called angular velocity principle. When an attacking plane began a bombing run, the depression angle of a line of sight to the target changed slowly. As the aircraft drew nearer, however, the rate at which the angle changed—or the angular velocity—increased rapidly, reaching its peak as the bomber crossed over its target. Since there was obviously some one instant at which bombs should be released to hit the enemy, there was just as obviously a particular angular velocity which marked that moment. The problem was to design an instrument that could measure the rate of change, determine the critical instant, and release the bombs automatically. To help them in the task, the NDRC workers had behind them experience in using gyroscopes for rate determination in lead computing sights,

plus access to the Illuminated Sight Mark 9, which could serve to establish a line of sight to a target. Both were utilized to produce a new equipment, the Bombsight Mark 23.

Although development was completed in 1944, the new bombsights were late in reaching the fleet. The company that accepted the contract for production design after the project was turned over to the Bureau of Ordnance was unable to undertake actual manufacture of the equipments. The Bureau then had to find a second contractor, one who entered the procurement picture late, was unfamiliar with the design, yet had to start production at a time when manpower and materials were critical. Then, when bombsights first became available, the supply was needed at training establishments. The result was that the most promising low altitude bombsight developed during the war never reached combat use. Instead, pilots used the attachment to the Norden sight, their own San Diego Bombsight, or developed tactical doctrines that permitted the use of the illuminated sights originally developed for gun control. Adjustable reflectors supplied by the Bureau permitted the line of sight to be depressed for work with bombs; combining that feature with their educated guess, airmen were able to take a heavy toll in enemy submarines and surface craft with a minimum of scientific help.

Efforts to develop a low altitude bombsight, stimulated by the search for submarine countermeasures, was paralleled by a research program to provide fire control equipment for dive bombing. Though the Third Reich and the fearful Stuka became identified with the technique early in World War II, it was really of older vintage. Credit for its origin is in dispute, but the tactics of dive bombing were perfected at Quantico shortly after the close of World War I. By 1928 Marine fliers were equipped with Curtiss Helldivers, the first of a line of planes designed especially for dive bombing. The term itself is properly descriptive of the technique. A Navy pilot, when asked to define it during World War II, came up with a dramatic description, emphasized by hand motions in the vertical plane: "When we speak of dive bombing, we mean straight down . . . right down the smokestack. If your airplane doesn't stand on its nose and lay eggs in their lap, then you are not dive bombing." That was, of course, an extreme view, not shared by all United States Navy pilots, but it dramatized a picture of a bombing approach especially valuable against naval targets.

Long before the outbreak of hostilities, the Navy was aware that dive bombing held more promise than horizontal bombing. Year after year in the last decade before the war, fleet practices demon-

strated the superiority of dive bombing. Even when horizontal bombers were equipped with precision bombsights, dive bombers, employing simple gun sights to establish a line of sight to the target, ran up the more impressive scores. Against a maneuvering target they held a practical monopoly on effective attacks.

While gun sights could be used for bomb control, the Bureau was anxious to provide bombsights that would increase the lethal probability of each dive. Once again the talent of the Norden Co. was enlisted. Progress suffered by competition with older projects, but a promising equipment was presented to the Bureau during the first year of the war. Known first as the Norden Aiming Angle Sight, then as the Bombsight Mark 16, the instrument was designed to permit planes to release bombs at altitudes above 5000 feet, yet retain the accuracy of dive bombing and its advantages of short fall time and high striking velocity. Shortly afterward, a simplified version of the sight, the Mark 17, was also accepted for consideration. Neither bombsight was placed in full scale production. Tests during 1943 and 1944 belied the early promise of the ordnance. Though the computations of the instruments were highly accurate, satisfaction was confined to the theorists. Both sights had to be used with flight techniques not normally expected of even highly trained pilots.

The failure of the two bombsights practically ended attempts to mechanize the control problem presented by dive bombing. Some accessories to existing equipment were developed, however, with the hope that pilots would find them more helpful than gun sights. A dive angle indicator was incorporated into the Aircraft Telescope Mark 3, for instance, but the innovation proved of little value. The obsolescence of telescopic sights antiquated the new with the old. A visual indicator for slip and skid—vital factors in a dive attack—met the same fate. The concentration required in controlling the plane and aiming at the target left the already overburdened pilots with no time to spare for additional instruments. Gun sights furnished no scientific answer to the bomb control problem, but they established a line of sight and they had the virtue of availability.

In normal dive bombing tactics the pilot had to keep the flight path of the plane above the target by an amount sufficient to compensate for the gravity drop of the bomb after it was released. The line of sight furnished by a gun sight was thus only a reference line, not an indication of the line along which a pilot should fly in order to score hits on the enemy. The deviation between the line of sight and the correct flight path was dependent upon several

factors—the dive angle, speed and altitude of the plane, and the type bomb to be released. A deviation in mils as measured on the reticle pattern of the gun sights could be established for each combination of the variables in the control problem, but a pilot could not be expected to memorize the aiming allowance for each of the many possible combinations. Instead, squadron doctrines were developed, grouping the factors into fixed combinations, and specifying a point of aim and release for each. The tactical rigidity imposed by the procedure was the price paid for bombing with gun sights, but the tactics were realistic. They provided naval aviators with a method of attack that remained far more effective than the highly mechanized horizontal bombing.

Though the bomb control problems posed by dive bombing were successfully met through tactical doctrines, a more promising technique was developed in 1943, when toss bombing was improvised. The new method differed from the old in that the bombs were released after the plane pulled out of the dive. The effect of the technique was to give the bombs a toss that compensated for the normal gravity drop of the bombs, making their line of fall coincidental with the original flight path of the plane. The aiming problem was simplified; the only allowances that had to be applied by the pilot were those for wind and target motion—problems common to both dive and toss bombing. Using the new technique, pilots were able to release bombs at altitudes up to 6000 feet and in dive angles ranging from 15° to 60° , yet attain accuracy comparable with that offered by the more restricted dive bombing.

The bomb control problem was mainly one of determining the exact moment during the pullout to release the bombs. Experience and tactical doctrines could serve pilots here, as in dive bombing, but instrumental aid was desirable. The latter part of 1943 was devoted to experiments, and early in the following year the Bureau launched a project to develop a new equipment designated Bomb Director Mark 1. Though toss bombing simplified some of the control problems posed by dive bombing, it introduced others that had to be solved before an automatic equipment could be developed. The proper moment of bomb release depended on distance from the target, which made ranging the key problem to a mechanical solution. Progress floundered on that difficulty for some months, but a way out of the impasse was discovered in mid-1944 through a scheme to use the decrease of altitude rather than of range as the source of the time-to-target information needed to determine the moment for bomb release. The altimeter

reading alone could not give the distance to the target, but when used with the dive angle recorded by a gyro apparatus, it provided the basis for a solution.

The new approach to the ranging problem removed the main obstacle to development. And none too soon because, in August 1944, the Bureau of Aeronautics expressed an urgent requirement for 500 toss bombing equipments. With the design still in a state of flux, regular manufacturing procedures were out of the question, so the Bureau of Ordnance arranged for the National Defense Research Committee to supervise procurement until a regular contract could be awarded. In that way production started before the end of 1944.

The Bomb Director Mark 1 required a minimum of attention from the pilot. He simply dove toward the target. When steady on a collision course, he pushed the bomb release button on his control stick. From that point on, the director began to work. Information on speed, altitude, and dive angle were automatically fed into the computer. After a short period of time—during which approximately one-sixth the distance to the target was covered—the computer was ready to calculate the proper moment for bomb release. A signal light then turned on to indicate readiness, and the pilot was free to pull out of the dive at his discretion. The bombs were retained in their racks until the force of the pull out was just right to furnish the desired toss, then were released for a free fall flight that duplicated the original collision course of the plane itself. Very few of the bomb directors were actually delivered during the course of the war, but their development was an important achievement. Not only did they mechanize bomb control, they offered a promising new approach to the fire control problems presented by torpedoes and rockets.

The two weapons, one old and one a wartime innovation, posed somewhat similar control problems. Each of them tended to retain the course and speed of the plane at the moment they were released, though the generally flat trajectory was altered by wind and rounded into a curve by the force of gravity. In the case of rockets, the boost given by their burning propellants tended to keep the trajectory relatively flat, so that the control problem was not unlike that offered by gunfire. The resemblance was fortunate, permitting both torpedo directors and gun sights to be used for aiming rockets once pilots were furnished sighting tables that helped them estimate the gravity drop of their armament.

When aircraft rockets were first introduced, the illuminated sights were most commonly used for fire control. The addition of

an adjustable reflector that permitted the line of sight to be raised to compensate for gravity drop was enough to meet the minimum requirements of rocket control. The main objection to that expedient stemmed not from inaccuracy, but from the addition of one more manual task to the many already facing pilots. In mid-1944 the Bureau met that objection by replacing the adjustable reflector with a sight whose reticle pattern included a sort of ladder of crossbars that could be used for lowering or raising the line of sight. The pilot, following squadron doctrine or the dictates of experience, simply selected one of the graduated rungs and sighted across it rather than through the center of the reticle pattern.

Modified illuminated sights proved valuable for use with rockets, as did torpedo directors, but the Bureau of Ordnance and its contractors continued an attempt to develop more accurate control equipments. One of the main obstacles to progress in rocket control stemmed from the inherent inaccuracy of the weapons themselves. Rockets could never compare with projectiles for accuracy, and their natural dispersion baffled all attempts to match the precision obtained with naval gunfire. Progress in devising control equipments was thus tied to that made in rocket development, and aircraft rockets were a wartime innovation. Advances were made, however, and as rockets became more accurate the Bureau supplied more precise control equipments. The Gun Sight Mark 23, a lead computing equipment, was modified for rocket use late in the war, and a rocket sight was developed for the Bureau by the California Institute of Technology. Both instruments became available at about the same time as the Bomb Director Mark 1. None was ready in time for widespread service use, but their development promised a mechanization of the rocket control problem just when V-J Day put an end to all combat evaluation.

The problem of torpedo control, superficially similar to that presented by rockets, was in many respects a more vital matter. The weapons themselves were complex and costly instruments. In contrast with rockets—especially the early ones—torpedoes were designed for precision. Even more important, torpedo attacks were apt to be more dangerous for pilots to undertake—a grim fact that was underscored at the Battle of Midway. The extreme hazards of attack needed the justification and consolation offered by an expectation of success.

At the start of the war the standard control equipment in use was the Torpedo Director Mark 28. The instrument was as good as the torpedoes it was designed to control, but experience soon

proved that not good enough. Prewar tactical training was based on low altitude attacks at slow air speeds. Such approaches gave pilots time to operate the director, which rewarded the considerable attention it required with a commensurate degree of accuracy. Unfortunately, neither the tactics nor the torpedoes were adequate for the demands exposed by war. The low and slow attacks made the planes too vulnerable. When higher altitudes and greater speeds were used, the torpedoes were damaged and nearly valueless. That part of the problem was overcome by a series of modifications that made the Aircraft Torpedo Mark 13 a reliable performer, but the improvement of the weapon merely confirmed the obsolescence of its director.

As soon as torpedo tactics began to change, the Bureau extended the useful life of the director by issuing a mathematical table that enabled pilots to alter the director settings for more realistic attacks. That step was a temporary expedient, however, and the development of new fire control equipment paralleled the modernization of aircraft torpedoes. Early in 1942 the germinal idea for a new director was conceived by W. B. Ensinger, a Bureau engineer who based his plan on the versatile Illuminated Sight Mark 8 and an original angle solver which indicated the proper moment to release a torpedo. That instant was a function of several values: the ratio of air to water travel for the torpedo, the altitude of the plane, and the ground speed at which the attack was made. All of these factors affected the speed at which the torpedo would reach the target, and in turn determined the proper instant for release. The distinctive feature of the new design, designated the Torpedo Director Mark 30, was that all the various factors were consolidated into one input, average torpedo speed. It had to be computed from the several values, but the task was simplified by the development of a circular slide rule, the Average Torpedo Speed Computer Mark 1, which pilots could use to determine the proper settings for the director. Later in the war, a computing mechanism took over that function and made the solution of the fire control problem nearly automatic.

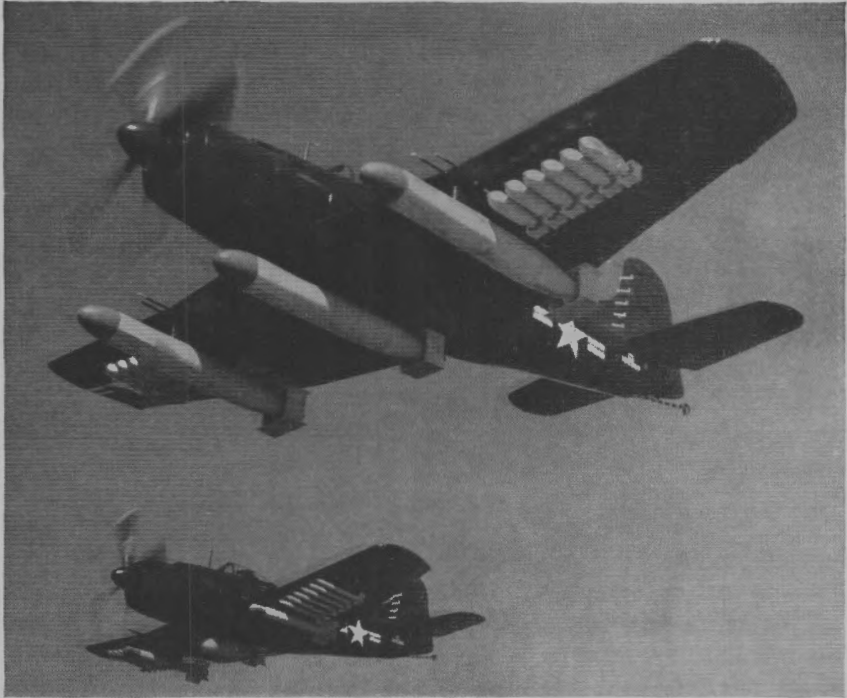
The idea for the Mark 30 moved from the mind of its inventor to the production lines with unusual speed. The Franklin Institute in Philadelphia assisted in the developmental work under an NDRC contract, and procurement started in July 1942. The Mark 30 was the last torpedo director for which a service requirement materialized, but its production did not mark the end of Bureau efforts in torpedo control. Pilots were not satisfied with existing equipment. Improved though it was, it still required too

much attention and placed too many limitations on evasive maneuvers. Many veteran fliers preferred to use an experienced eye and the aid furnished by a fixed gun sight. That feeling tended to grow steadily. Late in the war it became so strong that torpedo directors were actually removed from allowance lists and replaced by the educated guess that scientists deplored and aviators preferred. Before that happened, however, the Bureau of Ordnance and the Franklin Institute cooperated in the development of a director designed to allow pilots to maneuver during an attack without having to make manual adjustments to the control equipment. The result of that effort, the Torpedo Director Mark 32, never saw combat use, but it nearly met the desired goal. Though weighing only 1 pound, it handled all of the variables in the fire control problem and, even better, allowed the pilot to fly an evasive course up to the release point. The director was so promising that it was rushed into production early in 1943.

Limited service use soon showed that the equipment needed redesign before it could be considered ready for combat. The instrument was simply too delicate for the conditions prevailing in forward areas. Modification might have alleviated the problem, but no requirement for the new device materialized. Pilots continued to prefer proved tactical doctrines to complicated fire control equipments.

The basic problem represented in the rejection of the torpedo directors was one which applied to the whole field of aviation ordnance. Planes which once carried light machine guns and fixed sights were later replaced by aircraft which offered superior performance at the cost of new demands on the pilots. And the new planes carried a greater number of more complex guns, plus various combinations of other aviation weapons—torpedoes, bombs, rockets, and supplementary gun containers. Each presented control problems that required the addition of fire control apparatus; each was used under changing tactical conditions that varied the aiming procedures and demanded adjustments to that apparatus. Aids to flying and to firing multiplied so rapidly that the description seemed a misnomer: aviators were apt to consider them burdens.

The Bureau of Ordnance attempted to achieve simplicity from the first—the widespread application of the relatively simple gun sights was one result of that effort—but as weapons multiplied, the demands for additional fire control gear had to be met immediately. There was no time to wait until some one equipment could be designed to control all of the armament under all of the tactical situations in which it might be used. The development of such an



The multiplication of aircraft weapons outstripped progress in aviation fire control.

equipment was an important goal, however, and paralleled a trend that first seemed to work in the opposite direction. That was the introduction of air-borne radar sets. The first applications of the electronic gear were for search rather than fire control purposes, but the relationship between the two functions was obviously close. Radar, offering a way to penetrate many of the normal barriers to human vision, provided a valuable supplement to the optical sighting apparatus that was basic to most fire control equipments. As a supplement, radar merely added to the complexity pilots and maintenance crews already found baffling, but it also promised relief from some of the tasks that burdened pilots. Lead computing gun sights, for instance, were unpopular with aviators because the ranging operation required undue concentration. Radar could serve as a simple and accurate rangefinder.

Intensive ordnance applications of aircraft radar was retarded during most of the war by the incompatibility of search and fire control requirements. Surface ships faced the same problem, but they were able to carry many separate radar equipments, each

designed for a particular function. Space and weight restrictions precluded any such solution for aviation fire control. Late in the war, however, advances in radar development permitted ever wider applications of the new science. The direction of progress indicated what might be expected in the postwar years: integrated fire control apparatus which could use the potential of radar to detect, acquire, and track targets which could then be destroyed by any one of the many weapons included in the arsenal of aviation ordnance.

Chapter 16

FIRE CONTROL

EACH year the Bureau of Ordnance has to inform several prospective contractors that while fire control is properly in its province, equipment for putting out fires is procured by other agencies. To the average layman, damage control and fire control seem juxtaposed terms until it is explained that the latter refers to the system of directing the weapons of a ship—a science based on mathematics and the wizardry of mechanics, electricity, and electronics, rather than on the smothering capacity of carbon tetrachloride. Once the explanation is made, the number of interested contractors diminishes rapidly. Even in a technological nation like the United States the number of manufacturers capable of developing and producing the complex equipments used in fire control is severely limited.

A summary look at the problem explains the dearth of developmental facilities. Hitting a moving target from a gun platform that is both traveling along a course and rolling and pitching with the ship that carries it implies a complicated problem, even when the values involved are all constant. And fire control is characterized by variables, not constants. For instance, the obvious relationship between the angle of elevation of a gun barrel and the range of a projectile fired from it is affected by a number of factors. The velocity of a projectile, basic to range computation, varies with its weight, the temperature of the propellant, and the number of rounds previously fired from the same gun. During its flight the projectile is further affected in range or deflection by its own shape and rotations and by a wide range of atmospheric conditions—temperatures, barometric pressure, and winds, both at the surface and through all their variations along the trajectory of a round that might reach 20,000 feet above sea level and extend through extremes of wind velocity and direction. In rare cases, even the curvature and rotation of the earth must be considered in the control problem.

When the target happens to be an airplane or guided missile, a new dimension is added to complicate the geometry, and the time allowed for finding a solution and laying the guns is reduced to a few seconds. Most other weapons present fewer complications

than guns, but all of them—torpedoes, rockets, bombs, and depth charges—pose distinctive problems that demand rapid, precise solutions if the entire process of designing weapons and ships to carry them is not to be negated and reduced to expensive futility.

In the face of such problems the traditional "seaman's eye" has but limited use in estimating situations, and even a facile mind is unable to compute the mathematics of a fire control problem rapidly enough for the solution to be of any value. Such human attributes have been replaced by a system of ingenious instruments that collect information on the range, bearing, and elevation of targets, measure the rates of change of those values, provide ballistic corrections for the particular guns and projectiles in use, compensate for the tilt of the gun platform, the direction and velocity of the wind, and the course and speed of own ship, then compute gun orders from that information and transmit them to the guns. The instruments vary from small self-contained gun directors capable of collecting and computing all the information required for laying guns, to systems of equipments that extend from the top of the fire control tower deep into the bowels of the ship.

The development of the science of fire control and the evolution of instruments carried aboard a modern ship are recent phenomena. Despite the fact that mathematicians worked out an approximate solution to a projectile's trajectory as early as the sixteenth century, military and naval officers were uninformed and unconcerned. Disinterest continued throughout the seventeenth and eighteenth centuries. The treatises of Galileo and Newton were hardly ward-room literature, and neither naval ordnance nor tactics posed any requirements for fire control techniques or equipment. Gunnery was based on pointblank ranges, with ships standing yardarm to yardarm and firing muzzle to muzzle. Powder charges were not regulated, nor was the projectile load standardized. When circumstances demanded and the range permitted, guns were literally loaded to the muzzle with shot. On those rare occasions when some allowance for the curvature of trajectory was mandatory, the normal method was "sighting down the line of metal," or bringing the top of the breech and the top of the muzzle in line with the point of aim. This had the effect of elevating the gun by the amount of its taper, thus extending the range of shot. Within that framework, the point of aim could be further adjusted by shooting on the up roll or down roll to fire into either the rigging or the hull. Such was the status of fire control when the United States won its independence from England.

The Napoleonic wars that followed witnessed an important advance—the introduction of fixed gun sights—but their immediate acceptance was cool. Naval leaders were suspicious of what they regarded an unnecessary complication, and left to their army colleagues the gradual development of sights that were adjustable in elevation and deflection. Even as late as the Civil War, naval gunnery was as primitive as that employed against the Barbary pirates during the administration of Thomas Jefferson. True, the *Merrimac* and *Monitor* opened fire at a range of almost 1 mile, but most of the engagement between the two ironclads was fought at ranges of about 100 yards.

The turning point was at hand, however. The introduction of rifled guns and the development of superior powders so increased the accuracy and range of naval guns that the acceptance of gun sights was mandatory. Moreover, the drift of a projectile fired from a rifled barrel demanded some compensation for its deflection. This led first to the use of sights with an adjustable rear leaf, then, late in the century, to the adoption of telescopic sights that were adjustable for elevation, range and deflection. Another important advance came in 1898 when Lt. Bradley A. Fiske, the naval officer responsible for the telescopic sight, introduced a stadimeter range-finder that eliminated one of the most troublesome estimates in gunnery. Combined with well regulated powder charges, it substituted science for guesswork; used in conjunction with the new sights, it permitted relatively accurate gunfire with the rifled cannon then in common use. Own ship and target motion were still not scientifically determined, but their effects were at least roughly compensated for in deflection settings. Fire control was on its way to becoming a science when the United States Fleet engaged the Spanish at the close of the nineteenth century.

Once the new field became an area of active investigation, progress was rapid. The first decade of the twentieth century witnessed the invention of superior rangefinders, the range clocks that characterized the topside appearance of battleships, and communications systems that permitted information to be relayed to the guns from officers who worked at plotting boards to produce the calculations of elevation and deflection. Though the equipment itself was still rudimentary, the techniques worked out during the decade became the basis for many modern fire control practices. The centralization of control around plotting boards was especially significant as the origin of the plotting rooms and combat information centers on modern men-of-war. The initial exploitation of these advances was handicapped by the existing system of having

batteries made up of guns of various sizes, but that obstacle was removed when the United States Navy adopted its present system of dividing guns into main and secondary batteries. The division simplified the fire control problem considerably by reducing the number of ballistic calculations required for battery control. The new system marked the inauguration of the dreadnaught type battleship and prepared the way for further advances in fire control techniques.

The centralization of control introduced up to that point was largely confined to plotting. The actual laying of the guns was done at the mounts by the pointers and trainers, using information relayed to them by the officers who worked over the plotting boards. This was an obstacle to real coordination of fire control, but the British soon took the initiative in removing the barrier. While the Balkan and Moroccan crises were hurrying Europe on the road to World War I, the Admiralty worked out the principles of director firing, whereby the guns of a battery could be trained and elevated from some advantageous location away from the guns themselves. The English Vickers Corp. crystallized the naval ideas into satisfactory equipments, and gun directors were soon an integral part of the fire control system of His Majesty's Navy. The United States purchased the Vickers directors and associated transmitters and receivers for the control of 5-inch guns, then followed the English lead with designs of its own, so that when American ships crossed the Atlantic to join the British Fleet in 1917, they were equipped with directors capable of laying the secondary batteries and of transmitting train and elevation orders to the main battery guns.

Directors ultimately became the basic equipment in gun control for all batteries giving their mark designation to the fire control systems made up of the numerous instruments required to compute and correct gun orders. In their simplest form they constituted a master sight for the guns under their control; in later models they were sometimes complete fire control systems containing all the instruments needed to compute and transmit gun orders. Lacking those components, they simply stayed on their target, moving the guns with them in train and elevation. The guns themselves had to be corrected for parallax, or the difference between their line of sight and that of the director, then supplied with leads in train and elevation, but they could be moved and fired together with a precision impossible in local control.

Directors were not the only innovation the United States Fleet carried into the conflict. In the years just preceding the war a

rangekeeper was developed for the Navy by the Ford Instrument Co. The equipment simplified the plotting problem by drawing into a mechanical unit the various functions of the rate clock, and the plotting boards. Moreover, the equipment, designated Rangekeeper Mark 1, automatically handled the computation of deflection and certain of the ballistic problems involved in fire control. Target bearing and own ship's course and speed were introduced automatically; those estimated for the target were set in by hand. Through electrically driven computing mechanisms, the rangekeeper integrated the changes of range resulting from the relative motion of the two ships and gave a visual indication of the accuracy of the estimated data. Corrections still had to be worked out by tables or graphs and applied manually, but the Mark 1 was an important step toward the mechanization of fire control.

In a sense the solutions generated by the rangekeeper and sent to the guns were hypothetical since they were based on values which were set into the instrument and regarded as constants, but the coincidence of the hypothetical and the actual was assured by visual observations and the comparison of observed values with those generated mechanically. Gun order correctors used these "spots" to alter the settings of the equipment, which meanwhile furnished a smooth and continuous solution of the geometrical problem involved in aiming naval guns. Spotting was first done from some lofty position topside, but as battle ranges were extended a more elevated position was required. Balloons were first tried. Towed at a height of from 1000 to 3000 feet above battleships, they contained a spotter who remained in telephone communication with the ship. The daring spotters were able to furnish the required information on hits and misses, but the balloons proved dangerous, unwieldy, and a restriction on maneuverability. Aircraft soon replaced them and gained an important role in naval fire control. Not only did they prove an ideal platform for spotting, but by providing ships with information on ranges and bearings, they permitted firing at targets not even visible on the surface.

The postwar years witnessed the progressive development of superior equipment to replace the devices which served in 1917 and 1918. The first Ford rangekeeper was antiquated by more elaborate computers, and stable elements were developed to measure and compensate for the rolling motion of ships. These equipments permitted important refinements to the methods of director fire. Early systems were frequently little more than gun order transmission systems, whereby the proper train and elevation were indicated on dials at the guns themselves. Two

men, the pointer and the trainer, used hand controls to match the dials showing actual gun position with those that indicated the computed orders. The system provided centralized control for plotting and directing, but left the gun itself in local control. Moreover, the early directors coped with but did not solve the control problem posed by a ship's roll and pitch. Guns were fired only on the middle of the roll. That introduced stability, but it reduced to a fraction the time available for shooting. The postwar equipments removed both defects of the earlier directors. The "follow the pointer" method of matching dials was reduced to a mere standby or emergency measure, and automatic mechanisms were provided to lay the guns in accordance with the computed orders. Just as important, the stable elements permitted continuous fire, regardless of the position of the ship. By the time of the Japanese attack on Pearl Harbor, surface fire control was almost completely automatic. Some of the equipments afloat were considered obsolete or obsolescent, but they were basically sound and, after modification, most of them served throughout the war.

Although no less than 15 different types of gun directors and associated equipments were modernized and kept at sea, the bulk of service use for main battery control was borne by the systems built around two directors, the Marks 34 and 38. The former, originally designed specifically for cruisers, was the embodiment of several decades of fire control development. Having grown up like Topsy, it varied to a certain extent from ship to ship, depending on the date of installation and the progress of modernization, but the equipments shared several things in common: they were able to provide adequate fire control for main battery guns, and they were rough in operation, unpopular with crews, difficult to maintain, and far from the ultimate in fire control equipment.

Faced with making the most of what was available, the Bureau of Ordnance pursued two parallel courses: by a series of alterations the Mark 34 was pushed as close to the ultimate as the nature of its evolution permitted, and a successor, the Gun Director Mark 54, was placed under design. This new equipment removed almost all the defects of the Mark 34 and was also adaptable to the control of small, dual-purpose guns, but it was never able to prove itself in battle. The first of the new directors was not delivered until January 1946. Between the cumbersome Mark 34 and the modern Mark 54, stood the Gun Director Mark 38. Produced before Pearl Harbor for battleships and cruisers, the equipment

provided the basis for a very satisfactory fire control system. Progressive design changes kept the director and its associated instruments in pace with developments in guns and ammunition, and procurement of the Mark 38 continued throughout the war.

Although the prewar adequacy of main battery fire control tended to discourage the expenditure of talent, time, and money in extensive developmental effort, the overall picture was one of impressive progress. The mark numbers assigned to equipments in use in 1945 might have been familiar in 1940, but the performance hardly bore comparison. To a large extent the change was the product of an electronic revolution. Radio detection, adapted to ordnance in the form of fire control radar equipments, both supplemented and transformed the familiar control systems. As the radar art advanced, more and more functions were passed to it. From simple search devices the radar equipments gradually became the source of information on range, bearing, elevation, spotting, and target identification. Complete blind firing became possible and the trend toward centralization of control approached a climax. Radar scopes permitted more and more functions to be controlled from the plotting rooms, and the ultimate was reached in plans for a class of cruisers which were not even provided with main battery directors. Instead, the guns were controlled in train and elevation directly from the plotting rooms. This was of course the ultimate, rather than the typical, but the design indicated the direction main battery fire control could be expected to take in postwar years.

While the introduction of radar and the attendant emphasis on remote control of main batteries were perhaps the most significant developments in the field of surface fire control, several other innovations contributed to the general efficiency of the systems in use during World War II. Rangekeepers and computers, the heart of gun control systems, were modified to provide quicker solutions. Electrical systems were designed to replace the earlier mechanical equipments, and electronic instruments were invented as possible successors to the already ingenious electrical devices. Transmission systems for target designation followed the same line of evolution, working toward a really instantaneous method of relaying target information from search to fire control radars, then to computers and the guns themselves.

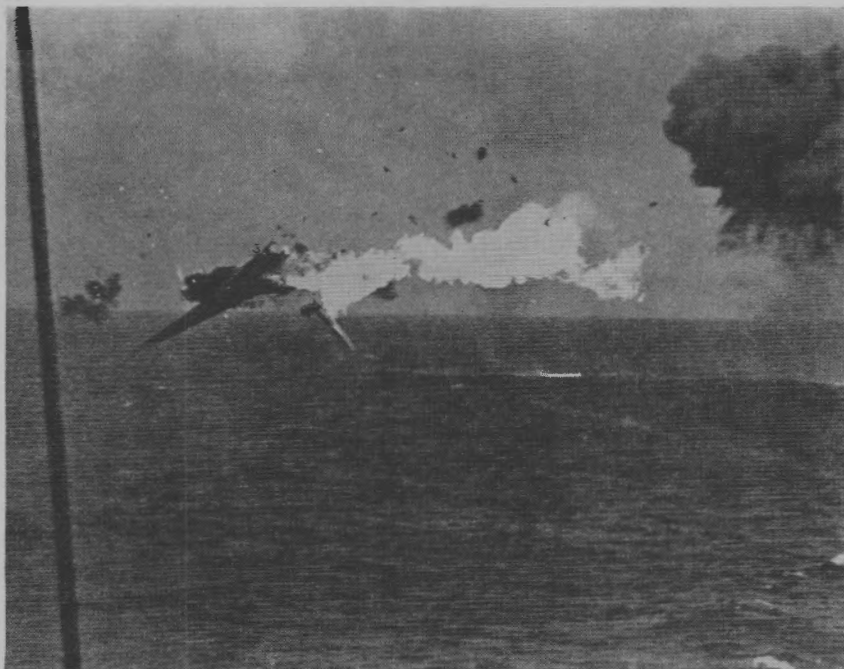
As important as these innovations were for the whole field of gunfire control, they reached their peak of development in systems designed for antiaircraft fire. Bolder steps were required there than in surface fire, and the Bureau naturally emphasized the

neglected rather than the adequate field. The result of that emphasis was the crystallization of new ideas into equipments that could cope with the greatest threat the war posed to the security of the United States Fleet.

Of course this menace was not born with the attack on Pearl Harbor. Even the primitive air warfare of World War I was spectacular enough to attract attention to the problem of insuring an adequate defense against a new weapon. And though bombing raids were then confined almost exclusively to land targets, the Bureau turned its attention to the design of guns and fire control equipment capable of coping with the extra dimension involved in aerial attacks. The first results of this effort were the introduction of 3-inch guns capable of almost perpendicular fire and the development of telescopic sights with the requisite flexibility in elevation. The new armament was quickly recognized as insufficient, however. Attention was next directed to modifications that would permit the employment of ordinary surface fire control equipment against air attacks. These efforts were not exactly abortive, since they later materialized in provisions for firing main battery guns against planes on a barrage basis, but they merely nicked the periphery of the problem. A proper defense against planes demanded a large volume of fire against close-in attacks and highly accurate fire from larger guns when greater range was required.

Unfortunately, the first part of that problem was sadly neglected in the years between the two wars, when the assumed adequacy of existing armament produced an ill-founded complacency. A high volume of fire at short ranges was readily available with .30 and .50 caliber machine guns. Neither was a powerful weapon, but a battery of eight fifties was capable of firing almost 5000 shots per minute. Nor did fire control appear much of a problem. Small machine guns were too light for complex equipments in any case, and with volume of fire rather than accuracy their forte, simple ring sights and tracer control seemed adequate. This conviction was strengthened by the success of fighter planes with light machine guns. Later events showed that there was no parallel, since planes normally fired at pointblank range, but complacency was fairly widespread until 1940. Then, with war already underway in Europe, the search for new guns and the development of heavy machine gun directors became critical problems for the Bureau.

Meanwhile, attention was concentrated on the design of equipment that could control the double-purpose guns that constituted the secondary battery of battleships and cruisers and the primary armament of vessels like destroyers. Research on this project



Short range defense against aircraft was the principal weakness of Navy fire control at the start of World War II.

started in 1926. Three years later, the development of the first anti-aircraft director, the Mark 19, was completed. This was a pedestal type instrument which was ultimately installed on a power-driven mount and equipped with a 15-foot stereoscopic rangefinder. Only battleships and cruisers received the directors, however, so the Mark 19 was at best only a partial answer to the problem of air defense. The Gun Director Mark 28, a manually driven instrument developed for the Bureau by General Electric shortly thereafter, was also designed primarily for large ships. A more versatile equipment was badly needed, and the Bureau initiated a third project in 1932, hoping to produce a director system capable of controlling dual-purpose guns on ships ranging in size from battleships to destroyers. The result of this program was the Gun Director Mark 33. This instrument like the Mark 28, was a complete fire control system within itself, since each director contained a rangefinder, rangekeeper, and stable element. This feature precluded the use of plotting rooms below deck and permitted installations on ships as small as destroyers. Later, when destroyer escorts were introduced into the Navy, a few of the direc-

tors were even procured to direct their surface fire in shore bombardment, but installations were never actually accomplished on these smaller vessels.

In operation, the Mark 33 was almost completely automatic once it was sighted on the target by telescopes. Present range was determined by its own rangefinder, and advanced range was computed by the rangekeeper, which received the course and speed of own ship and computed those of the target. This information permitted the director to supply the guns with orders for train, elevation, and fuze settings. Early in the war the Mark 33 was further improved by the addition of radar, which supplied smooth, accurate data and made blind firing possible. But for all its virtues, the Mark 33 suffered a notable defect: each equipment weighed almost 20,000 pounds. This was considered too much weight at best, and the problem was compounded by the fact that all the director components were designed for topside, even lofty, installation—a fact that gave the director the descriptive appellation, "apple on a stick." The unusual mounting made the equipment especially susceptible to vibration, and the concentration of several instruments into a single unit meant that the operating personnel were crowded and vulnerable.

While the defects were not prohibitive and the Mark 33 remained in production until fairly late in World War II, the Bureau started the development of an improved director in 1936, only 2 years after the first installation of a Mark 33. The objective of weight reduction was not met, since the resulting director system actually weighed about 8000 pounds more than the equipment it was slated to replace, but the Gun Director Mark 37 that emerged from the program possessed virtues that more than compensated for its extra weight. Though the gun orders it provided were the same as those of the Mark 33, it supplied them with greater reliability and gave generally improved performance with 5-inch gun batteries, whether they were used for surface or antiaircraft use. Moreover, the stable element and computer, instead of being contained in the director housing were installed below deck where they were less vulnerable to attack and less of a jeopardy to a ship's stability. The design provided for the ultimate addition of radar, which later permitted blind firing with the director. In fact, the Mark 37 system was almost continually improved. By the end of 1945 the equipment had run through 92 modifications—almost twice the total number of directors of that type which were in the fleet on December 7, 1941. Procurement ultimately totaled 841 units, representing an investment of well over \$148,000,000. Destroyers, cruisers, battle-

ships, carriers, and many auxiliaries used the directors, with individual installations varying from one aboard destroyers to four on each battleship.

The development of the Gun Directors Mark 33 and 37 provided the United States Fleet with good long range fire control against attacking planes. But while that had seemed the most pressing problem at the time the equipments were placed under development, it was but one part of the total problem of air defense. At close-in ranges the accuracy of the directors fell off sharply; even at intermediate ranges they left much to be desired. The weight and size of the equipments militated against rapid movement, making them difficult to shift from one target to another. Their efficiency was thus in inverse proportion to the proximity of danger. They lessened the danger of horizontal bombing attacks, but placed too great a premium on early target acquisition and rapid target designation. Even after radar lent its genius to the search, acquisition, identification, and designation problems, a ship could not hope to knock out a whole group of attacking planes before any of them got within close or intermediate range of the vessel. Moreover, the use of new air tactics, based on the employment of dive bombers, toss bombers, and torpedo planes, increased the importance of close-in defense. For that role the Bureau had little to offer in the prewar years except the .30 and .50 caliber machine guns. True, a 1'1 heavy machine gun was developed and placed in production during the 1930's, but when the outbreak of war in Europe pointed up the need for short and intermediate range air defenses the new gun was neither available in sufficient quantity nor popular with those who had used it. For fire control the mounts had only open sights and a rudimentary target designation system.

The gun situation improved rapidly. Between Hitler's invasion of Poland and the Japanese attack on Pearl Harbor, the Bureau of Ordnance acquired two heavy machine guns capable of filling the gap that existed between dual-purpose batteries and light machine guns. One was the Oerlikon 20-mm, the other the Bofors 40-mm. Both were excellent anti-aircraft guns; neither came with a fire control system more dependable than ring sights. Thus, the fire control sections of the Bureau were faced with the task of designing control systems for three heavy machine guns. In addition to that job, there was still no fire control system available for the 3''/50 guns which had been the Bureau's first answer to the threat of air attacks.

In the 28 months of grace afforded the United States before the war spread from the European continent, the Bureau initiated a series of projects to develop a heavy machine gun director. Equipments with designated mark numbers from 45 to 49 were placed on the drawing boards, and production was rushed on a Director Mark 44 which was to serve as a stopgap design for use on 1'1 and 40-mm guns. This was not an ambitious project. The Mark 44 was simply a target designator that could be used to control machine guns in train and elevation. Its principal advantage was that it allowed the weapons to be aimed from a more advantageous location than at the mounts themselves, though it did utilize a large spotting glass that increased the effectiveness of tracer control. The Naval Gun Factory rushed into production of the equipments in late 1941, but only 85 of the directors were ever built. Installations had to be confined to large ships that offered a fairly stable platform, and production difficulties were so great that adequate delivery schedules seemed impossible.

Difficulties notwithstanding, the Bureau would have been forced to stick with the Mark 44 except that developments in another field offered the promise of a better stopgap design—the Gun Director Mark 51. This equipment grew out of efforts to develop a sight for the 20-mm gun, a weapon too light for director control, yet too valuable to use with nothing more than a ring sight or tracer fire. What the Bureau wanted was a gun sight that would automatically and instantaneously compute the lead a gunner had to apply to his gun in order to insure a hit. This could be done by developing a gadget that could measure the angular rate of motion of the line of sight of a gun tracking a target, then utilize that rate to produce sight settings which included leads in azimuth and elevation. Gyroscopes, able to furnish both horizontal and vertical reference planes from which rate measurements might be made, offered a fairly obvious approach to the lead computing problem. But the simplicity of the whole project broke down after an initial statement of possibilities. Accomplishing the task in an equipment which could be produced quickly and cheaply posed both developmental and production problems of a high order.

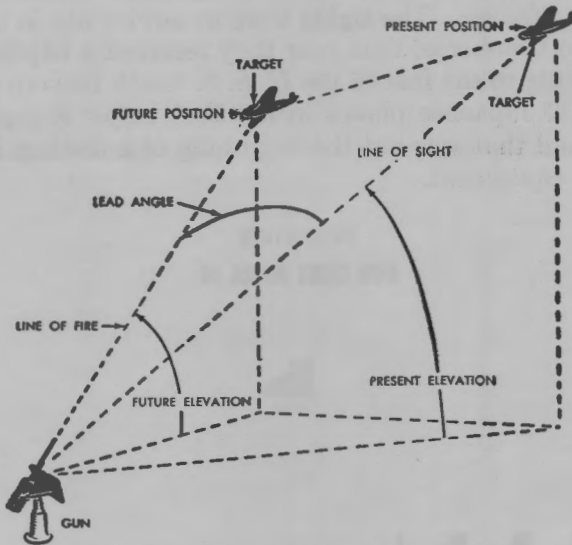
Fortunately, basic work on such a mechanism had been in progress for many years before World War II. Even more fortunately, the Bureau learned of this work in time to exploit it for both gun-sights and light directors. These opportune circumstances were the work of Dr. Charles S. Draper, a professor of engineering at the Massachusetts Institute of Technology. Back in the late 1930's,

while working on a bank and turn indicator for airplanes, the professor developed an instrument that used a spring suspended gyro to show rate of turn. Under the sponsorship of the Sperry Gyroscope Company, where Draper was a consulting engineer, an experimental model of the indicator was constructed. For various reasons the idea was abandoned, but the project was nonetheless important for the future. The idea had been crystallized and a rate gyro was in existence. Thus, when Dr. Draper later became interested in an antitank fire control problem, he recognized that the required gun lead must be connected with the angular rate of the target, and might be computed by a rate gyro similar to the one he had already built. Engineering associates of the professor were generally dubious, but the Massachusetts Institute of Technology agreed to back his experiments. Work on a lead computing sight was soon underway.

The early stages of the work were entirely unsupported by the Government. The National Defense Research Committee was informed of the project, but apparently shared the doubt of many of Dr. Draper's professional colleagues. The first official encouragement actually came from overseas. In the spring of 1941 the British technical mission led by Sir Henry Tizard visited Sperry and learned of Dr. Draper's project. Interested in its possibilities, they placed an order with the company for four experimental models. The inauguration of lend-lease soon ended English interest in the sight, but for the moment they lent encouragement to the project. Momentary support was enough; before the British order was completed, the Bureau of Ordnance learned of the project and became its sponsor.

This association, ultimately to grow into one of the Bureau's largest procurement programs, had fortuitous origins. An ordnance postgraduate at MIT learned of Dr. Draper's work and informed the Bureau that a new type gyroscopic sight was being made under a secret project at the Sperry Co. Already involved in two projects to produce such a sight, the Bureau immediately arranged for ordnance officers to inspect the Professor's work. What they found was a black box that contained two airspun gyroscopes. One was designed to compute gun lead in train, the other in elevation. The principle by which they worked was based on the gyroscopes' property of keeping a fixed direction in space except in response to a force applied to the spin axes, in which case they changed direction by an amount exactly proportional to that force and in a plane perpendicular to its axis.

This meant that when a sighting element was controlled in direction by gyroscopes and pointed at a target, the force required to keep it on the target then became a measure of its angular motion. The force was calibrated in degrees of lead that had to be applied for some set range for which the projectile's time of flight was known. The offsetting force was applied through spring linkage to mirrors in the sighting element itself, thus disturbing the line of sight by the amount of the required lead. A gunner using the sight saw a circle of light suspended in the sky. By keeping that image of a lighted reticle directly on the target he was automatically keeping the gun barrel pointed ahead of the plane enough to compensate for its motion and the projectile's time of flight, as well as above the target enough to allow for changes of altitude and the curving trajectory of the bullet. The only part of the operation not completely automatic was the range setting, which had to be estimated or preset for some range through which the plane would have to pass in order to attack the ship.

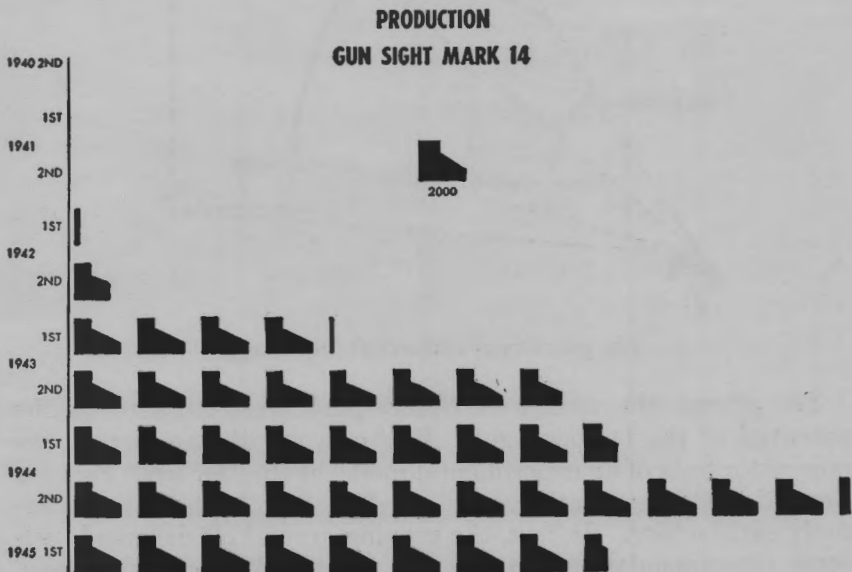


The geometry of anti-aircraft fire control.

The officers who visited the Sperry plant were quick to see the potential of the Draper sight. Within a month the Bureau arranged for tests of an experimental model at the Dahlgren Proving Ground. This evaluation, conducted in July 1941, was not entirely satisfactory. In fact, the proving ground officials made adverse recommendations on the gun sight. Within the Bureau,

however, the results were considered promising. Even though the accuracy of the experimental sight appeared inadequate, the device received enthusiastic support, with the result that the Bureau placed an order for 12 sights with the Sperry Co. Four of them were to be built in the form of pedestal mounts, since the Bureau foresaw that if the device worked at all it might be even more valuable as a heavy machine gun director than as a gun sight.

Events moved rapidly in the weeks that followed. Even before the dozen models were delivered, the Bureau followed its experimental order with a production contract. That proved possible after Sperry permitted the Bureau to test one of the Draper sights originally manufactured for the British Admiralty. The results confirmed the optimism over the device, and led to an order for 2500 sights. The new equipment was designated the Gun Sight Mark 14, and the initial order, risky as it seemed at the time, was dwarfed by the procurement program that followed. Approximately 85,000 were ultimately bought at a cost of roughly \$130,000,000, and few ordnance items had a more widespread distribution among the operating forces. The sights were in service use in the fall of 1942; late in October of that year they received a baptism of fire by contributing to the feat of the *U. S. S. South Dakota* when she shot down 32 Japanese planes in her first major engagement of the war. And that was but the beginning of a distinguished history for the equipment.



The Mark 14 was not without its serious problems, however, in the fields of production and maintenance. Engineering difficulties seemed insurmountable at first glance. The sight required gyroscopes mounted in gimbals which were light and frictionless, yet rugged enough to withstand the shock of gunfire. The tiny springs which were the very heart of the computing mechanism were flat leaves only six-thousandths of an inch thick, but they had to be supplied in enormous numbers. Moreover, the tolerance on their thickness was restricted to one ten-thousandth of an inch. Something of the nature of the problem was shown by the fact that over 90 percent of all the springs made during early production had to be rejected. The piping system that supplied the compressed air to spin the gyros at 10,000 revolutions per minute was also a source of engineering problems. In order to keep the system clear, the air had to be completely free of oil or water vapor. That required a closed air system operating from an unlubricated compressor through immaculate tubing that would not corrode and clog tiny orifices. These difficulties notwithstanding, the sights had to be produced quickly and rapidly in a production atmosphere characterized by priorities, scarce materials, and frequent design changes. Those, and a host of other problems, were solved by the Sperry and Crosley companies, the prime contractors, and by their innumerable subcontractors. Production schedules were not always met, but the sights were manufactured at an ever increasing pace and an ever decreasing unit cost. Procurement during 1944 was 2100 percent higher than in 1942, and the price of each sight dropped during the same period from \$2,532 to a low of \$925.

The intricacies that furnished so many headaches to experienced manufacturers were a source of even greater problems for the Bureau of Ordnance. The possibilities of breakdown or maladjustment were great; the possibilities of making repair aboard ship small. The main case of the gun sight was sealed at the factory to guard against air leakage and the probing fingers of unskilled seamen. That feature precluded fleet maintenance, placing the whole burden on shore establishments. In meeting this problem the Bureau ultimately established 24 maintenance stations at strategic locations all over the world. Their workload remained high, and their support placed a continual strain on the spare parts supply. The first estimates of replacement needs proved woefully inadequate, requiring large orders for additional spares that had to compete with new equipments for space on the production lines. Some mods of the sight had to be declared obsolete when their

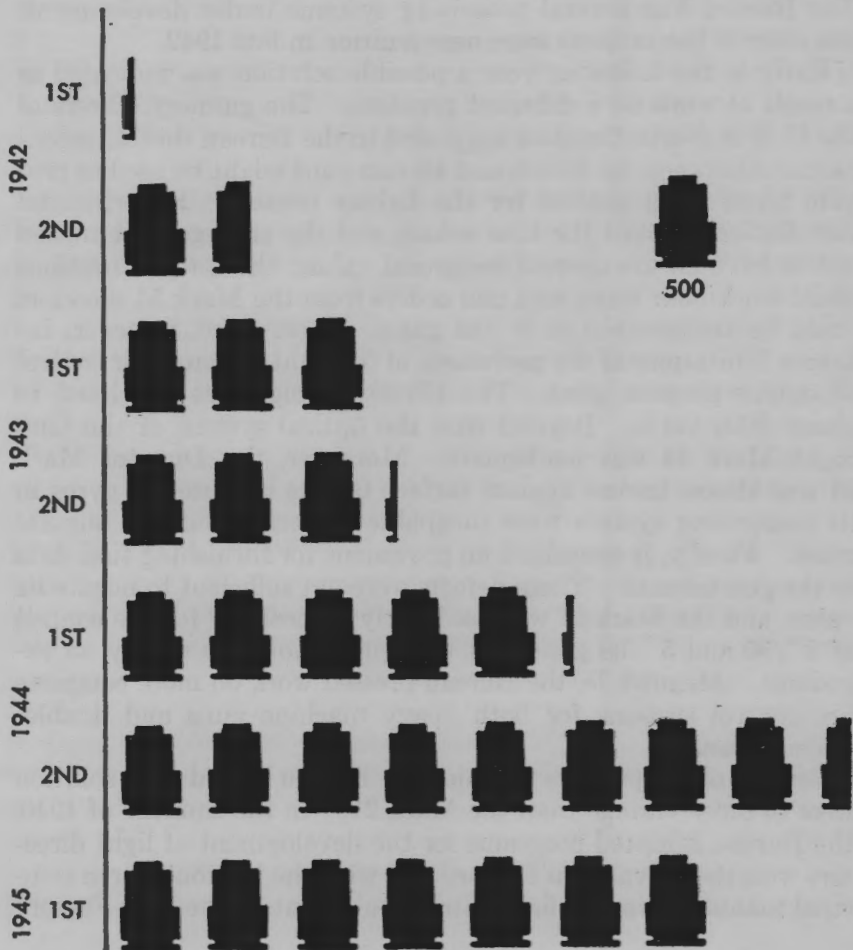
maintenance proved too severe a drain on the critical parts supply. Training, too, posed real problems with the sight. Simple as it was to operate, its function was widely misunderstood. In keeping with past experience, many gunners felt compelled to apply their own lead, with the result that a double lead destroyed accuracy. Others, from habit or suspicion, preferred to peer over the sight mechanism and follow the tracers they had learned to rely on for control. Training, practice, and supervision were required until the sight proved itself and won the esteem of its users. Despite all these difficulties, the popularity of the Mark 14 Gun Sight grew. Admiral Nimitz felt that it filled the war's most pressing need, and a further tribute came with the multiplication of the miniature enemy planes painted on the bridge screens of ships all over the world.

While the history of the Mark 14 sight would have been a distinguished one even if its usefulness had been confined to 20-mm guns, it proved of even greater value as the computing mechanism for the Gun Director Mark 51, a stopgap equipment designed to replace the unsuccessful Mark 44 as a heavy machine gun director. The possibility of this application of the lead computing sight was one of the reasons the Bureau had pursued the whole project despite the initial pessimism of proving ground officials. The original order with Sperry called for four of the dozen sights to be pedestal mounted so that they could be used as remote directors. The company's version was hardly more successful than the first of the Mark 14 sights tested at Dahlgren. Several defects caused the Bureau to pronounce it unsatisfactory. The promise was there, however, and a redesign was started immediately. Time was at a premium, so in January 1942, the Bureau awarded the Sperry Co. concurrent contracts for both development and production. This was a gamble like that taken with the Mark 14 itself, but both paid off handsomely. Early in May the first of the directors, a simple dummy gun pedestal that used the Draper sight as a computing element to determine train and elevation orders, was ready for successful testing at the proving ground. Within another month deliveries from regular production began.

The extent of the director's success was a surprise even to the Bureau. Both 171 and 40-mm guns showed considerable accuracy when controlled by the Mark 51. In marked contrast with the other equipments then under development or in limited production, it proved susceptible to cheap and rapid production. Sperry and its subcontractor, the Multiscope Corp. were able to deliver the first 100 units for less than \$2000 apiece, and experience soon per-

mitted voluntary price reductions by the manufacturers. Meanwhile, prospects for replacing the stopgap with an ultimate design seemed remote, so the Bureau increased its orders for the Mark 51. The number of heavy machine guns aboard combatant vessels was multiplying rapidly, and smaller vessels were slated to receive 40-mm mounts as soon as they became available for issue. This trend mushroomed the requirements for light directors, and until a superior equipment was available the Bureau felt that Mark 51's could be issued on a wide basis, then labeled expendable when any one of several developmental projects produced an ultimate installation.

PRODUCTION
GUN DIRECTOR MARK 51



The success of the Mark 51 solved one of the outstanding fire control problems facing the Bureau during the first year of war. Still demanding immediate attention was the matter of designing directors for use with 3"/50 and 5"/38 guns. For the smaller caliber, no control system was available. The larger double-purpose guns were satisfactorily controlled by Gun Directors Mark 33 and 37, but both of the more complex systems suffered defects. Neither offered real accuracy at short ranges, and neither permitted the kind of divided fire that was mandatory for an adequate defense against multiple attacks. The operating forces tried to circumvent those problems by using 5-inch guns in local rather than director control, but that was, in effect, a step backwards. A relatively light equipment that could control 3-inch guns and serve as an auxiliary director for 5-inch mounts was a pressing requirement. The Bureau had several promising systems under development, but none of the projects were near fruition in late 1942.

Early in the following year a possible solution was indicated as a result of work on a different problem. The gunnery officers of the *U. S. S. North Carolina* suggested to the Bureau that interconnections between the 5-inch and 40-mm guns might be used to provide blind firing control for the lighter mounts. Experimental installations proved the idea sound, and the arrangement turned out to have an unexpected reciprocal value: the interconnections could work both ways, and gun orders from the Mark 51 directors could be transmitted to 5"/38 guns. There were, however, inherent limitations of the usefulness of the light directors for control of double-purpose guns. The effective range was restricted to about 3000 yards. Beyond that the optical system of the Gun Sight Mark 14 was inadequate. Moreover, the Director Mark 51 was almost useless against surface targets because the gyros in its computing system were incapable of measuring low angular rates. Finally, it contained no provisions for furnishing fuze data to the gun mounts. These defects were not sufficient to negate its value, and the Mark 51 was used fairly extensively for the control of 3"/50 and 5"/38 guns, but the application was simply an expedient. Meanwhile, the Bureau pressed work on more complete fire control systems for both heavy machine guns and double-purpose mounts.

Several of the projects to which the Bureau looked for a solution were of older vintage than the Mark 21. In the summer of 1940, the Bureau initiated programs for the development of light directors with the Naval Gun Factory and with the Nation's three principal manufacturers of fire control equipment. The Gun Factory

turned out the Mark 44, the ill-fated director that gave way even as a stopgap design to the popular Mark 51. The Ford Instrument Co. worked on two directors, the Marks 45 and 49; the Arma Corp. devoted its talents to the conception of an equipment designated Mark 47; and General Electric accepted a contract for the development of Gun Director Mark 46. Each of the projects made some contribution to the subsequent history of heavy machine gun directors, but only the Ford equipments actually reached the production stage.

The first of these, the Mark 45, was completed by early 1942. Though originally conceived as a director for 1'1 guns, it was adapted to the control of 40-mm mounts as soon as the Bofors became a part of the Navy's armament. The director was in the form of a cupola, enclosed and protected except for an opening at the top through which the operator's head and shoulders projected. Its operation was similar to that of the Mark 14 gun sight in that leads in both elevation and train were instantaneously generated as a function of the angular rates introduced by tracking a target. Range was the only required input, and that was readily available since the director included a one and one-half meter rangefinder that doubled as a spotting glass. There was no comparing the two equipments, however. The Mark 45 was heavy, complex, and crowded. Its excessive weight restricted its use to battleships and cruisers; its intricacy threatened a long maintenance nightmare; its restricted quarters made prolonged watches unendurable for the operators. And if that were not enough, production difficulties precluded anything like an adequate delivery schedule. Confronted with so many problems, the Bureau stopped production on the Mark 45, returned it to the design stage, and placed its hopes on another Ford equipment, the Gun Director Mark 49.

This project was based in large part on experience gained with the Mark 45. The two equipments were similar in appearance and operating principles, but the Mark 49 was lighter and did not include the troublesome optical equipment. In its place, the Bureau intended to supplement the director with radar equipment that would make it capable of blind firing. That feature, plus the fact that the Mark 49 contained a stable element, made the director seem more promising than either the Mark 45, which it succeeded, or the Mark 51, with which it was in competition. By late 1942 the new equipment, minus its ultimate radar, was in production and ready for final tests. The first results were somewhat discouraging, but the Bureau decided to accept the director anyway,

on the theory that once its radar was ready for installation it would offer many advantages over the simple Mark 51.

Shipboard installations began in late 1942. Within a year there were approximately 200 in service use. This was not the director to replace the Mark 51, however. The equipment proved too cumbersome for use on destroyers, where its stabilization was of most value, and maintenance problems were numerous wherever it was installed. Since its highly vaunted radar was a year late in completing development, the director could not even offer the compensation of blind firing. For almost a year the Bureau kept the equipment in production, but by the fall of 1943 it was obvious that even when the director achieved blind firing it would be out of service too much of the time. Production was stopped and most of the installations were replaced with Mark 51 directors.

In 1942 the failure of a director that looked so promising might have seemed almost catastrophic. A year later it was little more than a disappointment. The interim had been long enough for the Mark 51 to prove itself an excellent machine gun director. Until advances in radar made a small, blind firing director feasible, the field of heavy machine gun control posed less urgent problems than those of developing an acceptable antiaircraft director to replace the Mark 51's which were controlling 3"/50 and 5"/38 double-purpose mounts.

The shift in emphasis from one program to another was well illustrated by the history of the Gun Director Mark 50, and equipment that grew out of parallel programs to develop machine gun and dual-purpose directors and was itself transformed from one to the other. This complicated situation dated back to 1941, when the Bureau began its serious efforts to produce a director for 3"/50 guns. Among all the projects then in existence, the most hopeful seemed to be the Mark 47 which the Arma Corporation was developing for the control of heavy machine guns. Its promise lay in the fact that it was based on an electrical rather than mechanical computer. That feature gave the equipment flexibility, and the Bureau felt that the addition of an electrical ballistic converter and fuze order computer might make it acceptable for controlling larger guns. The director was accordingly redesigned and designated the Mark 50. The only essential change entailed by the move was the addition of a new computer, yet the effect was to make the Mark 50 look like an all purpose director. It could control 1.1 and 40-mm guns as originally designed; with the new computer added, a simple flick of a switch made it suitable for use with 3"/50 and 5"/38 guns. On paper the Mark 50 looked like the

ultimate answer to the complicated anti-aircraft fire control problem. The director's solutions were instantaneous and reliable to ranges as great as 20,000 yards. It even offered blind firing through the use of a radar equipment that presented the target as simply as the optical telescope with which it was also provided.

The Bureau's original plans for the Mark 50 were modest enough. It was slated for installation aboard *Omaha* class cruisers, three old battleships, and certain large auxiliaries. For smaller vessels the Bureau planned to develop a lighter, less complex equipment. The Chief of Naval Operations had other plans, however. The versatile characteristics of the director made it seem applicable almost anywhere, and the Mark 50 was accordingly allocated to several hundred new construction ships that were to be provided with 5-inch batteries. Thus, the project that started out to convert a machine gun director into a 3"/50 fire control system grew into a major procurement program devoted mainly to control equipment for 5"/38 guns. But the proportions of the program were, like the virtues of the Mark 50, largely confined to paper. Deliveries that were scheduled to start in May 1942, did not begin for another year. Despite the experience of its manufacturer, the equipment was too complex for speedy production.

Even when the directors were available, they fell far short of their initial promise. Each installation weighed approximately 19,000 pounds, and that weight consisted of complex instruments that promised a variety of maintenance problems. The versatility of the director was of relatively little value. Its weight precluded its use with machine guns and even made it unacceptable for the control of many 3"/50 mounts. In some respects it was the best anti-aircraft director the Bureau had, but its limitations forced a restriction of the program. Orders were finally cut back to 43 units. The Mark 50 served as the basis for later fire control developments, but it did not solve immediate problems.

Fortunately, the collapse of the Mark 50 program did not force the Bureau to start a new and belated search for an adequate 3" gun director. Even before the end of 1941 some of the defects of the Mark 50 were anticipated, and the Bureau launched a parallel developmental program with the Sperry Co. A new director, designated Mark 52, was to be patterned after the Mark 51. Work lagged for the first 6 months while Dr. Draper and his assistants completed work on the Gun Sight Mark 14, but active development started in the summer of 1942. By then the specifications had been changed to include 5-inch ballistics, so that the new equipment could replace the Mark 50.

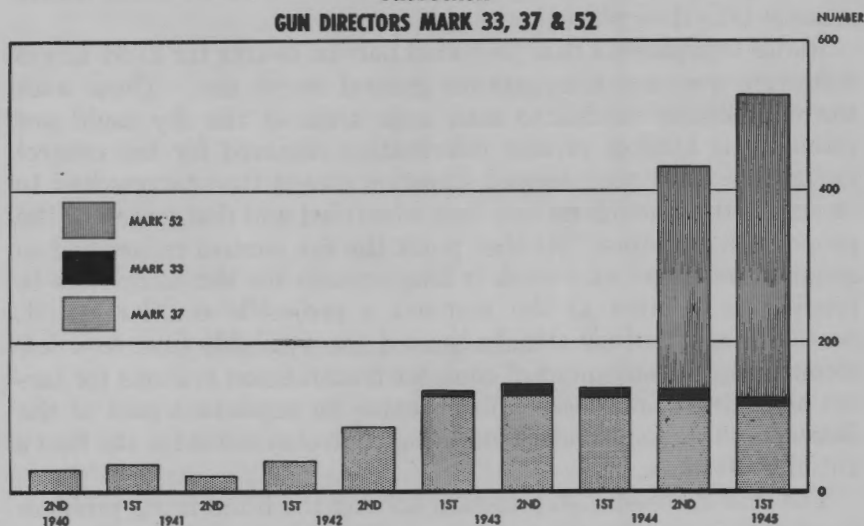
The principal problem involved in patterning a heavier director on the general design of the Mark 51 was the inadequacy of the Gun Sight Mark 14, so the Draper group began their work with the construction of a larger, more accurate sight. The result was that the Gun Sight Mark 15, similar to the older computing unit, but possessing refinements that extended its range and made it applicable to the ballistics of guns ranging in caliber from 40-mm. to 5 inches. This new sight served as the heart of the director, though it was supplemented by a simple Ford computer which was designed to furnish leads for surface fire when the angular rates were too small for the gyroscopic sight to handle. In addition, the Mark 52 director was furnished with a range indicating radar, a 6 power telescope, a fuze setting computer, gun order and parallax correctors, and with electrical signals from a wind transmitter. These basic equipments, supplemented by appropriate gun instruments, made the Mark 52 a fairly complete fire control system.

Even though design was still not complete in the spring of 1943, the Bureau gave its developers, the Sperry Co., a production contract. The original cost of the director was approximately \$21,000. Some price reductions followed, but frequent design changes exerted a generally upward pressure that tended to cancel out the advantages of experience. The changes slowed production, too, and combined with the normal difficulties of wartime manufacture, prevented deliveries until 1944. While waiting for the new equipments to come off the production line, the Bureau used early production models of the Mark 15 gun sight with Director Mark 51, thus improving their ability to control 3"/50 and 5"/38 guns. The expedient worked well, but the machine gun director lacked many features of the more complex Mark 52.

In the spring of 1944, deliveries of the new equipment finally began. Its performance proved worth the wait. During evaluation tests aboard selected ships, target drones were repeatedly destroyed on their first pass. In the course of the following year approximately 500 installations were made aboard ships originally slated to receive the abortive Gun Director Mark 50.

The completion of the Gun Director Mark 52 met the last of the requirements that had been anticipated at the outbreak of war. All of the Navy's antiaircraft guns could be controlled by one or more of the fire control equipments then in production—the Gun Sights Mark 14 and 15 or the fire control systems based on the Directors Mark 33, 37, 51, and 52. Meanwhile, however, new and pressing requirements were presented to the Bureau of Ord-

PRODUCTION
GUN DIRECTORS MARK 33, 37 & 52



nance. Enemy planes and submarines, capitalizing on poor visibility, frequently attacked during the twilight of dawn and dusk. Even fine optical systems were inadequate in those circumstances, and the need for blind firing control systems became urgent. The Gun Directors Mark 33 and 37 were equipped with satisfactory radar installations early in the war, but that was but a partial solution to the problem. They controlled only 5-inch guns, and they did not even permit divided control of those mounts. The fleet needed, and needed desperately, fire control equipments that were capable of blind fire, yet were small and light enough for installation with individual heavy machine gun and dual-purpose mounts.

The requirement was no real surprise. Its recognition had been the basis for the Bureau's prolonged efforts to perfect the Gun Director Mark 49 even after its many disadvantages were obvious. But there were many obstacles to meeting the requirement. Blind firing was dependent upon radar, and during the first two years of war that field was not sufficiently advanced to provide the kind of equipments needed for anti-aircraft work. Effective systems were necessarily large and heavy. While they could be used with directors like the Marks 33 and 37, their weight was prohibitive with smaller fire control systems. Moreover, the early equipments lacked the definition needed to distinguish between closely grouped targets or to detect attacking planes that came in close over the

water. Even when those particular problems were solved, others arose to take their place.

Radar equipments that provided narrow beams for good target definition were not adequate for general search use. Those with the wide beams needed to scan large areas of the sky could not provide the kind of precise information required for fire control purposes. That complicated situation meant that targets had to be acquired by search radars, then identified and designated to the proper gun directors. At that point the fire control radars had to acquire the target and track it long enough for the computers to predict its location at the moment a projectile could reach it. Since the speed of air attacks limited the available time to a few seconds, the development of complex transmission systems for target acquisition and designation became an important part of the Bureau's effort to provide blind firing control systems for the fleet's anti-aircraft guns.

The first successful step toward solving the blind firing problem came with interconnections between Gun Directors Mark 37, controlling 5-inch guns, and the Mark 51's directing heavy machine guns. Originally worked out aboard the battleship *North Carolina*, the Bureau sponsored similar alterations wherever they seemed feasible. That permitted blind firing of 40-mm mounts at ranges out to 3000 yards, the point at which the ballistic differences between 5-inch and 40-mm guns became too great for control from the same director. The system was also extended to work in both directions, so the light directors could be used to control 5"/38 guns when divided fire was needed. In the absence of any other way to fire heavy machine guns against unseen targets, the interconnections were a valuable expedient. They were far from the desirable solution, however. Destroyers had only one Mark 37 director; only battleships carried more than two. That severely limited the extent of divided blind fire that was possible with either dual-purpose or heavy machine guns. The goal of the Bureau was to provide each mount, from 40-mm twin assemblies through 5"/38 guns, with an individual director.

Another defect in the system of interconnections was the lack of parallelism between dual-purpose and heavy machine gun foundation installations. That problem was exposed by inaccurate fire, and then complicated by channels of cognizance. Gun mount foundations were prepared by the Bureau of Ships. Ordnance engineers who began investigating the problem discovered two discouraging facts: insufficient attention had been given to installation problems connected with heavy machine guns, and excessive

departures from parallelism between directors and guns were common in all major caliber batteries. The two Bureaus immediately met and established accuracy requirements commensurate with the gunnery standards of the forces afloat, but the situation could not be corrected overnight. The Bureau of Ordnance inaugurated a training program in battery alignment and the Bureau of Ships cooperated by adhering to ordnance specifications, but until those efforts could produce results, the problem was a blow to the system of interconnections that offered the fleet the only method of blind firing available in 1943.

Although no blind firing directors for heavy machine guns were in production during 1943, several were under development at a high priority. At Bureau request, the Office of Scientific Research and Development and the National Defense Research Committee lent their talents to the program. Under their auspices several projects were initiated. For the most part, efforts were directed toward using the Gun Directors Mark 51 and 52 as the basis for further development, but in an important respect the developmental work departed from the trends established early in the war. Instead of trying to adapt radar equipments to gun directors, the new programs were devoted to building fire control systems around radar sets. In blind firing, radar was the important thing; its performance could not be compromised for the sake of utilizing existing director systems.

Within that framework, research followed two basic approaches: those employing the disturbed line of sight proved so successful in the Gun Sights Mark 14 and 15, and those using the older technique of an undisturbed line of sight. Each offered peculiar problems. Radar had to be aimed directly at a target, otherwise no signals were returned that would permit tracking. Thus, if a radar-equipped director were pointed at a plane, then lead angles had to be computed and added to director position to produce gun orders. On the other hand, if a director employed the disturbed line of sight and was aimed ahead of a target by the amount of computed lead, then the radar dish had to be offset by the amount of that lead angle in order for it to stay on the target and permit smooth tracking. Paradoxically enough, the Gun Sight Mark 15 proved applicable to both techniques, though entirely different uses were made of the lead angles it computed.

Using one or the other of the two approaches, seven fire control systems were placed in development during 1943 and 1944. They varied in size and function from complex systems comparable to the Mark 37 to small directors that could be mounted on the guns

they were to control. Some were designed to control guns of one particular caliber; others featured a versatility that made them adaptable to a wide range of ballistics. The trend was in the latter direction. These were not simple directors like the Mark 51 and, to a lesser degree, the Mark 52; they were fire control systems that coped with the whole complex of problems inherent in laying naval guns. The half-century old trend toward centralization continued from a design point of view, but as far as gunnery was concerned, the opposite was true. Control was decentralized to the greatest degree possible, with the goal being independent yet complete control for each individual gun and mount.

Of the seven equipments that were under development, two moved from design to production in time to offer the fleet blind firing for its heavy machine guns and a greater degree of divided fire for its dual-purpose mounts during the last months of war. They were never more sorely needed than then, since guided missiles and the kamikaze created a situation reminiscent of that in 1941, when air power seemed such a serious threat to the security of the United States Fleet. The new fire control systems helped restore a sort of uneasy balance to the inexorable struggle between measure and countermeasure that marks the history of naval ordnance.

While airplanes posed the greatest single threat to the security of the United States Fleet, the prosecution of the war was for a while placed in even greater jeopardy by the imposing submarine force of the Axis powers. As far as fire control was concerned, the problems faced by the Bureau were as great for antisubmarine as for anti-aircraft warfare. Depth presented the same extra dimension in the one case that altitude presented in the other, and water was a more difficult medium to cope with. Obviously, neither optical instruments nor radar were of any value against a submarine unless the craft was running on the surface or at periscope depth. Detection, the first element in fire control, was dependent upon more primitive equipments.

As early as World War I, hydrophones were developed that could detect the presence of a submerged submarine, but they relied upon the enemy making some telltale noise. A U-boat could attack, then lie quietly below the surface with a good chance of survival. The odds in their favor were illustrated by the fact that only one-fifth of the submarines destroyed in World War I were caught below the surface. Even when hydrophones picked up a U-boat, its destruction was far from certain. The information supplied on

range and bearing was rough, at best; that on depth was practically nil.

Before the end of World War I a search was begun for some better method of underwater detection. An Allied committee worked out the principles of such a system during the last year of war, and the following decade saw their crystallization into equipments. The United States version of this internationally developed gear was called Sonar, for sound navigation and ranging. The technique used was one of echo ranging. Sound waves were sent out through the water from a transmitter suspended beneath the hull. When this sonic energy struck an object like a submarine—or, unfortunately, like a whale—echoes bounced back to a receiver. These sound contacts could be used to determine the range and bearing of an enemy U-boat.

Sonar was considerably better than the detection gear used against the Kaiser's U-boat, but it was not good enough to guarantee the destruction of the wolf packs kept at sea by the Third Reich. The inherent weaknesses of sonar unfortunately coincided with those of depth charges, the only exclusively antisubmarine weapon carried by United States ships at the start of World War II. Depth charges were exploded hydrostatically, which meant that some depth setting had to be established on the firing mechanism before the charges were released. This made the efficiency of the weapons dependent upon one of the most uncertain computations provided by sonar.

Another defect of the partnership was even more troublesome. When an attacking ship came within about 300 yards of a submarine, sound contact was lost. Since depth charges were either thrown abeam or dropped astern, the weapons could not be released for some seconds after the position of the enemy was last known. That blind interval gave submarines valuable evasion time and added another factor of chance to a situation that was already characterized by a lack of precision. Then, when the depth charges reached their set depth, they exploded whether a submarine was nearby or not. The detonations created a turbulence that disturbed sound echoes and delayed new contact with the enemy craft. This extended the evasion time allowed a U-boat and complicated the execution of a new attack by the surface vessel.

In the face of such a complex situation, fire control was almost nonexistent. Depth charges were released in patterns designed to produce a saturation effect in the area of ocean suspected of hiding the enemy. Volume, not accuracy, was the goal of this doctrine; skilled conning and a stop watch had to provide whatever measure

of fire control was possible. The Bureau of Ordnance attacked this problem along several fronts. Proximity firing mechanisms that reduced the need for depth settings were developed, thus circumventing two of the weaknesses of sonar—the uncertain estimate of depth and the turbulence created by charges that exploded and missed. The traditional ash cans were replaced by teardrop shaped cases that speeded the descent of the charges, reducing the evasion time allowed the enemy.

In the field of fire control proper, an intervalometer was developed to replace the seaman's eye and stop watch as the basic elements in depth charge control. This new device was an electronically operated timing mechanism that could control the number of charges in a pattern, their geometric arrangement, and the spacing between the charges themselves. The intervalometer promised to furnish depth charge control a measure of regulation long taken for granted with other weapons. That promise was not fulfilled during World War II, however. The particular charges for which the equipment was designed were never released to service. Since it was not applicable to existing ordnance, the intervalometer had to be placed back in a developmental status from which it did not emerge again until after the war.

While the efforts of the Bureau to improve depth charges and their control met with only limited success, real progress was made in other fields of antisubmarine warfare. The most important step was the introduction of the Antisubmarine Projector Mark 10, an adaptation of a British weapon known as the Hedgehog. This equipment was a multibarreled mortar that fired 24 missiles ahead of the ship on which it was mounted. The charges, each containing 31 pounds of TNT, fell in a roughly circular pattern centered about 250 yards ahead of the attacking vessel. The principal advantage of the new armament was that it permitted a fair measure of fire control. Since the projectiles were thrown ahead, an attack could be made while contact with the enemy was still fresh; since they did not explode unless they struck their target, no turbulence was created to destroy the chances of a reattack.

For the control of the new ordnance the Bureau procured two equipments, the Target Designation Transmitter Mark 8 and the Gun Train Indicator Mark 52. The first of these, located at the conning station, was used to transmit the desired angle of train to the projector. The gun train indicator received the electrical signals at the mount, where an operator matched the receiver pointer with a gyro pointer that indicated the true vertical. This one operation was sufficient to train the projector and compensate

for the effects of the ship's motion. Of course, these instruments were but parts of a transmission system. The ultimate accuracy of Hedgehog fire control was dependent upon the information used by the conning officer who operated the target designation transmitter. He was, in turn, dependent upon data received from sonar. When the first Hedgehog installations were made in early 1943, officers had to plan an attack on the basis of a navigational plot of own ship and target position, as revealed by the detection gear, or with the aid of a maneuvering board. Neither method was satisfactory, but a more nearly automatic method of utilizing the potential of sonar was on the way.

In 1942, when the Projector Mark 10 was just entering production, the Bureau requested the National Defense Research Committee and the General Electric Co. to develop an instrument that could compute a solution to the antisubmarine fire control problem. The result, though not comparable to the computers that provided gun orders, was a significant step toward simplifying the use of underwater ordnance. This was the Attack Plotter Mark 1, an electronic equipment that furnished a visual display of a tactical situation in much the same manner as a radar scope.

A large cathode ray tube was used as a screen. On it were shown the positions of the attacking ship and of any submarine with which the sound gear made contact. Connections with the ship's compass and dead reckoning analyzer moved a spot of light that indicated the course and speed of own ship. From that illuminated spot, lines of light were visible, indicating the sweep of the sonar beam. Wherever sound contact was made, another spot of light showed the position of the enemy. Since the screen was persistent, a display lasted for approximately 2 minutes, during which time new positions of the surface vessel and submarine were being displayed. The result was a current map of the entire situation. The operator could project an additional line on the screen to represent the course required to gain a favorable position relative to the U-boat, or to duplicate the range of Hedgehog projectiles. This technique permitted the officer conning an attack to make rapid computations of course to steer and time to fire.

Aside from its tactical aid, the attack plotter offered other significant advantages. Its total weight was only 700 pounds, its bulk no greater than a foot locker. Moreover, it proved relatively cheap and simple to manufacture—no mean advantage in a field that was characterized by complexity, high costs, and time consuming production techniques. Procurement figures rose

rapidly, and extensive installations were made on antisubmarine vessels.

During the course of the war the attack plotter was successively improved through attempts to make it as automatic as possible. A course finder was added to utilize the graphic presentation on the screen and compute both attack course and firing time. This relieved the operator of two mental calculations and made the attack plotter more nearly a director. In the last months of the conflict a new remote transmitter was added to the plotter so that it could be used with the prevailing doctrine of a two-ship creeping attack. The transmitter added to the cathode ray tube a new spot that represented the position of a second surface vessel. Successive ranges and bearings of the attack partner were used to keep the added blip of light in a location that showed the relative positions of the three vessels involved in a creeping attack—the U-boat and its two stalkers.

The attack plotter, the target designation transmitter, and the gun train indicator constituted a fairly complete fire control system for ahead thrown weapons. Even depth charge control was improved by the coordination of information that the plotter permitted. But these equipments were not the Bureau's idea of the ultimate solution to the antisubmarine fire control problem. A completely automatic system based on the director method of fire was the goal, and work in that direction paralleled the production and use of the Attack Plotter Mark 1.

The National Defense Research Committee and three private agencies—the Armour Research Foundation, Engineering Laboratories Inc., and the Librascope Corp.—accepted Ordnance contracts to develop an antisubmarine director. Each designed an equipment that made some contribution to the field, but only one of the attack directors, the Mark 2, reached production. Based on a mechanical computer, it seemed to offer promise. The solution proved arbitrary, however, and the procurement contract was canceled after 15 equipments were delivered. Other equipments seemed to offer more promise and the attack plotter that was already in use furnished a more accurate solution. None of the remaining projects reached the production stage during World War II, but their development provided the basis for postwar advances in the field of antisubmarine fire control. Even without them, the field was one which had witnessed real progress. In 1942 the United States seemed almost defenseless against the menace of submarine activity. Two years later the Battle of the Atlantic was won. Many factors contributed to that success, but

not the least of them was the development of improved depth charges, ahead thrown weapons, and the attack plotter and associated instruments that were used to direct these weapons.

One consolation about the U-boat menace was that our own submarines were matching those of the enemy in effectiveness. For a while they carried almost the entire burden of offensive warfare in the Pacific, ultimately racking up a total of 5 million tons of enemy shipping to their credit. A few small ships, not worth the cost of a normal attack, were sunk by shellfire, but the great majority were victims of the submarine's principal weapon, the torpedo. Around the effectiveness of the weapon itself a bitter controversy raged through much of the war, but for the fire control apparatus that controlled the torpedoes the fleet had only kind words. Expressing the sentiments of many veterans of the undersea service, one officer deviated from his subject in a war patrol report long enough to include an endorsement of a submarine's principal item of fire control equipment: "The Torpedo Data Computer has most certainly proven itself one of the most valuable fire control instruments of this war. Without it many of our submarines' multiple attacks would never have been possible and many of the simpler attacks would have been less effective. Despite the fact that it is a complicated mechanical and electrical precision instrument, it has stood repeated depth chargings without failing and with a minimum upkeep. I have yet to see a TDC out of commission or an attack made in which it was not used."

The equipment that won this respect from its users was developed for the Bureau of Ordnance by the Arma Corp. in the years before World War II. Though not entirely automatic, the computer reduced to a minimum the need for mental calculations by those plotting an attack. The speed and course of the submarine were automatically fed into the mechanical unit; data on the enemy's position and movement was manually inserted. The computer then solved the fire control problem and transmitted the necessary torpedo data to the tube nests, where settings for gyro angle, speed, and depth were mechanically introduced to the torpedo. When several torpedoes were to be released, the computer also calculated the offsets which were necessary to assure a lethal spread.

The first of the computers was developed in 1935, but they succeeded themselves rapidly in the years leading to Pearl Harbor. At the beginning of the war most submarines carried the Torpedo Data Computer Mark 3. Successful as it was, the equipment required modifications as experience revealed its defects. One of the first problems exposed was that the noise level of United States

submarines had to be lowered if they were to escape the enemy's detection gear. The mechanical instrument that applied gyro angles to the torpedoes turned out to be a prime offender in that respect, and alterations were essential. In the course of redesigning the equipment, the Bureau began experimenting with electrical rather than mechanical means for inserting gyro settings into torpedoes. The method proved successful. Other expedients had to be used with the older equipments, but the new technique was adopted for later computers. The complexity of modern torpedoes accelerated the trend, producing a climax in postwar instruments that relied entirely on electrical setting mechanisms.

Other problems were introduced by innovations in ordnance that could not be exploited with existing equipment. Radar data, for instance, could be only partially utilized by the TDC Mark 3, and the introduction of the Mark 18 torpedo required ballistic changes in the equipment. To cope with these new problems the Bureau produced the Torpedo Data Computer Mark 4, which incorporated the many changes suggested by over 2 years of war experience. To the extent that its hasty development permitted, the Mark 4 worked toward the ultimate goal of submarine fire control systems—a maximum flexibility for tactical applications, and the integration of data gained from associated detection instruments.

While submarines were by far the largest users of torpedoes, surface craft continued to carry the intricate weapons. At the beginning of the emergency even a few cruisers mounted tubes, but the trend was in the opposite direction. Topside space could usually be devoted more effectively to other armament, and tubes were gradually removed from ships larger than destroyers. Even some of these venerable craft lost what was once their principal armament.

Fire control was no real problem for those ships that continued to carry tubes. A torpedo director, a course indicator, and the necessary transmission and communication systems had been developed some years before the start of World War II.

The basis of the fire control system on most destroyers was the Torpedo Director Mark 27, a mechanical computing unit that determined the sight angle, adjusted it to allow for torpedo creep, then combined the corrected sight angle with relative target bearing to obtain the basic torpedo course. That information, along with the required torpedo settings, was transmitted to the course indicator at the proper tube mount. The system was relatively simple. Target data, instead of being collected separately, was received from the Gun Director Mark 37, or, later in the war, from the plan

position indicator of one of the ship's search radar equipments. In addition to simplicity, no mean virtue for fire control apparatus, the Torpedo Director Mark 27 possessed the advantage of being familiar.

Unfortunately, this last characteristic boomeranged to the disadvantage of effective torpedo fire control. While some complex equipments demanded and received constant maintenance, the familiar director tended to be taken for granted and left unattended. The result was that when the Bureau ordered alterations that turned attention to the directors, a widespread state of unsatisfactory maintenance was exposed. Production, too, was handicapped by the almost contemptuous familiarity of the Mark 27 director. The Naval Gun Factory had been producing the equipments since 1935. Manufacture had remained on a small-scale and craftsman were soon freed from dependence on the original drawings. Many parts did not even have to be made to precision measurements, since they were drilled or machined to fit at the time of final assembly. Each system was in a sense tailormade.

War brought requirements that the Gun Factory could not fill, however, and the Bureau turned to the General Mills Company, Minneapolis, Minnesota, for help in production. Delivery schedules had to be scrapped at the outset. Manufacture was held up by the state of the drawings furnished by the Gun Factory. Even after they were brought up to date as far as changes were concerned, the private plant continued to encounter difficulties. The drawings did not indicate the amount of hand fitting that was done at the Gun Factory, so mass produced parts, even when made by revised drawings, could not be assembled into satisfactory equipments. New drawings were required before large-scale manufacture was possible. The delays were not a real detriment to the war effort, however. The mission assigned to destroyers made their torpedoes secondary weapons. Despite the inadequacies of the fire control system, the Bureau received no requests for their redesign. Some work was done to adapt the submarine system for surface use, but it received little emphasis at a time when more serious thought was being given to the complete removal of torpedo tubes from destroyers.

The role that destroyers once played as torpedo craft was held during World War II by PT boats, a new and glamorous addition to the United States Fleet. Large surface ships only rarely could maneuver themselves into a position for a successful torpedo attack, but the swift motor torpedo boats, small and evasive targets themselves, proved natural partners for surface torpedoes. Effec-

tive fire control for the small craft was another problem, however. The system used on destroyers was not applicable to PT boats, which carried smaller torpedoes and had no Mark 37 gun director to furnish information on target position. Weight and size limitations dictated the design of a completely new equipment; until it was available, PT boats had to use bow and arrow techniques to control their principal armament.

The first efforts to design control equipment resulted in the development of the Torpedo Director Mark 29. Produced by the Sperry Products Corp., the instrument utilized the principle of a collision course. Though the director was accurate enough in evaluation tests, combat experience in the Pacific quickly exposed its inadequacies. The necessity of following a collision course with the enemy robbed the torpedo boats of the maneuverability upon which their success depended; an unsatisfactory optical system limited night use to a minimum, further reducing the tactical flexibility that appeared to be the PT boats' prime virtue. The Bureau was able to improve the director, but its principal defects were inherent in its design.

When the inadequacies of the Mark 29 became evident, the Bureau developed the Torpedo Director Mark 31, an adaptation of a relatively simple British device. The new equipment imposed only slight limitations on maneuverability. Once torpedo speed was inserted and the course and speed of the enemy were estimated, the attacking boat was free to change course at will, so long as an open sight bar was kept trained on the target. With no real alternative, the Bureau contracted with Bristol and Martin for approximately 800 Mark 31 directors, but the search for better equipment continued. PT boats needed true blind firing. The existing equipment not only lacked that characteristic, but it was not even provided with a satisfactory night sight.

In its search for a new, blind firing director, the Bureau of Ordnance was not a free agent. Any fire control equipment that it procured had to be designed for use with the search radar already installed on PT boats. That equipment fell far short of normal fire control requirements, but its replacement was not considered practical. A simple angle solver, the Mark 9, was developed to utilize the target bearing and range data obtained from the radar, but it was considered an interim measure. Meanwhile, contracts were let for three new torpedo directors. At war's end, nothing but experience had been gained by the efforts. The Director Mark 31 and the Angle Solver Mark 9 remained the standard torpedo control equipment for PT boats.

Each of the later projects stumbled on the same obstacle—the inadequacies of the radar on which they were based. Radar was throughout the war a primary factor in fire control development. Its introduction antiquated the equipments designed before radar was available; its limitations were a barrier to the kind of fire control systems suggested by its advent; finally, the continual progress in the field of radio detection assured a high rate of obsolescence for old equipments and frequent changes in the stated requirements for embryonic ones. Fire control was thus in a constant ferment. Mark numbers succeeded one another rapidly; modification numbers multiplied in a sort of geometrical progression. But out of it all came a group of fire control systems that made the United States Navy second to none in the accuracy of its fire.

The development and production of those equipments represented an achievement of the highest order. At the beginning of the national emergency the Bureau was almost entirely dependent upon the talent and resources of the big three in fire control—the Arma Corp., the Ford Instrument Co., and General Electric. Five years later a score of companies were producing instruments not even dreamed of when the armies of the Third Reich first began to move. A similar expansion was required in the field of optics, which was once as restricted as the related fire control industry. While radar tended to reduce the complete dependence on optical instruments that once marked most control systems, it could not replace visual equipment. Moreover, the expansion of procurement and the development of new ordnance increased the demand for optical components much more rapidly than radar could reduce it. Rangefinders, heightfinders, spotting glasses, lead computing sights, telescopic sights, and a host of other instruments required parts made of high quality glass and manufactured to exacting tolerances. Despite their enthusiastic response, the old leaders in the industry could not alone meet the demands of war. New companies had to enter the field, secure facilities, achieve know-how, and fill a gap that might have crippled the fire control effort.

Developments as well as production had to be accomplished, in order to meet the requirements of the Bureau. Out of that effort came night glasses, reflection reducing films, antifog and antirain compounds, and new methods of assembly to lick such ordnance problems as shipboard vibration, the shock of gunfire, and the enormous water pressure on exposed instruments aboard submarines. At the end of the war optics no longer occupied a paramount place in fire control, but the field was still important. Optical equipment was better, even if less vital than before.

The total cost of the fire control progress was well over one-half billion dollars, not including the uncounted millions spent for developmental projects or for arming airplanes. That cost was in part a measure of quantity production, but in larger part it reflected the peculiar difficulties of manufacturing fire control equipment. Mass production was never a really accurate description for the techniques that turned out such intricate apparatus. Even large orders in the hands of giant industries required many of the procedures usually associated with a neighborhood machine shop. Experience often permitted skilled producers to reduce complicated processes to assembly line levels, but the frequent design changes that accompanied a dynamic field worked against that trend. The Bureau attempted to accomplish modifications on a "not to delay production" basis whenever possible, but accurate gunfire maintained a priority over rigid delivery schedules.

The complexity that militated against rapid manufacture naturally had a tremendous impact on the problem of fleet maintenance. As fire control became more and more automatic, the number of components in each equipment or system inevitably increased in a sort of rough proportion to the new functions. The possibility of breakdown and the need for preventive maintenance grew just as the fleet received unfamiliar equipments and new men. Of course, the problem was of equal concern to the Bureau. Ease of maintenance had to be one of the criteria by which new ordnance was evaluated. Failure to achieve that goal was responsible for the scrapping of more than one director, and the continual search for simplicity was an ever present factor in the conception of new equipments.

The result was a sort of working compromise between requirements of performance on the one hand, and ease of maintenance on the other. Generally speaking, simplicity was achieved in operation, but not in upkeep. Training and the familiarity that came with experience had to accomplish what designers could produce only at the expense of untenable sacrifices in performance. That they could was proved when equipments once criticized as inadequate and unduly complex were later praised by those same critics for their performance and reliability. Then, when the veterans of World War II took their skills back to civilian life, a new group of seamen confused unfamiliarity with unfathomable intricacy and made long accepted equipments a new source of complaints.

Training aids and programs were but a partial answer to the problem. Though fire control instruments were not so complicated

that men could not be taught to use and maintain them, they were complex by almost any standards. That became especially true after lead computing sights and electronic equipment became important components in many control systems. With hundreds of parts in operation, breakdowns were inevitable. Obviously, a single failure might incapacitate an entire system until the defective part could be replaced. To assure that such replacements would be readily accessible at widely scattered places on the globe, the Bureau inaugurated a gigantic spare parts program.

The basis for such a project was almost nonexistent. At the beginning of the war there were few records on available spares and few spares on which to keep records. When requisitions began pouring in after Pearl Harbor they were accompanied by even greater requirements for components needed in new construction. With qualified manufacturers severely limited, the Bureau was thus confronted with rival demands. The dilemma was solved with a statement of policy in favor of spares. To keep a fighting ship fighting was declared more important than keeping a building ship building. This policy was implemented by the adoption of a system of open contracts, whereby manufacturers were given contracts valued as high as a half million dollars to supply spares on demand. The money amounted to a sort of open account against which the Bureau could draw at will and at top priority. When spare parts were needed, the manufacturer supplied them immediately from components that would otherwise have been used in the assembly of new equipments. If they were not on hand, the contractor made them at top speed. The system cleared away negotiations in advance, removing the host of barriers that might otherwise have stood between a spare parts order and its delivery.

Open contracts served as a crutch for the rather haphazard supply system of peacetime. They prevented its collapse long enough for the Bureau of Ordnance and Supplies and Accounts to cooperate on the establishment of a more permanent spare parts program. Working together, they established a supply system which was administered by the Ordnance Stock Office. Catalogues were prepared to facilitate the proper identification of parts, and the office served to process, screen, and identify fleet requests. The procedure coordinated a system which was dominated by urgency when open contracts were first employed. Planned inventories replaced frantic searches for vital parts and reduced to a minimum the unexpected interruptions of normal production that open contracts might otherwise have induced.

While the spare parts system was being formalized, the Bureau attacked the maintenance problem on a different front through the establishment of additional repair facilities to supplement the work of the fleet and its repair ships. Shore stations like those that guarded the performance of lead computing sights were set up at home and at such faraway places as Saipan, Guam, Samar, Okinawa, and Subic Bay. Additional flexibility was provided through the construction of miniature supply depots on barges that could be kept even closer to the operating forces. Something of the workload carried by the various elements of the supply system is indicated by their procurement and distribution of approximately \$12,000,000 worth of fire control spare parts during each war year.

At the end of the war the Bureau of Ordnance was in the position of a political party during an election year. There were many achievements to which it could point with pride, many problems that had to be viewed with alarm. For the most part, the first category was familiar enough. Even the American public, whose information was naturally restricted by security considerations, was aware of the fact that the United States Navy could justly boast of the world's best fire control. The fleet, on the other hand, shared the Bureau's realization that a great deal of work remained. The menace of the kamikaze accentuated the need for a greater number of blind firing directors, for the independent control of each gun mount, and for speedier means of target acquisition and designation. Higher target speeds, whether confronted in planes or guided missiles, further emphasized those same problems and presented requirements for better transmission systems and computers. Experience with radar indicated both its limitations and its still untapped potentialities; the enemy's familiarity with it demanded that the Bureau devise new safeguards against countermeasures that threatened to cripple one of the war's most important weapons. Antisubmarine warfare, too, presented new problems in the closing months of the war. The advent of snorkels, superior propulsion systems, and stronger hulls taxed the power of the ordnance that won the Battle of the Atlantic, requiring new weapons and new fire control equipments to direct them.

The addition of rockets to the United States arsenal opened a new field for work in fire control. The inherent dispersion of the rockets used during the war kept control requirements at a minimum, but the need for directors became pressing as more accurate rocket projectiles were supplied. Finally, the introduction of a radically new type of weapon—guided missiles—posed equally new

and complex problems that had to be solved through the development of control systems that could guide supersonic missiles on a collision course with distant, often supersonic, targets. That the many problems were neither unanticipated nor completely unsolved was shown by the course of the war. That the Bureau of Ordnance was far from satisfied with their solution was indicated by the extensive research program that characterized the postwar period.

Chapter 17

FIRE CONTROL RADAR

RADAR, a new word in the Nation's vocabulary, stands for radio detecting and ranging. Aboard ship, where it played a decisive part in every Pacific action between surface units from September 1942 through V-J Day, it often stood for the slim but decisive margin of superiority that brought victory over a determined enemy. In typical form it was a complex equipment sending out radio waves, receiving echoes when the beam struck an object, and converting those echoes into "pips" of light reflected on a tube face in such a manner that operators could determine the identity, bearing, range, and altitude of the object detected. But years of research, first leisurely and haphazard, then frantic and planned, preceded the development of the equipment and its utilization for fire control purposes.

With the possible exception of the Manhattan Project, no wartime program consumed as much money, effort, and talent as the development and production of radar equipments. And though the bomb's climactic arrival emphasized and exaggerated its contribution to victory, the service of radar was probably more important when analyzed in the long view that witnessed the desperate struggle to turn the tide of war in favor of the allied cause. Radar development was really a war in itself—a race against the scientists of enemy nations to convert an idea into practical designs, convert designs into workable equipments, make those equipments better and more rapidly than the enemy, develop countermeasures to opposing systems, and counter-countermeasures to protect the integrity of our own units. Allied victory in the war and this war within a war was the result of a rapid mobilization and coordination of scientific talent and resources. No use of radar bore more directly on the business of defeating the enemy than its use to aim the Navy's guns, and that particular accomplishment was the work of the Bureau of Ordnance.

Radar development has been centered in the second quarter of the twentieth century, but its origins are found in the late nineteenth century work of Heinrich Hertz. Working in 1886, the German physicist discovered two facts about radio waves: That they could be formed into beams like light and that, like light or

sound, the waves could be reflected. The truths were demonstrated in his laboratory the following year when Hertz bounced radio waves off a metal plate and detected the echoes in a circle of copper wire. There in a German laboratory was the forerunner of the radar sets that would one day train giant guns on an unseen target miles away, hit it, or spot the splashes of every miss. But preceding the final frenzy of activity that produced modern radar equipments lay years of dormancy, interrupted by infrequent but important developments.



Radar antennas ultimately transformed the topside appearance of naval vessels.

Naval interest in the possibilities of radio detection dated from the summer of 1922, when two of its scientists, Albert Taylor and Leo Young, inadvertently demonstrated the detection potential of radio waves. While engaged in short wave transmission on the Potomac, they noted that ship traffic distorted the signals they were sending across the river. The two men immediately recognized the practical use that might be made of their discovery. In a report to the Navy Department they suggested that by using the technique of radio transmission "destroyers located on a line a number of miles apart could be immediately aware of the passage of an enemy vessel between any two destroyers of the line, irrespective of fog, darkness, or smoke screen." Had their suggestion been adopted the result would have been far removed from the

modern concept of radar, but it represented an important attempt to make radio waves an instrument of detection as well as communication. The Naval Research Laboratory kept at the project from 1922 on, but the idea of employing continuous waves between two stations was abandoned in favor of a project to send out waves and receive their echoes at the same location.

Reduced to simple terms, the idea was to develop equipment that could beam radio energy at a target, detect the reflected echo, time the entire trip, divide by two and the speed of radio waves to determine the distance to the target, and present the information concerning bearing and range. The idea was practicable because radio waves could be focused in a beam and moved at the known speed of light. It was attractive because the radio beams could penetrate barriers that shut out light and human visibility. But the problem of utilizing known principles was not so simple as the principles themselves, and a whole range of obstacles had to be overcome before experiments beside the Potomac could lead to radar equipments whose antennas have transformed the topside appearance of the modern naval vessel.

One of the first problems to be solved involved the methods of transmission. Early experiments depended on continuous wave transmission. While that technique was suitable for detection that depended on an enemy interrupting waves being sent from one location to another, it was not adaptable for use with self-contained units that could detect an object by receiving an echo of the wave it transmitted. The early method compared to a man roaring at a cliff and receiving only an unintelligible echo. Short staccato shouts were necessary in order to produce useful and timeable echoes.

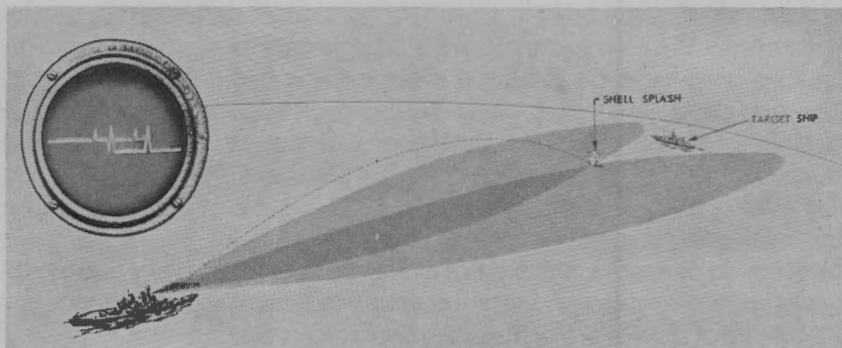
The solution to the problem lay in using pulses of radio energy rather than a continuous wave. Within three years after Taylor and Young initiated Navy work with radio detection, scientists at the nearby Carnegie Institution of Washington developed a practical way to utilize pulses of radio energy for detection work. The development came as a result of worldwide interest and research in the ionosphere, the region of electrically charged air that lies about 25 miles above the surface of the earth. In a successful attempt to prove the existence and determine the height of the strata, Drs. Gregory Breit and Merle Tuve devised equipment which shaped radio waves into short bursts or pulses of energy and directed them at the ionosphere. The time lag, infinitesimal as it was, was sufficient for each pulse to reach its target and bounce back as a clear and distinct echo. The echoes were collected in a

receiver that timed their round trips and thus determined the distance to the charged air. What the scientists developed was in essence a radar set. While the target was large and stationary, the principles on which their techniques were based were ultimately applicable to sets that could detect small, fast moving targets.

Proof of its practicality came in 1930, when an airplane flying over Washington was detected by radio echoes. Success gave impetus to the work at the Naval Research Laboratory, and eight years of preliminary research crystallized into a definite project to develop a device to furnish information on the location of enemy ships and planes. Early in the decade their work bore fruit with the development of the duplexer, a device which permitted a single antenna to serve for both transmission and reception. The new development considerably reduced the space and weight requirements of detection equipment and increased its attractiveness for shipboard use. Congress responded to the promising work with a \$100,000 allocation for radar work in 1935, and the House Subcommittee on Naval Appropriations maintained its interest in the project throughout the remaining years of peace.

Meanwhile, important developments were being made outside of the Laboratory and the Nation. Ionosphere research in other countries led in the same direction as in the United States, and in 1931 it produced the cathode ray tube, now a familiar item in television sets, as a means of visually presenting the echo signals that were received. Like the duplexer, the cathode ray tube represented a simplification of detection equipment and stimulated interest in the possibility of applying the gear to use at sea. While the English and Americans were making strides in improving radio techniques, the French had by 1935 actually developed detection equipment to protect their prize liner, the *Normandie*, from the fate of the *Titanic*. Ultra-short wave transmission, backed by parabolic reflectors, gave the instrument a range of up to four nautical miles. Channel buoys could be picked up at 2 miles, relieving the liner of much of the inconvenience and danger of approaches to fogged harbors. The technique of range determination were primitive compared to later developments, but the French installation was an important forerunner of subsequent radio detection gear.

While early thought, both here and abroad, was mainly concerned with navigational or warning application for the new devices, the potentialities of radio detection for fire control work were soon discovered. The first official contact of the Bureau of Ordnance



Cathode ray tubes provided visual presentation of echo signals.

with the new field of radar came in 1933, when the director of the Naval Research Laboratory called attention to the military possibilities suggested by their experiments. Though forecasting with caution, a prophetic letter suggested that the Laboratory could build a single "beam" transmitter and receiver which would be able to take ranges on any object from which a continuous echo could be received, take bearings on ships or planes by using the same echo, and indicate the rate of change of range to any object from which a continuous echo was received. Using that data, the equipment might then detect and track an unseen target with sufficient accuracy for fire control purposes, whatever the weather or light conditions.

The problems as well as the promise of radio detection was pointed out to the Bureau. In their experimental work the Laboratory had been restricted to the use of wavelengths ranging from 30 to 5 meters. Equipment was already under development which would transmit and receive 18 cm. waves, but the formation of a beam sharp enough for fire control purposes with the use of a reflector small enough to be used aboard ship demanded microwaves on the order of 10 cm. or less. In the mid-30's no practical way to obtain the transmitting power needed for such wavelengths was known, nor were receivers of sufficient sensitivity and selectivity yet designed. Nonetheless, the promise was obvious enough to interest the Bureau of Ordnance in the proposal. Prewar fire control instruments needed the help that radar could offer.

The means by which guns were aimed and fuzed to hit or burst near a target depended on optical sights and rangefinders. Targets were tracked and guns trained by men who kept the cross hairs of their telescopic sights on the enemy. Range was determined by an optical instrument that utilized the principle of tri-

angulation to measure the distance to the target. Providing that the target could be seen—a serious limitation for forces that had to fight around the clock in all weather—the equipments permitted accurate fire control. But even under favorable conditions, the system left much to be desired. Triangulation rangefinders suffered from notable defects: accuracy was directly proportional to the distance between the prisms of the instrument, and inversely proportional to range. The first impediment tended to make rangefinders large, bulky equipments—anathema to designers who worked under the restrictions imposed by severe weight and space limitations. The second defect was even more of a problem because it made two ordnance goals incompatible. Increases in the range of guns would inevitably mean poorer fire control in their utilization.

Radar offered a solution to both problems. The principles that revealed the height of the ionosphere could also measure the distance to a target. And it could do it in any weather. All that was needed to translate the promise into performance were instruments which could transmit radio waves with a short enough wavelength, and a device for measuring the fractional time lag between the transmission of a pulse and the return of its echo.

While the solution to the transmitting problem had to wait until 1940, a device for handling the infinitesimal measurements involved in radar rangefinding was already on hand. The cathode ray tube used in British ionosphere research was applicable. As the basis for an oscilloscope it became an electronic stopwatch capable of reading in millionths of a second, in fact, in thirtieths of one microsecond. On such a scale the range to an object 20 miles away could be measured with an accuracy of plus or minus 50 yards.

The actual incorporation of radar into existing fire control instruments raised a multitude of design problems, of course, and demanded finer discrimination than early experiments produced, but even as a separate device it offered a valuable supplement to the information sources upon which gunnery depended. When radar sets first became a practical reality, fire control had to be content with this indirect assistance, since the first sets were designed primarily for detection purposes, rather than for fire control. The first of these search sets to be developed by the United States Navy was ready for evaluation by 1937. Installed on an old four piper, *U. S. S. Leary*, it served to stimulate and guide the search for better equipments.

By 1939 the first naval radar set was already outdated by two superior models, one produced by the Navy, the other by the Radio Corp. of America, one of the few commercial agencies with an active interest in the early development of radar. The sets were installed in the battleships *New York* and *Texas* in time for evaluation during the fleet maneuvers of 1939. While the RCA equipment on board the *Texas* failed to give satisfactory performance, the NRL set on the *New York* became the prototype for Navy search radars. Designated the XAF, it was the first set to utilize the recently developed duplexer that permitted use of one antenna for both sending and receiving. The XAF proved satisfactory only for detection and range data, but the potentiality for fire control was illustrated by some success at furnishing data for firing against night destroyer attacks, spotting shell splashes, and even tracing the flight of large caliber projectiles.

As soon as evaluation was complete, the Navy decided to utilize the NRL design and the RCA facilities. Orders were placed for six complete equipments. Essentially Chinese copies of the XAF, the new sets were designated CXAM and installed in the fleet in 1940. Radar was far from perfect in 1940. It measured range with real precision, but furnished inadequate data on target azimuth; it could detect aircraft high above the horizon, but was blinded to low flying planes by reflections set up by ocean waves. But for all the problems that remained unsolved, the value of the new equipments was enormous.

The year that witnessed the installation of the first operational search radar also marked the beginnings of a concerted effort to adapt the new instruments to fire control requirements. Late in 1940, as a result of work initiated by the Bureau of Ordnance, the Bell Telephone Laboratories demonstrated a radar equipment which they called CXAS. The set operated on what was then an unheard of high frequency—an accomplishment made possible by the Laboratory's work on other electronic developments. The high frequency feature enabled the CXAS to outperform much higher powered models that used longer wavelengths, and made possible both narrower beams and smaller antennas. The equipment promised reliable target information at ranges out to 10 miles. Its range accuracy was comparable to that obtained optically and was considered adequate for surface fire control work. Target azimuth, always harder to determine than range, could be estimated within 1° or 2° by swinging the antenna back and forth and noting the point at which the strongest echo signal was received. This angular information lacked the precision needed

for many fire control requirements, but the equipment seemed applicable to main battery surface fire control problems.

Impressed by the demonstrations, the Bureau requested the manufacture of 10 equipments. Several changes were suggested to facilitate shipboard use, and the official designation of the design was changed to the FA Radio Ranging Equipment, and finally to Radar Mark 1. Western Electric undertook production of the new item, but only 10 were ever made. The first was installed on the *U. S. S. Wichita*, where performance fell short of expectations. Range was barely half that indicated by tests, and various improvements in the science of radar permitted the Bureau to abandon the design in favor of the superior Mark 3.

The Mark 1 was actually procured by the Bureau of Ships rather than by Ordnance, even though it was a fire control instrument. The reasons were clear in the origins of fire control radar, which simply grew out of developments in a field already under the cognizance of Ships. As the importance of radar to the fire control problem became more apparent, however, cognizance became a matter of more importance. The Bureau of Ordnance was faced with the problem of repackaging Bureau of Ships radar, then redesigning the oscilloscopes and other instruments inside gun directors in such a way that the new devices could be integrated with existing fire control equipment. The best interests of gunnery could hardly be served by a procedure that directed one of its newest and most powerful tools through unnecessary channels, where officers responsible for design were less familiar with gunnery problems, and less impressed with the vital importance of rapid improvements in fire-control radar. Close liaison was of course maintained between the two bureaus, and Ordnance stipulated the military characteristics and installation requirements for fire control radar, but the overlapping responsibility was a matter of annoyance even when the results were not serious.

The first step toward the solution to the problem was taken in the summer of 1941 by the conclusion of an informal agreement between the two bureaus. In general, the agreement gave the Bureau of Ordnance cognizance over all aspects of fire control radar except its radio features. The agreement was formalized in October 1941, and was followed by parallel agreements with the Bureau of Aeronautics. The result was that Ordnance, in addition to its former concerns of determining packaging, military requirements, and mechanical design, gained complete control over the production of equipments and their installation in ordnance locations aboard ship. To execute the new responsibility, a fire control radar sub-

section was organized in the Research and Development Division in late 1941. Formed just before the attack on Pearl Harbor, the unit grew rapidly after war began. Since the vital electronic features of the equipments were still in BuShips' hands, frequent conferences were scheduled between the interested units in the two bureaus.

The reorganization, by making interest and cognizance more nearly coincidental, paved the way for a smoother development of the new fire control tool. Early in 1942, the contracts already let out for such radar equipments were transferred from Ships to Ordnance, which placed all subsequent contracts. Improved as the situation was, cognizance remained a source of irritation throughout the war. The Bureau of Ordnance necessarily exercised a strong control over the fire control radar group in the Bureau of Ships, with the result that the engineers were often irritated at what they interpreted as outside interference. Late in December 1943, the cognizance problems between the two bureaus were reduced by a broadening of Ordnance's area of production responsibility, but the arrangements still left much to be desired. Nor were relations with the Bureau of Aeronautics conducive to progress. Ordnance had a fairly free hand in the development of aircraft fire control radar, but the translation of developments into instruments in service use required a closer coordination between the two material bureaus than existing channels could provide. One discordant personality could retard vital agreements. Under the force of war the defects in administration could be overlooked in favor of more urgent matters, but the return to peace restored the problem to the interested bureaus for solution.

While the problem of cognizance was being adjusted late in 1941, the Bureau of Ordnance proceeded with the work of designing an improved radar for fire control purposes. The Mark 1 laid the groundwork for future progress, but in comparison to later developments, it was a primitive equipment. The most obvious need was for operation at still higher frequencies. Behind this lay the fact that for any given antenna size the width of the beam decreased and the gain increased as frequencies were raised. The fairly broad beams occasioned by the low frequencies first used were sufficient for good range data, but the angular information so vital to fire control required more definition than broad beams could give. Radar could not even discriminate between two separate targets unless they were more than a beam's width apart. Thus frequencies had to be raised in order to secure the narrow beams which could provide definition and precise angular information.

The problem could be illustrated by a man with a flashlight. Using a broad beam, he could move the light back and forth for several degrees and still keep his target illuminated. But if he focused the light into a single narrow beam, a slight movement would leave his target in the dark. The broad beam would be desirable for search purposes, but he would need the fine beam if he wanted to compute the azimuth of the object. The same situation was true for shipboard radar. The broad beams of radio waves sent out by low frequency transmission were valuable for searching out targets and measuring their range, but accurate gunfire obviously depended upon an equally precise measurement of target angle. Part of the answer was well known. Narrow beams could be produced by the use of short waves. The problem was to find a technique for transmitting short waves with enough power to provide adequate range. With the equipments known in 1941, radar had to choose between keen but myopic sight or a fuzzy sort of farsightedness. Range and definition were apparently mutually incompatible. Until a way was found around that dilemma, the Mark 1 could hardly be basically improved and the way to better developments was at least partially blocked.

Fortunately, the solution to the problem was already on its way to the United States as the first fire control radar equipment was under development. The power necessary to transmit microwaves with the frequencies needed for a narrow beam and the strength needed for long range lay in a cavity tube named the magnetron. Though first available in early 1941, the tube was itself the result of long years of intermittent development. For its principle the new device went back to a magnetic tube invented by an American engineer shortly after World War I. No practical use was found for the tube in this country and the idea passed around the world in succeeding years. Germany, Russia, France, and Japan all added improvements to the invention during the prewar years without appreciating the power potential of the tube itself. Shortly before the outbreak of war in Europe, the magnetron gained attention in England, where it fitted in with a recognized need. Since 1936 the English had been constructing a radar network around the island as a protection against any surprise attack by planes. English scientists needed to use microwaves for the same reason as the Bureau of Ordnance, and they needed even greater transmission power if approaching planes were to be picked up in time for the warning to be of any value. Because very little of the energy sent out by a radar set ever reached a target, and an even tinier echo bounced back to the set, a powerful warning sys-

tem needed a compact instrument that could duplicate the power of a giant radio station.

Seeking the solution to the problem, Professor Oliphant of the University of Birmingham joined the hundreds who had tinkered with the magnetic tube since its invention in 1921. But now there was a difference. The maternal characteristics of necessity entered the picture, and the professor made of the magnetron a practical answer to a vital need. The old magnetic tube was transformed into a device capable of developing great surges of radio energy. No larger than an ink bottle, the vacuum tube employed an axial magnetic field to whirl electrons at high speed, generating far greater power than a conventional tube that merely controlled a straight flow of electrons. Radar's dilemma was solved by the magnetron, which combined the high frequencies needed for fire control with the transmission power required to extend the range of short wave radio beams. A revolution in radio introduced a new avenue of progress for naval fire control.

The United States was not long without the development. In August 1940 a mission led by Sir Henry Tizard arrived in this country to arrange for a complete interchange of technical information between the two nations. The National Defense Research Committee was interested in the proposal and countered the British proposition with a mission of its own to London. The field of radar was one of the first in which the principle of free exchange was crystallized, and British technical knowledge represented one of the outstanding examples of reverse lend-lease. And of all the British contributions, the magnetron was the most important. Even before the formal arrangements for the Radar Exchange Plan were completed, the tube was rushed to the United States for duplication and development for mass production.

Most of the basic developmental work was done under NDRC or OSRD contracts by the Radiation Laboratory at the Massachusetts Institute of Technology. Some commercial agencies, notably the Raytheon Co. and the Bell Telephone Laboratories, worked on the tube, however, and the latter made particularly significant contributions to the task of readying the magnetron for production and use in the United States. Work on the tube itself finally resulted in over 70 different types of magnetrons capable of producing either continuous or pulsed waves in lengths ranging from 50 centimeters down. The result of their application was a revolution in the field of radio detection. Not only were immediate obstacles to the progress of fire control radar removed, but the very

horizons of the science were pushed back, permitting enormous progress in the field.

Even before the development of the Mark 1, radar was in the field of ultra-high-frequencies; after the magnetron, it was in the field of microwaves. The results were numerous. Shorter wave lengths meant higher frequencies, and higher frequencies meant narrower beams with the kind of resolution needed for fire control information. Moreover, the narrow beams suffered less from interference caused by ground or wave reflections and permitted detection of so small and low a target as the periscope of a submarine. Even installation problems were eased, since short wave antennas were much smaller than those required for transmission on lower frequencies. Of course, the developments permitted by entry to the new field of microwaves were neither born full-grown like Athena, nor, like Topsy, the result of undirected growth. But the direction of progress was now clear and the Bureau of Ordnance proceeded to exploit the new possibilities suggested by the magnetron.

More than one path lay open to the Bureau, however, and important policy decisions had to be made before it could embark on any extensive radar program. In a field as new as radar and in one pursued with the urgency it experienced, stability was elusive. The progress represented in the rapid transition from short waves to microwaves, for instance, might normally have taken a full generation or more to accomplish. Yet, under the stress of European war, research moved radio detection from one stage to another with a speed that engineers could not hope to match. While that particular advance was phenomenal, even for radar, rapid changes were typical of the new art. Progress was the goal, but success imposed a dilemma of its own. The rate of equipment obsolescence was greater than production rates. Faced with such a situation, Bureau planners had to decide whether they should hold out for the crystallization of advanced designs incorporating the known promises of the field, or rush into production with what might be inferior products. The first alternative offered the best equipment and the fewest production problems and expenses; the second offered more immediate deliveries to the fleet.

The answer to the question was laid down in the fire control development program. The plan recognized two Bureau objectives: First, to get a new and improved military device perfected and into operation in the fleet ahead of the enemy; secondly, to meet the rapidly changing military requirements as they were dictated by changes in the offensive tactics of the enemy. An analysis

of the alternatives and the objectives indicated, or at least justified, the decision to produce the first workable design at hand, rather than wait for a potentially superior design at a later date. While admittedly expensive, the policy undoubtedly narrowed the gap between laboratory and fleet equipments.

In operation, the policy meant a rapid multiplication of both marks and mods of radar equipment, so that almost no item staved off obsolescence for longer than 2 years. Almost 50 separate marks were under development during the war, and modifications and field changes were continually in progress. The severe productive load on the Nation's electronic facilities guided radar progress in that same direction. A 2-year time lag was inevitable between the initiation of a development and its installation in the fleet. In the meantime, changing military requirements had to be met by modifying existing equipments. Since that procedure often offered only a partial solution to a problem, new developments were often initiated coincidental with modifications which were in progress to achieve the same result. That policy sometimes resulted in the production of new sets that were not too superior to radars already in service, but through such means progress was inexorable.

The policy evolved to cope with an immediate problem proved of broader value than its planners expected. Experience showed that the superior designs for which there was a natural temptation to wait almost invariably took longer to produce than its developers had predicted. Moreover, until training and practice was possible, the best designs were of less value than the more primitive but familiar ones already in the fleet. Because of the service tendency to prefer the familiar, the gradual changes represented in a rapid succession of marks and mods were more acceptable at sea than radical equipments which gained their improvements at the cost of strangeness. Perfection was sacrificed for speed, but not at the cost of good performance. One of the most remarkable things about the whole radar program was the ability of the men in the fleet to get better than predicted performance out of whatever equipments were available.

As the radar program unfolded in accordance with the Bureau plan it naturally tended to divide into separate phases. The first concern was radar for the control of surface batteries, then for anti-aircraft batteries. Target designation and identification later became primary concerns, followed by attention to countermeasures and miscellaneous devices designed to improve the performance of the various equipments. While the developmental work was closely integrated and overlapped in time, the program repre-

sented a roughly chronological outline of the Bureau's radar activities.

In following through the development program the radar designers did not have a free hand even within the framework of the stated Bureau policy. Radar represented only one of many tools in fire control and it suffered from its late arrival. Especially for the surface and dual-purpose batteries which were the first to receive attention, satisfactory gun directors of complex and expensive design were already in service. While the optical systems were far from perfect, they had the advantage of being proved before the outbreak of the war. Thus, despite all its promise, radar was a stepchild slow to win affection. Design had to be tailored to fit in with existing fire control systems. That influence on radar design often imposed severe restrictions, especially from the standpoint of the weight and size of equipments that had to be installed in directors. Directors were already crowded with both men and material. Suggested rearrangements within gun directors to allow more space for radar, thus permitting better design, proved unpopular until the new science had proved its tactical value. And that was made more difficult because of the restrictions.

This was the familiar dilemma of the inexperienced man who wants to get a job to gain experience. The situation was considerably alleviated once the new tool was proved in combat, but throughout the wartime radar development program, desirable operational characteristics had to be sacrificed in order to conserve weight and space. A late example of the effect of restrictions on designs came when a dual-purpose radar for the Gun Director Mark 37 had to be abandoned after it was well over half finished and after nearly \$2,000,000 had been spent on its development. The shelving was required when it became obvious that the set weighed 1000 pounds more than its original design specification. Nonetheless, the trend was in the direction of greater exploitation of the potential of radar and a more complete integration of the new equipments into fire control systems. The early models were the most restricted, but they proved sufficient to win fleet approval for the new techniques.

Even the Mark 1, primitive as it was, became a fairly reliable adjunct to main battery fire control after the magnetron was retroactively applied. But even before the limited production of the Mark 1 was completed, the development of succeeding models was underway. A Mark 2 project, featuring a closer integration of the radar and optical components, was abandoned before com-

pletion when the magnetron permitted the development of new transmitters. Efforts turned to incorporating the benefits of both experience and new discoveries into a completely new equipment, the Mark 3. Although it operated on the same frequency as the Mark 1, the new equipment gained an effective range three or four times that of its predecessor, as well as greater accuracy in determining range and bearing. The latter came from a larger antenna and the development of new scanning techniques which gave the Mark 3 a bearing accuracy of plus or minus 2 mils, as compared to 200 mils for the Mark 1. Range accuracy improved in a slightly less spectacular degree, but the visual presentation of the data was considerably improved.

The Mark 3 contained many defects which were subsequently corrected in the Mark 8, but with its installation in the fleet radar came of age. This was the instrument with which the fleet learned to fight at night and thus gained a real advantage over an enemy whose radar was in a much more rudimentary stage of development. The Mark 3 was employed in almost all the early Pacific battles. In October 1942 operations in the Solomons, for instance, the Mark 3 controlled the *Boise's* guns in a night action when she blazed away at a vastly superior fleet that had to pay 10 to 1 for its inferior fire control. Within a fortnight the Mark 3 won acclaim again when the big guns of the *South Dakota* used its information to sink a Japanese capital ship 8 miles away with only two salvos. Examples multiplied with the progress of the war and performance improved with experience. Combat tested equipments with a ruthlessness laboratories could never duplicate, but the laboratories could and did correct the defects almost as rapidly as they were exposed.

Even before the Solomons operations in which the Mark 3 won such acclaim, its successor, the Mark 8, was undergoing trials at sea. The first installation, made on the *U. S. S. Indiana* in August 1942, proved only a qualified success, but improvements soon slated it as the main battery replacement for the Mark 3. In almost every respect it represented an advance over the earlier set, but its most significant innovation was its so-called "B" presentation of data, a system whereby targets showed up on an oscilloscope as a plot of range versus bearing. Employing a new type scanning antenna, the presentation of target information became clearer and more useful. The Mark 8 went through a series of modifications that improved performance and moved much of the gear from crowded directors to less critical space below decks. In its various

forms it became the main battery equipment with the most battles to its credit.

Despite the success of the Mark 8, the development of a successor was under way before the end of 1942. The utilization of higher frequencies and improvements in discrimination, bearing, and range were the goals. Early in 1945 the results of the project materialized with the first fleet installations of the Mark 13. Not only were the designers' goals met, but the new equipment featured reduced weight, improved serviceability, and a reliability that made it a model for future radar developments. At war's end improvements were still being initiated, but the radar already installed proved adequate for the military requirements of the naval war in the Pacific. The equipments gave the fleet the ability to deliver accurate surface fire under complete radar control during night engagements. On many occasions the technical superiority thus gained offset a numerical inferiority and became the margin of victory for the United States.

Providing radar for antiaircraft fire control—the second phase of the Bureau's developmental program—was a much more complex problem than that related to surface batteries. An extra dimension was involved, imposing the requirement that the exact position of the target be accurately and continuously known in three coordinates—range, bearing, and elevation. Moreover, the high speed and small size of air targets magnified the normal problems of radar fire control. An already complex situation was further complicated by rapidly changing military requirements. Methods of air attack varied with time and place, making tactical demands as great a challenge as the technical problems involved. Thus, the two objectives of the radar program—beating the enemy in the race to perfect radar and meeting the changing requirements—both faced their most serious challenge in this one phase of the developmental program. The first objective was met in this as in every other phase of radio detection, but the second proved more difficult. Throughout the war, operational requirements for antiaircraft fire control radar were ahead of the radar techniques and equipments available. The best known case in point was the vulnerability to Japanese kamikaze attacks.

The utilization of radar was, of course, only one small part of the problem. The whole field of antiaircraft fire control was in its infancy at the outbreak of the war. Throughout the early part of the conflict designs continued in a state of flux, as experiments, experience, and the recognition of requirements led to rapid changes in fire control systems. Radar development was naturally asso-



Vulnerability to kamikaze attacks underscored the need for a better utilization of radar.

ciated with and governed by the progress made with the directors and systems of which it was an adjunct.

The basic objective of the antiaircraft development program was to provide accurate gunfire under complete radar control during periods when poor visibility rendered optics ineffective. Within that frame of reference, the Bureau wanted the method of operation of the various parts of the fire control system to remain essentially the same whether radar or optics was in use.

The problem of aiming guns at a small, fast moving target involved a series of requirements which, in turn, governed the development of radar. The first step in the destruction of an airplane was the determination of the target's exact position in space. With that information—provided it was accurate, smooth, and very nearly continuous—a computing device could predict orders to the guns. To obtain such information with radar required that the target be tracked with angular and range errors held down to a matter of a few mils and yards, respectively.

Both tactical and technical problems were obstacles to the accomplishment of what would under the best of conditions have been

a real achievement. Attacking aircraft often came in groups or made their approach close to land or other ships. That imposed the requirement that the tracking radar have discrimination enough to exclude other objects close at hand and keep centered on the target. The technical solution to the tactical problem was the development of radar with the extremely narrow beams made possible by the magnetron and microwaves, but the solution to one problem simply introduced another. Before the end of the war equipments were developed featuring tracking beams with a width of less than 2° in bearing and elevation. Such a beam provided the resolution and definition needed to track an attacking plane, but the solution to the tracking problem introduced that of target detection. Picking up a speeding aeroplane with a radar beam that supplied a "cone of vision" of only a few degrees required the development of some means to supply the tracking radar with the target position. Both speed and accuracy were prerequisites, since the speed of air attacks precluded the possibility of assigning any search function to the narrow tracking beams. And finally, before guns could be directed at a detected plane, the target had to be properly identified as an enemy. Thus radar, as one element in anti-aircraft fire control systems, was required to acquire the target from the sky, transfer it to a narrow beam capable of tracking a small object at a high speed, identify the target as friend or foe and, if the latter, supply the information that would bring and keep the proper guns on that particular target.

All of these diverse problems involved in using radar to defend a ship against air attack were not recognized in the early phases of the developmental program. Because anti-aircraft equipments required a greater integration between the search and control functions of radar detection than was necessary for the control of main batteries, the anti-aircraft program suffered more from the divided responsibilities between the Bureaus of Ships and Ordnance. Throughout the war the designers of ship search radar thought primarily in terms of navigation and early warning, either ignoring or underrating the importance of search equipment for target designation to radar controlled anti-aircraft guns. The result was that relatively wide beams were used for tracking air targets simply because the width, undesired for tracking, at least insured that the beam could be gotten on the target. The compromise was necessary, but represented a real sacrifice of characteristics which the Bureau of Ordnance recognized as desirable.

Fleet experience confirmed the soundness of the Bureau's position. As a substitute for the desired development of search radars

providing rapid target acquisition and detection, Ordnance started projects for the development of its own target designation radar, plus equipments for transmitting target designation from search radar to gun directors. Because it was working in an area outside its cognizance, the Bureau was discouraged in its efforts. And at the end of the war none of the developments designed to decrease the time interval between detecting a target and taking it under radar controlled fire were completed and ready for production. No solution could be obtained through fire control radar developments alone because the problem encompassed the entire radar and data transmission system on a ship.

While no ideal or complete solution to the varied problems was produced during the war, considerable progress was made. Control of 5-inch guns against aircraft was the first objective of the program, and the Bell Telephone Laboratories were given the job of modifying the Mark 3 for that purpose. To the functions of the Mark 3 the derivation of elevation angle was added; lobe switching in elevation, the same technique used to give the Mark 3 its accuracy in azimuth, proved the answer. Except for a new antenna and an additional indicator for the pointer, the new model, designated the Radar Equipment Mark 4, was essentially the same as the Mark 3. Late in September 1941, the first installation was made in the destroyer *Roe*. Before the end of the year production models were available for installation.

The new equipment, while far from perfect, proved both versatile and effective. Over 600 were installed before production was finally stopped in the spring of 1944. The Mark 4 was generally installed on the double-purpose battery directors of battleships, cruisers, and destroyers. Even at the end of the war, after many of the equipments had been replaced by more modern types and others had been lost in battle, over 300 Mark 4's remained in service. This was the equipment that won its reputation aboard the *South Dakota* when on October 16, 1942, the battleship shot down 38 of 38 attacking planes. Surface craft, too, suffered from the equipment's effectiveness since it was controlling large double-purpose guns. In some respects the device was more efficient for surface than for antiaircraft work; one of its principal deficiencies was that it could not give accurate elevation data on planes that approached the ship at an angle of less than about 10°. Other fleet criticisms of the Mark 4 were directed at the unsatisfactory "pip" presentations on the elevation and train indicators, resulting in operator fatigue, and at its only moderate tracking accuracy. Successive modifications effected improvement, but ordnance

designers were meanwhile developing its successor, the Radar Equipment Mark 12.

By late 1942 the new design had superseded the old, but production problems delayed service use of the Mark 12 until mid-1944. Deliveries scheduled for May 1943, for instance, were not actually ready for shipboard installation until early 1944. Once the sets were available in quantity, however, the production of the Mark 4 equipments was halted altogether. Its replacement, operating on a higher frequency, eliminated most of the minor defects, but still contained two major defects: an inability to track low angle targets and insufficient resolution in the presence of multiple targets. Time limitations meant that the Marks 4 and 12 were the only radars to see wartime service for their particular functions, but later developments running into the postwar period promised the elimination of the remaining defects in the existing systems.

The outstanding weakness of the Marks 4 and 12—failure to detect low flying targets—was met by a high priority development that produced the Radar Equipment Mark 22. A supplement rather than a replacement for the Marks 4 and 12, this equipment was designed to permit low angle elevation determination. Produced on a crash basis, the new model contained features which were significant for the future progress in antiaircraft radar for control of large guns. Operating on a higher frequency than its predecessors, the Mark 22 provided a fan-shaped beam for scanning in the vertical instead of the horizontal plane. The combination of a rapid scan and a narrow, 1° beam provided adequate elevation data on attacking planes all the way down to the horizon. The haste with which the Mark 22 was pushed through resulted in unsatisfactory packaging, but it nonetheless pointed the way toward the solution of some of the outstanding problems for antiaircraft fire control radar.

Considerably less success accompanied the program to provide radar for the control of the heavy machine guns used for close-in defense against attacking airplanes. Throughout the last year of war that constituted the most urgent fire control problem faced by the Bureau. In general, the requirements for satisfactory heavy machine gun director radars were the most difficult of all to fulfill. Performance had to be comparable in most respects to that required for heavy antiaircraft directors, yet weight and space restrictions were approximately 66 percent more severe. The design problem was further complicated by the fact that the radar and its mount were of necessity the largest part of any fire control system for heavy machine guns. That meant that the radar had to be an

integral part of the system, not an added adjunct, as was essentially the case for equipments used with main batteries.

Few organizations in the United States were capable of undertaking such a problem, and they were naturally overburdened with work throughout the war. Nonetheless, projects to provide radar equipments for heavy machine and medium range gun directors were underway by early 1942. While no equipments resulted from the projects early in the war, mainly because of the instability in the director programs for the same guns, techniques and designs were worked out that late in the war were incorporated in the Radar Equipments Mark 28, 29, and 34, which were used with the Gun Directors Mark 57 and 63. Progress in this particular phase of the radar program never approached that made with equipments for the larger director systems, but it at least made possible the establishment of goals for postwar radars that were hardly dreamed of in the desperate months of war.

Even though the kamikaze attacks emphasized the fact that fire control for close-in defense was far from perfect, the overall picture presented by the utilization of radar was one of real accomplishment. In less than 5 years a new technique experienced a growth that would have been a credit to a whole generation of scientists. The Bureau of Ordnance itself was responsible for the development of 27 separate fire control radar equipments, many of which went through a series of modifications. In addition to the equipments for the control of both surface and anti-aircraft guns, the marks represented developments that applied the new science to the Norden Bombsight, torpedo directors on PT boats, beacons for shore bombardment, and numerous other military uses.

The cost of the entire program is hard to compute because of the widespread nature of research, but its magnitude is indicated by the fact that one agency, the Radiation Laboratory, spent over \$30,000,000 a year during the war on basic electronic research and the development of radar components, techniques, and equipments. While no other one agency did such extensive work in the field, many laboratories, both commercial and government, expended a major portion of their research and development facilities on radar work. Most of this basic work was not, of course, initiated or directed by the Bureau of Ordnance, but without the benefit of allied work the task of the Bureau would have been both more difficult and more expensive.

During the relatively short period from 1941 to the end of the war, Ordnance expended approximately \$14,000,000 for fire control radar development. The production that resulted from the de-

developmental work cost another \$400,000,000 during the wartime period and encountered problems at least a match for those that beset the researchers. Even more than development, production was the real test for the Bureau. The war had to be fought by equipment in the fleet, not laboratory ideas or bread board models. And just as combat gave all ordnance equipment its ultimate tests, productibility was the criterion by which each of the many designs had to be judged. Not all of the designs passed the test. Twenty-seven fire control radar equipments were developed by the Bureau of Ordnance; 10 types were produced for use in the fleet or in training schools. Only seven of those, the Marks 3, 4, 8, 12, 18, 22, and 28 actually got into the fighting war. In fact, only three, the Marks 3, 4, and 8, were available for the bulk of the engagements in which the United States Fleet participated.

Despite the limited number of equipment types that got through production in time for combat, the record was an achievement rather than an indictment of the Bureau or its contractors. The policy of the Bureau as stated by Admiral Blandy was to be radical in research, conservative in adoption. The field of fire control radar represented an excellent example of that policy in application. Two other factors contributed to the situation: the state of the Nation's electronic industry and the dynamic nature of fire control radar design.

At the outset of the national emergency the electronics industry was necessarily young and comparatively small. The war brought rapid expansion, however, and between 1940 and 1945 the industry grew from a \$1 hundred million base to a capacity valued at \$21½ billion dollars. This 2500 percent expansion could not have been accomplished without growing pains. The deluge of service orders that required the industrial expansion was of such magnitude that even the phenomenal rate of growth could not match the demands of war production. Since the manufacture of electronic equipment consisted largely of assembling purchased components, the press of orders induced a chronic shortage of vital parts. Prime contractors competed with one another for the available components; within their own plants they were forced to divide the supply between competing projects.

The success of the entire electronic program was threatened by essentially chaotic conditions. In August 1942, the Joint Communications Board and the War Production Board attempted to cope with the situation by establishing the Electronic Precedence List. This was, in effect, a priority system within the priority system that governed all war production. The list established

categories for each item of electronic equipment in the order of decreasing urgency, as determined by the Joint Chiefs of Staff. Thus, projects might be labelled by any letter number combination from A-1 to C-100, according to their relative importance to the war effort. Contractors were required to print on each of their orders for components whatever priority symbol was assigned the project for which the parts were required. Producers filled the orders in strict accordance with the precedence symbols. Theory was somewhat modified in practice, but the system was fairly well enforced by the War Production Board.

The precedence list did serve to maintain order within the electronics industry, but the procurement of fire control radar equipment became more rather than less difficult. Search radar and sonar comprised category A; air-borne radar was considered second in urgency; fire control radar shared with electronic equipment for other offensive weapons the unenviable category C. Even within that designation, the equipment fared poorly, bearing classifications from C-32 through C-38. The relatively low rating meant that fire control radar was in a poor competitive position in the race for the thousands of components making up each of the equipments. No real relief came until August 1944, when fire control radar was assigned an A-90 classification. And even then the shortage of parts remained a barrier to all-out production.

Even greater obstacles to the volume of procurement desired by the Bureau were created by concurrent development and production. The equipment was needed too urgently for the Bureau to wait for crystallization of designs before starting manufacture. The result was that contracts were let for production of equipments that were not really ready for satisfactory service at sea. Then, as continuing development suggested improvements, the necessary changes were introduced into the assembly line. This was ordinarily done on a "not to delay production" basis, but the change-overs could seldom be accomplished without some loss. Different components were often required, in which case the slow process of securing the parts had to start again. Modifications also demanded the manufacture of field change kits for the modernization of the equipments started before the contractor could incorporate the changes on his assembly lines. Thirty or forty changes during the course of production on one equipment were not unusual, and the situation became so complicated that field changes had to be made on field changes. A classic example of the problem was furnished by the Radar Equipment Mark 12, for which

over 30 field modification kits were produced before the first equipment was delivered. As equipments changed almost overnight, every aspect of the radar program suffered. Spare parts requirements changed too frequently for intelligent planning, and crystal balling led to the purchase of far more parts than the fleet could use. The result was frustration for the planners, waste of money, and an unnecessary drain on the critical components supply.

The results of instability in the radar program were also felt both before and after equipments were manufactured. At the outset the contracting procedures were complicated. Manufacturers were reluctant to accept a fixed price contract when faced with the prospects of introducing successive changes to the material they agreed to produce. Letters of intent served to inaugurate production by permitting contractors to spend a specified amount, but these agreements often had to be reinstated because definitive contracts were difficult to negotiate. Even when a contract was finally drawn up, redetermination was required frequently to keep pace with the modifications introduced during manufacture.

Installation and maintenance provided new headaches after equipment was delivered. Because plans changed frequently or were never definite in the first place, various Navy yards used different techniques for installation. When ships later needed repairs at some other yard the technicians were faced with unfamiliar problems. Experience could solve such problems, but in such a new field experience was a novelty.

Despite the ever-changing situation which prevailed in the fire control radar program, the equipment poured to the fleet. The appearance of chaos proved superficial. With the invaluable assistance of the Bell Telephone Laboratories and the Western Electric Co., the Bureau was able to meet every installation deadline throughout the war. The close corporate connections of the two companies permitted a relatively smooth flow from development to production, minimizing the difficulties of maintaining production with fluid designs. The fact that fire control radar contracts made up a large part of the workload at the laboratories and plants permitted a degree of top level supervision not available at the other companies that accepted Bureau contracts for radar equipment. The concentration of contracts was not considered desirable by the Bureau, but circumstances required it and results justified it.

V-J Day naturally brought the termination of many contracts for the modern radar equipments that were just entering the fleet

when the Japanese Empire fell, but over 5000 had already been sent to sea or to training schools. They were expensive and imperfect, but whatever their recognized deficiencies, they represented as much as any other one weapon the margin of United States superiority over the enemy.

Chapter 18

MACHINE TOOLS

AS the touchstone to success in war the old axiom about getting there "fustest with the mostest" lost no validity in the years between the Civil War and Pearl Harbor, though the technological changes of the period enormously complicated the requirement. The twentieth century introduced the concept of total war and the phrase was nowhere truer than in its application to the economic life of belligerent nations. If battles were not actually won on the production lines, they could nonetheless be lost there.

Industrial potential has become an integral part of a nation's military prowess. Preparation for conflict necessarily involves the translation of potential strength into actual strength through the conversion and expansion of production lines. Some of the material items needed for war require only an increased rate of manufacture of articles familiar in peace, but ordnance rarely has a commercial counterpart; its production requires different tools. Since many ordnance items have a useful life span measured in seconds, the number that have to be produced—and, therefore, the number of tools needed for the job—are astronomical. Thus, military might rests on industrial capacity which, in turn, is largely dependent for its vitality upon a single industry—the machine tool business.

The vital product of this group, as defined by its makers, is "a power driven, complete metal-working machine, not portable by hand, with one or more tool-holding devices, used for progressively removing metal in the form of chips." The work of the machine tool is accomplished by "rotating metal against a cutting tool, as in a lathe; by rotating the cutting tool against the metal, as in milling machines or drill presses; by moving the tool longitudinally against the part to be machined, as in a shaper; or, by moving the metal longitudinally against the tool, as in a planer." The more complex tools are merely combinations of these basic processes. Ranging in weight from less than 200 pounds to over 100 tons, machine tools vary in size from small bench drills, no bigger than a suitcase, to huge milling machines which are often larger than a small house.

In 1940 the industry upon which the Nation's industrial expan-

sion was dependent consisted of 400 plants. Two hundred were devoted exclusively to the production of machine tools, while the remainder were marginal producers that manufactured other items as well. Most of the plants were small units, in many cases family owned, with capital investments of less than \$1,000,000. At the end of 1940, the total capital investment of the industry did not exceed \$250,000,000, and one firm accounted for approximately \$20,000,000 of that total. The 200 principal companies produced about 95 percent of the 200,000 tools manufactured in 1940; dollar-wise, some 30 firms accounted for 65 percent of the volume. The industry was geographically concentrated in the New England States, Ohio, Illinois, and Wisconsin. Often characterized as the aristocrat of industry, the machine tool group constituted a conservative industry whose standards were reflected in the close tolerances demanded of its products.

The machine tool business is the capital goods industry "par excellence." A degree of industrial expansion is needed to maintain the industry, let alone expand it, yet the production of machine tools in the United States has been a feast or famine business. The stimulus of the First World War pushed production up to a yearly average of \$157,000,000 between 1915 and 1920, but the following year witnessed a decline to \$36,000,000. The industrial expansion that accompanied the boom of the late 1920's raised the value of production to \$185,000,000 in 1929, but the results of the great depression were so disastrous to the industry that purchases dropped to barely \$22,000,000 in 1932.

Foreign orders were all that kept the American machine tool industry going during the early depression years. In the bleakest year, 1932, Japanese and Russian orders accounted for approximately 65 percent of the total output. Throughout most of that decade the two nations were among the industry's best customers. As late as 1939, Japan was a significant factor in the market with her purchases of general purpose machine tools valued at over \$20,000,000. European orders, too, increased with the rise of German power. Hitler began to retool for war soon after he came to power in 1933; by 1938 the production of the German machine tool industry was eight times the volume of 1933. In contrast, the French machine tool industry was absolutely flat; England's, although excellent, was much too small to meet the needs of the increasing armament program.

The result was an unprecedented demand for American machine tools. England, France, and Russia placed urgent orders. Smaller countries—Belgium, the Netherlands, and Rumania—also

entered the market. Japanese orders accelerated until the island empire took the full-time output of one of the largest firms. Prices skyrocketed. Owning a machine tool plant, it was said, was almost as good as a license to print money. Lathes, a few years earlier a glut on the market, advanced in price from \$1,800 to \$5,000, and there were spectacular price increases for all items. In a few instances, dormant plants were reopened with cash advanced by foreign buyers to cover the cost of rehabilitation, raw materials, and payrolls.

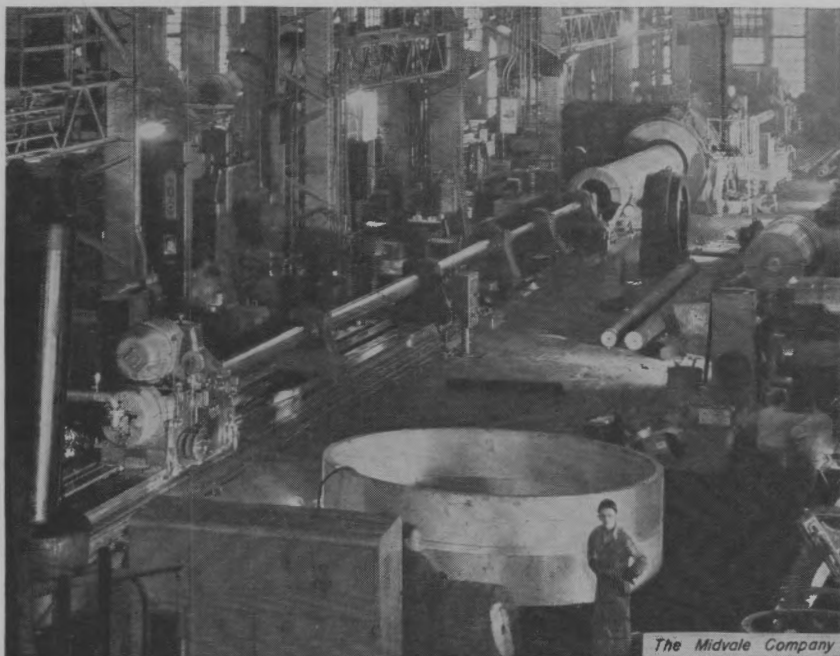
In 1939 the United States began competing with foreign purchasers for the output of its own industry. These new orders gave a fresh spurt to the expansion of the machine tool business. Sales for 1940 reached the \$440,000,000 mark, then advanced to three-quarters of a billion dollars in the following year. All-out war in 1942 brought an astronomical increase to \$1,320,000,000, and the output of 1943, valued at \$1,180,000,000, was not far behind. Production declined to \$497,000,000 in 1944 and reached a 6-year low in 1945, when the output was priced at \$407,000,000. But telescoped into the 5 war years was a dollar volume that exceeded the production of the previous 40 years.

In meeting these demands the industry resorted to every possible expedient. New plants were constructed, old ones modernized. Companies not remotely connected with machine tool manufacture but with excellent records for machining work in other lines were brought into the ranks of the industry for the first time. Thousands of men were trained in the intricacies of building machine tools, raising employment from 37,000 in 1939 to a peak of 123,000 in 1942. Even with this increased labor force, overtime was common. Many plants operated around the clock. Outside help was obtained through the subcontracting of parts, subassemblies, and, in some cases, even of whole machines. Through these techniques tools were sent to the Nation's overburdened production lines, but not rapidly enough to prevent the bottlenecks that plagued the Bureau's procurement program. Ironically, the industry responsible for mass production in other plants could not use mass production methods in its own shops.

Although foreign orders were largely responsible for the initial buildup of the machine tool industry in this country, the great flow of exports proved an impediment to the expanding American rearmament effort. Foreign commitments often made it impossible for tool builders to accept American orders. Some of the tools marked for shipment abroad were of the heavy type which took time to build and could be turned out by only a few of the best

equipped machine tool firms. This was the very equipment required for the increasing ordnance programs. Other defense establishments were meeting the same problem. Early in 1940, as a result of pressure applied by the Bureau and other service activities, export licenses were refused on millions of dollars worth of machine tools awaiting shipment to Russia, Japan, Romania, France, and Belgium, on the ground of prior naval need.

In July 1940, the Administration of Export Control was established to license the export of all critical commodities. The results were a boon to the Bureau. A \$2,000,000 project order of July 30, 1940, was assigned to the Naval Gun Factory for the purchase of some of the tools withheld from export. The amount was soon raised to \$6,092,712, permitting a more realistic program for the procurement of the embargoed tools. Part of this equipment was absorbed by Bureau of Ordnance stations; the bulk of it, however, went to private contractors—Bethlehem Steel, Crucible Steel, the Midvale Co., and United Engineering Co. Included among the items was a complete forging outfit which was utilized in the critical projectile program. Likewise, the heavy gun lathes, milling machines, and grinders seized at this time proved invaluable.



This \$300,000 double end boring lathe was awaiting shipment to Russia in 1940 when it was commandeered by the Navy.

In addition to playing a key role in spotting and securing this vitally needed equipment, the Bureau used its available but altogether too limited funds for the purchase of carefully selected machine tools. Considerable sums were spent in replacing worn out and out-dated equipment, but emphasis was on the purchase of the general purpose machine tools most important to the ordnance effort as a whole. In this program, pool orders were used extensively. The pool order mechanism, originated by the Army-Navy Munitions Board, placed orders carrying a 30 percent down payment in advance of actual needs of war contractors, thus encouraging output at a rate which manufacturers could not have afforded otherwise. For example, in 1940 the Bureau placed a \$500,000 pool order for milling machines. This equipment was greatly in excess of the requirements of the Gun Factory and the new Naval Ordnance Plants. The surplus, made available to private producers, helped meet the shortage in a highly important type of machine tool. Again in 1941, the Bureau used the pool order to advantage in procuring over \$10,000,000 worth of centerless grinders and automatic screw machines for the 20-mm. and 40-mm. projectile program. A \$4,300,000 pool order for gun production equipment in 1941 contributed greatly in hastening this weapon to the fleet in the following year.

The development of a machine tool catalogue proved invaluable in the Bureau's industrial mobilization. In the mid-1930's the Navy Department, utilizing tool experts from the various bureaus, perfected a simple machine tool classification system which both standardized nomenclature and provided a means for determining requirements. Mimeographed and loose-leaf bound, the publication listed all applicable types of machine tools and plant equipment by function, then by source of manufacture and supply. The types were broken down into commercial sizes and space was provided for entry of the quantity of each size required for the production effort. Ordnance experts, adapting the classification system to their own needs, prepared production equipment charts which showed every machine tool and item of shop equipment used in making the major ordnance equipments. Listing available sources of supply together with the cost of the tools, these charts enabled the Bureau and its contractors to order machine tools with a minimum of delay.

In addition, the Bureau maintained a record of every machine tool in the ordnance establishment as well as those furnished to private producers under facility contracts. The manufacturer

of each machine was noted along with data on the type and size of the equipment, its location, electrical characteristics, cost, ownership status, delivery date, and the Bureau assigned identification number which was stamped on the machine. This information, adapted to IBM machine accounting, furnished a ready reference to the thousands of machine tools engaged in ordnance production. For example, if a specific type of tool was urgently needed in a critical program, an IBM run would show within a few minutes where such tools were located; the availability of the equipment could then be determined.

As a result of the Bureau's action, ordnance establishments and a few major contractors were relatively well tooled at the time of the Japanese attack. Their requirements, however, were infinitesimal compared with the demands of contractors who entered the ordnance program after Pearl Harbor. On the other hand, actual war also marked an intensification, already under way, of the activities of civilian agencies charged with the overall direction of the American economy. Interest in the field of machine tools was particularly acute. This interest resulted in a more efficient control in the procurement and distribution of machine tools under the War Production Board.

Attempts at overall coordination of the machine tool program were both numerous and changing. The National Defense Advisory Commission, created by President Roosevelt on May 28, 1940, was replaced in January 1941 by the Office of Production Management. Within a year the OPM gave way to the War Production Board. The activities of the NDAC in the field of machine tools were largely exploratory and consultative. More effective control of machine tools was established by OPM—priority ratings, filter forms, master preference lists were all utilized to improve unsatisfactory situations in the machine tool supply for the defense effort. The War Production Board, building on the experience of its predecessors, worked out with the Army-Navy Munitions Board a machine tools distribution system which proved generally satisfactory to the armed forces. This plan allocated 75 percent of the monthly production of machine tools to the military, with the major supply branches and bureaus sharing according to fixed ratios. Within this assigned quota, each bureau worked out its own master precedence list. Although this arrangement eased the distribution problem, shortages in particular types of machine tools plagued the Bureau until the closing days of the war.

In point of time, armor was the first of the Bureau's programs to feel the impact of the machine tool shortage. As early as 1939

the Chief of the Bureau commented that "the critical items in the expansion of armor plants are machine tools, presses, and planers which require 18 months to secure and install." Fortunately, the commandeering of foreign machine tools in 1940 reduced this time lag considerably. Next, machine tools for antiaircraft guns threatened to be the Achilles heel of the ordnance program. Only the deliveries of the pool orders for general purpose tools which had been placed in 1940, enabled the Bureau to keep pace with the modest demands of this early procurement program. Following Pearl Harbor, the increased demands for munitions emphasized the short supply of machine tools and many of the Bureau's important projects felt the pinch. Tools for the torpedo program caused the most concern. This situation was critical from early 1942 until the fall of that year, when joint efforts of the ANMB and the WPB finally uncovered enough of these tools to meet ordnance needs.

Aircraft production was a program of primary interest to both the Army and the Navy. Its importance so increased as the war progressed that within 1 year after Pearl Harbor all programs had to give precedence to aircraft. This policy, applied to the shortage in machine tools, meant that new tool procurement had to be justified in terms of aircraft or antiaircraft armament. Procurement of aviation ordnance and antiaircraft guns benefited from this emphasis; on the other hand, important programs for mines, projectiles, depth charges, and other ordnance items suffered. The overwhelming stress on aviation lasted until the summer of 1943, then reappeared in 1944 with even greater emphasis in the Army's B-29 procurement. Two-thirds of the machine tool capacity of the country was then devoted to the production of equipment needed to speed the bomber output; new tool requirements for all other munitions, including the Bureau's mushrooming programs for high capacity projectiles, VT fuzes, and rockets, had to be satisfied from the remaining third. Tooling the production lines for VT fuzes and high capacity projectiles was a touch and go proposition until well into 1945. The demand for rockets was also insatiable and the machine tool bottleneck constituted a real problem up until the very day of Japanese capitulation. As late as August 1945, the Bureau complained that the Army's cutbacks in heavy artillery equipment following V-E Day had failed to release the expected number of machine tools for rocket work. In fact, the rocket program was so urgent that it was often necessary to send search parties from the Bureau and the WPB to scour production centers

throughout the Nation in the hope of turning up idle and unreported tools.

The difficulties encountered in procuring machine tools pointed up the necessity of making the most efficient use of the available equipment. More efficient cutters, tool servicing and conservation, novel uses of old tools, surveys to spot idle equipment, and substitution of materials to reduce machine operations, all paid dividends in the Bureau's machine tool program.

The use of carbide cutting tools proved extremely effective. A German invention, the carbide tool consisted of a hard cutting surface, usually tungsten, which was grafted to the tip of the cutter. This device removed metal at a much faster rate than the high-speed-steel cutters with which most of American industry was equipped and at the same time offered a much longer service life. Carbide tools were not employed extensively in this country at the beginning of the emergency. In the first place, the development of these tools was of recent origin and knowledge of their use was not widespread. Further, the machine tools common to the American industrial system were of such low horsepower that they could not operate carbide cutters; the required machines were high in power and high in price. Fortunately for the production effort many of the machines could be converted to the operation of the carbide tipped cutters.

Before the war, in anticipation of organizing for mass production and aware of the potentialities of new materials, the Bureau invited carbide and stellite tool manufacturers to demonstrate their products at the Gun Factory in Washington. The results were so successful that the Gun Factory installed many high-powered machine tools in order to utilize the more effective cutting devices. The remarkable increase in production which accompanied the change was also marked by a considerably lower unit cost. The application of carbide tools was gradually extended to other Bureau establishments, and private firms with ordnance contracts were urged to switch to these tools where practicable. The results were uniformly good. By applying carbide tools to work on turbine bulkheads, for instance, the Naval Torpedo Station, Newport, increased the average tool life 500 percent while reducing the machining time to one-fourth that required with high-speed-steel tools. In the turret lathe department of a large plant, a 30 percent increase in output was attributed to the adoption of carbide cutters. Similar examples are legion. Tool engineers sent by the Bureau to make plant surveys became missionaries who often brought to poor producers a message of salvation through the use of carbide

tools. This enthusiasm was reflected in official reports: "The company is a poor producer . . . there is a very limited use of carbide tools," "the contractor will get high production and good quality because of the excellent application of carbide tools;" "these people have done nothing to improve their machinery operations by the use of carbide;" "employees should be trained in the use of carbide tools." Training programs were stressed and thousands of machinists received instruction in the manufacture, use, and maintenance of carbide tipped tools.

Although the application of carbide tools to ordnance work made great strides during the war, the potentialities of these devices were not fully exploited. Offering advantages of increased production in shorter time and at lower cost than high-speed-steel tools, carbide cutters were assured an expanding role in future ordnance programs.

The Bureau effected further economy in machine tools by encouraging the redesign of ordnance components to reduce metal removal. In no field was this used to more advantage than in the critical anti-aircraft machine gun program. For example, by changing the design of the 40-mm slide from a steel casting to a steel tube welded to a plate, 1 company released 16 machines to other war work and saved 119,000 machine-hours. The Chrysler Corp. changed the housing of the 40-mm from a solid billet of steel to a forging and freed 17 important machines. Another company was able to transfer 13 machine tools to other work by redesigning the Bofors gun pawls from forgings to strip steel stampings. The trigger cover of the Oerlikon gun was originally made from a 6-pound solid steel forging which was whittled down through 29 operations on a dozen machines. Redesign reduced machine operations from 29 to 15, saved 2 pounds of steel per piece, hours of machining, and 90 percent of the cost. The 20-mm hammer axis bolt, the piece that hit the shell, had a slotted head of elaborate shape, but the adoption of a simple cone-shaped bolt eliminated several machine operations and cut costs to about one-twelfth that of the original design. These illustrations are but a few of the hundreds that could be cited.

The Bureau did not need to be reminded that idle tools worked for Hitler and Tojo. Indeed it was a cardinal tenet of Bureau policy that machine tools must not stand idle. From time to time inspectors were instructed to make surveys of the Government-owned machine tools under their cognizance, for the purpose of uncovering surplus items. Tools reported to the Bureau as surplus were immediately diverted to plants where they could best

serve the production effort. During the war, 9683 idle machine tools were transferred to full-time ordnance production. The inspectors also cooperated with the Critical Tool Service of the War Production Board by locating urgently needed tools. When the Critical Tool Service began this task in May 1942, there was no systematic and nationwide plan for finding and utilizing every idle tool. The new program, involving clearing house principles, not only located idle tool capacity but matched it locally with contractor's critical requirements. Any surplus which could not be employed locally was reported to the state or regional WPB offices and matched with regional requirements. Remaining surpluses were reported to Washington. Started as an experiment in the industrial areas of Pennsylvania, the plan exceeded expectations in providing a single and national organization to handle tool problems. Through this program many idle tools were channeled into ordnance establishments.

A further aid in stimulating the flow of idle machine tools to production lines came in a June 1943 directive from the Under Secretaries of the War and Navy Departments which authorized the transfer of such equipment between the services without the transfer of funds. This directive, based on proposals originally initiated by the Bureau, speeded the exchange of vitally needed equipment by relieving procuring agencies of the interminable amount of detailed paper work required under the old system. In many cases the issuance of a shipment order was all that was necessary to move the tools. Within the next 2 years there was an increasing flow of machine tools between the armed services. By the time of the Japanese surrender in August 1945, the War Department had furnished the Bureau of Ordnance with 3036 machine tools and over 23,000 capital and supply items. On the other hand, the Bureau shipped many surplus machine tools to War Department activities.

An early irritation in the tooling of ordnance projects arose from contractors' insistence on specific makes of machine tools even though competing builders offered quicker deliveries. Indeed, there were situations where critical tools were placed in storage because the builder lacked either an established name or a competent sales organization, although his tools were of a standard type of general utility. To overcome this situation the Bureau demanded that contractors take the earliest available tool that would do the job. Producers were furnished the names of builders for each type of machine tool and no assistance was given a contractor

until it was determined that he had not restricted his "shopping" to a favored builder.

In many cases the impossibility of obtaining a desired machine made it necessary to adapt equipment to uses for which it was not originally intended. Resourceful contractors found ingenious ways to apply old tools. A two-spindle machine was needed to drill, countersink, and tap holes in both sides of the 40-mm breech-block. Not having such a machine, tool engineers tied an old vertical drilling machine in with a new tapping machine. A hydraulic press, originally designed to straighten rear axle housings, was converted into a broaching machine for use on the breech-block of the same gun. One company resurrected a planer-type grinding machine from the discard and put it to work on the 40-mm. gun sight. Simple attachments and minor adjustments were often all that were required. In one case, an old lathe equipped with a device costing only \$700 was able to perform work ordinarily done on an automatic profiling lathe. Again, an inexpensive attachment made it possible for a boring mill to accomplish the work of a hard-to-get Keller machine. Not all adaptations were so easy. For example, a Bureau contractor needed a large planer for finishing 5"/38 gun mount base rings and the available planer, one that measured only 6 feet between the columns, was too small. Since at least a year would have been lost in waiting for a planer of suitable size, it was necessary to rebuild the small machine to accommodate the work. The columns were moved 16 feet apart and a new cross rail, rail support, and feed shaft were added. A table and "outriggers" completed the new machine. These illustrations are typical of the hundreds of adaptations made by resourceful contractors. The Bureau was able to speed the production of ordnance equipment by making these practices known to producers faced with similar problems.

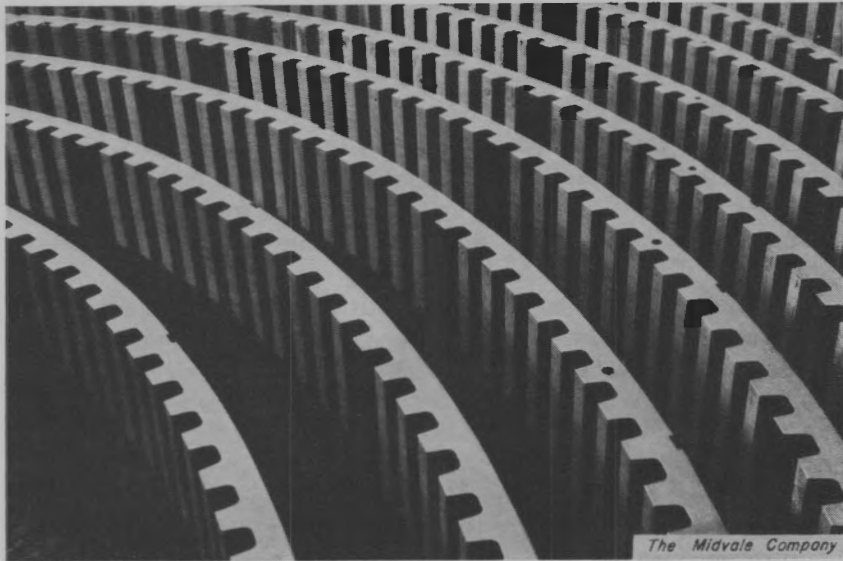
The initial shortage of machine tools emphasized the importance of both the servicing and conservation of cutting tools. In furthering this program, the practices of outstanding producers were made available to ordnance activities. These reports stressed the proper selection of cutting tools, the use of new cutting alloys and materials, improved tool practices in grinding, care and maintenance, and effective measures for the repair of damaged or broken tools. The success of the Bureau in this field was reflected in the speedy rehabilitation of broken tools with concomitant savings in materials and manhours. The salvage activities initiated at the Naval Ordnance Plant, Center Line, Mich., early in 1943, furnish

excellent examples. Many of the tools salvaged were special drills, cutters, reamers, and other equipment that could not be ordered one day and received the next. Delivery was sometimes 26 weeks removed from the date of the order. In one instance, a new form cutter would have cost \$300 and entailed a 6-week delay. The salvage job took 5 hours. At Center Line, 125 cutters and drills worth \$1,500 were salvaged in 96 hours for less than \$500. Delivery time on replacements for these tools varied from 4 weeks to half a year. Tools broken in half, which once might have been thrown away, were repaired in a few hours. According to the assistant superintendent of the NOP, "Fixing up . . . broken tools . . . kept the gun plant rolling when there were no other tools to be had."

The use of secondhand machine tools was not widespread in Bureau establishments. In the first place, most of these machines were snapped up by private industry in the rapid expansion of facilities required to meet the urgent demands of foreign governments for machine tools. Secondly, the high price of the tools compared unfavorably with the cost of new machines; not infrequently, used tools brought more than new items. An added disadvantage arose from the fact that highly skilled personnel were required to operate the machines if the close tolerances characteristic of ordnance were to be achieved. Scarcity, cost, and difficulty of operation all tended to minimize the value of secondhand tools in ordnance programs.

The Bureau invested over \$300,000,000 in machine tools for war production. Purchases of machine tools ranged from a complex 16,000-ton capacity forging press costing \$1,600,000 to a relatively simple bench lathe at \$900. Running concurrently with the acquisition and distribution of these tools was the necessary planning for their orderly disposition at the end of the war. The tremendous cost of machine tools, the difficulty of their procurement, and their basic importance to ordnance programs combined to dictate careful planning in disposal. The Surplus Property Act and Property Disposition Directives provided general regulations for the disposal of facilities; the implementation of these directives was a matter for Bureau action.

During World War II the Bureau financed the industrial expansion of several hundred ordnance manufacturers through facility contracts. These contracts made available to producers the means to build or buy plants, enlarge existing plants, or to buy machine tools and other equipment for installation in plants already owned or leased. Under the Surplus Property Act and the directives gov-



Training racks to rotate and position gun turrets must be machined to an accuracy of 2/1000 of an inch.

erning the sale and disposal of Navy-owned surplus property, contractors could make known their wishes as to what part of the Navy-owned property they desired to buy under the terms of their facility contracts. As for machine tools, the surplus disposal regulations contained specific pricing criteria. The selling price of machine tools to the public was based on the condition and age of the equipment; at 3 years, the discount from the purchase price was 49.8 percent, at 5 years, 60 percent, and at 15 years, 70 percent. Contractors in possession of tools had to pay an additional 5 percent. This price was easily determined from property cards maintained by the Bureau and from similar records in the offices of the Inspection Service in the field. The contractor indicated on a purchase schedule the machine tools he wished to buy, and listed the unwanted items on a removal schedule. These lists were screened in the Bureau against the known requirements of the postwar period. By the time contractors had made their purchases and the Bureau had satisfied its needs, there were few machine tools left to sell the public.

Two basic policies governed the disposition of the machine tools acquired in the termination of facility contracts; first, the old and inefficient tools in the Naval Ordnance Establishment were replaced by the newer and more modern tools surrendered by the con-

tractors; second, a War Reserve tool pool was to be maintained in a state of readiness to meet future emergencies. Tools in excess of the requirements of these two programs were to be turned over to the War Assets Administration for sale to the general public. In attaining the first objective, machine tools valued at over \$75,000,000 were installed in various ordnance establishments. Incidentally, the oldest machine tool replaced was a lathe of 1885 vintage which had been in operation at the Naval Gun Factory throughout World War II.

Long before the cessation of hostilities the Bureau prepared a list of machine tools which were to be put in a state of preservation for long-term storage as they became available from contractors. Designated the War Reserve, the list was composed of light, medium, and heavy general purpose machine tools which experience proved difficult to procure. Among the types included were gear hobbers, gear generators, gear checkers, horizontal boring mills, multiple spindle automatic lathes, jig borers, and profilers. An age limit was set up to insure that only new machines were on the list, and a contractor Navy Inspector certification as to quality was required. The Naval Ordnance Plant, South Charleston, W. Va., was selected for the storage of the War Reserve pool. Close to the primary centers of naval ordnance production, with ample floor space, and already equipped with the heavy cranes required to move the bulky machine tools, this NOP was ideally situated to assume this function.

Even before V-J Day, as ordnance programs were cut back or terminated, machine tools were shipped to South Charleston if there was no urgent production need for them in other ordnance work. The end of hostilities witnessed the wholesale cancellation of facility contracts which, in turn, greatly augmented the supply of desirable machine tools for the War Reserve. This was not simply a problem of picking out sizes or model numbers. Many tools relatively new by ordinary time-usage standards had become old tools because of their 24-hour-a-day, 7-day-a-week use in the hands of inexperienced operators. A screening process was necessary to guarantee that only tools in good condition were sent to the War Reserve.

Under the supervision of experienced mechanics every machine tool was torn down, repaired, and sprayed with preservatives before reassembly and storage. Spare parts were preserved as carefully as the machines for which they were purchased. Placed in dynamic dehumidified storage, both machine tools and spare parts were safe from deterioration. At least one complete set of special

production tooling for each major ordnance item was also preserved at South Charleston. These tools consisted of jigs, fixtures, dies, gages, attachments especially designed and developed for standard machine tools, and special hand tools for specific operations. During an emergency, production tooling applicable to almost any ordnance program could be withdrawn from storage and shipped to contractors with minimum delay.

The value of the machine tools channeled into the War Reserve pool exceeded \$60,000,000 and included over 10,000 pieces of equipment. Maintained under the most modern methods of storage, these carefully selected general purpose tools proved invaluable to naval ordnance establishments and commercial contractors when the Korean crisis required increased production schedules.

Chapter 19

CONTRACT PROCEDURES

UNTIL the existence of a national emergency created new patterns of procurement, the evolution of Navy contract procedures was an example of Topsy-like growth. Historical chance rather than logical decision served to establish procedures that later gained sanctity from precedent. Examples abound. Aircraft contracts were handled by the Bureau of Supplies and Accounts because planes were once considered "supplies." Contracts for submarine machinery were personally signed by the Secretary of the Navy for no better reason than the fact that some early Secretary, fascinated by the underwater craft, insisted on examining all such contracts. In still other cases, some one item would gain special attention because of the interest of a congressional committee. Cases multiplied over the years and, as one historian observed, "these precedents, once established were, in the normal operation of bureaucracy, difficult to change."

Ordnance contracts were not immune to the peculiar whims of the Secretary's office. Early in 1909, Secretary Meyer, for reasons now shrouded in oblivion, directed that all contracts for armor, gun forgings, and projectiles should be prepared by the Bureau of Ordnance and submitted to his office for signature. Contracts in this category were designated NOD's. Although the Bureau was authorized to make contracts for items not expressly reserved for the Secretary's attention, the right was not exercised. All other equipment was purchased on Naval Ordnance contracts, designated NO's, which were executed by the Bureau of Supplies and Accounts.

Whether procurement was made directly by the Bureau under the NOD contracts signed by the Secretary or through the contracting procedures of Supplies and Accounts, the basic requirements were rooted in statutes. Such was the structure of this legal framework that the Navy was in the unusual position of entering the world's greatest conflict with a Civil War weapon—Revised Statute 3709. Enacted in 1861, this law required advertisement of proposals and competitive bidding, with the contract going to the lowest bidder offering materials which complied with specifications. Subsequent legislation and administrative rulings further restricted, rather than liberalized contract requirements. Contract

forms became almost as limited as methods of negotiation. Cost plus a percentage of cost agreements were prohibited after World War I, confining nearly all contracts to the fixed price type. Though always preferred by the Bureau of Ordnance when circumstances permitted, fixed price contracts resulting from advertised proposals were the least conducive to speedy procurement.

Archaic as these procedures were, they possessed the virtues of being traditional and essentially simple. Developed over the years, both Nod and NOs contracting was familiar to Bureau personnel. Weaknesses were obscured or excused by the fact that in most cases speed of procurement was not a vital consideration. Besides, even the cumbersome methods could be invoked with fair speed as long as procurement remained on a low, maintenance level.

Of the two contract types—Nod and NOs—open to Ordnance, the former was the more expeditious. Procurement of armor, gun forgings, and projectiles was initiated by advertising for bids. On a specified date the collected offers were opened and considered for the selection of the lowest responsible bidder. A contract was then drafted by Bureau personnel, approved as to form by the Judge Advocate General, and sent to the Secretary's office for signature. Actual administration of the contract was the responsibility of the Bureau. These steps did not take long to accomplish. A Nod contract was normally prepared within 1 week after bids were opened; another week sufficed for its execution by the Secretary. On those rare peacetime occasions when a matter demanded real urgency, a contract was specially drafted and carried by hand through the Secretary's office.

The great bulk of Bureau procurement was accomplished by NOs contracts resulting from requisitions on the Bureau of Supplies and Accounts. This method was slower than the use of Nod contracts, but long range planning was the rule and economy rather than expeditious action the prime consideration in peacetime. Preparation of a requisition, its transmittal to BuSandA, the accumulation of bids, and the return of proposals to the Bureau of Ordnance for comments and recommendations were all time consuming. After a recommendation for award reached the Bureau of Supplies and Accounts, however, a formal contract was usually submitted within 10 days. In years of peace the work load was light enough for the whole process to be accomplished within a comparatively short time.

That idyllic situation ended many months before Pearl Harbor. As early as 1933, the picture began to change with the gradual armament buildup introduced by the Roosevelt admin-

istration. The acceleration of that program by the events of 1939 and 1940 completely changed the tenets of military procurement. The anachronism of traditional methods became readily apparent as urgency replaced economy as the first principle of Navy purchasing. New machinery was vital for satisfactory procurement. Streamlined administrative techniques were indicated as a partial answer, but even more important was the removal of legal restrictions on the sources from which the Navy might draw its equipment.

These restrictions were, like contract procedures, rooted in the national tradition. In the years preceding World War II, Congress customarily embodied restrictive legislation in annual appropriations designed to prohibit the purchase from private manufacturers of any material that could be produced in navy yards or arsenals "in the time required, at not excessive cost." In effect, such provisions restricted the purchase of guns, projectiles, fuzes, and many other items of naval ordnance from commercial sources. A natural result was the gradual disappearance of private facilities capable of such manufacture. The Bureau was vigorous and outspoken in its opposition to this legislation. Before congressional committees and in correspondence with legislative leaders it pressed the point that dependence upon Government-owned plants was dangerous. Examples were close at hand. The Bureau depended upon the Naval Gun Factory for the production of the major share of its gun and mount equipment. Even in peace, however, that source was inadequate to keep pace with an armament program. Requirements above its capacity had to be filled by War Department arsenals—a source certain to be lost to naval ordnance as Army needs grew.

In other ways, too, the legal restrictions were hazardous. An inevitable result was the loss of ordnance know-how among the Nation's manufacturers. Gun and armor making, for example, became almost lost arts in the interlude between the two wars. The Bureau argued that some ordnance production by private firms was essential, if only to prepare industry for the manufacture of similar items in wartime. Further, the placing of ordnance contracts with private firms insured competition which kept down costs and furnished an incentive for industry to apply to naval ordnance problems its research facilities, its latest technical developments, and its manufacturing processes. "Competition in brains" was essential. To the extent that the Bureau was deprived of the opportunity for commercial purchase, to that same extent it was deprived of industrial ideas, initiative, research, and inventions that could improve material, reduce costs, and lead to new and

more effective weapons. The adverse effects of such restrictive legislation could not be overcome by its repeal or waiver at the outbreak of war; the need for immediate action was fairly obvious by 1939.

The Bureau was not alone in its opposition; all branches of the Navy united in a concerted attack. Congress held its ground for a time, but the Appropriations Act for 1939 marked the beginning of a more liberal trend. Although this legislation carried the usual restrictive provisions, the Secretary of the Navy was authorized to grant waivers when such action was necessary for national defense. This exception to the usual requirements removed an important limitation on the Navy's power to contract. Beginning July 1, 1939, the Bureau of Ordnance was allowed to procure material from either public or private plants according to a flexible formula based on requirements, efficiency in manufacture, and long range planning. In the face of skyrocketing material requirements, the proportion of equipment furnished by private contractors increased rapidly.

Another liberal change in contract procedure was effected in January 1940, when the Secretary of the Navy authorized the Chief of the Bureau to award and administer all NOD contracts for ordnance material. These contracts for armor, gun forgings, and projectiles were subsequently identified by the symbol NOrd. Though they still had to be submitted to the Judge Advocate General for legal examination, the Secretary's approval and signature was no longer required. Thus the NOrd was a streamlined version of the NOD. The elimination of restrictions and the development of new administrative techniques were proceeding hand in hand.

Five months later a much more important change in Navy contract procedures was effected by congressional enactment of Public Law 671, a legislative milestone that swept away peacetime restrictions, revolutionized many traditional procedures, and geared Navy contract methods for war. The main provisions of the act authorized procurement through negotiated contracts without advertisement or competitive bidding and permitted the use of cost-plus-fixed fee contracts. Of course, the old restrictions were not thrown away heedlessly. The new, timesaving, negotiated contracts could only be used when the Secretary felt that the price was fair and the need urgent. At the time the law was passed the more liberal provisions were intended to supplement, not displace, the older and more conventional methods of contracting, but the day soon arrived when peacetime processes were completely reversed. Under an increasing pressure for rapid procure-

ment, the majority of ordnance contracts were negotiated under the provisions of this law. It supplied the degree of flexibility that paved the way for a tremendous, almost incredible, wartime expansion.

Public Law 671 accelerated Navy procurement in still another way. Capital problems often hindered manufacturers who were willing to accept ordnance contracts but lacked the expensive equipment needed for initial production. Advance payments offered an obvious solution, but proved impossible because of old legal restrictions. An act of Congress in 1911, did authorize the Secretary to make partial payments during the progress of work on naval material, but it did not permit payments in excess of the work actually accomplished. Public Law 671, on the other hand, allowed advance payments to contractors in amounts up to 30 percent of the contract price. With money in hand, manufacturers were able to acquire the facilities necessary to launch production.

Facility contracts soon became an important part of the Bureau's procurement program. These contracts, designated NOrd(F) experienced the same general procedural evolution as the NOD. First written in the Bureau, the documents were approved by the Judge Advocate General, signed by the Secretary, then returned to the Bureau for administration. After September 1941, more speed in processing was made possible by permission for the Bureau to bypass the Secretary's office and proceed with the execution of the contracts after their examination by the JAG. Facilities contracts systematically built up the industrial capacity of the Nation. New plants were constructed, old ones were modernized or enlarged. For many items of ordnance equipment they constituted an inevitable first step toward procurement. Without the stimulus offered by prewar NOrd(F) contracts, the machine tool situation would have been even more critical than it was and many of the industrial miracles that marked wartime production would have been impossible.

The total of administrative and legislative changes in 1939 and 1940 provided the Bureau with five types of contracts by which ordnance items or facilities could be procured: NOrd contracts for armor, gun forgings, and projectiles, written and executed by the Bureau after competitive bidding; NOrd contracts negotiated under the provisions of Public Law 671; NOs contracts negotiated by representatives of both Ordnance and Supplies and Accounts, then written in BuSandA in response to requisitions; NOs contracts written by BuSandA on Ordnance requisitions, but awarded

after competitive bidding; and the NOrd(F) contracts by which the Bureau financed critical industrial expansion.

These contracts were initially administered by the Financial Division, but the general reorganization of the Bureau in February 1941 shifted primary cognizance to the Contracts and Requisitions Section of the newly created Production Division. Originally composed of 1 officer, the section was expanded within a few months to include 8 commissioned lawyers. In addition to this staff, the Office of the Under Secretary provided the advisory services of a civilian lawyer. Within the Bureau there was neither a theoretical nor a practical dividing line between the duty of contract negotiation and that of contract preparation. All officers did both. The civilian representative of the Under Secretary, however, worked solely on contract preparation and review.

The attack on Pearl Harbor resulted in an immediate and tremendous increase in procurement requirements. President Roosevelt, in an executive order of December 27, 1941, declared that "the successful prosecution of the war requires an all-out industrial mobilization of the United States in order that the materials necessary to win the war may be produced in the shortest possible time." To speed this mobilization, the President, exercising the power conferred by the First War Powers Act of December 18, 1941, granted to the Navy and War Departments general authority to contract through negotiation. This order went even further than Public Law 671 and left to the discretion of contracting officers the choice between negotiation and advertisement for bids. This permissive authority to negotiate contracts was replaced early in 1942 by the War Production Board's Directive No. 2 which, to all intents and purposes, made contracting by negotiation mandatory. Some months later an amendment to this directive established the premise that price was no longer the first concern of Government purchasing by directing that primary emphasis be placed upon "deliveries or performance at the times required by the war program."

Legislative changes, the advent of all-out war, and the creation of new government agencies required parallel changes in the Navy's contract procedures. As far as the Bureau was concerned, the main organizational problem was the existence of a middleman—the Bureau of Supplies and Accounts—between Ordnance and its manufacturers. NOrd contracts for armor, gun forgings, and projectiles could be processed rapidly, whereas requisitions for items handled through BuSandA frequently required 2 months to reach

a contractor. The benefits gained through Public Law 671 and the WPB directive were more than offset by the tremendous increase in procurement. Supplies and Accounts lacked the administrative flexibility to keep pace with the accelerated program, as well as the technical knowledge to handle the details of contracts for the specialized equipment requisitioned by the material bureaus. Questions relating to specifications, guarantees, tests, inspections, and the like, had to be referred back to the cognizant technical bureau, exposing the embryonic contracts to new labyrinths of correspondence and red tape. The routine of peace was inapplicable to war; prodigious effort on the part of BuSandA was not enough. Specialized knowledge utilized through direct channels was mandatory, but the knowledge was a natural monopoly of the technical bureaus and the channels for procurement were anything but direct.

In July 1942, the Chief of the Office of Procurement and Material, in order to bring the debate into the open, queried the technical bureaus as to whether all procurement should not be centralized in the Bureau of Supplies and Accounts. This proposal had long been debated. As early as March 1933, a Board on Consolidation of Purchasing Activities had been convened by order of the Secretary for the purpose of determining whether major advantages would accompany the centralization of all procurement in the Bureau of Supplies and Accounts. The Board recommended that the type and amount of purchasing permitted the Bureau of Ordnance not be changed. Delays, additional paper work, loss of contact between the Bureau and the contractor, as well as complications in the control of payments, reservations, and final settlement of contracts were all determining factors in the Board's decision. Further, it was emphasized that "these disadvantages, serious even in normal times, would make still more difficult the functioning of the Bureau of Ordnance in the event of a national emergency requiring immediate and tremendous expansion of its activities."

When the question of centralization was raised again in July 1942, Admiral Blandy opposed it on the demonstrable grounds that the requisitioning system, while adequate in peace, was too ponderous for the wartime procurement of technical naval ordnance. The Admiral commented: "My plea is to retain for urgent or difficult items, a system which accelerates procurement instead of retards it. If the fleet fails to get weapons or ammunition on time, it will hold the Bureau of Ordnance responsible, not the Bureau of Supplies and Accounts. I . . . should have control over the procurement procedure and its speed. I should decide when

a better business deal, obtained through prolonged negotiations, should be waived in emergency to get quick production. After all, the fact that we are running a business is secondary to the fact that we are fighting a war." An officer with less weight but a more unbridled wit seconded the Admiral's plea with the popular observation that BuSandA did not stand for Bureau of Speed and Action.

Other technical bureaus, especially Aeronautics, joined the Bureau in advocating decentralized and direct procurement procedures. Their efforts were successful. Any prospect of centralization of all Navy purchasing activity in the Bureau of Supplies and Accounts was ended for the duration of the war by a directive issued by the Secretary of the Navy on December 13, 1942. Promulgated on the basis of authority granted by the First War Powers Act of December 18, 1941, and Executive Order 9001, this was perhaps the most important directive affecting procurement issued by the Secretary during the war period. Organization and contract cognizance were both revamped.

Two major changes altered the traditional cognizance structure. The first, as if a direct answer to Blandy's plea, allowed the chief of each bureau to determine which contracts should be negotiated by Supplies and Accounts. Under the authority conferred by this section of the directive, Admiral Blandy arranged for the Bureau of Ordnance to handle its own contracts for the research, development, and production of all ordnance equipment. Only simple purchases of standard stock items were subsequently channeled through BuSandA. A second innovation ordered each bureau to establish a legal office headed by an appointee of the Under Secretary. Prior to this, the Procurement Legal Division in the Office of the Under Secretary maintained a representative in the Bureau's Production Division to aid in preparing contracts for the approval of the Judge Advocate General. After the reorganization, however, the Under Secretary's representative and the JAG's review were both eliminated. The bureau legal offices, coordinated by the Procurement Legal Division, rendered the advice and services formerly supplied by outside agencies. The new plan gave bureaus the independence necessary for quick and direct action on contracts within their cognizance.

Within the Bureau of Ordnance several changes were made to take advantage of the new contracting procedures. An Assistant Director for Procurement was appointed to act for the head of the Production Division on contract matters. Personnel for the new office were recruited from the former Contracts and Requisitions

Section, the unit that formerly transmitted contract information to the Bureau of Supplies and Accounts. Further reinforcements came from the Office of Procurement and Material, which assigned seven experienced negotiators who had been transferred from BuSandA. This arrangement might have been unsatisfactory, since the Bureau lacked cognizance over the borrowed negotiators, but close personal relationships resulted in cooperation and a successful procurement team. Each negotiator became a specialist in some specific field of ordnance procurement, thus gaining an intimate knowledge of the manufacturing facilities, techniques, and problems for a particular field of production. Their principal duty was to assist the Bureau Negotiation Board—a varying body that included the Assistant Director for Procurement and the head of the technical section having cognizance over the equipment to be procured.

In initiating a supply contract the interested technical section prepared an analysis of its procurement program. This summary showed total requirements, amounts already on contract, as well as current and prospective rates of delivery. The technical section also selected the contractor, though its choice was governed by WPB directives, the available labor supply, and the need to utilize the entire productive facilities of the Nation. This analysis and selection was forwarded to the Plant Equipment Section for approval. If a check indicated that the suggested contractor had the facilities needed to complete the order, the embryonic contract moved on to Production Planning for certification that the procurement was in accord with Bureau policies. In the next two steps a priority was assigned by the Priorities and Expediting Group and a Controlled Materials Plan allotment number was designated by the Itemized Planning and Progress Section. The cumulative analysis was then forwarded to the Assistant Director of Production, an officer who acted for his division chief in determining whether proposed procurement could be conveniently placed in a Naval Ordnance Plant. If he approved the use of a private manufacturer, the Assistant Director for Procurement then obtained clearances from other Navy agencies. The proposals were ready for the legal office and the preparation of a formal contract.

Progress was not always so smooth, of course, but the Negotiation Board provided a means to expedite the process. When disagreements or problems arose during the evolution of a contract the Assistant Director for Procurement called a meeting of the board. Negotiators and even representatives of concerned manufacturers

often sat in on these meetings to help solve whatever problems threatened to delay the completion of the contracting procedures. Once the issues were settled, the steps involved in preparing a satisfactory arrangement could be completed.

These typical procedures might result in any one of six types of contracts that the Bureau employed in its expanding procurement program: letters of intent, fixed price contracts, cost-plus-fixed-fee contracts, fixed price contracts with redetermination clauses, no price contracts, or incentive fixed price contracts. In each case the names were generally descriptive of the cost arrangements involved. A letter of intent authorized a contractor to begin work with the assurance that he would be reimbursed for his expenses up to a fixed amount if a definitive contract did not materialize. These letters were commonly used when the requirements for immediate production were too urgent to await the determination of a fair and equitable price for the items under procurement. A variety of factors—fluid specifications, inexperience of a manufacturer, lack of substantiating data—might cause such dilemma, but a letter of intent allowed the solution of cost problems and the inauguration of production to proceed concurrently. Some obvious dangers were inherent in these arrangements, however, and the use of letters of intent was kept at a minimum. In no case could they remain in force for over 60 days without the approval of the Office of Procurement and Material. A letter of intent was usually followed by a contract of the fixed price variety. This form was preferred whenever enough information could be obtained to permit the determination of a price acceptable to both the Bureau and the manufacturer. While this was often impossible, the majority of contracts issued by the Bureau were of the fixed price type.

In those cases where the preferred type was impracticable—research and development work and the private operation of Naval Ordnance Plants were examples—cost-plus-fixed-fee contracts were used. These contracts guaranteed the producer a fixed profit that never exceeded 7 percent of his actual costs as determined by the Cost Inspection Service of the Bureau of Supplies and Accounts. The use of this type was limited because it did not compel contractors to keep costs down to the levels that prevailed with fixed price contracts. Used even more sparingly was the fixed price contract with redetermination clause. This imposing title was applied to agreements which established an initial price for items, but required the contractor to present a statement of his cost after the completion of a portion of the work and to negotiate a lower price if his profits were excessive. Frequent use of the type was avoided

because it left unscrupulous contractors free to withhold planned economies until after the redetermination, then reap high profits on the balance of the contract. Such contracts were useful, however, in cases where costs appeared likely to decrease as contractors gained experience. Reliable manufacturers were willing to pass savings on to the Government, but were often unable to guarantee or predict such price reductions while contracts were being negotiated.

A no price contract obligated the contractor to present his costs after the completion of a portion of the job and negotiate a firm price at that time. If no agreement could be reached, the contract permitted the responsible officer to fix a price, but obligated the Bureau to present to the Court of Claims the contractor's claim for a higher payment. A further provision established a billing price at which contractors were paid until a price was fixed. No price contracts had many of the advantages of letters of intent and were especially suitable where the manufacture of an item started before the crystallization of its design, then ran concurrently with the final development of the equipment. In such cases, the urgency of a letter of intent needed to be combined with the permanence of a formal contract; those were the especial virtues of no price agreements. In some instances the type was modified to permit a fixed price for a portion, with the remainder to be tabbed under a no price agreement.

A small number of incentive fixed price contracts were executed by the Bureau during the war. Applicable only to cases in which reliable information on costs over a long period of time was available, this type permitted a contractor to increase his profits within a previously established pattern as he reduced the price of the item furnished under the contract.

During the period of the Bureau's expanding cognizance over procurement, certain clearance procedures were established by the Secretary of the Navy and by other governmental agencies which limited the freedom of the Bureau of Ordnance to contract. The purpose of these clearances was to coordinate procurement between the different bureaus of the Navy and to coordinate Navy procurement as a whole with that of other government war agencies so that available manpower, raw materials, and facilities could be allocated on the basis of urgency of need.

On December 28, 1941, the Secretary of the Navy issued a directive that supply and facilities contracts involving more than \$200,000 were not to be executed unless authorized by his office. Since, in June 1940, the Secretary had delegated all contract work to the

newly created Office of the Under Secretary of the Navy, clearance of these contracts was actually handled by that office. The member of the Procurement Legal Division assigned to the technical bureau approved the contract before it was forwarded to the Under Secretary. After approval by the Under Secretary's office, all contracts involving an expenditure of over \$500,000 were sent to the Office of Production Management for final clearance, and after the abolition of that agency in January 1942, to the War Production Board.

To assist the Under Secretary in his work as coordinator of the business side of the Navy, the Office of Procurement and Material was established in January 1942, to supervise the procurement functions of the various bureaus. Mr. Frank M. Folsom, an executive with the War Production Board, became the first head of the Procurement Branch of the new office and was vested with authority to approve contracts which were formerly cleared by the Under Secretary. At the time of Mr. Folsom's transfer to the Navy Department, Mr. Donald Nelson, chairman of the War Production Board, authorized him to clear the Navy contracts which were usually forwarded to that agency. This arrangement expedited the placing of contracts without loss of essential control by the War Production Board.

Requests for clearance of Bureau supply contracts were prepared by the negotiators attached to the office of Assistant Director for Procurement. In practice, clearances were a matter of form. The negotiators usually ironed out any difficulties with the Office of Procurement and Material before the formal submission of the contract for clearance. In fact, no ordnance supply contract was refused clearance during the war period.

Although the Office of the Assistant Director for Procurement was primarily interested in placing contracts for ordnance materials, a necessary concomitant of this work was the coordination of cutbacks in material programs. In this field the action of the Assistant Director was exercised within well defined limits set by Bureau policy. In general, when a cutback was necessary the high cost producer bore the burden of the cut, with no attempt being made to distribute the reduction uniformly to all the contractors supplying the item. To avoid waste of public funds and critical materials, the contractor was permitted to reduce production gradually.

The termination of contracts did not assume major importance until June 1945, and by that time general procedures and policies had been crystallized in Joint Army-Navy Termination Regula-

tions. In contrast to other bureaus that established termination units divorced from procurement, the Bureau of Ordnance employed its contract personnel in terminations. Working under a familiar administrative organization and possessing an intimate knowledge of the background of the particular contract being terminated, contract personnel were ideally situated to expedite the heavy load of terminations following the close of the war.

Chapter 20

INSPECTION ADMINISTRATION

STORIES compounded on half truths, lightly propped by isolated facts and drawing their drama or their horror from reputed incidents of ordnance failure are, like camp followers, the inevitable concomitant of every war. Sabotage or greed are often ingredients in the rumors, but causation is incidental, varying with the teller. Malfunction, not fat capitalists or stray wrenches, is the true villain. Exaggerated and embellished as such stories become, the grain of truth that breeds them is the nightmare of the Bureau of Ordnance and the particular concern of its inspectors. While a patriotic and conscientious industry has deglamorized their role as detectives, technological progress has increased the importance and the problems of the man whose popular image stands with calipers at the end of each assembly line.

Ordnance, along with other naval material, was once inspected by the officers of the ship slated to receive it, but the system was antiquated by progress. There were doubtless risks involved in firing solid shot in the days of the smooth bore cannon, but the possibilities of a modern projectile being defective have been multiplied by the number of its components. Increased complexity and the large scale manufacture demanded by modern warfare have acted as a dual force, leading to the development of the contemporary Naval Inspection Service. The problems of World War II reshaped the structure of that service, but the organizational pattern of the ordnance inspection system was clearly defined by the 1920's. At this time the Bureau exercised administrative and technical control over two types of inspection organizations: first, Inspectors of Ordnance in Charge, who were responsible for the quality of ordnance in the Bureau's own facilities, such as ammunition depots, ordnance plants, and proving grounds; and second, Naval Inspectors of Ordnance, who were stationed at private plants engaged in the production of specialized ordnance material and equipment. The NIO was more than an inspector; he was the vital link between the Bureau and the contractor. For the Bureau he saw that it got the material it required, while at the same time he assisted the manufacturer in fulfilling his contract.

The other material bureaus of the Navy also maintained separate and independent inspection offices in their own facilities, as well as in the principal industrial centers of the United States. Under this system the technical bureaus inspected their own material at the source of manufacture. This frequently resulted in multiple Navy representation at plants, with each bureau inspecting material independently of the other. The system was wasteful and extravagant. On April 5, 1927, the Bureaus of Ordnance, Aeronautics, Engineering, and Construction and Repair took the first step toward the consolidation of the inspection service. Inspectors of Naval Material were established with responsibility for inspecting components used in the fabrication of complete articles. Inspectors of the various bureaus continued to operate in their own plants and in those that produced finished articles in amounts sufficient to justify the retention of a resident inspection force.

Overlapping still existed, but the partial consolidation of inspection services relieved the technical bureaus of a great volume of work. Under the demands of a peacetime Navy, characterized by problems of maintenance rather than procurement, the new system worked well, and many areas of conflicting inspection were eliminated. The shift to procurement in the late 1930's, however, revealed weaknesses in the system which for a time threatened to become a "bottleneck" in the flow of vitally needed ordnance material to the fleet.

During World War I the Ordnance program involved an expenditure of approximately \$1,000,000,000. On Armistice Day 1918, the personnel in Ordnance inspection numbered 1580—4 officers in the Bureau, 160 officers in the field, 521 civilians, and 895 enlisted men. This program paled into insignificance by comparison with the expenditure of \$1,500,000,000 in 1941. There was also an increase in the number and complexity of ordnance items. Likewise, in 1918, the plants producing weapons were relatively concentrated in the eastern states, whereas, by 1941, there was a decentralization of production throughout the United States. It was clear that the inspection task facing the Bureau would require much more effort than in 1918.

The magnitude of the problem is illustrated in the procurement of torpedoes and projectiles. During the First World War, 982 torpedoes were inspected and delivered. By April 1941, there were 8600 torpedoes in production and project orders for an additional 7800—a total of more than 8 times the number delivered to the Bureau during World War I. In projectile procurement a similar situation existed. The minimum requirement of 131,900 major

caliber projectiles for 1941 was in sharp contrast to the 68,600 manufactured in 1917-18. In 1941 there was also a requirement for 100,000,000 antiaircraft projectiles—an item for which there was no counterpart in earlier wars. These examples are typical of practically every field of ordnance.

The critical situation facing the Bureau was emphasized by the fact that the entire personnel in the offices of the Inspectors of Naval Material, then performing considerable inspection for the Bureau of Ordnance as well as work for other bureaus, was no larger than the ordnance inspection force in 1918. Even this skeleton organization was plagued with vacancies which could not be filled. Inspectors asked for help and none was available. In many instances it was reported that because of personnel shortages, inspectors were forced to spend the major portion of their time on paper work. Lt. Comdr. Lewis L. Strauss, a Reserve officer responsible for the Bureau's inspection program, concluded early in 1941 that the "consequences of these conditions is that [the Bureau] will face a situation in a very few weeks where inspection will either have to be so perfunctory as to be useless, or where material will accumulate in the plants of contractors awaiting delivery for want of inspection. Many of these contractors have so little working capital they cannot continue production unless and until they are paid for goods completed. If goods are not completed, inspected, and accepted, they will not be paid for. Production . . . is in danger." Delay in attacking the problem threatened to make the solution more complex, retard production, and reduce vital inspection to a nominal status.

As a solution to the problem, the Bureau evolved a multipointed program based on the Strauss recommendations. In outline, the program called for civil service examinations in cities throughout the Nation's industrial areas for civilian assistant inspectors, for the revision of obsolete and unnecessarily strict requirements, and for the destruction of the traditional sex and age barriers. Speed rather than economy had to characterize the program. Within the Bureau, plans were made to expand inspection training facilities at the Gun Factory. These recommendations covered the basic problems relating to inspection, and during the following months they became focal points in the revitalization of ordnance inspection.

The recruiting of qualified civilian inspectors was particularly urgent. During the normal peace years the Bureau had encountered no difficulty in hiring well trained and experienced inspectors. The Civil Service Commission, through its local repre-

sentatives, had found prospective candidates, examined them for competency, and supplied a list from which vacancies could be filled.

The rapidly expanding naval ordnance program was matched by that of the Army, which competed for personnel from the Civil Service lists. Shortages in civilian personnel soon threatened to become a "bottleneck" in the inspection system and, through this, in the production program. Although the Civil Service Commission was no longer able to secure enough people to fill existing vacancies, it was unwilling to surrender its prerogative of providing lists of eligibles from which selection of employees had to be made. Lists became delayed for longer and longer periods, and contained fewer and fewer names.

Emergency arrangements were made to secure personnel. In some districts, inspection officers were permitted by the local civil-service representatives to interview prospective candidates and to give probationary appointments to those who appeared to be qualified. The applicants then filled out civil-service forms which were processed as though they were original applications. While this arrangement provided some flexibility in choosing personnel, it also created new problems. Inspection offices were not prepared to handle the personnel procurement. Since there was no specially trained force to conduct interviews and select employees, the work was done by top management, who had more important duties, or by section heads. When the latter was the case, the work was placed in the hands of men inexperienced in the employment field and already overburdened with work. Under such conditions it was inevitable that there should be lack of uniformity in the standards for selection. Individuals who would not have been considered for employment in ordinary times were often selected.

Another weakness in the arrangement soon became apparent. Acting on his own judgment, an inspector sometimes hired and placed on the payroll an apparently qualified applicant, only to discover later that under civil-service rules the man was not eligible for the job. Such appointees had often left good positions in private industry to accept the probationary appointment; they were thus left stranded when they failed to meet requirements. As a result, many qualified applicants refused probationary status because they were unwilling to run the risk of being placed in a similar position.

Early in 1941 the Civil Service Commission yielded to constant Bureau pressure and agreed to modify the requirements for in-

spectors. The changes included an increase in the number of types of experience from which applicants could draw; permission to substitute education for experience, and vice versa; and an increase to 65 years in the age limit of eligibility. These modifications were a spur to the lagging recruiting program and hundreds of well qualified people were added to the inspection rolls.

The recruiting program was also stimulated by the employment of women in the grades of "Under" or "Minor" Inspectors of Ordnance Materials. The decision to use women was based upon the fact that during World War I female inspectors had been used with success to inspect machine gun parts at the Savage Arms Co. and in other ordnance production plants. Further, a survey of the British inspection system showed that 58 percent of the shop inspection personnel was female. This strengthened the Bureau's belief that the Navy had not made adequate use of women inspectors; Naval Inspectors of Ordnance were instructed to take immediate steps to train women for these positions. Later, the Bureau of Ordnance opened some of the higher paid categories of inspection positions to women.

Another way in which the Bureau sought to secure trained inspectors was by providing instruction for both officer and civilian personnel in the Ordnance Inspectors School at the Naval Gun Factory in Washington. Originally established in 1940 with a faculty of 4, the OIS was expanded in the summer of 1941 to provide instructions for June graduates of engineering colleges who were to receive commissions in the Naval Reserve. The first of these classes, consisting of 100 ensigns, arrived on July 1, 1941. Sessions for training civilian inspectors were also established during the same year, with the first group reporting in November. The principal emphasis was placed on gages and physical testing, but instruction in 14 subjects rounded out the accelerated educational program. After 8 weeks of study the graduates were sent out as inspectors in the mushrooming ordnance buildup. In 1942, the Shore Establishments Division of the Secretary's Office established Navy Inspector Schools for civilians in New York City, Chicago, and San Francisco. Financed with funds from the Bureau of Ordnance and other material bureaus, the 3 schools channeled over 2800 people into the inspection service. As the training program expanded, the Bureau gradually restricted its courses at the Gun Factory to advanced specialized work.

The experience of the Bureau in building up its inspection forces led to the belief that changes in the administrative organization of the inspection service were vitally needed. There were five

different groups of inspectors then operating in the field: Naval Inspectors of Ordnance, Inspectors of naval material, Inspectors of Naval Aircraft, Inspectors of Machinery, and Supervisors of Shipbuilding. As a result of this administrative hierarchy there were many plants in which two or more naval officers operated independently, or, where one officer served two or more administrative bodies in the Department. In the Navy Department itself there were, according to Lieutenant Commander Strauss, "no less than five offices dealing with inspectors, sending them instructions and data, requesting reports, and competing with one another to a greater or less degree in the procurement of officer personnel, and in some cases competing for civil-service personnel in the higher classifications." Quite often inspectors, particularly those with a dual capacity, received 2, 3, and 4 letters in different phraseology dealing with the same matter. Many of the companies were working on their first Navy contract and were "bewildered by the apparent lack of unity in Navy inspection and the necessity for [the inspectors] to serve two or more masters all with equal authority."

In a memorandum to Secretary Knox, on July 14, 1941, Strauss recommended that a General Inspectors' Office, independent of the bureaus, be established in the Secretary's Office to consolidate the administration of all field inspection. Such an office, Strauss reasoned, would simplify administrative procedures, reduce paper work, and effect economies in space and personnel.

The Secretary found the suggestion attractive and requested comments from the bureau chiefs as well as from various boards and offices. A majority approved the proposal, but no action was taken. Vigorous opposition, based on a fear that the plan might impede the incipient procurement program, stemmed from the Chief of Naval Operations and the Chiefs of Ships, Aeronautics, and Supplies and Accounts. The delay, however, was only temporary. In less than a year, primarily through the efforts of Under Secretary Forrestal, a consolidated inspection administration was in operation.

Mr. Forrestal's interest in the inspection system had been quickened by one of those petty but interminable headaches of wartime administration—the unexpected request for an elusive fact. In December 1941, his office was asked to furnish the names of all firms with vital Navy contracts which did not operate on Sunday. Lacking a department of odd intelligence, the Under Secretary turned to the Naval Inspection Service for the information. No answer was available. Plant inspectors knew, of course,

but the complicated structure of the service prohibited the existence of any one source of inspection information or authority. Failure to produce an answer indicted the service for inefficiency and emphasized the sprawling nature of the system. Some weeks later, Mr. Forrestal instructed the firm of Booz, Fry, Allen and Hamilton, who were already engaged in management surveys in the Department, to look into the material inspection service. The Booz survey supported the Strauss recommendations and buttressed Forrestal's opinion of the soundness of the original proposal.

On May 2, 1942, Mr. Forrestal, in the capacity of Acting Secretary of the Navy, directed that an Inspection Administration be established in the Office of Procurement and Material for the purpose of consolidating the "administration of all material inspection activities of all material bureaus of the Navy Department." The new office was to promote the effectiveness of operations within the inspection service, particularly to the end of speeding up deliveries of end products without sacrifice of necessary quality. To achieve this objective the Inspection Administration standardized procedures, simplified practices, reports and forms, and made reorganizations whenever they seemed necessary for more efficient operation. Authority and responsibility were decentralized in order to speed action on matters affecting production. It disseminated to the field information promulgated by the Navy Department and other government agencies, and offered advice on all matters concerning officer and civilian personnel, their recruitment, training, promotion, and transfer. Other duties included the keeping of personnel records, the regulation of rates of pay for corresponding jobs, and the inspection of field offices and their organization, personnel, and procedures.

Under the new organization the various bureaus continued to have cognizance over the specifications and standards of inspection for their own products. On technical matters, direct communication between the bureaus and the field offices was continued, but copies of such correspondence were sent to the Inspection Administration Office whenever they had a bearing on administration. Administrative matters, whether originating in a bureau or a field office, were cleared with the central office.

The reorganization of the inspection service made it unnecessary to maintain a large inspection administration section in the Bureau, and both officer and civilian employees were gradually released for other duty. The principal matters channeled to the Inspection Administration dealt with personnel, operating funds, supplies, establishment and disestablishment of offices, general in-

spection policies, complaints or commendations on technical inspection, organization, and office procedures. In these fields the new office assumed responsibility for certain of the vexing and annoying details of administration which hindered Inspectors in the performance of their major task. Throughout the war, however, the Bureau exercised complete management and technical control over the Naval Inspectors of Ordnance.

Naval Inspector of Ordnance offices were maintained at plants that had major contracts for the manufacture of specialized ordnance equipment and material. Prior to the emergency, four offices sufficed; by December 7, 1941, there were 17: the A. O. G. Corp., Providence; Bausch & Lomb Optical Co., Rochester; Blaw-Knox Co., Martins Ferry, Ohio; Consolidated Steel Corp., Los Angeles; Chrysler Corp., Detroit; Navy Yard, Washington; Excel Foundry & Machine Co., Fall River; Ford Instrument Co., Long Island City; General Electric Co., Schenectady; Joshua Hendy Iron Works, Sunnyvale, Calif.; Herring-Hall-Marvin Safe Co., Hamilton, Ohio; Midvale Co., Philadelphia; Carl L. Norden, Inc., New York; Northern Pump Co., Minneapolis; Pontiac Division G. M. C., Pontiac; Willys-Overland Motors, Inc., Toledo; and the York Safe & Lock Co., York. In addition there were two resident naval inspectors of Ordnance offices, both under the NIO, General Electric.

During the course of the war, additional NIO offices were established at Triumph Explosives, Elkton, Mr.; International Harvester Co., Chicago; Westinghouse Electric, Sharon, Pa.; U. S. Rubber Co., Charlotte; Crucible Steel, Harrison, N. J.; Eastman Kodak, Rochester; Bullard Co., Bridgeport; and the E. W. Bliss Co., Brooklyn. The large number of prime contracts made by the Bureau necessitated the opening of some 20 RNIO offices throughout the country. In several instances where it was not expedient to establish a Naval Inspector of Ordnance, a number of INM offices were staffed by the Bureau. Such offices operated at Miehle Press, Goss Printing Press, Danley Machine, Vickers Inc., Hygrade Sylvania, Jefferson Electric, and Victory Ordnance.

Inspection offices, staffed with both military and civilian personnel, ranged in size from small units employing less than a dozen people to activities with 25 officers and 300 civilian clerks and inspectors. At the height of the ordnance program approximately 1500 clerks and inspectors were employed by the Naval Inspectors of Ordnance and the Resident Naval Inspectors of Ordnance, 4460 in INM offices on ordnance work, 670 in the contractor-operated Naval Ordnance Plants, and 78 in various other activities. The

work of this civilian contingent was supervised by 564 officers who operated on a budget of over \$18,000,000. In addition, hundreds of inspectors were employed in the Bureau's own factories.

One of the primary duties of the Naval Inspector of Ordnance was to see that ordnance material complied with drawings and specifications. In addition it was his responsibility to see that the material was produced on time—a task greatly compounded by the exigencies of war. Some 20 collateral duties complicated this requirement; security, property accounting, industrial mobilization, contract administration, and the very difficult material planning, scheduling, and coordinating functions often required more man-hours than straight inspection. Also, some manufacturers were lethargic in the face of emergencies, some sought an impossible perfection, and others were overwhelmed and discouraged by the difficulty of dealing with the complex conditions imposed by priorities, scarcity of materials, shortage of skilled labor, and inadequate finances. Such cases called for positive action. As Admiral Blandy expressed it, "a good Inspector must combine the functions of confessor, advisor, stimulator and if need be, a spur. In simple words it is up to the Inspector to put the PROD in PRODUCTION."

Valuable as were administrative changes and training programs, inspection problems were not solved without a major improvement in inspection technique itself. Fortunately, by 1941 there existed in the Bell Telephone Laboratories and a few other advanced industries a technique for improving the quality of material, while at the same time reducing both production and inspection costs. Known as statistical quality control, the process was based upon modern statistical analysis which distinguished significant variations from insignificant ones, and provided information on quality to any specified degree of certainty. The most important single aspect of statistical quality control was the ability to reduce scrap by preventing the manufacture of defective pieces.

An Ammunition Quality Evaluation Unit was established in the Research Division early in 1943 to apply the new process in both contractor-operated ammunition plants and in facilities producing ammunition components. The techniques introduced by AQE proved so effective that by the end of the war the full range of ordnance production was marked for the application of quality control. Early in 1946, a Quality Control Division was set up with responsibility for the quality of ordnance material from design test to final use or scrapping. Bringing principles of higher mathematics to pragmatic use in production and inspection, the Division saved millions of dollars for the Bureau and private industry.

Chapter 21

INCENTIVE AND AWARD PROGRAMS

AS a material bureau, Ordnance has always had to rank production as its primary concern. Even the development of new weapons, the most glamorous part of the role of the Bureau, was only preparation for the ultimate job of procuring vast amounts of war goods for the fleet. Whether measured in terms of money or of man-hours, this project dwarfed the other activities of the Bureau. Throughout the war, munitions had to be secured in such unprecedented amounts that the magnitude of the job was obvious, but even before the outbreak of hostilities the Bureau was faced with unusual production problems. Preparations for an impending conflict had to be made rapidly and the dormant ordnance facilities revitalized at a time when war still seemed remote to the average American. Profits were high in the industrial world and manufacturers were busy turning out vast amounts of the peacetime goods by which the Nation was long accustomed to measure its standard of living. As long as commercial goods could be sold rapidly and profitably, industrialists were reluctant to accept ordnance contracts. New tools were almost invariably required. High investments were necessary for an operation of questionable duration, small profit, and known exactitude.

Even when manufacturers accepted contracts, they had to fit the new work into existing schedules. The result was frequent delays in meeting ordnance commitments. Within plants, labor posed special problems. Ordnance goods almost invariably demanded more skilled work than was required for normal commercial goods. Rigid specifications demanded the closest tolerances and exacted the best work of skilled labor. And since ordnance work was only a part-time concern in most plants, low absenteeism was a prerequisite for proper scheduling. Both industry and labor would respond to patriotism, but before the outbreak of war quickened that emotion, some special stimulus was needed. To provide it, the Bureau launched an incentive program that finally proved so successful and popular that it became the prototype for those of both the Army and Navy.

The program that culminated in the familiar Army-Navy E evolved through several stages. Soon after becoming Chief of

the Bureau in February 1941, Admiral Blandy initiated an informal sort of incentive program based on the time-honored Navy precept: "Praise in public, censure in private." Contractors who were doing an excellent job were permitted to fly the Bureau of Ordnance flag over their plants; the laggards were called to Washington for censure.

This informal arrangement was shortly succeeded by a more elaborate program. In June 1941, Secretary of the Navy Frank Knox urged the Bureau to develop a plan with the twin goals of stimulating production and of solidifying opinion behind the defense program. The assignment was given to Lt. Comdr. Lewis L. Strauss, a Reserve officer whose primary duty was the direction of the critical inspection program for the Bureau. In preparing a set of suggestions, Strauss was forced to choose between the alternative principles represented by a black list and a white list. The former was considered the more effective for stimulating production since it would focus public attention on a delinquent contractor, but this powerful weapon was also the more dangerous for the user. Short of an all-out war, political repercussions would almost inevitably follow the black-listing of a prominent company. Moreover, the chances of injustice were great. To make a procedure effective, all alibis would have to be rejected, yet there were often circumstances when the Bureau itself was responsible for a contractor's failure to meet schedules. And even if a black list served to stimulate production, the ill feeling created would be an obstacle to the improvement of morale—an essential ingredient for a successful program. In the light of such considerations, Lieutenant Commander Strauss recommended to Admiral Blandy a variation of the white list or roll of honor.

Based in principle on the axiom that "the possession of an award or a recognition is a challenge to those who have not earned it," the idea was to give those contractors who best served the Bureau some visible indication of official gratitude. The existing program suggested the use of the Bureau flag for that purpose, and buttons or insignia for each worker were also envisioned. By implementing the competitive instincts of both capital and labor and by exploiting the kind of exhibitionism that leads men to dangle keys from watch chains and fill lapels with buttons, the Bureau hoped to provide the incentive necessary for the peacetime production of war goods. The visible indications of commendation were petty, but underlying the scheme was dependence on the inherent patriotism of the country.

In commenting on the proposals to President Roosevelt, Under Secretary Forrestal wrote: "I have always believed that men will work for symbols just as hard as they will for money—and if there is the slightest foundation for this belief, it is obvious that [the] national emergency will emphasize it." Cynics who considered the view as the tongue-in-cheek variety were soon silenced. The plan was approved when Admiral Blandy submitted it to the Secretary, the details were worked out in the Bureau, and the plan worked.

Once the idea for the incentive program was approved and the Bureau received authorization to proceed with the project, the details of the program were worked out rapidly. Drawing on his contacts from civilian life, where he was a senior partner in the firm of Kuhn, Loeb & Co., Strauss was able to secure top flight promotional talent to guide the project through its formative period. From within the Bureau came the idea of using the Navy E, which ultimately became the popular symbol for the whole program. Originating in 1906 as a gunnery trophy, use of the letter to denote excellence had spread to other fields of fleet activity. Now that some symbol was needed for use on plant flags and workers' buttons, the Bureau decided to lend the prestige of the E to the incentive program. With the tradition of the fleet behind it and a question-inducing unfamiliarity surrounding it, the symbol appealed to the experts who were working on the details of the plan.

Before the end of July 1941, the mechanics of the program had been completed. In addition to the Ordnance flag, the E burgee, and provisions for plant-supplied buttons for workers, the proposal called for a Board of Awards to select the companies to be honored and for public ceremonies at the presentation of each award. To aid in publicizing the plan and to stimulate competition for Ordnance recognition, the Bureau published a *Naval Ordnance Manufacturers' Bulletin* for industrial circulation.

In July 1941, the Board of Awards met for the first time and selected 14 companies for recognition. While success in meeting or exceeding scheduled deliveries formed the criterion for selection, geographical distribution and company size were important factors in the beginning. East, Midwest, and West, big plants and small, were represented in the initial selection. Executives from each of the firms were invited to Washington for ceremonies in the Secretary's Office on July 25, and the presentation of flags was later repeated at the plants themselves.

The first recipients were the Arma Corp., New York; Bausch & Lomb Optical Co., New York; Cameron Iron Works, Texas; E. I. du Pont de Nemours & Co., Delaware; Fisher Body Division, General Motors Corp., Michigan; Ford Instrument Co., New York; International Nickel Co., West Virginia; Keuffel & Esser Co., New Jersey; Midvale Co., Pennsylvania; Miehle Printing Press & Manufacturing Co., Illinois; Norris Stamping & Manufacturing Co., California; Northern Pump Co., Minnesota; Pollack Manufacturing Co., New Jersey; and Textile Machine Works, Pennsylvania.

The program proved successful almost immediately. In plants that received the recognition a definite improvement of morale was reflected in increased production. Since the awards covered a 6-month period, efforts to add a renewal star to the plant flag insured a continuing incentive. Other firms expressed an interest in gaining the recognition, and the placing of Ordnance contracts was speeded. Labor, too, showed an interest in the program. As individuals they appreciated the symbols that indicated their contribution to national defense: As a group they evidenced the same competitive instincts that characterized industry.

Bureau expenses in connection with the program were small. The Ordnance flags, E pennants, and the printed bulletins represented the only cash outlay required, aside from the cost of clerical help used in connection with the work. Even during the formative period when the program was guided by civilian experts, the expenses were slight; most of the outsiders worked for only nominal pay, yet remained available for consultation even after the Bureau assumed direction of the work. From a small investment the returns were great. Presentation ceremonies were almost invariably big occasions, especially when the honored firms were located in small communities. Governors and Senators often joined high ranking naval officers to lend added prestige to the ceremonies. Throughout the fall of 1941, new firms joined the original 14. Before the year was out, 94 companies flew the Ordnance flag and the Navy E pennant, stimulating production within their plants and providing publicity and competition for the incentive awards.

Success invited duplication, and the Bureaus of Ships and Aeronautics soon copied the Ordnance example and instituted production incentive programs of their own. Having three Navy bureaus competing for attention introduced a variety of complications. Since the same firms often took contracts for two or more of the agencies, a situation was possible where a plant might be proudly flying the emblem of one of the bureaus while occupying a promi-

ment spot on the private black list of another. Moreover, the duplication of awards tended to reduce the publicity value of official recognition. Such was the situation when the attack on Pearl Harbor brought the whole incentive question to a climax.

The outbreak of war automatically ended two of the problems the programs had been devised to solve. Manufacturers were no longer reluctant to accept government contracts, and public opinion could be counted on to support the war effort without any artificial stimulus. Nonetheless, the Navy Department decided against abandoning the programs. Their value had already been proved by increased production and reduced absenteeism in plants that gained recognition for cooperation, and war brought more problems than it solved. Longer hours and fewer holidays demanded new sacrifices on the part of management and labor, and the chance of a derogatory distinction between men in uniform and those in industry made attention to worker morale all the more important. But the presence of three parallel Navy programs suggested a reorganization, so on January 1, 1942, the various incentive plans were officially merged into one program based on that initiated by the Bureau of Ordnance. The old E for excellence in gunnery became an even more comprehensive E for production.

The merger naturally required a new administrative organization. A Navy Board for Production Awards was established to supersede the separate selection agencies within the Department, and to pass on nominations submitted by the bureaus. To make the new awards truly all Navy affairs, the Coast Guard and Marine Corps were brought into the program. Until May 1942, when a new Incentive Division was created in the Navy Department, administration of the system was shared by the participating agencies and the Office of Public Relations. Each bureau was represented on the Board of Awards and could suggest companies that deserved recognition. Within Ordnance, the work was directed by the Public Relations Officer with the advice of the Production Division.

Once the new Incentive Division was created in mid-1942, a new procedure developed. Administration of the award system passed to the new division, with liaison officers in the bureaus and various field representatives responsible for furnishing the information on which selections for the Navy E were based. During the 6 months that the Navy E program functioned, 35 new ordnance contractors joined 94 which won recognition before the Bureau plan was adopted as a model for the entire Navy Department. Both prime and subcontractors received awards for out-

standing production work, and manufacturers of products as diverse as heavy forged armor and small machine gun parts won the coveted symbols of commendation.

After the incentive programs were centralized and coordinated through a separate division in the Under Secretary's Office, the scope of operations became more comprehensive. The original Bureau of Ordnance goals were extended to include the ambitious aim of fostering "a spirit of unity and interdependence between the men and women of the homefront plants and those on the fighting fronts." Workers whose job seemed trivial were apt to get disaffected and careless, with absenteeism the consequence. While the E awards coped with the problem indirectly, more direct action was necessary. To handle the problem the Incentive Division mobilized the techniques of advertising, merchandising, promotion, and showmanship to convince workers that no matter how petty their contribution might be, they were a vital part of the Nation's war effort. Stress on quantity and quality in production was supplemented by attacks on such retarding factors as absenteeism, job changes, loafing, and carelessness.

Although policies were made in the Under or Assistant Secretary's Office, execution was in the hands of the District Industrial Incentive officers who worked in the field. The Nation was divided into 17 districts, roughly paralleling those already created for naval inspection. Within each area the incentive officers worked as practical psychologists, centering their attention on those plants in which the management asked for help. Any firm that fell behind on work critical for Navy procurement could get aid on request. Later, the Division extended its attention to include naval establishments as well. Any of a variety of techniques might be adapted to sell workers the idea of working harder. Favorite methods included personalized appeals by men recently returned from combat, the exhibition of restricted films designed to show the close relationship between production and combat, "warcasts" over plant address systems, as well as the more conventional poster and equipment displays. Incentive work was a round-the-clock affair. Night shifts naturally demanded more attention than day workers, and the selling job had to be repeated frequently.

While the effects of incentive work could not be measured statistically, the beneficial results were obvious enough to justify the extensive programs undertaken by the Navy Department. Testimonials from management and labor leaders reported results that often bordered on the spectacular. At the Columbian Rope Co.,

for instance, production of bomb bay doors jumped from 5½ to 11 a day after the district officer staged a rally at the plant. The Russell Electric Co. reported a decrease in absenteeism from 13.5 to 2.2 percent after the Navy inaugurated an incentive program at the plant. Another firm experienced a drop in absent percentages from 15 to 5 percent, and the 3 isolated testimonials could be multiplied any number of times. Experience gained as the program progressed was put to good advantage and more and more persuasive techniques were developed as the war continued.

While the Bureau of Ordnance inaugurated and the Navy adopted an incentive program, other government agencies were experimenting with similar plans. About February 1942, the War Production Board promulgated an industrial program based on the Ordnance model, but complicated by dependence on joint labor-management committees for decisions. The Army-Navy Munitions Board followed with a star award for producers of machine tools, and the Maritime Commission introduced an "M" pennant for outstanding work in shipbuilding. Meanwhile the War Department, after experimenting with ideas for an overall award, established an Army A based on the model of the Navy E. The complications which the Navy Department had erased within its own organization by merging the bureau plans into the all-Navy E award were now back on a grand scale. Public confusion and a reduction of the publicity value of awards stemmed from the multiplicity of programs and tended to rob recognition of its incentive value. Since the Armed Services employed the greatest number of contractors, the Army-Navy duplication was the most harmful aspect of the mushrooming trend toward similar incentive programs.

Recognizing the problem, both services cooperated in efforts to work out a common solution. In June 1942, the Under Secretaries of War and Navy agreed to merge the two programs; within a month the Army-Navy E production award was inaugurated. In most respects the new scheme followed the procedure already developed for the Navy E. All firms engaged largely in production of war goods or in construction projects for either of the services were eligible for the new award. Government establishments, private plants, prime and subcontractors were all considered.

Administrative machinery naturally became more complicated after the Army A joined the Navy E. Within the Bureau of Ordnance, recommendations were collected from field inspectors. From those reports, the public relations officer drew up the Bureau nominations for the award. Before proceeding further, the

recommendations had to be approved by the cognizant sections of the Production Division, then passed on by other interested bureaus. If the suggestions were approved, they were then submitted before one of the monthly meetings of the Navy Board of Production Awards. After passing the last Navy obstacle, each nomination still required concurrence by an Army board before a company could be notified of its selection.

Before the program ended, more than the administrative machinery was changed. When the Bureau of Ordnance originated incentive awards, production was almost the sole consideration. As the program broadened to include first other Navy agencies, then the Army as well, other factors were added to the equation. They included maintenance of fair labor standards, avoidance of work stoppages, success in overcoming production obstacles, training of additional labor forces, effective management, record on accidents, health, sanitation and plant protection, utilization of subcontracting facilities, cooperation between management and labor on production problems, conservation of critical and strategic materials, and low rate of absenteeism. The attempt to draft a precise formula for determining recognition called to mind the famous "boloney" quotation of Al Smith, but the confounding of the program with new considerations made little real change. In the final analysis, effectiveness still had to be measured in terms of success in maintaining production schedules. The new awards proved as coveted as the old and no drop in their incentive value was apparent.

Each Army-Navy E pennant could be flown for 6 months. After that interval a star was added to the burgee if the company deserved a renewal; otherwise the flag was surrendered. After 2 years of success in holding an award, companies needed reconsideration only once a year in order to retain the privilege. When production dropped following recognition, the award could be withdrawn—the closest thing to blacklisting that was attempted. The procedure was unusual, but of the 284 awards sponsored by the Bureau of Ordnance, 11 were withdrawn when the companies failed to live up to production schedules. Before the joint program ended with the selections of August 1945, a total of 4283 plants were honored. Eight of those firms received 6 stars, the largest number awarded to any company, and all of them were among the Bureau of Ordnance contractors who received the original E award in July 1941.

In addition to working with the Army on the joint E program, the Bureau of Ordnance collaborated with the War Department

on the publication of a monthly magazine originated by Army Ordnance and devoted exclusively to armament. The periodical, entitled *Firepower*, was designed for distribution among the personnel recruited in the early stages of the war to man the new and expanded arsenals and ordnance establishments. Through pictures and short articles it aided the training of the workers while explaining the vital nature of their contribution to the war effort. After the fourth issue was distributed in September 1943, Army Ordnance withdrew from the project.

Convinced that the magazine had real incentive value, the Bureau expanded its title to *Naval Firepower* and assumed sole responsibility for its publication. An all-WAVES staff directed the project until its termination in October 1945. With a circulation between 95,000 and 100,000 issues a month, the periodical was distributed wherever the commanding officers of naval establishments felt the need for furnishing workers an added incentive. Each copy represented a 5-cent investment in worker morale, and three surveys by the *Naval Firepower* staff reported ample returns in production stimulus.

Although the various incentive programs ended with the war, the Bureau of Ordnance had unfinished business on its hands. Some manufacturers who had made outstanding contributions to Ordnance production were still unrecognized. Outstanding among them were the producers of the VT fuze, shrouded in secrecy as long as hostilities existed. The end of the war lifted the security veil for the first time and permitted public commendation of the companies involved in the fuze program. To honor the firms the old Ordnance production award, father of the all-Navy E and the later Army-Navy E, was revived. Thirty-two contractors won the right to fly the Bureau flag and the E burgee, while the employees of the plants were given the customary pin emblazoned with an E for production. One firm, the Mill Hall, Pennsylvania, plant of Sylvania Electric Products, Inc., was awarded a flag with 4 stars, indicating 30 months of successful production work on the VT fuze.

Still other belated awards were made in the immediate postwar period. Since many companies which made real contributions to war production failed to qualify for the Army-Navy E, yet deserved some public recognition for a job well done, the Navy Department decided to issue Certificates of Achievement to cover such cases. Invited to participate in the program, the Bureau of Ordnance scanned its production files for deserving companies and sent 277 recommendations to the Secretary's Office. Along with

the nominations of the other bureaus, the companies then received formal certificates and letters from the Assistant Secretary expressing Navy appreciation for their contributions.

With the production award program completed, the Bureau turned its attention to those who had made outstanding contributions in other than industrial fields. Months before Pearl Harbor, Under Secretary Forrestal suggested that awards be arranged for individuals whose inventive genius aided the cause of war production. With the perspective gained by peace, the Bureau of Ordnance was able to implement such a plan, and the Naval Ordnance Development Award was instituted. Civilians, private companies, service units, and government agencies were all eligible for a certificate of distinguished service, a letter from the Chief of the Bureau, and appropriately designed emblems. The high order of service and magnitude of the contribution to ordnance research and development were the most important factors weighed in selecting recipients for the honor. While mainly a scientific award, contributions of a technical, administrative, or advisory nature were all considered. Nominations were entirely a Bureau concern, but suggestions were solicited from other naval and government activities, especially the Office of Scientific Research and Development and the National Defense Research Committee.

With the vital need for stimulus relieved by peace, the various postwar awards were a matter of recognition for its own sake rather than for incentive value. They marked a transition to normal public relations concerns. A need for security naturally stunted information work during the war years, just as the need to stimulate production dictated the use of whatever information could be safely released. The change to peace quickly brought a reversal of emphasis. The Industrial Incentive Section gave way to the Public Relations Section. After functioning briefly as a part of the Administration Division, the activity was transferred to Planning, where it was better able to secure information for public release. The transition was complete by December 1945.

An exact appraisal of the results of the incentive program proved impossible. The intangibles involved defied attempts at statistical presentation. But even without the benefit of scientific analysis, the program was clearly a success. That promotional ingenuity that has resulted in fabled feats of salesmanship was more than enough to persuade American industry and labor to go all-out for production. Patriotism furnished the basic drive; incentive work provided direction, stimulus, reward, and the information necessary to prove the importance of even the most trivial roles.

The Bureau of Ordnance was well aware that it took all the parts to make a gun, but the producer of some minor part might be expected to forget.

Chapter 22

PERSONNEL

THE Reserve officer has often been described as the Navy's secret weapon in World War II. Virtually nonexistent at the outbreak of the European conflict in 1939, the reserve organization on V-J Day numbered over 90 percent of the 316,000 officer complement. Ninety-five percent of the 5000 officer personnel under the jurisdiction of the Bureau of Ordnance held reserve or temporary commissions. Representing a 28-fold increase over the 170 Reserves on Ordnance duty in World War I, the World War II complement was not built up without a series of trials and tribulations.

The peacetime Naval Reserve was composed of two groups; the Organized Reserve and the Volunteer Reserve. The Bureau of Ordnance was particularly interested in the Ordnance specialist enrolled in the Volunteer Reserve under an O-V(S) classification. The total number in this group in the prewar years ranged between 35 and 100 officers. These men, together with regular officers who had previously served in the Bureau or its field stations, and retired officers with a major interest in ordnance, composed the War Slate from which the Bureau was to staff its establishments in the event of mobilization. The O-V(S) officers, in the main, were mechanical, electrical, and metallurgical engineers, several of whom were prominent in the production and research activities of the Nation. Lending distinction to the War Slate were such men as John P. Gaty, senior engineer with the Beech Aircraft Corp.; Frank E. Goeckler, senior production engineer with The Midvale Co.; V. N. Krivobok, head designer for Lockheed Aircraft Corp.; William A. Mudge, chief of engineering for the International Nickel Co.; Jerome Strauss of Vanadium Steel Co.; Norman E. Waldman of Bendix Aviation Corp.; and Winston S. Patnode of the research division of General Electric Co. Unfortunately, the value of these men to the Bureau was in inverse proportion to their repute, since the importance of their civilian work precluded a call to naval service. Many of the Reserves whom the Bureau hoped to secure immediately in case of an emergency were "active," but their activity was confined largely to correspondence work in Navy regulations, ordnance and gunnery, and similar courses; the limited

peacetime budget could rarely afford the luxury of 2 weeks duty for these Ordnance technicians.

Even in the face of the increasing tempo of the war in Europe, there was little inclination in the Navy to rouse the reserve organization from its lethargy; as late as January 1941 the War Plans Section of the Bureau estimated that 109 Reserve officers would be enough to meet the requirements of full mobilization. This ridiculous estimate, considerably below World War I figures, was rejected by the Chief of the Bureau, who believed that 1500 officers would more nearly approximate the needs of the Ordnance establishment. Procurement was not to be restricted to the engineering personnel that had traditionally comprised the O-V(S) organization. In case of war the Bureau would be involved not alone in a major technical enterprise, but in a major business as well; lawyers, accountants, statisticians, bankers, merchants, and other men of administrative background could all be utilized. Late in 1942 it was anticipated that the Bureau and its field establishments would need 3882 Reserve officers by July 1943, and that an extension of the war to mid-1945 would double those requirements. This represented a substantial deviation from the original estimate of 109 which had been advanced in January 1941.

The first real effort on a Navy-wide scale to build up the Reserve system was initiated in the spring of 1941 when the Bureau of Navigation, shortly to be renamed the Bureau of Naval Personnel, centered its attention on the engineering students soon to be graduated from college. A board composed of representatives from the various bureaus, headed by Adm. H. E. Yarnell, visited the major colleges east of the Mississippi River in an attempt to interest technical students in a naval career. Of the 3000 men added to the rolls through the work of the group, 470 entered the Ordnance system in the summer of 1941. Although many colleges were represented, the majority of the Ordnance recruits came from such outstanding engineering schools as Massachusetts Institute of Technology, Purdue University, Lehigh University, Georgia Institute of Technology, Yale University, Carnegie Institute of Technology, and Case School of Applied Science. Also included were graduates of the Harvard Business School, Wharton School of Finance of the University of Pennsylvania, and other schools of business as well as liberal arts graduates with majors in physics, chemistry, and mathematics.

The work of the Yarnell Board supplemented the long established procedures for the handling of the Naval Reserve. An officer procurement center in each of the 13 naval districts, gen-

erally headed by a retired captain, was charged with the responsibility of recruiting Reserve officers in the area. A *Naval Reserve Manual*, prepared by the Bureau of Navigation and enumerating the educational qualifications and experience required for the numerous activities in the Navy, served as the "bible" on which district officials based their decision on the acceptability of a candidate. After a candidate passed a physical examination it was usually a month or 6 weeks before the intelligence staff completed its investigation. When the district reports had been completed, the papers were forwarded to Washington where they were first sent to the Bureau of Medicine and Surgery for review of the findings of the local medical examiner. From BuMed the application was routed to the personnel office of the bureau under whose cognizance the individual was applying. All applicants under O-V(S) or O-V(P) classifications were referred to the Bureau of Ordnance. Before Pearl Harbor the number of applications received by the Bureau never exceeded 20 a day. In case of a favorable recommendation by Ordnance, the Bureau of Navigation issued the commission.

In the somnolent years of peace this leisurely system worked well enough, but under the impact of war the whole procurement system began to bog down; district procurement offices simply could not keep pace with the avalanche of applications which followed the Japanese attack on Pearl Harbor. Both individual applicants and the hard pressed bureaus and offices in the Navy Department, desperately in need of personnel, urged speed, but the backlog of applications continued to mount in the districts. In 1942 the process was so slow that the Bureau was forced to bring in many people under civilian service contracts while their commission applications were being processed. Upon receiving a commission they were ordered to report to active duty in the same job they had been holding on civilian contract. Finally, the complaints became so vociferous that in April and May 1942, both the Secretary's Office and the Bureau of Naval Personnel made studies of the procurement organization.

The surveys brought results. Streamlined procedures designed to hasten the commissioning of officers from civilian life were adopted. The procurement program was removed from the supervision of the commandants in the naval districts and placed directly under the jurisdiction of the Bureau of Naval Personnel. Offices of Naval Officer Procurement were established in key cities throughout the country. Intelligence investigations were curtailed. In fact, late in 1942 when the procurement offices were

swamped with volunteers, commissions were issued without intelligence review with the understanding that if derogatory information was later uncovered the commission would be revoked. Actually there were very few cases which required such drastic action. Further, the applications no longer had to follow the long and tortuous mazes through the Bureau of Medicine and Surgery. Doctors were attached to the Bureau of Naval Personnel with the sole duty of reviewing the findings of the district medical officers. The bureaus were also eliminated from the review, but their representatives were assigned to BuPers in a liaison capacity. The new system worked. The time lag between application and commission was materially shortened and the backlog of applications inherited from the districts was soon eliminated.

Even after the recruiting activities were running smoothly, there was a continuing effort on the part of the Bureau of Ordnance to exercise its own independent facilities for procuring individuals of specific qualifications. Bureau representatives, building on the experience of the Yarnell Board, continued recruiting activities in universities and colleges. Industrial leaders and personnel officers of corporations were cultivated with the hope that they would steer into the Naval Reserve well qualified men who were facing a draft into Army khaki. Speaking engagements were welcomed—indeed sought—as a subtle means of propagandizing the opportunities for Reserve officers in ordnance. Personal contacts with prospects through friends already in uniform and on duty in the Bureau sent hundreds of well-trained civilians to officer procurement centers with the written request that the individual be recommended for an Ordnance billet.

Ordnance officers were generally ordered to indoctrination training before being assigned to a duty station. In 1941 and early 1942, however, the Ordnance establishment was so understaffed that many of the newly commissioned officers moved directly from civilian life to the Bureau or to one of the field activities. By September 1942 the situation was reversed; Ordnance had more officers than permanent billets. More officers were therefore sent to indoctrination schools, many of them progressing to advanced instruction before they were detailed to permanent assignments. Thoroughly trained officers were desirable, but in many cases the action was dictated by the need to keep the men occupied until Bureau expansion made a place for them. At the end of the war approximately 80 percent of the 8000 officers who at one time or other served in Ordnance billets had received general or specialized training.

Ordnance played an important role in the Navy's indoctrination program; it was, in fact, the first of the Bureaus to use this type of training. Recognizing the need of easing the transition of new officers from civilian life to wartime service, the Bureau worked closely with the Bureau of Navigation in establishing the Naval Reserve Officers School of Indoctrination at the New York Maritime Academy in the Bronx. Better known as Fort Schuyler, the school opened on July 7, 1941, to receive a class of 150 ensigns slated for ordnance duties. The 2 months course included instruction in the elements of naval history, leadership, discipline, responsibilities and duties of officers, customs, etiquette, Navy regulations, administration, personnel, communications, and ordnance. Lectures by professors from neighboring universities on industrial management, business administration, and related subjects were featured on the schedule. In addition, at least 5 hours a week were devoted to close order drill.

Frequent field trips broke the monotony of classroom routine. The New York area contained many installations of peculiar interest to ordnance personnel. Visits to the Naval Ammunition



Fort Schuyler.

Depots as Iona Island and Lake Denmark; the Army's Picatinny Arsenal, Dover, N. J.; the New York Navy Yard; the Naval Ordnance Plant at Baldwin, Long Island; the Federal Shipbuilding Corp.; the Ford Instrument Co., and other factories producing naval ordnance served as valuable supplements to the instructional program.

Prior to 1942 only O-V(S) officers went to Fort Schuyler. In December 1941, Governor Lehman offered the Navy additional facilities at the Maritime Academy which made it possible to increase the capacity of the school to 2000. Though the Ordnance group was soon in the minority, the Bureau always regarded Fort Schuyler with proprietary interest, and the majority of the new O-V(S) officers were graduates of that institution.

Fort Schuyler was but the first step in the Bureau's training program. It was not uncommon for officers to attend 3 or 4 schools before being ordered to a permanent billet. As a rule the graduates of Fort Schuyler were sent immediately to the General Ordnance School for 2 months instruction before being ordered to one of the special schools for advanced study in aviation ordnance, radar, fire control, or underwater ordnance. In all, the training facilities enrolled over 16,000 ordnance officers.

The General Ordnance School was an outgrowth and successor of the Ordnance Inspectors School which had been established at the Washington Navy Yard in 1940 to train inspectors for the Bureau's mushrooming production program. Organized in the summer of 1942, the 2 months course at the GOS was designed to familiarize new officers with the manufacturing techniques, design principles, and operations of the major ordnance items. Shop trips and practical demonstrations of ordnance equipment in the Naval Gun Factory punctuated the daily lectures. The course quite naturally dealt with fundamentals and left the complicated details of modern ordnance to the specialty schools.

In addition to the indoctrinated group, the GOS frequently included ensigns from the Bureau who had not attended Fort Schuyler. These officers were in most cases slated for specialized ordnance training. Another category included older, higher ranking officers, called from sea duty to serve as instructors in NROTC or midshipmen schools. Instruction was not confined to Ordnance officers. From time to time the Bureau of Naval Personnel sent prospective destroyer escort officers to the GOS for training. Three weeks at the school followed by 1 week at the Antiaircraft Training and Test Center, Dam Neck, Va., completed the course. By the

fall of 1945, the General Ordnance School had furnished instruction to 4913 Ordnance Reserve officers.

The Bureau sent over 7000 officers to special schools for advanced instruction. Of this number 2102 were trained in ammunition and ammunition details, 1457 in aviation ordnance, 1304 in radar, 1211 in underwater ordnance, 500 in fire control, and 500 in miscellaneous specialties. Many training facilities were utilized in this program. Numerically, the majority of the trainees were graduates of schools scattered along the Atlantic seaboard, principally the Ammunition Handling School, Hingham, Mass.; the Radar School at Massachusetts Institute of Technology; the Bomb Disposal School, Washington, D. C.; the Naval Mine Warfare School, Yorktown, Va.; the Antiaircraft Center, Dam Neck, Va.; and the Naval Air Technical Training Center, Jacksonville, Fla.

Prior to Pearl Harbor the officers coming out of indoctrination schools were assigned to ordnance duty solely on their paper record. In January 1942, the Bureau adopted personal interviews as the major basis for assignment. From that time on Bureau personnel representatives visited the indoctrination schools, talked to the entire ordnance group on the organization of the Bureau, its shore establishment, and the possible opportunities for various types of duty available to that particular class. Personal interviews followed, the first of several to which the officer was subjected as he advanced through the GOS and the specialty schools. Through this painstaking work the personnel experts in most cases produced the right man for the right job. The system was not perfect but it marked the difference between an average personnel job and a good one. Noting the success of the Bureau, other Navy Department activities adopted similar methods for their assignment work.

The assignment of Reserve officers was handled in pools. There was a pool of aviation ordnance officers, another for torpedo trained officers, and others for the fields of underwater ordnance, ammunition, fire control, and advanced base duties. Lastly, officers not having highly specialized training comprised a general pool. The object of the system was to divide the total number of ordnance officers into sufficiently small units so that the personnel officer could acquire a real knowledge of the men in the group he supervised.

Within the limitations imposed by time, the important requirements of the Ordnance organization, and the inevitable problems of politics and red tape, the Bureau attempted to give each officer an opportunity to study the assignments available to him and choose his own billet. It was not always possible to grant the

request, but in a large proportion of cases the individual officer determined the general course his naval career would follow. Dissatisfied officers were given an opportunity to express themselves. Despite the impersonality of war, Ordnance officers remained individuals, rather than names on an IBM card. The Gun Club spirit was necessarily diluted by the influx of new officers, but "Ordnance looks after its own," retained some validity. The assignment of officers was more than a matter of taking a newly commissioned officer, training him, sending him to a job, then moving him as the needs of the Ordnance organization dictated.

A constant difficulty in the assignment of personnel arose from the insistence of the Bureau of Naval Personnel on a standard rotation program. The Bureau of Ordnance had no quarrel with a flexible system, indeed, with the cooperation of BuPers, it had long alternated its officers between shore and sea duty on the theory that "the men who produce weapons will be those who use them." There were, however, many cases in which a standard rotation program worked to the real detriment of the Ordnance organization as a whole and to the morale of the individual officers in particular. Functional components, the organization of personnel and material created and employed for the performance of specified tasks at an advanced base, furnished an excellent example. Naval Operations predicted long in advance of a proposed campaign the type of functional components required to staff the invasion operations. These units were then assembled within the United States, sometimes more than a year in advance of the proposed date of the operation. Carefully trained officers stood by until time for transportation to a staging point in the advanced theater, then moved on to the subjugated area after the attacking forces had accomplished their mission.

It was inevitable, with the ultimate speed of the American advance across the Pacific, that many planned offensives never took place. There were cases, especially in the latter stages of the Solomons campaign and in the actions following New Guinea, in which only one functional component was used out of the 4 or 5 that had been assembled. Thus, many Ordnance officers who had spent a year or more in training found that they had no work to do on arrival in the advanced theater.

The Bureau contended that the intelligent utilization of these technically qualified officers dictated that they be returned at once to the United States, given refresher training in recent ordnance developments, and reassigned to a functional component. The experience of these men would be invaluable to a new unit. The

Bureau of Naval Personnel, however, refused to consider the return of the officer to the United States until the individual had completed "a normal tour of duty in the advanced theater." Throughout the South Pacific, carefully trained Ordnance officers, lacking an assignment in their specialty, served in billets which failed to utilize their potential. Ordnance never succeeded in persuading BuPers that anything could properly be done to improve the situation.

Late in 1942 a new problem arose when the number of young officers on duty in Washington attracted the attention of both Congress and the press. Speeches, news stories, and editorials constantly emphasized that "too many young officers, who ought to be at sea [were] sitting behind desks in the Navy Department." Desk admirals was the descriptive term frequently applied to this group. Under the mounting criticism, the Navy established the policy that in general no officer under the age of 30 would be assigned to Washington unless he were physically disqualified for duty afloat or unless his highly specialized qualifications could not be duplicated in an older officer. The impact of the new policy was severe, and the Bureau of Ordnance was hard pressed to fill the vacuum created by the departing group. Officers were recalled from sea duty. Additional replacements were secured by interrupting the training of students at specialty schools. Whenever possible, administrative billets were filled by WAVES, just then entering the Navy in large numbers. A few of the young officers at training schools came within the exceptions and could be utilized, but on the whole the Bureau was denied many officers who were well qualified for Washington duty.

The exodus of the "under 30" group was not without compensation, for it hastened the use of WAVES in the Bureau. Reluctance of senior officers to accept women was swiftly broken down, the early skepticism turning to enthusiasm as the new recruits demonstrated their competence. At the peak of employment there were 199 WAVE officers on duty in the Bureau, and many more throughout the Ordnance field activities. In the main, they filled assignments which were administrative, but in a few cases they held billets demanding considerable technical responsibility. The unit charged with the acceptance testing of explosives was entirely staffed by WAVE officers, and the excellent Bureau incentive publication, *Naval Firepower*, was edited by an all-WAVE staff recruited from the newspaper business.

Every WAVE officer reporting to the Bureau had received 2 months general indoctrination training at the Women's Reserve

Midshipmen's School at Smith College. To facilitate their entry into the ordnance field, a special course of 1 months' duration was established at the Naval Gun Factory in September 1943. Designed to furnish a general background on the major ordnance items and nomenclature, the school trained 130 WAVES during its short existence. By January 1944, ordnance training for WAVES became a luxury which had to be abandoned when the pace of the war effort required their immediate service after being commissioned.

Another difficulty centered around the supply of ordnance equipment for training purposes. During the early months of the war "first come, first served," was the ruling maxim. There was little or no effort to evaluate the real needs of the various activities, with the result that ordnance equipment was spread unevenly among schools performing the same type of training. In many cases even this unequal distribution had been obtained by dipping into the stock of battle damage spares. This situation was not corrected until late in 1943, when the issuance of the "Type Ordnance Lists" standardized the equipment for each training activity. Further, these lists made it possible to include estimated training requirements in the initial procurement of all new ordnance items. Some idea of the importance of the procurement of training equipment may be gained from the fact that approximately \$15,000,000 worth of antiaircraft machine guns were allocated to the training program.

Personnel classification also presented a problem. Failing to indicate completely the qualifications of many of the officers, the inadequacy of the Naval Reserve classification system had long been recognized. But in September 1944, when the Bureau of Naval Personnel announced a new system, it found most of the bureaus opposed. The Bureau of Ordnance was among this number. Agreeing that the new system was good, the Bureau nevertheless opposed adoption on the ground that the mechanics of installation would impose a tremendous burden on already overworked staffs. The Bureau of Naval Personnel was adamant. A circular letter of September 1944 outlined the classification system in detail, and instructed each commanding officer ashore and afloat to submit recommendations within 30 days for the reclassification of all officers under his jurisdiction. Although the circular letter described the method for effecting the new classifications, made careful distinctions between general service and special service groups, and laid out in great detail the new designations which were to replace the old, there was considerable latitude for inter-

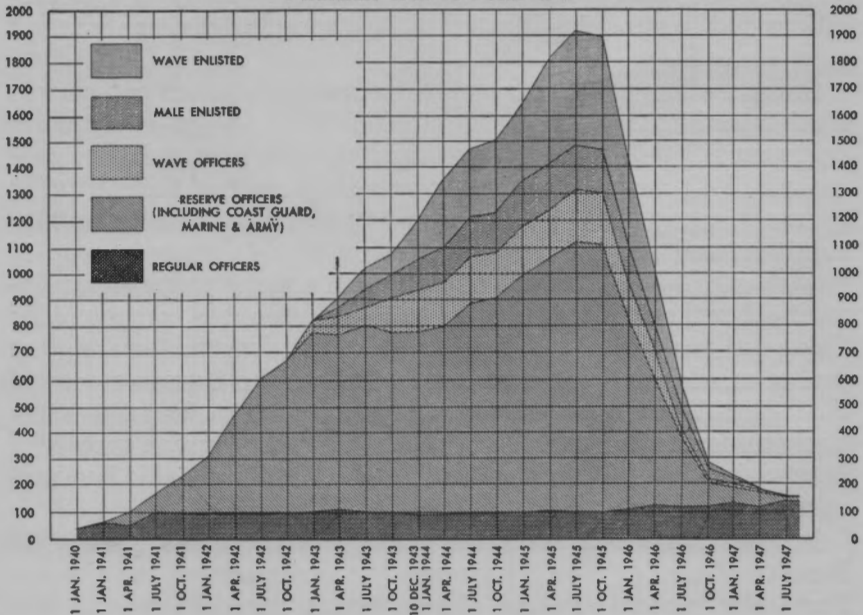
pretation as to just what qualifications should determine the classification. Reporting officers could put a wide variety of interpretations on the same classification since a specific definition was not given for each.

Ordnance Reserve officers were grouped into seven categories: administration, research, and production S(0), design of ordnance equipment S(0-1), maintenance and operation of aviation ordnance S(0-2), design, installation or maintenance of fire control or hydraulic equipment S(0-3), handling and maintenance of ammunition and ammunition components S(0-4), maintenance of torpedoes S(0-5), and maintenance of underwater ordnance equipment other than torpedoes S(0-6). Confusion was compounded: There was great variety in the interpretation of instructions, a great deal of misclassification, and loss of time as the Bureau reviewed the tremendous mass of correspondence relating to the officers formerly under its jurisdiction. In most cases the Bureau succeeded in retaining an ordnance classification for the officers who had previously carried an O-V(S) designation.

In June 1945, high point for military employment, some 4500 Reserve officers were on duty under the cognizance of the Bureau. Forty-nine percent of these officers were engaged in general ordnance duty under an S(0) classification, 1 percent in design, 19 percent in aviation ordnance, 6 percent in gun, mount, and fire control maintenance, 10 percent in ammunition maintenance, 7 percent in torpedo maintenance, and 8 percent in underwater ordnance maintenance. Sixty-five percent were on duty at ordnance field activities in the United States, 18 percent at sea or on shore duty overseas, and only 17 percent on duty in the Bureau. A further analysis of this group showed that over 99 percent were college graduates, 70 percent possessing an engineering background. The service of each officer averaged approximately 3 years.

The rapid return of Reserve officers to civilian life following the Japanese surrender recalled the hectic days of 1941 and 1942 when many of this group entered the Ordnance Establishment for the first time. The experience of that period was not lost. The development of a strong, active, and efficient Naval Reserve of ordnance specialists was therefore one of the most important of the Bureau's postwar programs. Seminars in recent ordnance developments, attractive training programs, and annual tours of duty for members of the Volunteer Ordnance units were all designed to furnish the Bureau with a group of well-trained Reserve officers available for immediate recall in case of an emergency.

**MILITARY PERSONNEL ON DUTY IN THE BUREAU OF ORDNANCE
1 JANUARY 1940 TO 1 JULY 1947**



The responsibility of guiding and indoctrinating the entire Ordnance organization fell upon a small, hard core of regular and retired officers. Early in 1941 this group in the Bureau was composed of 43 regular and 22 retired officers. Pitifully inadequate in number, this group was unequal to the tasks they were loyally attempting to handle. A similar condition existed at the ordnance stations. Quick and radical remedies were necessary. In spite of objections from some of the Admirals afloat, 40 experienced ordnance officers were brought out of the fleet and assigned to billets in the Bureau. One officer in the fleet remarked that "Spike Blandy is mobilizing the Gun Club on the beach." This "mobilization" was not long continued; Reserve officers began to take up the slack and during the war the complement of regular officers on duty in the Bureau seldom exceeded 100.

It was always a cardinal tenet in naval ordnance faith that the Bureau and its activities must be manned by line officers of the Navy. Since these officers normally alternate gunnery duties in the fleet with ordnance duties on shore, the men responsible for the design and production of ordnance are therefore the same men who use it. The basis of this policy originated in the fear that officers long ashore, no matter how good their intentions, might fail to

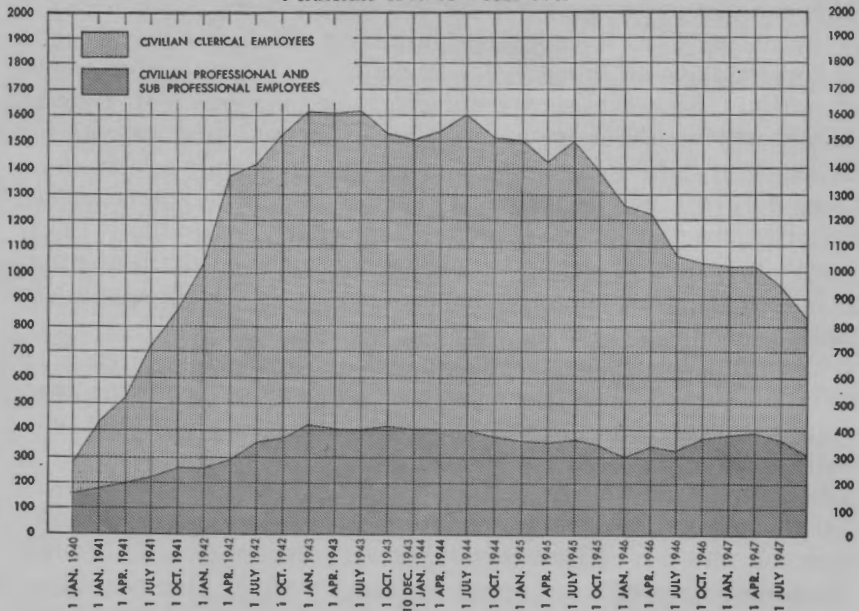
grasp the fleet's essential needs and thus impair its battle efficiency. This course has recognized disadvantages. There is inevitably a desirable degree of technical specialization which few line officers, in view of their other activities, can attain. There is also a lack of continuity in certain types of ordnance positions. In time of war, moreover, the demands for the services of these officers for duties other than ordnance is so great and the supply relatively so small that officers with sufficient experience must be spread thinly over the jobs which must be done. The policy is inevitably questioned from time to time but the advantages, not to say necessities, of linking the personnel who produce weapons with those who use them have won every argument.

The rotation of officers of the regular Navy between sea duty and ordnance duty ashore was continued throughout the war. Two years of duty in the Bureau was considered an optimum tour, but demands from the fleet and other important activities made it difficult to adhere to a set period. In some instances it was essential to hold key officers in the Bureau for longer periods. Considerable numbers of Reserve officers were also rotated. Although there was a more or less constant exodus of younger Reserve officers from ordnance duties within the continental limits of the United States to ordnance base and sea duty, there was no firm rotation policy.

The application of the rotation policy vested the continuity of operations to a large extent in the Bureau's civilian employees, particularly the engineering personnel, many of whom had a long and unbroken tenure. The engineering, drafting, and clerical work of the organization rested in civilian hands almost exclusively in peace and to as large an extent as civilian workers were available in wartime. The shortage of civilian workers often made it necessary for the Bureau to utilize enlisted personnel in jobs which could have been filled more appropriately by nonmilitary people. This was especially true of drafting and secretarial positions.

The Bureau frequently found it impossible to obtain top scientific personnel through the Civil Service Commission, and in such cases individuals were employed under personal service contracts. Several internationally known scientists were brought into Bureau work through this type of contract. Albert Einstein served as a consultant on problems relating to high explosives. Dr. John von Neumann, a mathematician, conducted research on the theory of shock waves and detonation which furnished the theoretical basis for new applications of air burst. Dr. John G. Kirkwood of Cornell University developed theoretical methods for determining the

**CIVILIAN PERSONNEL ON DUTY IN THE BUREAU OF ORDNANCE
1 JANUARY 1940 TO 1 JULY 1947**



effectiveness of explosives. Dr. George Gamow, widely known for his work as a scientist as well as for interpretive books on modern physics, contributed research on the theory of initiation and detonation of explosives. Dr. Robert W. Woods of Johns Hopkins, an experimental physicist, worked on the interaction of shock waves and on shaped charges.

The personal service contract was flexible and expeditious and proved particularly attractive to college scientists, since it permitted them to continue teaching and at the same time engage in vital war work. In 1942, the number of people working for the Bureau on personal service contracts totaled 120. By 1943 the number had declined to 68, and at the end of the war it was down to 19. Throughout the war, the personal service contract proved an excellent vehicle for the special, intermittent employment of scientific personnel whose services could not be secured through more regular channels.

The officer and civilian personnel in the Bureau and field establishments increased from 25,348 on January 1, 1941, to 125,783 on July 1, 1945. Percentagewise only 2.5 of this total was assigned to the Bureau in Washington. Within a year following V-J Day, Ordnance personnel had been reduced to 55,390. At the time of

his detachment in September 1947, Admiral Hussey wrote: "Too much cannot be said for the loyalty, initiative, and energy of all the personnel, both military and civilian, whose devotion made possible the contribution of this Bureau to the accomplishment of the Navy's mission during the war and the subsequent demobilization. Their efforts were guided throughout by recognition of the need for constant application, progressive thinking, and intelligent planning. In the . . . years of the war they labored with a sense of their direct relationship with the fighting front and in the postwar period, with a spirit exemplified by a poster found in many offices of the Bureau: 'The more we sweat in peace, the less we bleed in war'."

Chapter 23

ARMY-NAVY COOPERATION IN ORDNANCE

ONE of the paradoxes of World War II was that the constant progress toward the greater specialization of weapons was also accompanied by a growing tendency for ordnance activities afloat and ashore to overlap. This resulted in a close and ever growing degree of cooperation between the Bureau of Ordnance and the Ordnance Department of the Army.

The pattern of this collaboration was firmly established long before the attack on Pearl Harbor. Through the work of the Army-Navy Munitions Board, the Army Industrial College, and the Army Ordnance Technical Committee, much valuable work in the field of procurement planning was accomplished in the period between the two World Wars. In the 1930's there were a number of verbal agreements on which service would procure items in case of an emergency, and by the end of the decade most of these had been reduced to writing. During that time the Army was producing for the Navy, and the Navy for the Army, with their respective roles largely determined by which had the facilities and which the money. The production of 5-inch projectiles at Frankford Arsenal is illustrative. Navy orders for this ammunition, resulting from the Bureau's development of the 5-inch double-purpose gun, served to keep this famous arsenal with its highly trained workmen in operation—and therefore, in a state of readiness—at a time when Army Ordnance funds were low. New projectile line equipment—machine tools, heat treating furnaces, conveyors, and presses—was procured with Bureau funds. In the 4 years before the war, from 8 to 12 percent of the Bureau's budget was spent for Army-produced material—small arms, ammunition, projectiles, and fuzes from Frankford Arsenal; anti-aircraft equipment from the Rock Island Arsenal; gun mounts from Watertown; and major caliber and secondary guns from Watervliet. Rear Admiral Furlong stated that this relationship was "as close and direct as the cooperation between the bureaus within the Navy itself."

One of the outstanding examples of coordination was in the field of aviation ordnance. Until the coming of the airplane, the coast-line was a rigid barrier separating land and naval forces. Neither could encroach further upon the domain of the other than the

maximum range of its guns. The airplane, however, vastly expanded the area in which land-based and sea-borne forces operated. In the Atlantic and Pacific, the Air Force constantly ranged out to sea in search of enemy naval targets, surface and submarine, and struck a great many powerful blows. The carrier-based planes of the Navy often hit at enemy forces and installations ashore, sometimes crossing mountains to reach their targets.

The Air Force therefore used torpedoes, mines, depth bombs, and special armor-piercing bombs. It would have been absurd for the Army to attempt to develop and produce these items when Navy experience and facilities were available. Yet in the case of torpedoes that is exactly what the AAF attempted to do. Anticipating a demand running into the thousands, the Air Force devoted scientific manpower, laboratory facilities, and much money to the abortive effort. In the end the Bureau supplied the needs of the AAF with several hundred torpedoes only a few of which were employed in action. On the other hand, guns used in both Army and Navy aircraft were developed and produced by the Army, from which the Navy procured its total supply. In the case of bombs, standardization for both Army and Navy was common, the designation "AN" preceding mark numbers. Most of these, including incendiary and general purpose bombs, were produced for both services by the Army, while others, notably armor-piercing and depth bombs were produced by the Navy. The famous Norden Bombsight used by the Air Force was developed under the Navy's aegis, and procured primarily under Navy contracts. Of the 43,292 sights produced by Navy sources at an approximate cost of \$500,000,000, five-sixths represented procurement for the Army Air Force.

The stress of war intensified this cooperation. Many joint activities, ranging from a Committee on Standard Drawing Practice to a subcommittee on Plastics Material Specifications, made a substantial contribution to the war effort. Wartime cooperation, however, was not limited to formally established boards, committees, and scheduled conferences. In many instances, it was largely a matter of officers from the two services working together on a day-by-day basis. Strong personal and professional friendships developed from this close contact and greatly facilitated the solution of urgent problems. Telephone calls, informal conferences, and memoranda were the bases of some of the most valuable cooperative undertakings.

Admirals Blandy and Hussey were close friends of Maj. Gen. Levin H. Campbell, an Annapolis graduate who became Chief of

Army Ordnance in 1942, and these officers set an excellent example for their staffs in furthering mutual assistance. Admiral Hussey, testifying before a House Appropriation Subcommittee, told the story of this cooperation simply and effectively in one sentence: "I am in at least weekly touch with General Campbell and my people are in daily touch with his people." On another occasion, in speaking of General Campbell, the Admiral declared: "there is no need to extol him as a master of ordnance, but I wonder if all realize to what extent he was a master of cooperation. Never once did I have occasion to go to him for help but what that help was made available, usually in far greater measure than was asked."

The friendly relationship between the two ordnance groups enabled them to achieve as high a degree of cooperation as that existing anywhere in the services. With it they were carrying out the instructions set forth by President Roosevelt on November 19, 1942, in a memorandum to the service secretaries. The President wrote: "I am also worried about instances where the Army and Navy supply agencies are not in complete cooperation. For example, if in some item the Navy does not have the goods on hand at the moment, it should immediately ask the Army whether it can fill the item from the Army stock on hand. This applies vice versa. There should be a complete interchange of critical items, and bookkeeping red tape should be reduced to a single page memorandum form. No . . . officer is going to jail for doing the right and practical thing in the war effort—even if he violates 57 regulations in so doing. . . ."

The number of areas in which cooperative procurement could be effected, however, was limited by the diversity of the basic requirements of the two services. Ordnance is complex. Each piece of equipment must operate at a high degree of precision and function at maximum efficiency in order to inflict the greatest possible damage on the enemy. Therefore, it was essential that each service keep the end use in mind. This resulted in the development and production of weapons having many general similarities, but varying in many important details. Both services use guns, but naval guns have always had different requirements of range and power from those used by armies. They have different weight limitations, different mounts, and wholly different gunnery problems to solve. For example, a naval gun can be much heavier than a land gun because it does not have to be operated over muddy roads and up steep slopes, and it has to be heavier because it must be able to defeat armor far greater than that ever encountered ashore. It fights on a perfectly flat terrain where con-

cealment is usually impossible, and its long range hitting power is in reality the chief defense of the ship which bears it.

Thus we find many categories of naval guns, particularly in the larger calibers, which have no counterparts at all in field guns. Even where calibers are almost identical, the naval gun differs significantly from the comparable land gun. The extreme was reached in the submarine gun, with its "wet" mount, which was able to withstand the effects of long submersion in corrosive salt water. Dirt and dust are foes of the Army. The Navy fights a constant battle against corrosion.

The gunnery problems inherent in firing from a swiftly moving, rolling, and pitching gun platform against a distant maneuvering target are unlike those which prevail ashore. And the fact that fire control apparatus can be incorporated in the same large and internally rigid structure which houses the guns makes it possible to design gunnery control devices on a scale of lavishness completely unknown in land ordnance. As a result, the Bureau developed various types of directors, computers, stabilizers, and other instruments which are peculiar to naval ordnance and comprised a large part of its total procurement.

When it comes to such underwater weapons as torpedoes, mines, and depth bombs, the peculiarly marine characteristics of their use is too obvious to need stressing. The major concern of the Army with all the paraphernalia of hand-to-hand, tank, and trench warfare, is of only relatively minor interest to the Bureau of Ordnance.

Although both services constantly sought to extend the areas of cooperative procurement, it was fully agreed, and it was indeed a basic policy throughout the war, that no compromise in respect to military requirements or to quality in design could be tolerated merely for the sake of common procurement. Admiral Hussey, in discussing the allocation of responsibility in the field of joint supply, wrote: "Basically . . . for those items which are common to both, the service having the paramount interest will procure and supply to both. For those items where changes are needed to meet the specific requirements of one user . . . the procuring service will endeavor to incorporate in the basic design such modifications as will meet those needs without impairing its utility for the originator. Failing such a happy solution, modifications to meet the needs of the one user will be undertaken concurrently with the production of the basic item as originally required."

The average annual expenditure rate of the Army Ordnance Department was approximately \$7,000,000,000 while that of the

500 ARMY-NAVY COOPERATION IN ORDNANCE

Bureau of Ordnance was \$4,000,000,000. By the end of the war approximately 10 percent of the dollar expenditure of each service was being devoted to procurement of equipment and weapons for the other. Included were 112 major items furnished to the Navy by the Army and 61 supplied for Army use by the Navy. The Bureau's program of procurement for the Army was greatly stepped up in the closing months of the war because of the tremendous Army demand for rockets and VT fuzes.

The success of the efforts of the two ordnance groups in the field of common procurement drew the praise of both the Secretary of the Navy and the Under Secretary of War. A detailed study directed by the 2 officials revealed only 8 fields in which it was felt that coordination should be expanded or instituted, namely, watches, binoculars, moored submarine mines, certain pyrotechnics, armor, rockets, 20-mm. and 40-mm. projectiles and components, and cartridge cases.

In ordnance research, as in procurement, close liaison between the services characterized the Army-Navy relations. Capt. William M. Moses, Director of the Research and Development Division, characterized this teamwork as follows: ". . . duplication of effort is avoided and conservation of resources is obtained to a very satisfactory degree, insofar as the Navy is concerned . . . through the very close contact maintained between the Research and Development Service of the Army Ordnance Department and the Division of Research and Development of the Navy Bureau of Ordnance. Representatives of each service regularly attend the conferences and meetings held by the other. It is doubtful if a day passes during which direct personal contact is not established by some members of the respective research organizations. By mutual agreement between the two services, the Army Ordnance Department assumes the responsibility for research in regard to certain weapons, whereas the Navy Bureau of Ordnance assumes corresponding responsibility for other items. Because of the complexity of the problems involved, no specific rules for this division of responsibility can be laid down. The general rule is that the service having primary interest handles the development. So far as I know, there has been no single instance . . . where satisfactory arrangements have not been worked out by the two services." Nor was cooperation merely born of war. Close liaison predated the national emergency with a peacetime research program devoted to an increased interchangeability of materials, components, engineering standards, and specifications.

This history is replete with instances of cooperation on the use of facilities. The Army Arsenals at Watertown and Watervliet produced Navy guns, and Navy plants manufactured big guns and ammunition for the Army. Many projectile lines in private plants controlled by the Navy were turned over to the Army. Similar coordination existed for components of 40-mm. guns and ammunition, bombs, rockets, and other items. Army Ordnance built and operated most of the powder and propellant facilities which supplied both services. And it was a standard practice that before a plant was released by one service the other was always advised.

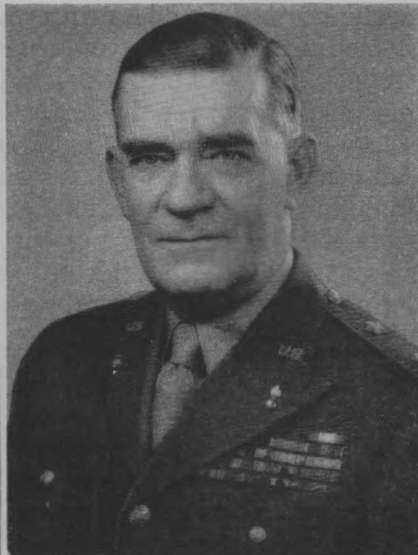
Progress also was made in the field of specifications. In 1943 the Joint Army-Navy Committee on Specifications was established to develop standards for items used by both services but not covered by Federal specifications. By March 1945, the JAN Committee had approved approximately 150 joint specifications, and was processing additional ones at the rate of 15 a week. These included fuzes, aircraft armor, welding of armor, bombs, and bar stock for the manufacture of small projectiles. This was not a new field of collaboration, for the first specification for gun forgings was issued in 1916, and with revisions by joint action was still in effect at the close of World War II.

Although a Joint Army-Navy Packaging Board was not formalized until late in the war, there was much informal coordination in this area throughout hostilities. During the war several hundred representatives from both services attended training courses conducted by the Forest Products Laboratory in Madison, Wis. As a result of this cooperative effort, many JAN packaging specifications were issued. On the whole, however, the greater part of the packaging program was outside JAN issuances, with each service packing to meet the individual requirements of the other. That there was room for improvement in standardized packing was realized, and peacetime plans envisioned working committees with representation from all services in the belief that such a move would improve the technique of wartime packaging.

The arrival of peace did not lessen the teamwork between the Bureau and the Army Ordnance Department, as might have been expected, but rather intensified the close cooperation and exchange of information which had characterized their relationship during the war years. The value of this cooperative effort had been proved in time of crisis. The realization that peacetime budgets would be restricted was an incentive for the two organizations to work together to obtain maximum results from their appropria-



Major General Campbell



Major General Hughes

Architects of Cooperation

(Photographs from American Ordnance Association)

tions. In fact, during the demobilization period the Bureau of Ordnance transferred to the Army material valued at \$84,834,000. The need for such cooperative action throughout the services was pointed out by Representative Wadsworth in a hearing before the House Appropriations Committee in 1944:

" . . . Let's take a look at what we call our postwar period. Let us estimate some of the elements which will be influential in swaying the judgment, rightly or wrongly, of the people and the Congress of that day. When this war is over it may be that we shall have run up a national debt approaching \$300,000,000,000. . . . Already we visualize other financial obligations or commitments. . . . And do not forget that while these expenditures are going on, the taxpayers, millions of them, crying for some measure of relief, may turn desperately to find a place where big slashes can be achieved. It is more than probable that their attention will be riveted upon the military services and that the cry will go up all over the country that there aren't going to be any more wars; that we do not need more than a flimsy skeleton of a national defense structure.

"That's what happened in 1920, that is what happened after every war in which we have engaged. I do not need to remind you

of the cruel, bitter price which our country has paid in lives and treasure as a result of that sort of performance back through the years. In all seriousness I say to the men in responsible command in all our military services that they must look ahead and be prepared to justify before the Congress and the people of that day the maintenance of adequate military forces. And in preparing the services against that day they must cooperate one with the other in every conceivable effort in the reduction of expenditures, to wipe out all unnecessary duplication, to eliminate waste. . . . The solutions which we recommend may well be inadequate unless the services themselves join hands, one with the other, and help us. By so doing you may contribute the greatest measure of assistance to us in our work. But more important still, you may erect a sound and understandable defense against those traditional post-war tendencies to which I have referred. Do not forget what happened in the past."

The lessons of the past were not forgotten by ordnance leaders. The fact that the common procurement of many items was so successful did not obscure the fact that there were very definite areas into which it should not be carried. Admiral Hussey and General Campbell, two of the chief architects of the cooperative effort, were well aware of this limitation. Admiral Hussey stated: "Unquestionably, the ordnance interests and problems of the Army and Navy overlap . . . and were Army Ordnance and the Navy's Bureau of Ordnance to operate entirely independently of each other, there would be much undesirable duplication. . . . But I would sound a note of caution that because of . . . examples of successful procurement by one service, of the needs of both, it does not follow that one service, or even a combination of the two, could efficiently meet all the problems of both. The fields of naval ordnance and ground ordnance do overlap, but in the main they are well separated and deal with problems largely unique to their respective selves. . . . Such wide variations in considerations to be met are the rule rather than the exception."

General Campbell expressed the same idea in *The Industry-Ordnance Team*: "Army Ordnance and Navy Ordnance want common designs and common procurement where such can be had without detriment to their objective—winning a war. The services should not subscribe to an oversimplification of their problems which may well result in sending American boys to war with weapons less than the best. Where American lives are at stake, we cannot afford to take chances. An informed public will not want us to do so."

Perhaps the best tribute to the effectiveness of the joint procurement policies was given by James Forrestal, the first Secretary of Defense, who attributed the genesis of the Unification Act to the work of the two service organizations. In an address before the Army Ordnance Association, he declared that unification "had its practical beginnings in the relationship between Army and Navy Ordnance, particularly the personal relationship between Admiral Blandy and Admiral Hussey of the Navy and General Campbell and his successor, General Hughes, of the Army. These men showed that sincerity of purpose and honest effort at cooperation could pay high dividends."

Chapter 24

KOREA

THE Bureau of Ordnance emerged from World War II with responsibility for a gigantic business concern. With a capital value of approximately \$1,250,000,000, the empire was spread over the Nation, embracing establishments varying in size from small degaussing stations of half an acre to the large Naval Ordnance Test Station, Inyokern, Calif., with an area only slightly smaller than the State of Rhode Island. Over 100 field establishments, including 20 ammunition depots, 11 Naval Ordnance Plants, a mammoth gun factory, a railroad system operating on 1500 miles of track, and 2 of the finest scientific laboratories in the world, were all visible evidence of the gigantic effort extended to put down a threat to the Nation's existence. The facilities were the tools with which the Bureau armed a fleet and outfitted planes with the weapons that made them an integral part of the Nation's sea power. This task involved the full range of activities required for the production of firepower, from the conception of new ideas for ordnance through its manufacture, installation, and maintenance.

With the coming of peace, however, the need for such activities diminished. As early as February 1945, weapon requirements began to fall. Many contracts with commercial firms were cut back or terminated and the workload in ordnance plants dropped. V-J Day naturally accelerated that trend. Many of the vast facilities created during the war at the cost of hundreds of millions of dollars were no longer required and, in any case, could not be kept up under the economy-dictated budgets common to democracies in peacetime. A major problem thus confronted the Bureau: What disposition should be made of the vast ordnance empire? World War I precedent, fresh in the minds of many people who had seen ships rusting at anchor in the two decades between the wars, suggested an easy solution: Let the plants sit idle on the chance that they might prove useful in some future war. World War II experience, marked by the rapid dissipation of a once powerful military force, suggested another alternative: Alienate the facilities in order that they might contribute to the peacetime economy of the Nation. But the memory of hectic months spent in building an industrial potential in 1940 and 1941

remained as a warning of the danger and gigantic expenses incurred by a nation that starts from scratch to meet each threat to its sovereignty. The Bureau and the military establishment as a whole heeded the warning and inaugurated a program that ultimately became the basis for the support of naval operations in Korean waters.

As soon as cutbacks in procurement were possible, the Bureau began collecting the machine tools that were released from use. These were classified, catalogued, repaired, and stored at the Naval Ordnance Plant, South Charleston, W. Va., under dehumidified storage that guaranteed their readiness in case of future need. This inactivation and maintenance of equipment was the forerunner of the servicewide Industrial Mobilization Plan, promulgated by the Munitions Board in March 1948. This program was a blueprint for future action, designed to avoid a repetition of the frantic planning that characterized the first years after the declaration of a national emergency in 1939. To the extent that World War II experience provided a guide, all of the problems likely to occur during mobilization for war were anticipated under some aspect of the plan. Each of the services maintained its share of the expenses of the program out of annual appropriations, and a feasibility test was devised to serve as a sort of peacetime proving ground to check the practicability of the plan. The cold war between the United States and the Soviet Union served to keep the plan alive until June 1950, when the President's decision to resist Communist aggression in Korea subjected the whole mobilization plan to the kind of trial by ordeal that feasibility tests could never duplicate.

The essential bases of the Mobilization Plan, as far as the Bureau of Ordnance was concerned, were the Departmental Industrial Reserve of Production Equipment, which, in bureaucratic language, referred to the machine tools preserved after World War II; the Naval Industrial Reserve Ordnance Plants, which included 27 facilities maintained in standby condition or leased to private industry under recapture provisions; the Industrial Preparedness Studies that represented advance planning for almost all the problems that could be anticipated in connection with production of ordnance items; and finally, the Plant Allocation Plan, wherein hundreds of manufacturers were slated for particular production roles in the event of an emergency.

All over the Nation the Mobilization Plan shifted into gear in support of the Korean operations, but nowhere was it more important than in the production of ordnance items. The inherently



Rear Adm. Albert G. Noble, Chief of the Bureau from September 1947 to December 1950, and his successor, Rear Adm. Malcolm F. Schoeffel.

destructive nature of weapons precludes commercial counterparts. Some components of ordnance items are naturally in everyday use, but for the most part they are mysteries to private industry. Neither the know-how nor the facilities are readily available. Both those deficiencies were provided for in Bureau plans. The techniques of armament production were kept alive in the naval ordnance plants that provided the peacetime needs of the fleet, and the industrial studies provided a concise way to transmit production information to private contractors. Engineering details as well as model plant layouts, lists of required materials, and descriptions of the requisite machine tools were all included in the studies. With them, a manufacturer could borrow know-how and skip the delaying stages of trial and error that often characterized the initial production of ordnance material.

The other deficiency, machine tools, was in large part alleviated by the Bureau's reserve supply of industrial equipment. By drawing on the stockpile at South Charleston, the Bureau often expedited production by furnishing contractors the tools they needed within a few days after a contract was granted. The value of the

system was evident by comparison with either World War II experience, when machine tools were often a bottleneck to production, or with the delays and problems incidental to inaugurating production of weapons that required the purchase of new tools from an industry unprepared for a sudden avalanche of orders.

As valuable as these provisions of the Industrial Mobilization Plan proved to the Bureau, tremendous problems remained. The partial nature of the mobilization complicated the procurement structure by introducing a concept which demanded that weapons procurement reach a scale adequate for national protection without disrupting the civilian economy. On the whole, the system proved satisfactory, but it was obviously inadequate for continued application in the event of all-out mobilization. Another troublesome aspect of the mobilization blueprint was the breakdown of the Plant Allocation Plan. Very often the results of competitive bidding precluded the use of the firm originally slated for a particular production role. In other cases, private contractors accepted so many subcontracts that they were unable to assume their scheduled role as prime producers of a particular ordnance item. These deviations naturally complicated the procurement programs of the Bureau.

Even where pre-Korea plans proved applicable, contracting was attended by many difficulties. The depletion of ordnance reserves to equip reactivated ships and support those already in Korean waters demanded a rapid extension of procurement. The Naval Ordnance Plants that the Bureau had in reserve were able to assume a major role in initiating production, but the utilization of private industry was essential, if for no other reason than to acquaint them with ordnance production and assure an industrial potential capable of quick realization if the international situation deteriorated further. Placing contracts was not a mere matter of advertising for bids, then waiting for manufacturers to respond. The nature of ordnance material is such that capable contractors were seldom numerous. They had to be sought by the Bureau and contracts negotiated after discussions with the responsible manufacturers who proved willing to accept ordnance projects.

Negotiated contracts did not mean the end of competition; rather, the procedure intensified the responsibility of Bureau officials. In one case, for example, a manufacturer with a fuze contract was asked to provide the couplings used to connect fuzes to the warheads of guided missiles. Though he seemed the logical source for the item, his price was \$600 per coupling. Amazed at the unexpected cost, the Bureau resumed negotiations with

other firms, finally found a contractor whose quoted price of \$125 seemed reasonable by comparison. Further shopping turned up an even more advantageous offer, however, and a contract was finally let to a reliable producer who agreed to a unit price of \$27. While the price variations in the case were not normal, the problems of combining negotiation with competition were typical of the post-Korea contracting procedure.

Several other considerations governed the procurement processes. Numerous sources were desired for each major item, so that complete dependence on any one firm could be avoided. This goal was well illustrated in the production of 5-inch aircraft rockets, where 6 companies were engaged to manufacture motors and 11 sources were found for rocket heads. That permitted a production rate of 100,000 rockets per month under normal working conditions, and left room for considerable expansion through the use of multiple shifts. Geographical dispersion was a requisite, too, or an enemy attack could deprive the fleet of needed weapons.

Dispersion was industrial as well as geographical. The expressed will of Congress and the need to utilize the full potential of the Nation required the incorporation of small industries into the ordnance procurement program. On the other hand, the technological complexity that narrowed the field of large industries available for Bureau contracts was an even greater barrier for most small companies. Had they possessed the facilities and manpower needed for most armament manufacture, they would hardly have been small companies. The Bureau coped with the problem through a variety of means. Each naval ordnance establishment in the Nation was made a center for small business firms, providing information on items needed and explaining the contracting procedures of the Bureau. Many of the prime contractors were requested to establish small business specialists who could help interested firms gain subcontracts for those items within their purview. A liberal policy regarding progress payments to such firms served as a further inducement. Finally, the Bureau arranged a traveling exhibit of ordnance products applicable to small-scale manufacture. The mobile unit visited every State in the Nation, bringing many firms into ordnance production for the first time. The success of these measures is indicated by the fact that approximately 30 cents of each procurement dollar spent after Korea went to plants employing less than 500 persons.

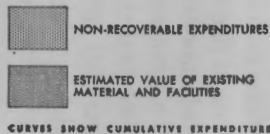
In many respects the period following the Communist invasion of South Korea was reminiscent of the early months of World War II. Despite the reserve plants and tools, for instance, addi-

tional facilities and equipment were urgently needed. Changes in manufacturing techniques were partly responsible, but the use of new ordnance was the most important factor in creating industrial deficiencies. Over half the procurement dollars spent by the Bureau went for weapons not even in existence during World War II. Some of them could be produced with conventional industrial equipment, but others required the design and fabrication of new machine tools and the creation of expensive facilities. During the first 12 months after the invasion of South Korea the Bureau spent approximately \$80,000,000 on facilities in private plants, and the expenditure rate for the following year was approximately the same. The largest single outlay was for a guided missile plant at Pomona, Calif. The formal ground breaking for the plant on August 6, 1951, represented the inauguration of a new industry in the United States and indicated both the magnitude of the facilities problem and the direction of Bureau endeavor.

But if the facilities problem was reminiscent of the pre-World War II era, some aspects of the procurement program were decidedly new. The whole philosophy underlying the program was different. Instead of concentrating on reaching a quick volume of production on the first good weapons that could be furnished, the Bureau sought to create an industrial base capable of mass production without actually engaging in such large-scale manufacture. Operational requirements were to be met, but the Bureau wanted to avoid the accumulation of inventories, and the peaking of production. There was a calculated risk in the policy that magnified the problem of administration, but the program created a potential that could be realized quickly if needed, and at the same time guarded against stockpiling ammunition that the Bureau's development policy might soon make obsolescent.

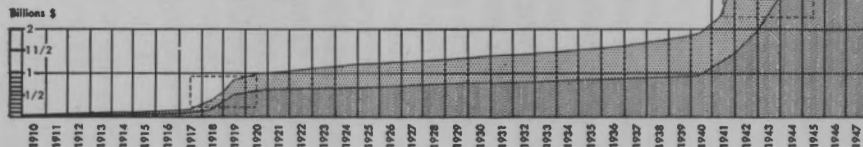
Concentration on the newest and best weapons, rather than on the first types that could be supplied in large numbers, was possible because of the advanced state of weapon development in the Bureau of Ordnance. Between the end of World War II and the decision to support the Republic of Korea, the main emphasis within the Bureau was placed on research programs. Most were of a long term nature, since immediate production seemed unlikely, but many of the projects were close to fruition in June 1950. The events of that month naturally caused a shift of emphasis from development to production, but the research programs were by no means terminated. Instead, attention was centered on those projects that seemed near to completion. Results were at hand within a year, and 1951 became a high-water mark for weapon

IN 1947 ROUGHLY 60% OUT OF EVERY DOLLAR SPENT BY THE BUREAU OF ORDNANCE DURING THE PRECEDING 40 YEARS WAS STILL IN EXISTENCE IN THE FORM OF UP-TO-DATE ORDNANCE FACILITIES AND MATERIAL



MORE THAN 80% OF ALL THE MONEY SPENT SINCE 1910 WAS SPENT IN THE FOUR FISCAL YEARS 1942, 1943, 1944, 1945

ONLY ABOUT 4% WAS SPENT IN THE 3 YEARS OF "EXPANSION" CAUSED BY THE 1st WORLD WAR



Billions \$

17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1

THESE APPROPRIATIONS HAVE BEEN "EXPENDED"

AMMUNITION, BATTLE LOSSES, "SCRAPPING", HOUSING, SUPPLIES... ALL NON-RECOVERABLE EXPENDITURES

THESE STILL "EXIST"

EXPENDABLE MATERIAL \$4,000,000,000

AMMUNITION, BOMBS TORPEDOES, MINES ROCKETS, DEPTH CHARGES NETS, ETC., ETC., ETC.

GUNS, FIRE CONTROL, ETC. \$4,500,000,000

ALL NON-EXPENDABLE ORDNANCE AFLOAT AND ASHORE INSERVICE OR STORED IN RESERVE

SHORE ESTABLISHMENTS \$1,250,000,000

PLANTS, FACILITIES, DEPOTS, MAGAZINES, LABORATORIES, ETC.

development. At a record rate, new armament was pushed from the laboratory to the production line. Some of it was of a long-lead-time nature and slated for future installation on new construction; other weapons were pressed into production to meet immediate needs in the Korean area.

Bureau emphasis, in both development and procurement, was in three main fields: aviation ordnance, defense against air attack, and antisubmarine warfare. Measured in terms of dollars, the first of these projects was the most important. The expenditures testified to the important role of air power as an integral part of sea power; the weapons purchased with the money testified to the increasing complexity of modern ordnance. Accelerating aircraft speeds challenged ordnance designers to develop armament capable of coping with the peculiar problems of air warfare. More powerful ammunition, higher rates of fire, and greater muzzle velocities were all essential if firepower was to keep pace with progress in aircraft propulsion systems. While World War II guns proved of immense value when the air war started over Korea, the arrival of jet planes underlined the need for new armament. The Bureau accordingly pushed the development of a successor to the Hispano-Suiza, the 20-mm cannon carried by naval planes during the last war. The Mark 12, with a cyclic rate much higher than the older gun, helped firing rates keep pace with jet propulsion. Progress in ammunition more than kept abreast. Projectiles with a significant increase in explosive power were ready for delivery by the time the new guns were installed in the fall of 1952.

Concurrently with the development and initial procurement of the Mark 12, the Bureau maintained research for even better armament. Guns with far higher rates of fire were placed on the drawing board. Of course, the developmental problems inherent in such complex mechanisms posed innumerable barriers to the movement of the weapons from bread boards to the operating fleet. Gun development demanded parallel advances in related fields. Without it, a point of diminishing returns threatened progress. Even the Mark 12 ran into barriers that reduced its total effectiveness. Powders were developed which could give the required muzzle velocity, but the heat, pressures, and friction involved in rapid fire accelerated barrel erosion and reduced the service life of each gun.

The addition of tin to the powder decreased coppering enough to double the service life of each barrel, but even that progress was far from the goal of the Bureau. For larger guns the use of nitroguanadine, a cooler burning propellant, offered longer gun life, but

the small size of 20-mm cases precluded its use with aircraft guns. The problem remained unsolved, but experiments with liquid propellants indicated that the barriers to gun development posed by propellant problems might soon be removed. And even in the face of such problems, the procurement of the Mark 12 represented a major achievement in developing a gun which, short service life notwithstanding, was able to give fighter pilots the kind of rapid fire required to register a kill against jet propelled enemy planes.

Target speed was not the only problem involved in determining desirable aircraft armament. The development of armor light enough for use on aircraft posed new demands on ordnance designers. More powerful guns and ammunition were a partial solution, but progress in that direction was limited, not only by the problems inherent in gun design, but also by the fact that the recoil forces of conventional guns placed definite limits on the calibers that could be installed on aircraft. The war in Korea emphasized the need for greater aircraft striking power against enemy air and ground targets, and the Bureau of Ordnance helped fill this service requirement with a new rocket, the Mighty Mouse.

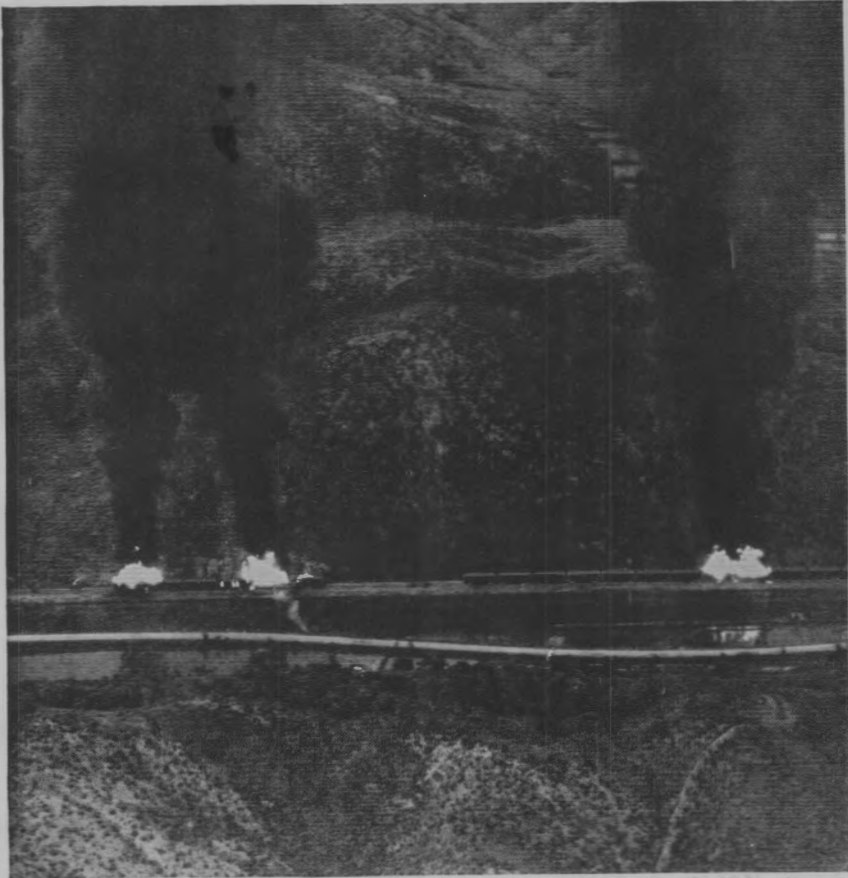
Aircraft rockets were not new. During World War II the Bureau procured them in sizes varying in diameter from 2.25 inches to almost a foot, but Korean operations witnessed production of the first air-to-air rocket ever developed for operational forces of the Navy and Army. The Mighty Mouse, a 2'75 folding fin rocket, was designed to be fired from multiple tube launchers suspended from the wings of planes. The new weapon promised a tremendous boost to the firepower available to United States planes. Though developed for air-to-air use, the Bureau supplied a variety of heads that added to the versatility of the rocket and made it a potent weapon against most land targets.

Early in the Korean fighting the United Nations military forces were confronted with a land target that challenged existing armament. Despite a hostile topography, the North Korean forces made extensive use of heavy tanks in their drive down the peninsula. The antitank weapons of World War II were brought into play against them, but the Russian-made armor proved more than a match for the available weapons. A superbazooka, rushed into production by the Army, gave the infantry an effective antitank weapon, but normal aircraft armament remained impotent. In meeting this threat to American forces the Bureau of Ordnance broke all records for weapon development. In a period of only 23 days, a new rocket, nicknamed the Ram, was designed, tested, and readied for mass production at the Naval Ordnance Test Station,

Inyokern, Calif. Utilizing the shaped charge principle on a 6.5-inch warhead, the Ram proved capable of destroying the largest tanks the enemy had in Korea. The same principle of making high explosive heads in a cone shape, with the open end of the cone facing forward, was also applied retroactively to the 5-inch aircraft rocket developed during World War II. This peculiar shape had the effect of focusing the blast of the explosion to a point, producing a tremendous concentration of energy and a penetrative effect. The new heads made effective antitank weapons of both the Ram and the 5-inch HVAR.

These advances in aviation weapons demanded parallel progress in the field of fire control. Faster planes, increased muzzle velocity for their guns, and the introduction of new rockets would have been of little avail without fire control systems capable of exploiting the advantages of the improved armament. Fortunately, the Bureau's postwar research program laid the basis for new systems that could be rushed through development and into production after the outbreak of war in Korea. Between June 25, 1950, and July 1, 1952, two new equipments actually went into production and a third passed the prototype stage. The first of these to reach the fleet was the Bomb Director Mark 3, Mod 4, a toss bombing equipment that permitted the use of new streamlined bombs from faster planes than were in operation during the last war. For larger planes the Bureau developed and procured the Bomb Director AN/ASB-1, a bombardier operated device that offered pilots wide limits of maneuvering freedom throughout the approach to a target, permitting greater accuracy in bombing and more freedom in evading attacking planes and antiaircraft fire. These two equipments will be joined by a pilot-operated fire control system for attack planes that will incorporate radar ranging and permit coordinated control of all the weapons carried by fighters.

The procurement of these aircraft fire control systems offered an excellent example of another problem—the steadily rising cost of ordnance material—which confronted the Bureau throughout the period in its endeavors to furnish the fleet with the most modern equipments. The technological advances that made superior armament possible had an inflationary effect on ordnance price tags. Increased performance from weapons was secured at the cost of increased complexity and that, in turn, entailed expensive procedures in every stage of weapon evolution from the laboratory to the production line. Fighter fire control systems, for instance, once required little more than a metal ring sight for aiming light machine guns. The cost of the equipment might have been meas-



Naval aircraft carried seapower far inland for strikes over Korea.

ured in terms of cents. At the beginning of World War II the Bureau supplied fleet aircraft with illuminated sights that gave better performance at a unit cost of about \$185. Later in the war, lead computing sights were developed with an item price of approximately \$650, and they led to the postwar development of systems so advanced that after a few seconds target tracking by the pilot the equipment computed the ballistics automatically and produced a high percentage of hits while leaving the pilot relatively free for evasive action. The \$2,000 price tag carried by these equipments was a shock to taxpayers, but they were a vital part of the Nation's firepower. Even the cost of those "modern" equipments was cheap compared with the price of the control systems placed in production after Korea. The new systems, made essential by the higher speeds of United States planes and their

targets, incorporated advances in several fields of science to provide greater efficiency in gun and rocket firing, increased range and accuracy, navigational aid to the aviator, and greater safety for the plane. The cost approaches \$25,000 per unit—many times that of the fire control systems first used against Communist planes over Korea—but is cheap in terms of payload, overall efficiency, and increased human life expectancy. Whether cheap or not, the price tags were an inevitable result of the race between measure and countermeasure. The new fire control systems and bomb directors insured a continuance of the accuracy that has been an outstanding characteristic of naval air firepower since the Bureau of Ordnance introduced the Norden Bombsight.

The problems introduced by improvements to planes naturally affected antiaircraft weapons as well as aviation ordnance. In the duel between guns and planes a full cycle seemed to have been completed before the invasion of South Korea. At the beginning of the European war in 1939, the future looked bleak for capital ships. After a period of heavy losses, however, ship defenses were improved by the introduction of new guns for close-in defense and by the use of proximity fuzes and radar fire control with the larger, double-purpose guns. The innovations restored a balance to the ships versus planes struggle, but the last year of war introduced new doubt as to the outcome. The kamikaze exposed the weaknesses of the close-in defenses and shifted a greater burden to the longer ranged guns just when their potential was being strained by the increased ranges from which attacks were being made. The German guided glide bomb, the Japanese Baka's, and the American Azon, Razon, and Bat were all indications of the trend toward longer ranged air attacks. Moreover, the increased speed of attacking planes severely taxed the computing systems of fire control equipments. Thus, the picture of naval defenses against aircraft was anything but bright at the end of World War II. The field naturally became a major area of Bureau activity and, after the invasion of South Korea, that attention shifted in emphasis from long range research to concentrated development and the initial production of new weapons.

One line of approach was the improvement of antiaircraft guns. For older ships and as interim armament on new construction vessels, the Bureau ordered hundreds of 3"/50 rapid fire guns in both twin and single mounts. The automatic loading features of the gun nearly tripled the rate of fire that could be achieved by hand loading. An even superior 3-inch antiaircraft gun passed from development to production and is slated for service use. Charac-

terized as "the fastest and most efficient antiaircraft weapon ever built," the new gun is but one of the many defenses developed by the Bureau to protect the fleet against high speed bombers, supersonic guided missiles, and Buck Rogers fantasies of the future. Improvements were not confined to 3-inch guns. A new 5-inch gun fires several times faster than the 5"/38 which established such an enviable record in World War II.

The new guns were accompanied through development and into production by fire control systems capable of exploiting their potential. This was another field in which technological advances, reflected in higher aircraft speed, enormously complicated the Bureau's problem. After Korea, however, significant progress was made in translating the results of years of research into production line equipments. The new tactical problems and the superior guns designed to meet them demanded control systems that could reach out farther to acquire faster moving targets, concentrate on those that held the most danger for the attacked ship, then transmit the information to the proper guns rapidly enough to destroy an enemy plane during the relatively few seconds that a modern aircraft can be brought under fire. As a result of the post-Korea emphasis on the program, a twentyfold increase in production was secured for one modern fire control system, and two others were pushed through development and sent to the fleet for evaluation. Even that bugaboo of World War II, the time lag involved in the transfer of a target from search to fire control radar, was slated for an early demise as a result of the development of new target designation systems that permit earlier acquisition of hostile aircraft and thus lengthen the time during which an aerial target can be kept under fire.

Larger, faster firing, and longer ranged antiaircraft guns aimed by fire control systems based on the most recent inventions in the field of electronics provided the first logical approach to the anti-aircraft problem, but the limitations on progress in that direction are obvious. Extreme range and a high degree of accuracy are apparently mutually incompatible goals in gun development, yet both are essential for successful defense against supersonic aircraft or missiles. The possibility of atomic attack emphasized the dilemma by making a 100 percent defense almost a minimum requirement. Antiaircraft fire was never that effective in World War II, and postwar improvements to weapons were at least in part cancelled out by parallel advances in airplane construction. Further improvement in the velocity, range, and accuracy of anti-aircraft projectiles seemed possible only if they were equipped

with propulsion systems for prolonged speed, aerodynamical surfaces designed for long range support, and guidance systems that could correct for errors in the original aim or compensate for course changes of the target. The addition of wings, motor, and controls to a projectile made it something quite different, of course, and efforts to produce such a weapon opened a new field of ordnance—guided missiles. The evolution of such missiles started in World War II, and subsequent developments in electronics helped move them from science fiction magazines to production lines.

Innumerable technical problems plagued their development, but more mundane considerations were also important. Cost, for instance, was a real barrier to rapid development. A great deal of experimental information was required, but the preparation of a typical anti-aircraft guided missile for proof firing cost approximately \$85,000. At that rate, the collection of data was severely handicapped. Considerable progress has already been made in coping with the problem. The construction of a flight simulator permitted accurate performance tests of guided missiles or their components at a fraction of the cost involved in actual firing tests, and a high altitude test chamber provided a proving ground for ram jet engines by reproducing the atmospheric pressures encountered over a wide range of altitudes. By stretching each developmental dollar further, the new facilities speeded the debugging of missile designs. Moreover, congressional appropriations for guided missile work expanded 10 times after 1950, permitting the concentration of effort that is making the new weapons a reality.

Guided missiles are by no means exclusively anti-aircraft devices, but the main emphasis in the Bureau of Ordnance was on a surface-to-air missile. Flight tests, real and simulated, demonstrated that guided missiles, backed by promising control systems, represent the ultimate in defense against attacking aircraft. In 1951 Congress approved the conversion of two heavy cruisers to guided missile ships.

The third major program pursued by the Bureau of Ordnance after the beginning of the Korean affair was that devoted to anti-submarine ordnance. Here, as with anti-aircraft armament, the Bureau faced a general problem reminiscent of that confronted in the early days of World War II. Under the grim necessity of countering the Nazi submarine threat, the Bureau developed an arsenal capable of checking, if not destroying the enemy undersea fleet. Improved depth charges, depth bombs, the Hedgehog, and the Mousetrap were introduced, and effective tactics were worked

out for their use. By the end of the war, however, the interminable race between measure and countermeasure was threatening to turn against the Allies again. The introduction of snorkel submarines, the development of superior propulsion systems, and the construction of hulls that could withstand water pressure at depths between 500 and 1000 feet all tended to negate the weapon advances that won the Battle of the Atlantic in 1943. Germany actually ended the war with more submarines than she had in the beginning, and they were far superior craft.

After the war there was evidence that the Soviet Union was building a large submarine fleet. That threat, coupled with the almost disastrous experience of two World Wars, led to a concentration on new weapons for underwater warfare. In the immediate postwar years the effort was largely devoted to long range research programs, but after June 25, 1950, emphasis was placed on accelerated design work and the initial production of new weapons. Conventional antisubmarine weapons were improved, a new one was introduced, and the submarine's own principal armament, the torpedo, was converted into an effective antisubmarine weapon. This last achievement was largely the result of the development of homing systems that permitted the weapons to seek their targets. In addition to the valuable homing feature, torpedoes were given greater effectiveness through the substitution of electrical for mechanical firing systems.

More spectacular than improvements to torpedoes was the development of an antisubmarine rocket, placed in production after the beginning of hostilities in Korea. With considerably more high explosive in its warhead and a greater range than the Hedgehog, the rocket was slated for an important place in the Nation's antisubmarine program. Deliveries began in 1952, paralleling installations of a new fire control system designed to permit the simultaneous use of torpedoes, Hedgehogs, and rockets.

While a new weapon was being improved, an old one—the depth charge—was rescued from threatened obsolescence. During World War II the time-honored ash cans fell into low esteem. Some of their old reputation was salvaged after the Bureau developed influence firing mechanisms and streamlined cases, but ahead thrown weapons offered a greater lethal probability and were better adapted to detection and fire control gear. That basic situation was not altered in the postwar years, but the Bureau did succeed in developing improved charges capable of destroying submarines at great depths. Fire control, too, was supplied by the development of intervalometers that automatically established a multi-charged pattern calculated to increase the chances of a kill.

While aviation ordnance, antiaircraft guns and missiles, and underwater ordnance constituted the main Bureau programs in the postwar period, they by no means monopolized the ordnance effort. Of the three, only the first proved applicable to the fighting in Korea, and the day to day activities of the fleet naturally required considerable Bureau support. Naval support of the Korean campaign consisted largely of amphibious operations and shore bombardment, both of which required large amounts of ammunition. At the end of February 1953 naval ships and planes had fired 310,000 tons of ammunition in Korea. This figure is all the more astounding in the light of the fact that it is only 23,000 tons short of the expenditure for World War II.



The U. S. S. New Jersey delivering a salvo off Korea, where shore bombardment exceeded the ammunition expenditure rates of World War II.

Supplying ammunition in adequate quantities naturally posed a series of problems, both logistic and productive. At the beginning of hostilities the Naval Magazine at Port Chicago, Calif., was the only active ammunition transshipment facility on the west coast. All the demands of the Navy, Army, and Air Force had to be met through that one activity until other facilities could be reactivated on the Pacific coast. The ammunition itself was largely World War II stock, reworked during the postwar years so that it met the standards of naval ordnance. The reclamation program furnished nearly 4 million tons of ammunition at a cost

of approximately 3 percent of its replacement value. The quality of the ammunition was guaranteed and logistical problems were eased by the establishment of mobile quality evaluation laboratories and rework facilities in the Japan-Korea area, eliminating the heavy shipment and handling costs involved in returning defective material to continental ammunition depots for rework.

While initial demands were met from the World War II stockpile, the Bureau inaugurated new production of projectiles and fuzes to keep continental stocks from being depleted. Outstanding features of the new construction were a greater use of steel for brass in cartridge cases, the introduction of the cold extrusion process, and the adoption of packaging techniques that promised a longer shelf life for pyrotechnics and proximity fuzes. Procurement figures were not spectacular, but a broad and dispersed industrial base was created. In a fuze program, for instance, where only one plant was engaged in production at the outset of the Korean war, the Bureau placed assembly contracts with eight independent facilities and engaged 22 prime contractors to manufacture components.

The Navy mission of shore bombardment off the Korean coast, aside from accelerating ammunition production, stimulated the development of superior fire control equipments for main batteries. The result was the introduction of new radar sets that extended the scope of target acquisition, and the development of computers that freed battleships and cruisers from restrictions on course and speed while bombarding unseen shore or inland installations. No longer as vulnerable to enemy fire, the ships could deliver the firepower that is the punch in American sea power. Bombardment at a rate of three rounds a minute, 24 hours a day, for almost a year and a half gave Communists ashore small opportunity to escape that punch. Throughout the volume of fire the ships were able to maintain the Navy's long record for superior fire control. Occasionally, superior was too pallid a word. One report told how the *U. S. S. Rochester*, at a range of 13 miles, wiped out a Red gun emplacement with the expenditure of a single 8-inch projectile. The element of fluke was strong, but fluke or not, it was characteristic of the accuracy made possible through modern fire control equipments backed by the genius of radar.

The cost of the various programs pursued by the Bureau after the outbreak of fighting in Korea ran high. The appropriations for fiscal year 1951, outdated even before the new period started because of the June 25 invasion by the Communists, were not nearly enough to finance mobilization. Three supplementals were

required, bringing the total funds for the year to approximately \$1.8 billion. The second year of war found requirements even heavier, and Congress responded with about \$2 billion. Facilities and personnel naturally absorbed large quantities of the money as the Bureau and its establishments expanded from a pre-Korean level of 38,675 employees, military and civilian, to slightly more than 75,000 on July 1, 1952, but much the biggest slice went for ammunition—projectiles, rockets, bombs, torpedoes, and mines. Viewed another way, aircraft armament consumed about 50 percent of the appropriations, with the remainder divided between surface ships and submarines. Considered a third way, half the dollars were spent for weapons developed after World War II, while the other half went for repeats of familiar ordnance.

Several trends in weapon development were apparent from the activity of the period. Ranges increased generally as a result of new propellants and novel types of guns, projectiles, and missiles. Velocities followed a similar curve, inspired by the need to match the increased speed of air targets. The role of electronics in naval ordnance grew more important, forming the basis for homing devices, proximity fuzes, and fire control equipment. Finally, complexity became a characteristic of new equipments. This was on the debit side. Simplicity, reflected in ease of operation and maintenance, was always a primary goal for ordnance designers, but an elusive one. Operational techniques could generally be kept simple, but maintenance problems grew in direct proportion to the adaptation of electronics to the requirements of firepower. That this was in large part a training problem was proved by the fact that equipments which gave good service during World War II became the subjects of complaints when they had to be manned by less experienced men, but the identification of the problem was far from its solution. That required reexamination of training techniques and a reevaluation of weapon requirements so that ease of maintenance could receive as high a design priority as could be granted without a dangerous sacrifice of military performance.

At the beginning of 1953 the Bureau of Ordnance faced a wide variety of technical problems. The basic situation was never likely to alter greatly. Ordnance development is inherently dynamic. In the face of an inexorable contest between measure and countermeasure, static fields quickly contain only archaic weapons. That was the philosophy which underlay the Bureau's postwar emphasis on research and development, then dictated the nature of its mobilization after the invasion of South Korea.

APPENDIX

CHIEFS OF BUREAU, DIVISION DIRECTORS, SECTION HEADS, AND COMMANDING OFFICERS OF MAJOR ORDNANCE ESTABLISHMENTS, MARCH 1941 TO SEPTEMBER 1945

CHIEF OF BUREAU (A)---	Rear Adm. W. H. P. Blandy, USN. Vice Adm. George F. Hussey, Jr., USN.
Staff Assistants (A1)	Capt. H. R. Greenlee, USN (Ret.). Comdr. M. F. Schoeffel, USN. Comdr. E. E. Herrmann, USN. Capt. L. L. Strauss, USNR.
ASSISTANT CHIEF OF BUREAU (B).	Capt. G. B. Davis, USN. Rear Adm. T. D. Ruddock, USN. Rear Adm. G. F. Hussey, Jr., USN. Rear Adm. W. A. Kitts 3d, USN. Capt. C. H. Jones, USN.
Assistant to Assistant Chief (B1).	

ADMINISTRATIVE DIVISION (Ad)

DIRECTOR (Ad)-----	Capt. G. B. Davis, USN. Capt. C. H. Jones, USN. Capt. A. D. Mayer, USN. Capt. Samuel B. Brewer, USN. Capt. M. R. Kelly, USN.
Office Management (Ad1).	Lt. Comdr. R. D. Russell, USNR. Lt. A. Z. Schneider, USNR. Lt. Comdr. J. H. Lumley, USNR.
Civilian Personnel (Ad2).	Mr. H. M. Klee. Lt. Comdr. R. S. Trigg, USNR.
Ordnance Stations (Ad3).	Capt. J. C. Byrnes, USN (Ret.).
Naval personnel (Ad4).	Capt. W. R. Van Auken, USN (Ret.).
Industrial Relations (Ad5).	Lt. D. W. Armstrong, USNR. Lt. Comdr. H. F. Linder, USNR. Lt. Comdr. W. R. Consedine, USNR.
Publications (Ad6)	Lt. P. J. Chittenden, USNR.
Shipments (Ad7)---	Lt. C. H. Chapman, USNR.
Ammunition Stock Recording System (Ad8).	Lt. W. H. Fox, USNR.

PRODUCTION DIVISION (Pr)

DIRECTOR (Pr)-----	Capt. T. D. Ruddock, USN. Capt. G. F. Hussey, Jr., USN. Capt. W. A. Kitts 3d, USN. Capt. R. W. Holsinger, USN. Capt. R. H. Roberts, USN. Mr. W. E. Hayes.
Chief Production Engineer.	
Assistant Director in Charge of Production (Pra).	Comdr. A. G. Noble, USN. Comdr. H. M. Briggs, USN. Capt. W. W. Juvenal, USN. Capt. J. R. Van Nagell, USN.

PRODUCTION DIVISION (Pr)—Continued

Assistant Director for Procurement (Prb). Originally Contracts and Requisitions (Pr2).	Capt. H. L. Merring, USN. Capt. S. P. Fullinwider, Jr., USN.
Assistant Director for Property Disposition (Pre).	Lt. J. L. Frederick, USNR.
Production Planning (Pr1).	Comdr. H. D. Krick, USN. Comdr. J. H. Hogg, USN. Comdr. L. C. Quiggle, USN.
Aviation Ordnance (Pr2).	Capt. F. L. Busey, USN. Capt. D. J. Sullivan, USN.
Plant Equipment (Pr3).	Lt. Comdr. O. O. Hagen, USN (Ret.). Comdr. H. R. Mytinger, USN (Ret.). Capt. Walter L. Tann, USNR.
Inspection (Pr4)----	Comdr. Lewis L. Strauss, USNR. Comdr. Overton Harris, USNR. Comdr. John W. Fretz, USNR.
Guns and Mounts (Pr5).	Capt. A. D. Blackledge, USN. Comdr. A. D. Mayer, USN. Capt. W. W. Juvenal, USN. Capt. J. S. Laidlaw, USN. Capt. J. R. Van Nagell, USN. Comdr. F. C. Manville, USN.
Ammunition (Pr6)--	Comdr. R. W. Holsinger, USN. Capt. M. A. Sawyer, USN.
Chief Engineer-----	Mr. F. F. Dick.
Fire Control and Optics (Pr7).	Comdr. A. F. France, USN. Capt. Elmer Kiehl, USN. Capt. K. H. Noble, USN. Capt. F. S. Withington, USN.
Chief Engineer, Optics.	Mr. Lawrence Radford.
Underwater Ordnance (Pr8).	Capt. T. D. Westfall, USN. Comdr. D. S. Crawford, USN. Capt. R. H. Roberts, USN. Capt. C. H. Bushnell, USN.
Armor, Projectiles, Bombs, and Rockets (Pr9).	Comdr. C. E. Braine, USN. Capt. William Granat, USN. Capt. A. D. Mayer, USN. Comdr. A. H. Bateman, USN. Capt. G. D. Linke, USN.

RESEARCH AND DEVELOPMENT DIVISION (Re)

DIRECTOR (Re)-----	Capt. G. L. Schuyler, USN. Capt. S. R. Shumaker, USN. Capt. W. M. Moses, USN. Capt. C. L. Tyler, USN. Capt. F. I. Entwistle, USN.
Assistant Director (Rea).	Comdr. G. C. Hoover, USN. Capt. S. R. Shumaker, USN. Capt. C. L. Tyler, USN. Capt. F. I. Entwistle, USN. Capt. E. M. Parker, USN.
Special Assistants to Rea.	Capt. P. E. Pendleton, USN. Lt. Comdr. Hudson Moore, USNR. Lt. P. J. Martini, USNR.
Chief Engineer (Rec).	Mr. P. H. Girouard.

RESEARCH AND DEVELOPMENT DIVISION (Re)—Continued

Planning and Engineering (Re1).	Lt. Comdr. V. Hicks, USNR. Comdr. A. J. Couble, USN. Capt. E. N. Parker, USN. Comdr. K. S. Masterson, USN.
Ammunition and Explosives (Re2).	Comdr. G. C. Hoover, USN. Comdr. J. A. Snackenber, USN. Comdr. J. H. Sides, USN. Comdr. J. A. E. Hindman, USN.
Armor, Projectiles, Bombs, and Ballistics (Re3).	Mr. A. Wertheimer. Comdr. T. J. Flynn, USN. Capt. W. A. Walter, USN.
Fire Control (Re4).	Capt. M. E. Murphy, USN. Capt. D. P. Tucker, USN. Capt. C. E. Voegeli, USN.
Guns and Mounts (Re5).	Lt. Comdr. H. B. Brumbaugh, USN. Capt. F. F. Foster, USN. Capt. C. H. Anderson, USN. Capt. J. S. Champlin, USN.
Underwater Ordnance (Re6).	Capt. J. L. King, USN (Ret.). Capt. L. W. McKeegan, USNR. Capt. E. M. Crouch, USN. Capt. C. H. Bennett, Jr., USN (Ret.).
Foreign Ordnance (Re7).	Lt. Comdr. C. S. Piggot, USNR.
Aviation Ordnance (Re8). Originally Assistant for Aviation (Reb).	Comdr. M. F. Schoeffel, USN. Capt. S. E. Burroughs, USN. Capt. J. S. McClure, USN. Capt. D. B. Young, USN. Capt. N. W. Ellis, USN.

FLEET MAINTENANCE DIVISION (Mn)

DIRECTOR (Mn)-----	Comdr. F. H. Dean, USN. Capt. William Granat, USN. Capt. J. H. Jacobson, USN. Capt. E. M. Crouch, USN.
Assistant to Director (Mna).	Comdr. R. H. Roberts, USN. Capt. D. S. Crawford, USN. Capt. A. F. Converse, USN. Comdr. W. C. France, USN. Capt. M. R. Kelly, USN. Capt. W. H. Duvall, USN.
Planning (Mn1)----	Lt. Comdr J. M. Miller, USN (Ret.). Comdr. R. H. Roberts, USN. Capt. H. B. Brumbaugh, USN. Capt. C. S. Weeks, USN. Capt. J. A. Callaghan, USN.
Ammunition (Mn2)-	Comdr. M. G. Johnson, USN. Comdr. P. F. Johnston, USN.
Underwater Ordnance (Mn3).	Comdr. L. A. Reinken, USN. Capt. J. A. Callaghan, USN. Capt. R. D. Smith, USN.
Fire Control (Mn4)-	Comdr. A. F. France, USN. Capt. R. B. Tompkins, USN. Capt. C. L. Clement, USN.
Guns and Mounts (Mn5).	Comdr. W. C. France, USN. Capt. Roger Brooks, USN (Ret.).
Aviation Ordnance (Mn6).	Capt. W. V. R. Vieweg, USN. Capt. I. E. Hobbs, USN. Comdr. S. J. Lawrence, USN.
Shipments (Mn7)---	Lt. Comdr. W. F. Wetzell, USNR.

PLANNING AND PROGRESS DIVISION (PL)

DIRECTOR (PL)-----	Capt. Leighton Wood, USN. Capt. A. G. Noble, USN. Capt. E. E. Herrmann, USN. Capt. W. M. Moses, USN. Capt. W. Granat, USN. Capt. O. A. Weller, USN. Capt. S. B. Macfarlane, USN (Ret.).
Underwater Type Assistant (PLa).	Capt. W. A. Gorry, USN. Capt. R. H. Roberts, USN.
Antiaircraft Type Assistant (PLb).	Capt. E. E. Herrmann, USN. Capt. J. F. Crowe, USN.
Aviation Type Assistant (PLc).	Capt. B. L. Braun, USN. Capt. J. B. Sykes, USN. Capt. W. G. Switzer, USN. Capt. N. W. Ellis, USN. Capt. O. A. Weller, USN.
Ammunition Type Assistant (PLd).	Capt. J. A. Snackenberg, USN. Capt. D. M. Tyree, USN.
Training Liaison (PLe).	Capt. M. R. Kelley, USN. Comdr. A. J. Benz, USN.
Inventory Control (PLg).	Comdr. F. S. Oden, USN.
Postwar and Demobilization Planning (PLh).	Comdr. H. N. Coffin, USN.
Logistics Planning (PLi).	Capt. Radford Moses, USNR. Capt. H. N. Coffin, USN.
Directives (PL2)----	Comdr. C. R. Criddle, USN.
Progress and Reports (PL3).	Capt. L. B. Bye, USNR. Lt. Comdr. D. C. King, USNR. Lt. Comdr. R. W. Ince, USNR.
Foreign Liaison and Defense Aid (PL4).	Lt. Comdr. H. C. Parker, USNR. Lt. Comdr. T. Chatham, USNR. Lt. Comdr. J. E. Conrad, USNR. Lt. Comdr. F. W. Frost, USNR.

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Assistant Director (Fia).	Capt. A. G. Zimmerman, USN (Ret.). Capt. F. G. Richards, USN. Lt. E. J. Lewis, USN. Mr. A. J. Pepin, Jr.

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NAVAL MAGAZINE

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 Lt. Comdr. Edward Newton Leonard, USN.
 Capt. Andrew DeGraff Mayer, USN.
 Forest Park, Ill----- Capt. James A. Flint, USNR.
 Indianapolis, Ind----- Comdr. George P. Kraker, USN.
 Capt. Warren E. Gladding, USN.
 Louisville, Ky----- Comdr. Kenneth M. McLaren, USN.
 Comdr. Charles E. Briner, USN.
 Capt. Fred D. Kirkland, USN.
 Lt. Comdr. Roger M. B. Briggs, USN.
 Macon, Ga----- Capt. Arthur B. McCrary, USN (Ret).
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 Milledgeville, Ga----- Comdr. S. K. MacKlean, USN.
 Capt. Russell G. Sturges, USN.
 Pocatello, Idaho----- Capt. Walter E. Brown, USN.
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 St. Louis, Mo----- Lt. Comdr. R. H. Robinson, USNR.
 Comdr. L. J. Kanitz, USNR.
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 York, Pa----- Capt. Lee Payne Johnson, USN.

NAVAL ORDNANCE TEST STATION

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NAVAL POWDER FACTORY

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 Newport, R. I----- Capt. Thomas Withers, USN.
 Capt. Frank H. Roberts, USN.
 Capt. Frank G. Fahrion, USN.
 Capt. John H. Carson, USN.

INDEX

- Abel, Frederick, 187-88
Aberdeen Proving Ground, 236, 281, 293
Aeronautics, Bureau of, 50, 119, 331, 362, 415, 455
Air Force, 165-71, 349, 497, 513
Albanite, 195
Allegheny Ludlum Steel Corp., 50
Allied Submarine Devices Investigation Committee (ASDIC), 135
Allis-Chalmers Manufacturing Co., 253
Aluminum Co. of America, 208
Aluminum powder, 191, 208
Amatol, 202
American Can Co., 126
American Chain & Cable Co. Inc., 175
American Laundry Machinery Co., 314
American Locomotive Co., 126, 253
American Oerlikon Gazda Corp., *see* AOG Corp.
American Steel Foundries, 47
Amertorp Corp., 127
Ammunition, 186-218, 231-33, 245, 501, 520-22; *see also* fuzes, projectiles, rockets
Ammunition depots, *see* Naval Ammunition Depots
Ammunition Handling School, Hingham, Mass., 487
Ammunition Quality Surveillance Program, 218
Amphibious support, 60-62, 88, 180, 183, 310-15, 520
Anaconda Copper Co., 74
Angle Solver Mark 9, 402
Antiaircraft Bomb Mark 34, 338
Antiaircraft Defense Board, 220
Antiaircraft Training & Test Center, Dam Neck, Va., 486, 487
Antisubmarine Projector Mark 10, 136-37, 396-97
Antisubmarine Projector Mark 20, 137
Antisubmarine Projector Mark 22, 137
AOG Corp., 237, 239-40, 241, 468
Applied Physics Laboratory of Johns Hopkins University, 277-78
Arbor Mark 7, 148
Arma Corp., 387, 388, 399, 403, 473
Armor, 8, 29, 438-39; cast, 46-48; cognizance, 33-35; critical situation, 32, 35; description, 36-37; expansion of facilities, 37-38, 42-43; impediments to expansion, 38-42; light, 48-50; research, 44-48; spares, 50-51
Armor & Projectile Laboratory, 49-50
Armor Steering Committee, 45, 47-48
Armour Research Foundation, 398
Army Industrial College, 496
Army-Navy cooperation, armor, 45; facilities, 191-92, 214, 501; machine tools, 442; mine campaign against Japan, 165-71; postwar, 501-04; research, 500; specifications, 501; weapons, 224, 231, 331, 334-37, 354, 355, 496-500
Army-Navy E Award, *see* Incentive programs
Army-Navy Munitions Board, 191, 437, 496, 506
Army Ordnance Board, 202
Army Ordnance Technical Committee, 496
ASDIC, 135
Ash cans, 132
Attack Director Mark 2, 398
Attack Plotter Mark 1, 397-98
Average Torpedo Speed Computer Mark 1, 364
Aviation ordnance, Army-Navy cooperation in, 496-97; bombs, 335-40; fire control, 344-67; guided missiles, 340-44; guns, 332-35; in Korea, 512-16; mines, 162, 165-71; rockets, 302-10; torpedoes, 118-24
Awards, *see* Incentive programs
Azon, 516
Bachmann, W. E., 204, 205
Badger Ordnance Works, 197
Baka bomb, 267, 516
Baldwin Locomotive Co., 258
Bard-Parker Co., Inc., 244

- Barth, Theodore H., 351, 356
 Bat, 29, 340-44, 516
 Batteries, 82, 86, 112, 114-15, 281-82
 Bausch & Lomb Optical Co., 468, 473
 Bazooka, 293, 513
 Bell Telephone Laboratories, 28, 149, 343, 414, 418, 426, 431, 469
 Bendix Aviation Corp., 80
 Bermite Co., 245
 Bethlehem Steel Co., 38, 42-43, 45, 57, 126, 251, 253, 436
 Birmingham, University of, 418
 Black powder, 187, 199-201
 Blandy, Admiral W. H. P., 9, 10, 42, 56, 102, 105, 109, 217, 223, 232, 237, 257, 260, 284, 287, 304, 429, 454, 469, 471, 497, 504
 Blaw-Knox Co., 47, 48, 227, 228, 234, 258, 468
 Blind firing, 231, 391-94
 Bliss Co., E. W., 124, 127, 468
 Blueprints, *see* Drawings
 Bodine Electric Co., 230
 Bofors Co., 221-22, 224
 Bofors gun, 219, 272, 378; associated equipment, 230-32, 384-88; purchase of, 221-24; design problems, 225-26; improvements in, 224-25; performance, 234; production, 226-30, 233-34
 Bomb containers, 338
 Bomb Director AN/ASB-1, 514
 Bomb Director Mark 1, 361-62
 Bomb Director Mark 3, 514
 Bomb Disposal School, Washington, D. C., 487
 Bombs, antiaircraft, 338-39; armor-piercing, 335-36, 497; atomic, 16; demolition, 336; depth, 336-38, 497; fire control for, 350-62; Napalm, 330-40; retro, 151, 301-02, 306
 Bombsight Mark 3, 351
 Bombsight Mark 11, 351
 Bombsight Mark 15 (Norden), 351-56, 428, 497
 Bombsight Mark 16, 360
 Bombsight Mark 17, 360
 Bombsight Mark 20, 357
 Bombsight Mark 23, 358-59
 Bombsights, low altitude, 356-59
 Booz, Fry, Allen & Hamilton, 467
 Breit, Gregory, 410
 Brill Co., A. C. F., 129-30
 Bristol & Martin Co., 402
 British Purchasing Commission, 237, 239
 Brown, Vice Admiral Wilson, 310
 Budd Induction Heat Treating Co., 68
 Bullard Co., 468
 Bureaus, *see* under specific name
 Burk, P. W., 225
 Bush, Vannevar, 25, 72, 277
 Bushnell, David, 156-57
 California Institute of Technology (CIT), 123, 196-98, 295-301, 304-09, 310-11, 314-17, 323-25, 327, 363
 California Powder Co., 189
 Camden Forge Co., 253
 Cameron Iron Works, 135, 240, 258, 473
 Campbell, Major General Levin H., 497, 498, 502, 503, 504
 Carbide cutting tools, 440-41
 Carnegie-Illinois Steel Corp., 32, 38, 40, 42, 43, 44
 Carnegie Institute of Technology, 482
 Carnegie Institution of Washington, 74, 75, 80, 276, 410
 Cartridge cases, steel, 215-17, 521
 Cartridge tanks, 217
 Casablanca, 55, 311
 Case School of Applied Science, 482
 Cathode ray tube, 397, 411, 413
 Central Torpedo Office, 128-29
 Certificate of Achievement, 478-79
 Chemical torpedoes, 116-18
 Chief of Naval Operations (CNO), 12, 60, 73, 87-88, 145, 161, 183, 206, 308, 325, 389
 Christie, Rear Admiral R. W., 105
 Chrysler Corp., 225, 228, 441, 468
 Columbian Rope Co., 475
 Composition A, B, C, 203, 205, 208-10
 Compton, Lewis, 41
 Congreve, Sir William, 292
 Conservation, 46-47, 215-17, 228, 234, 245, 443-44, 521
 Consolidated Steel Corp., 260, 468
 Construction and Repair, Bureau of (later BuShips), 33, 34
 Continental Gin Co., 240, 260
 Continental Roll & Steel Foundry Co., 47
 Contracts, 6, 28, 163-64, 508-09; centralization vs decentralization, 453-55; clearances, 458-59; increasing

Contracts—Continued

procurement 449-50, 453; prior to World War II, 449-50; procedure, 456-57; restrictions on, 450-53; terminations, 459-60; types, 449, 452-53, 457-58

Coordinator of Research & Development, Office of, 24, 28, 136

Coral Sea, Battle of, 330

Cordite powder, 194, 223

Coso and Coso, Jr., 322

Council of National Defense, Advisory Commission to, 41

Creeping attack, 145-46

Crosley Corp., 277, 285, 383

Crucible Steel Co., 57, 126, 227, 436, 468

Cutteroo, 315

CXAM, 414

CXAS, 414

Damage control, 287-88

Danley Machine Specialties, Inc., 468

DBX, 207-08

Decoupling, 196, 512-13

Degaussing, at advanced bases, 87-88; British pioneering and aid in, 69-71, 73, 75, 80; defined, 71; deperming, flashing, and wiping, 82-86; Flash-D, 86; fluxmeters, 75-76; magnetometers, 80-82; merchant ship, 88-89; personnel, 74; ranges, 75-80, 84-85, 88

Depth Bomb Mark 17, 337

Depth Bomb Mark 29, 337

Depth Charge Mark 2, 133, 141

Depth Charge Mark 3, 133, 139, 141

Depth Charge Mark 4, 133, 139, 141

Depth Charge Mark 5, 133

Depth Charge Mark 6, 133, 139, 140-41, 142, 143, 153

Depth Charge Mark 7, 133, 139, 141, 153

Depth Charge Mark 8, 145-49, 153

Depth Charge Mark 9, 141-44, 148

Depth Charge Mark 10, 151, 152-53

Depth Charge Mark 11, 149, 150

Depth Charge Mark 12, 149, 150

Depth charges, ahead thrown weapons, 136-38; fire control for, 394-96; harbor defense, 151-53; hydrostatic, 139-44; influence, 144-50; post WW II, 519; production, 153-54; WW I and following, 132-36; *see also* specific depth charges

DINA, 195

Dive bombing, 360-61

Doenitz, Grand Admiral, 131

Drag ring, 122-23

Draper, Charles S., 379-80, 389; *see also* Gun Sight Mark 14

Drawings, 57, 226-27, 256-57, 327-28, 401

Duplexer, 411

Du Pont Co. (E. I. du Pont de Nemours Co.), 189, 191, 193, 203, 205, 473

Eastman Kodak Co., 285, 468

Edison, Charles, 34

Einstein, Albert, 493

Elco Boat Co., 240

Electric Storage Battery Co. (EXIDE), 112

Electric torpedoes, 21, 29, 110-16

Electronic Precedence List, 429-30

Electronics industry, 429-30

Engineering, Bureau of, 18

Engineering Laboratories, Inc., 398

England, *see* Great Britain

Ensinger, W. B., 364

Entwistle, Lt. Comdr. F. I., 351

Erie Forge Co., 253

Erwood Co., 281

Excel Foundry & Machine Co., 468

Explosive D, 202-03

Explosives, Amatol, 202; Explosive D, 202-03; DBX, 207-08; DINA, 195; HBX, 206-07, 338; RDX, 204-06; requirements of, 186; Tetryl, 202; TNT, 97, 110, 132, 133, 136, 141, 145, 149, 202, 204, 301; Torpex, 205-07; Tritonal, 207; UWE, 207; *see also* propellants

Explosives Investigation Laboratory, Port Townsend, Wash., 18, 20

Explosives Investigation Laboratory, Stump Neck, Md., 18, 20

Explosives Research Laboratory, Woods Hole, Mass., 205

Export Control, Administration of, 436

Federal Telephone & Radio Corp., 230

Fire Control, 21, 30, 251, 368-69; anti-aircraft, 374-94; antisubmarine, 394-99; aviation ordnance, 302-03, 344-67, 362-63, 514-16; blind firing, 391-94; bombs, 350-62; development prior to WW II, 369-73; intervelometers, 396, 519; Korea, 517; main bat-

- Fire Control—Continued
 tery, 373-74, 521; maintenance, 383-84, 404-06; optics, 345, 403, 412, 421, 424; production, 403-04 (*see also specific equipments*); radar, 408-432 (*see also specific equipments*); torpedo, 363-65, 399-03
- Fire Control Development Program, 419-21
- Fire Control Radar, 374-75, 403, 521; aircraft weapons, 350, 365-66; anti-aircraft D-P guns, 423-27; anti-aircraft heavy machine guns, 427-28; cognizance, 415-16; development of search radar and application to fire control, 408-19; development program, 419-21; main battery, 421-23; procurement, 428-31 (*see also specific equipment*).
- Firepower*, 478
- Fisher Body Co., 258, 260, 473
- Fiske, Lt. Bradley A., 370
- Fivonite, 195
- Flashless pellets, 193-94
- Fluxmeters, 75-76
- Folsom, Frank M., 459
- Ford Instrument Co., 228, 230, 371-72, 387, 403, 468, 473
- Forrestal, James, 40, 466-67, 472, 504
- Fort Schuyler, 485-86
- France, 54, 55-56, 411, 417, 434, 435
- France, Comdr. A. F., 223
- Frankford Arsenal, 496
- Franklin Institute, 357, 364-65
- Fulton, Robert, 157
- Furlong, Rear Admiral W. R., 10, 38, 39, 40-41, 72, 73, 88, 102, 222, 238, 439, 496
- Fuzes, 61, 62, 143-45, 151, 231-32, 311, 272-74, 521; *see also* VT fuze
- Galileo, 369
- Gamow, George, 494
- Gaty, John P., 481
- Gazda, Antoine, 237, 239, 240
- General Cable Corp., 73
- General Electric Co., 75, 76, 81, 101, 112, 230, 260, 263, 376, 387, 397, 403, 468
- General Machinery Ordnance Corp., 253
- General Mills, Inc., 401
- General Ordnance School, 486
- General Steel Castings Corp., 47, 48
- George Washington University, 295
- Georgia Institute of Technology, 482
- German science & weapons, 30-31, 69-70, 100-101, 117, 131-33, 155, 156, 288-89, 293, 408-09, 417
- Gilbert & Barker Co., 230
- Goddard, Robert H., 293-94
- Goeckler, Frank E., 481
- Goss Printing Press Co., 260, 468
- Graumann, R. L., 232
- Great Britain, 73, 75, 80, 127, 135, 136, 156, 172-73, 204, 206, 208, 224, 237-39, 288-89, 345-46, 347, 371, 396, 413, 418, 434
- Greist Manufacturing Co., 244
- Guggenheim, Daniel, 293
- Guided missiles, 29, 406-07, 508-09, 510, 517-18; Bat, 340-44; Pelican, 342-43
- Gun Containers Mark 1 & 2, 334
- Gun Director Mark 19, 375-76
- Gun Director Mark 21, 386
- Gun Director Mark 28, 376
- Gun Director Mark 33, 376-78, 386, 390, 391
- Gun Director Mark 34, 373
- Gun Director Mark 37, 377-78, 386, 390, 391, 392, 400, 401-02, 421
- Gun Director Mark 38, 373-74
- Gun Director Mark 44, 379, 384, 387
- Gun Director Mark 45, 387-88
- Gun Director Mark 46, 387
- Gun Director Mark 47, 387, 388
- Gun Director Mark 49, 387, 388
- Gun Director Mark 50, 388, 389
- Gun Director Mark 51, 230-31, 379, 384-88, 390, 392, 393
- Gun Director Mark 52, 390, 393
- Gun Director Mark 54, 373
- Gun Director Mark 57, 231, 428
- Gun Director Mark 60, 231
- Gun Director Mark 63, 231, 428
- Gun Train Indicator Mark 52, 396, 398
- Guns, buildup of facilities, 252-56; decoppering, 196, 512-13; definition, 248; impediments to production, 255-57; manufacturing processes, 248-51; rapid fire, 267-70, 516-17; test, 270; turret, 262-67; types, 248; *see also specific guns*
- Guns, .30 caliber, 219, 332-33, 375, 378
- Guns, .50 caliber, 219, 220, 234-35, 332-34, 375, 378

- Guns, .60 caliber, 333
 Guns, 20-mm. Hispano-Suiza, *see* Hispano-Suiza gun
 Guns, 20-mm. Oerlikon, *see* Oerlikon gun
 Guns, 17-1, 219, 220, 272, 378
 Guns, 37-mm., 223
 Guns, 40-mm. Bofors, *see* Bofors gun
 Guns, 3-inch, 257-58, 267-68, 375, 516-17
 Guns, 4-inch, 261
 Guns, 5-inch, 21, 220, 257, 258-61, 268, 272, 286-87
 Guns, 6-inch, 21, 251, 269-70
 Guns, 8-inch, 251, 269
 Guns, 12-inch, 265-67
 Guns, 14-inch, 252, 265
 Guns, 16-inch, 251, 263
 Guns, 18-inch, 252
 Gun Sight Mark 3, 231
 Gun Sight Mark 4, 231
 Gun Sight Mark 14 (Draper Sight), 230, 379-84, 390
 Gun Sight Mark 15, 390
 Gun Sight Mark 17, 349
 Gun Sight Mark 18, 347-48
 Gun Sight Mark 21, 348-49
 Gun Sight Mark 23, 348-49, 363
 Gun Sight Mark 25, 349
 Hale, William, 292
 Harriman, Mrs. J. Borden, 223
 Harvard Business School, 482
 HBX, 206-07, 338
 Hedgehog, 136-38, 151, 396-97
 Hendy, Joshua, Iron Works, 328-29, 468
 Hercules Powder Co., 198, 199, 284
 Herring-Hall-Marvin Safe Co., 260, 468
 Hertz, Heinrich, 408
 Hickman, C. N., 294
 Hispano-Suiza gun, 238, 333-34, 512
 Holston Ordnance Works, 205
 Hoover Co., 284
 Howard, Henry, 222
 Hubbard Co., 174
 Hudson Motor Car Co., 240
 Hughes, Major General Everett S., 502, 504
 Hussey, Vice Admiral George F., Jr., 11, 23, 59, 210, 258, 495, 497, 498, 499, 503, 504
 HVAR (High Velocity Aircraft Rocket), 306-07, 514
 Hydrophones, 394
 Hygrade-Sylvania Corp., *see* Sylvania Electric Products, Inc.
 Hytron Corp., 281, 284
 Illuminated Sight Mark 8, 345-46
 Illuminated Sight Mark 9, 346
 Incentive programs, administration of
 Army-Navy E awards, 476-78; administration of Navy E program, 474-75; Army-Navy E award, 470, 476; BuOrd recipients, 473, 477; evolution of Navy E, 470-72; multiplicity of, 473-74, 476; postwar awards, 478-79
 Indiana Ordnance Works, 197
 Industrial Mobilization Plan, 506-08
 Industrial Preparedness Studies, 506
 Inspection, 58-59, 199, 218, 256, 441-42, 446; personnel, 462, 468-69; prewar organization, 461-62; recruiting and training inspectors, 463-65; reorganization, 465-68; statistical quality control, 469; weaknesses, 462-63
 International Harvester Co., 127, 129, 468
 International Nickel Co., 473
 Intervalometers, 396, 519
 Iwo Jima, 61
 Japan, 31, 51, 61-62, 72, 107, 109, 117, 130, 132, 162, 165-71, 177-78, 236, 261, 263, 267, 330, 382, 417, 422, 434, 435, 516
 Jean Bart, 55-57
 Jefferson Electric Co., 468
 Jewett, Frank B., 24
 Johns Hopkins University, 277-78
 Joint A-N Committee on Specifications, 501
 Joint A-N Committee on Standard Drawing Practices, 497
 Joint A-N Packaging Board, 501
 Joint Communications Board, 429
 Kamikaze planes, 13, 234, 267, 322, 406, 423, 428, 516
 Kaydon Engineering Corp., 228
 Keuffel & Esser Co., 473
 K-gun, 134-35, 141
 King, Admiral Ernest J., 56, 105, 220, 270
 Kirkwood, John G., 493
 Kitts, Rear Admiral W. A., 3d., 325
 Knox, Frank, 471
 Konoye, Prince, 171

- Korean Conflict, ammunition, 520-22;
 anti-aircraft weapons, 516-18; anti-
 submarine ordnance, 518-19; aviation
 ordnance, 512-16; cost, 521-22; mo-
 bilization planning, 505-08; procure-
 ment processes, 508-12; trends, 522
- Krivobok, V. N., 481
- Krupp, Otto, 221
- Krupp Works, 44-45, 221
- Kwajalein Atoll, 61
- Labor, Department of, 42
- Lansing Paint & Color Co., 203
- Lead Computing Sight Mark 1, 347
- Lear, General Ben, 290
- Lehigh University, 482
- Lehman, Gov. Herbert, 486
- LeMay, Major General Curtis, 167
- Lend-Lease, 4, 5, 239-40, 380, 418
- Leonardo, 214
- Librascope Co., 398
- Light Armor Battery, 49-50
- Lincoln, Abraham, 16
- Lindbergh, Charles A., 293
- Linke, Commander G. D., 47
- Lockwood, Vice Admiral Charles A.,
 104, 105, 108
- Low Altitude Bombing Attachment,
 356-57
- Luftwaffe, 272
- Lukas-Harold Corp., 354
- Lukens Steel Co., 43
- Machine tools, 4, 64-65, 228, 324, 452,
 506-08; buildup of industry, 435; cat-
 alogue and classification, 437-38;
 coordination, 438, 442; critical pro-
 grams, 438-40; description of indus-
 try, 433-34; defined, 433; disposal,
 444-45; foreign orders, 434-36; pres-
 ervation, 446; storage, 506; stretch-
 ing use of, 440-43; tooling BuOrd es-
 tablishments, 436, 444-46
- McKay Co., 175
- McQuay-Norris Co., 285
- McVay, Rear Admiral C. B., Jr., 271
- Magnetic Airborne Detector (MAD),
 302
- Magnetic exploders, development, 99-
 101; duds, 106-09; prematures, 104-
 06; security, 101-02
- Magnetometers, 80-81
- Magnetron, 417-19, 421-22, 425
- Maritime Commission, 8, 89, 253
- Mark and Mod. defined, 21n
- Massachusetts Institute of Technology
 (MIT), 230, 341, 379, 380, 418, 428,
 482, 487
- Materials Handling Laboratory, Hing-
 ham, Mass., 218
- Maumelle Ordnance Works, 203
- Medicine & Surgery, Bureau of, 483
- Merchant ships, arming of, 260
- Metals Disintegrating Co., 208
- Midvale Co., 38, 42-43, 57, 126, 227, 251,
 253, 436, 468, 473
- Midway, Battle of, 330
- Miehle Printing Press Co., 258, 468, 473
- Mighty Mouse, 513-14
- Mine Modification Unit, 168
- Mines, between 1919-41, 159-60; Ger-
 man, 70, 159; historical, 156-58; mod-
 ification, 168; objectives, 158; re-
 search & production, 160-65; types,
 156, 159-61, 167; warfare against
 Japan, 162, 165-71; WW I activity,
 158
- Mine Warfare School, Yorktown, Va.,
 487
- Mine Warfare Test Station, Solomons,
 Md., 164, 165
- Minnie Mouse, 300
- Missiles, *see* Guided missiles
- Mitchell, Major General William, 271,
 287
- Modern Welding Co., 241
- Morgenthau, Henry, 38, 237
- Moses, Captain William M., 500
- Mousetrap, 137, 151, 299-300
- Mudge, William A., 481
- Multiscope Corp., 384
- Munroe, C. E., 210
- Munroe effect, *see* Shaped charges
- Napalm bombs, 339-40
- National Academy of Sciences, 17, 23,
 25, 136
- National Advisory Committee for Aero-
 nautics, 17
- National Carbon Co., 281, 284
- National Defense Advisory Commission,
 438
- National Defense Research Committee,
 25-26, 122-24, 136, 137, 194-95, 196,
 204, 206-07, 294-304, 306, 307-08, 316,
 323, 325, 340-44, 357, 358, 362, 380,
 393, 397, 398, 418

- National Fireworks Co., 193, 245
 National Forge & Ordnance Co., 251
 National Munitions Co., 245
 National Research Council, 17, 23
 National Supply Co., 227
 National Tube Co., 65
 Naval Air Technical Training Center, Jacksonville, Fla., 487
 Naval Ammunition Depot, Balboa, C. Z., 213
 Naval Ammunition Depot, Charleston, S. C., 213
 Naval Ammunition Depot, Crane, Ind., 212, 326
 Naval Ammunition Depot, Earle, N. J., 213-14
 Naval Ammunition Depot, Fallbrook, Calif., 213, 329
 Naval Ammunition Depot, Hastings, Nebr., 165, 213, 232
 Naval Ammunition Depot, Hawthorne, Nev., 165, 210, 211, 326
 Naval Ammunition Depot, Hingham, Mass., 218
 Naval Ammunition Depot, Iona Island, N. Y., 486
 Naval Ammunition Depot, Lake Denmark, N. J., 210-11, 486
 Naval Ammunition Depot, McAlester, Okla., 165, 213, 232
 Naval Ammunition Depot, Mare Island, Calif., 268
 Naval Ammunition Depot, New Orleans, La., 213
 Naval Ammunition Depot, Oahu, Hawaii, 213
 Naval Ammunition Depot, Puget Sound, Wash., 213
 Naval Ammunition Depots, general, 198, 210-14, 218
 Naval Ammunition & Net Depot, Seal Beach, Calif., 213
Naval Firepower, 478, 489
 Naval Fuel Depot, Yorktown, Va., 82-83
 Naval Gun Factory, Washington, D. C., 2, 129, 226, 252, 257, 262, 267, 337, 345, 379, 386, 401
 Naval Inspectors of Ordnance, 461, 469
 Naval Magazine, Bangor, Wash., 213
 Naval Magazine, Cohasset, Mass., 213
 Naval Magazine, Port Chicago, Calif., 211, 213, 520
 Naval Magazine, Theodore, Ala., 214
 Naval Mine Depot, Yorktown, Va., 18, 165, 168, 207
 Naval Mine Warfare Test Station, Solomons, Md., 18, 164, 165, 168
 Naval Net Depot, Melville, R. I., 185
 Naval Net Depot, Tiburon, Calif., 185
 Naval Ordnance Development Award, 479
 Naval Ordnance Laboratory, 18, 27, 72-86, 143, 159-60, 168, 517
Naval Ordnance Manufacturers Bulletin, 472
 Naval Ordnance Plant, Baldwin, N. Y., 2, 5, 486
 Naval Ordnance Plant, Canton, Ohio, 5, 252
 Naval Ordnance Plant, Center Line, Mich., 5, 240, 241, 252, 443-44
 Naval Ordnance Plant, Forest Park, Ill., 5, 93, 126, 129
 Naval Ordnance Plant, Indianapolis, Ind., 5, 354
 Naval Ordnance Plant, Louisville, Ky., 5, 252
 Naval Ordnance Plant, Macon, Ga., 5
 Naval Ordnance Plant, Milledgeville, Ga., 5
 Naval Ordnance Plant, Pocatello, Idaho, 5, 253
 Naval Ordnance Plant, St. Louis, Mo., 5, 127, 129
 Naval Ordnance Plant, Shumaker, Ark., 326
 Naval Ordnance Plant, South Charleston, W. Va., 5, 37-38, 40, 42-43, 51, 227, 252-53, 446, 506
 Naval Ordnance Plant, York, Pa., 5, 227, 233-34
 Naval Ordnance Plants, general, 5, 20, 508
 Naval Ordnance Test Station, Inyokern, Calif., 18, 295-96, 326, 505, 513
 Naval Personnel, Bureau of, 482-84, 488
 Naval Powder Factory, Indian Head, Md., 2, 20, 190, 191, 193-94, 197-98, 203, 295
 Naval Proving Ground, Arco, Idaho, 51, 253
 Naval Proving Ground, Dahlgren, Va., 18, 37, 50, 216, 236, 283, 293, 295, 381
 Naval Research Council, 24

- Naval Research & Inventions, Office of, 18
- Naval Research Laboratory, 17-18, 23, 45, 116, 410, 411, 414
- Naval Torpedo Station, Alexandria, Va., 124, 125, 126, 129
- Naval Torpedo Station, Keyport, Wash., 125, 129
- Naval Torpedo Station, Newport, R. I., 2, 18, 93-129, 189, 210
- Navol torpedoes, 18, 116-18
- Navy Department Council for Research, 23
- Nelson, Donald, 459
- Nets, AKN-AN operations, 181-83; amphibious operations, 180-82; British aid, 172-73; changes after Pearl Harbor, 178-79; cost, 176, 183; design problems, 174; individual ship protection, 179-80; installations, 173, 176, 182-83; production problems, 174-76; types, 174, 179, 181-82; summary, 184-85; WW I, 172, 176
- Newton, Isaac, 291, 369
- New York Ordnance Works, 203
- Nimitz, Admiral C. W., 105, 165, 167, 384
- Nobel, Alfred, 188
- Noble, Vice Admiral, A. G., 251, 507
- Norden, Carl L., 351-56
- Norden, Inc., Carl L., 353, 360, 468
- Norden Bombsight, 351-56, 428, 497
- Norris Stamping & Manufacturing Co., 473
- Northern Ordnance, Inc. (originally Northern Pump Co.), 230, 253, 258, 260, 468, 473
- Oerlikon gun, 219, 378; adoption, 237-38; ammunition, 245; British experience, 236-37; performance, 245-47; production, 239-44
- Oerlikon Machine Tool Works, 236
- Office of Procurement & Material, 457, 459
- Office of Production Management, 227, 438
- Office of Scientific Research & Development, 25, 26, 28, 275, 393, 418
- Office of War Mobilization, 42
- Okinawa, 61
- Okonite Co., 74
- Oliphant, N. L., 418
- Operation Starvation, 167-171
- Optics, 345, 403, 412, 421, 424
- Ordnance, Bureau of (Note: Since this entire volume deals with BuOrd, entries under this heading are kept at a bare minimum), Blandy reorganization, 10-13; buildup of facilities, 2-8 (see also specific weapons); cognizance, 1; expenditures WW II, 1, 3 (see also specific weapons); field establishments, 2, 4-8, 505 (see also specific establishments); production summary, 14; organization for research, 20-23; prewar organization, 8-10; retrenchment after WW I, 1-2
- Ordnance Department, U. S. Army, see Army-Navy cooperation in ordnance
- Ordnance Inspector's School, 465, 486
- Ordnance Production Award, 471-73, 478
- Ordnance Stock Office, 405
- Ordnance Test Unit, Dam Neck, Va., 18
- Oscilloscopes, 413, 415, 422
- Parke, Davis Co., 193
- Parker-Majestic Co., 281
- Parsons, Rear Admiral W. S., 460
- Pasadena Design Unit, 327
- Patnode, Winston S., 481
- Patton, General George, 290
- Pelican, 342-43
- Pelouze, Jules, 187
- Penn Forge Co., 253
- Personnel, 2, 44, 74, 522; civilian, 493-95; key personnel, 523-28; number & distribution, 494; Reserve officers, 481-91; retired officers, 492; USN officers, 492-93; WAVES, 489-90
- Phelps Dodge Corp., 74
- Picatinny Arsenal, 191, 486
- Piney Point (Va.) Torpedo Range, 125
- Plant Allocation Plan, 506, 508
- Plotter Mark 1, 397-98
- Plotting boards, 370
- Pluramelt, 50
- Polaroid Corp., 346
- Pollack Manufacturing Co., 473
- Pompom, 223-24
- Pontiac Motors Division of General Motors, Inc., 127, 129, 240, 241, 468
- Pool orders, 437
- Porcupine, 314

- Position firing, 349-50
 Poudre B, 188
 Powder tanks, 217
 Power drives, 228, 229-30, 253-54
 Precision Manufacturing Co., 127
 Projectiles, armor-piercing, 53-59; common, 53, 66-67; high capacity, 59-66, 439; historical development, 52-53; illuminating, 67-68; inspection and testing, 58-59; manufacturing technique, 57-59; production WW I, 462-63
 Projectors, *see* antisubmarine projectors
 Propellants, Army production, 191; black powder, 199-201; decoppering, 196, 512-13; flashless, 192-96; historical development, 186-90; indexes, 190-91; manufacturing process, 190; rocket, 196-99; *see also* Naval Powder Factory, Du Pont Co.
 Proximity fuze, *see* VT fuze
 Purdue University, 482
 Quality control, 469
 Quality Evaluation Laboratories, 521
 Radar, 16, 18, 30, 143, 343, 365-66, 406, 408, 416; *see also* Fire Control Radar
 Radar Equipment Mark 1, 415, 416, 421-22
 Radar Equipment Mark 2, 421-22
 Radar Equipment Mark 3, 415, 422, 426, 429
 Radar Equipment Mark 4, 426-27, 429
 Radar Equipment Mark 8, 422-23, 429
 Radar Equipment Mark 12, 427, 429, 430
 Radar Equipment Mark 13, 423
 Radar Equipment Mark 18, 429
 Radar Equipment Mark 22, 427, 429
 Radar Equipment Mark 28, 428, 429
 Radar Equipment Mark 29, 428
 Radar Equipment Mark 34, 428
 Radar Exchange Plan, 418
 Radford, Admiral A. W., 330
 Radiation Laboratory, MIT, 418, 428
 Radio Corporation of America, 275-76, 285, 414
 Railroad battery, WW I, 60
 Ram, 513-14
 Rangefinders, 370, 376, 412, 413
 Rangekeeper Mark 1, 372
 Raton Manufacturing Co., 244
 Raytheon Manufacturing Co., 281, 284, 418
 Razon, 516
 RDX, 204-06
 Remington Rand, 354
 Research, 13, 14, 16-31, 44-48, 90, 500, 510-512; *see also* specific weapons; Office of Scientific Research & Development; National Defense Research Committee; Naval Ordnance Laboratory; Naval Research Laboratory
 Research & Development, Coordinator of, 136
 Reserve officers, *see* Personnel
 Reserve Ordnance Plants, 506
 Reynolds Metals Co., 208
 Rifling, 52, 54, 250, 370
 Ring sights, 231, 344
 Rocket Launcher Mark 1, 311
 Rocket Launcher Mark 5, 305-06
 Rocket Launcher Mark 7, 313, 328-29
 Rocket Launcher Mark 8, 311-12, 316
 Rocket Launcher Mark 11, 313
 Rocket Launcher Mark 20, 299
 Rocket Launcher Mark 22, 300
 Rocket Launcher Mark 24, 315
 Rocket Launcher Mark 25, 314
 Rocket Launcher Mark 26, 315
 Rocket Launcher Mark 31, 321
 Rocket Launcher Mark 32, 321
 Rocket Launcher Mark 50, 317-18
 Rocket Launcher Mark 51, 318
 Rocket Launchers Mark 101 & 102, 322
 Rocket Launchers, general, 322, 326
 Rockets, 29, 300, 327, 439, 509, 518; aircraft, 302-10, 513-14; antiaircraft, 322; antisubmarine, 137, 298-305; beach barrage, 310-15; bombs, 297-98; cost, 294; demolition, 313-15; description of, 291; historical development, 291-94; in Korea, 509, 513-14; motors, 296; procurement, 304, 315, 323-29; propellants, 196-99, 297, 298, 309; retro-bomb, 301-02, 306; spin stabilized, 292, 316-18; types, 321-22
 Rockets, 2725 (SCAR), 307-08
 Rockets, 375, 304-06
 Rockets, 475, 310-11
 Rockets, 5", 306-07, 514
 Rockets, 772, 298-99, 314-15
 Rockets, 11775, 308-10
 Rocket ships, 312-13, 318-20, 322
 Rock Island Arsenal, 496
 Roebbling's Sons Co., John A., 175

- Romania, 64, 434, 435
 Roosevelt, F. D., 25, 34, 35, 38, 453, 472, 498
 Russell Electric Co., 476
 Russia, *see* Soviet Union.
 Russo-Japanese War, 157-58
 San Diego Sight, 358
 Schoeffel, Rear Admiral M. F., 356, 507
 Schuyler, Captain G. L., 279
 Section T, OSRD, *see* VT fuze
 Sensitive Research Co., 75
 Shaped charges, 210, 514
 Ships, Bureau of, 8, 18, 26, 34, 89, 109, 136, 184, 253, 392-93, 415, 425
 Shroud ring, 123
 Shumaker, Captain, S. R., 279
 Signal Corps, 26
 Skinner, Lt. Leslie A., 294
 Small business, 153, 161, 174-75, 215, 254, 509
 Smith College, 490
 Smith Co., A. O., 126
 Smithsonian Institution, 293
 Smokeless powder, *see* propellants
 Snackenberg, Captain J. A., 325
 Sonar, 135, 143, 146, 395, 397
 Soviet Union, 109, 417, 434, 435, 513, 519
 Spares and spare parts, 50-51, 126, 264, 332, 383, 405, 431, 446
 Special Board on Naval Ordnance, 20, 202
 Special Ordnance Plant, York, Pa., 233
 Sperry Gyroscope Co., 111, 230, 380, 383, 384, 389, 402
 Stabilized Bombing Approach Equipment, 352-53
 Standard Machinery Co., 227
 Standards, U. S. Bureau of, 276-77
 Steel Cartridge cases, 215-17, 521
 Strauss, Jerome, 481
 Strauss, Commander Lewis L., 463, 466, 467, 471-72
 Struthers Wells-Titusville Corp., 253
 Submarines, German, 55, 69, 79, 131-32, 143, 151, 154-55, 302, 406, 518-19
 Submarines, Japanese, 132, 151, 177-78
 Submarines, U. S., degaussing, 84-85; fire control, 399-400; guns, 261-62, 266; mines, 160, 162, 165; torpedoes, 29, 91, 94-118, 127, 519
 Sunflower Ordnance Works, 197
 Supplies & Accounts, Bureau of, 405, 449, 453-55
 Surigao Strait, Battle of, 264
 Sylvania Electric Products, Inc. (originally Hygrade Sylvania), 284, 285-86, 468, 478
 Tarawa, 61, 62
 Target Designation Transmitter Mark 8, 396
 Taylor, Albert, 409-10
 Telescopic sights, 345, 370, 375
 Tennessee Eastman Co., 205
 Terrestrial Magnetism, Department of, *see* Carnegie Institution of Washington
 Texhoma Co., 175
 Textile Machine Works, 473
 Thoradson Transformer Co., 230
 Tiny Tim, 308-10
 Tizard, Sir Henry, 276, 380, 418
 TNT, 97, 110, 132, 133, 136, 141, 145, 149, 202, 204, 301
 Tojo, General H., 16
 Torpedo Data Computers, 399-400
 Torpedo Director Mark 27, 401
 Torpedo Director Mark 28, 363-64
 Torpedo Director Mark 29, 402
 Torpedo Director Mark 30, 364-65
 Torpedo Director Mark 31, 402
 Torpedo Director Mark 32, 365
 Torpedo Mark 1, 21
 Torpedo Mark 2, 112-13
 Torpedo Mark 7, 91, 118-19
 Torpedo Mark 8, 91, 92
 Torpedo Mark 9, 91, 112
 Torpedo Mark 10, 91, 94-95, 110, 112, 120
 Torpedo Mark 11, 91, 93
 Torpedo Mark 12, 91, 93
 Torpedo Mark 13, 91, 119-24
 Torpedo Mark 14, 91, 94-96, 99, 103, 110, 112, 114
 Torpedo Mark 15, 91-94, 103
 Torpedo Mark 16, 117-18
 Torpedo Mark 18, 94, 113-15
 Torpedo Mark 19, 115
 Torpedo Mark 20, 113, 115
 Torpedo Mark 23, 96
 Torpedo Mark 25, 122
 Torpedo Mark 26, 115-16

- Torpedoes, 439, 497, 518; airplane, 118-24; Central Torpedo Office, 128-29; deep running, 93, 95, 96-99, 120; electric, 21, 29, 100-16; fire control, 363-65; 399-403; general characteristics, 91; German, 111-12, 113, 114; magnetic exploder for, 99-109; Navol, 18, 116-18; production, 124-29; submarine, 94-118; surface, 91-94; tubes, 129; warhead controversy, 109-10; WW I, 462
- Torpedo Speed Computer Mark 1, 364
- Torpex, 97, 110, 115, 205-07, 301, 338
- Toss bombing, 361-62
- Treasury, Department of the, 38-40
- Triumph Explosives, Inc., 232, 468
- Turrets, 253-54, 262-67
- Tuve, Merle A., 276-77, 279-81, 410
- Uhlan gear, 96
- Union Steel Casting Division of Blaw-Knox Co., 48
- United Engineering Co., 436
- U. S. Rubber Co., Charlotte, N. C., 232, 468
- UWE, 207
- Vickers, Inc., 228, 253, 468
- Victory Ordnance Corp., 245, 468
- Vieille (French chemist), 188
- Vinson Shipbuilding Program, 124
- Vinson-Trammell Act, 6, 38-41
- von Neumann, John, 493
- von Rundstedt, Field Marshall, 289-90
- Vosseller, Commander A. B., 357
- VT fuze, 16, 29, 322, 439; administration, 276-78; APL, 277-78; background, 271-76; batteries, 281-82; description of operation, 278-79; in battle, 286-90; production, 283-86, security, 286; vacuum tubes, 281
- Wabash Ordnance Works, 205, 207
- Wadsworth, Representative J. W., 502
- Waldman, Norman E., 481
- War Production Board, 45, 429, 438, 453, 459
- Washington Naval Conference, 1922, 1, 32, 35, 124
- Waterbury Tool Co., 253
- Watertown Arsenal, 496, 501
- Watervliet Arsenal, 252, 496, 501
- WAVES, *see* personnel
- Webster Electric Co., 228
- Wenner-Gren, Axel, 222
- Western Electric Co., 275, 281, 415, 431
- Westinghouse Electric Corp., 113, 114, 116, 127, 129, 230, 468
- Wharton School of Finance, University of Pennsylvania, 482
- Williams Oil-O-Matic Heating Corp., 230
- Willys-Overland Motors, Inc., 468
- Woods, Robert W., 494
- Woofus, 315
- Yale University, 482
- Yards & Docks, Bureau of, 184
- Yarnell, Admiral H. E., 482
- Y-gun, 132-33, 134-35
- York Safe & Lock Co., 222, 225-27, 228, 233, 468
- Young, Leo, 409-10
- XAF, 414
- X-ray, 199
- Zacharias Zombie, 339, 340

11

The first part of the report
 deals with the general
 situation of the country
 and the progress of the
 work during the year.
 It is followed by a
 detailed account of the
 various projects and
 the results obtained.
 The report concludes
 with a summary of the
 work done and the
 conclusions reached.
 The following is a
 list of the projects
 carried out during the
 year:

1. The first project
 was the study of the
 effect of temperature
 on the rate of reaction
 between A and B.
 The results show that
 the rate increases
 with increasing
 temperature.
 2. The second project
 was the study of the
 effect of concentration
 on the rate of reaction
 between A and B.
 The results show that
 the rate increases
 with increasing
 concentration.
 3. The third project
 was the study of the
 effect of a catalyst
 on the rate of reaction
 between A and B.
 The results show that
 the rate increases
 when a catalyst is
 used.