

The Charles Stark Draper Laboratory

68 Albany Street, Cambridge, Massachusetts 02139

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A Division of
Massachusetts
Institute
of Technology



The Charles Stark Draper Laboratory

68 Albany Street, Cambridge, Massachusetts 02139

Dr. C. S. Draper, President

TO: Draper Lab Employees
FROM: C. Stark Draper

Enclosed is a copy of a recently published brochure, intended to make known to a wider audience the Laboratory's accomplishments and capabilities and its continuing aspiration to advance technology in the service of man.

We hope that it will serve to expand your own knowledge of the Laboratory and make the nature of your employment more meaningful to your family and friends.

Stark Draper

THE CHARLES STARK DRAPER LABORATORY



Our Cover Design stresses the fact that at Draper Laboratory geometry is the name of the game. Dynamic geometry is the principal tool of the science of navigation, guidance and control, the language of the universe, the pathway to the cosmos.

The Status Quo

The Charles Stark Draper Laboratory, formerly the Instrumentation Laboratory of the Massachusetts Institute of Technology, began in 1935. It was created as an integral part of the Department of Aeronautics and Astronautics. The Institute felt then, as it still does, that learning by doing is the best practice for the advancement of education in technical subjects. The Laboratory operated for thirty-five years as a Departmental Laboratory within M.I.T.'s academic structure, this educational process supported by advanced technology contracts serving primarily to further the aims and objectives of the government.

The Laboratory has been an important factor in attracting active minds to M.I.T. at both student and faculty levels. Its professional staff has accomplished many successes at the very forefront of advanced technology required by the government programs. Over the years of its life, as the Laboratory has grown, the hard question has arisen as to the propriety of a university managing such an enterprise devoted to very specific needs of the government. The Institute, in reappraisal of its position, decided that its interests and those of the government can best be served by separation of the Laboratory from the scholastic and academic machinery with which the Institute serves the public weal. Thus in June 1970 the Laboratory became a Division of the Institute, with administrative independence but with mechanisms which will permit the continuation of joint educational and research ties with the parent institution. In this new status the Laboratory enjoys an unprecedented degree of autonomy, and accepts a similar burden of responsibility for the conduct of its business. Its maturity is exemplified by its own roster of Officers and its own Board of Directors. Other management changes will take place when conditions demand them or when they are opportune.

The future of the Laboratory may be a matter of wonder but it not a matter of concern. The record of the Laboratory was made by anticipating the future, not as a formidable foe to be faced but as a good place to work. Responsibility has a way of settling on those who can handle it, and the Draper Laboratory has proved itself in a thousand ways. Its accomplishments of today will, as they have in the past, make tomorrow's history.

History

The history of the Laboratory is pretty much the history of Dr. Charles Stark Draper, the eponymous founder and current President of the Laboratory. Dr. Draper's remarkable career began when, as a second lieutenant in the then-young Army Air Corps, he became fascinated by the possibilities he could envision in flying by instruments. His interest has never flagged, and his relentless pursuit of perfection continues. He entered M.I.T. as a student in 1922 and has been continuously associated with the Institute ever since. It is M.I.T. legend that he took more courses for credit than anyone in Institute history. He became an Assistant Professor in the Department of Aeronautics and Astronautics in 1935, the year of the founding of the Laboratory, and has succeeded to all the possible faculty positions — Associate Professor in 1938, Professor in 1939, Department Head in 1951, and Institute Professor in 1966. He is President of the International Academy of Astronautics, Chairman of the National Inventors Council, and holds fellowships and memberships in some twenty societies devoted to the advancement of science.

He has been awarded the highest honoraria of the Navy, the Air Force, the Department of Defense, and NASA. He holds the Thurlow Award of the Institute of Navigation, the Medal of Science Presidential Award, and encomiums of some fifty more of the most prestigious organizations that recognize outstanding contributions to scientific progress.

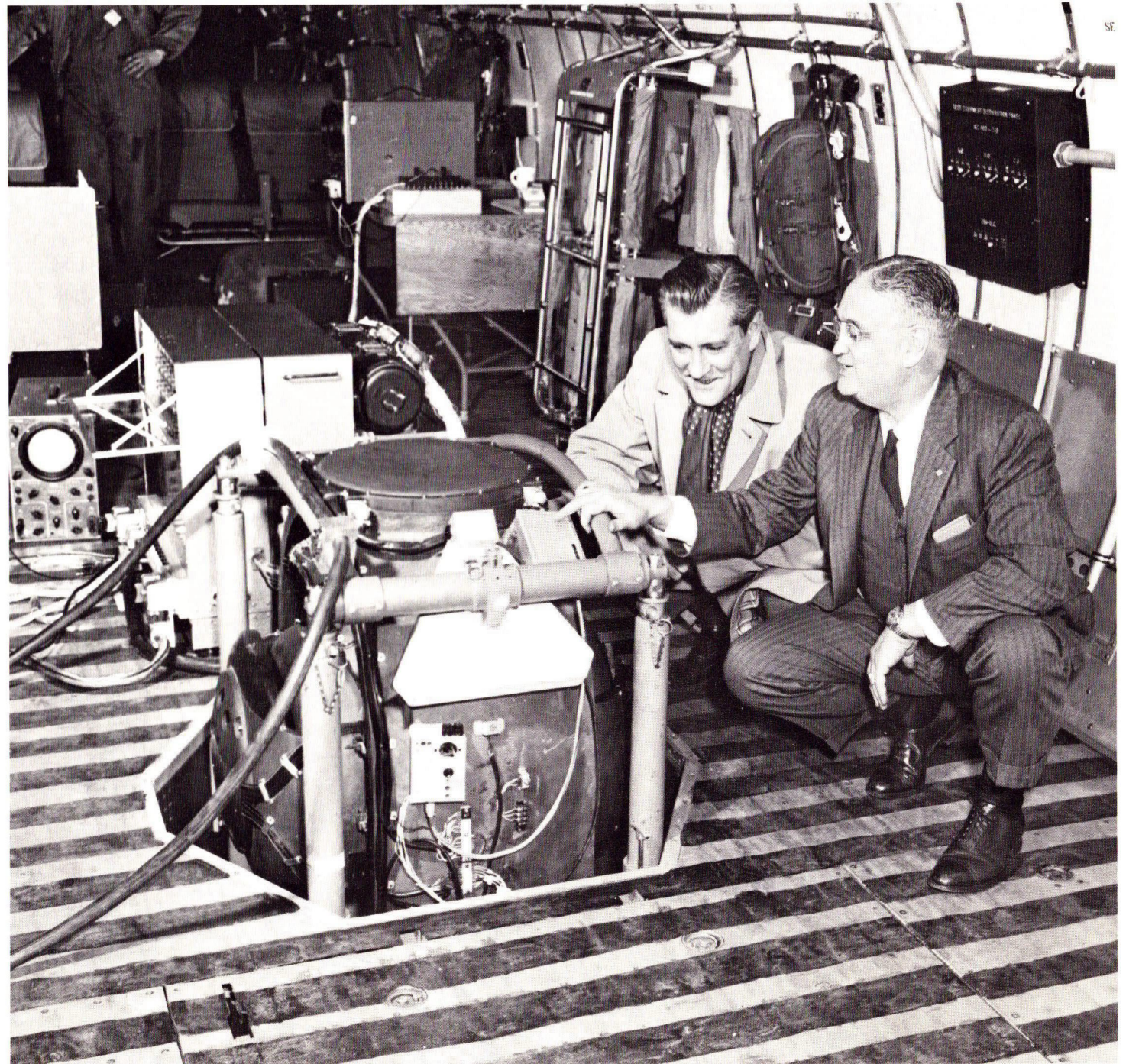
The Laboratory's earliest excursions into systems engineering were directed to the problems of fire control and aircraft instruments. In the 1930's the largest part of the Laboratory's attention was directed toward sensors and their improvement. Dr. Draper's intense interest in fire control systems coincided with World War II. This led the Laboratory into the field of controls for weapons and flight vehicles, and significant contributions were made to the national effort. The Draper Mark-14 gunsight, first used in battle in 1942, enabled the U.S.S. South Dakota to shoot down 32 Japanese Kamikazes in a single engagement, an unprecedented anti-aircraft score. A long succession of constantly improved gunsights has enabled the



Navy to meet the demands of range and accuracy in gunnery to provide superiority in fire power. The Draper A-4 gun-bomb-rocket sight used aboard F-86 fighters in the Korean war is generally accorded a significant share of the credit for the more than 10:1 kill ratio our pilots experienced in combat with MiG fighters.

In August 1945 the Laboratory reported to the Air Force that inertial guidance for long-range, high-precision bombing missions was feasible. Since then the Laboratory has sought constantly to improve navigation through the use of gyroscopic devices and specific-force instruments. A Draper stellar-inertial guidance system incorporating a stable platform successfully guided a B-29 from Hanscom Field, Bedford, Mass., to Wright-Patterson Field, Dayton, Ohio, in June of 1949. The first fully inertial system, SPIRE, flew a B-29 from Bedford to Los Angeles in February, 1953. This and many succeeding flights established the feasibility of all-inertial aircraft navigation and vehicle control. SPIRE's successor, SPIRE JR., successfully flight-tested in November of 1957 in a C-97 aircraft, incorpo-

TV Commentator Eric Severeid and Dr. Draper inspecting Spire, Jr. onboard a C-97 aircraft prior to the historic 1957 flight



rated dramatic reductions in size and weight and demonstrated improved performance.

Dr. Draper and the Laboratory began work on marine navigation using inertial devices early in 1950 by development of the MAST (Marine Stable Element) system. This was the first system to give a precise indication of the vertical and azimuth during ship maneuvers and was successfully tested at sea in March 1954. The first SINS (Ships Inertial Navigation System) was shore-tested in January of 1954 in a van driven from Boston to Newburyport, a distance of 30 miles. First shipboard tests were conducted aboard the U.S.S. Canisteo on a 15-day round trip cruise from Norfolk, Va. to Long Island, N.Y. Succeeding tests were made on cruises into the Mediterranean and Caribbean Seas.

Formal work on a guidance system for intercontinental ballistic missiles began in January 1954. A short time later the Laboratory became an associate contractor on the Air Force ICBM program. By 1955 the system was developed to such performance capability that its design could be accepted as the basis for the equipments to

guide the operational Thor intermediate-range ballistic missiles. Hardware for the system was produced by industry and the production version was first tested in a closed-loop configuration at Cape Canaveral in December of 1957.

During the late stages of Thor Dr. Draper and the Laboratory began work on a guidance system for Polaris, a 1500-mile missile to be launched from a submerged platform. The first fully inertial Polaris was shore-launched in January of 1960 and the first from a submerged submarine in July of 1960. The Draper Laboratory's second-generation Mark II Polaris system designed for a 2500-mile range missile, was successfully tested in February 1962.

Concurrently with the Polaris effort, work proceeded on an inertial platform for the Titan intercontinental ballistic missile. The use of beryllium instead of steel and aluminum as a structural material was an important advance which eventually made possible a system capable of industrial production. The first inertially-guided Titan flight was made in July 1961.

It is an historical fact that at Dr. Draper's Laboratory so much

Polaris missile launch



experience and knowledge are derived from development of a specific system that a successor system requires only the application of the new knowledge. Thus the instruments, and the systems, grow in sophistication, making possible new refinements in performance and reliability and new successes in the fields for which the Laboratory has such unique capability. Such a system evolved from Polaris with improved inertial components, a more powerful general purpose computer and associated missile improvements. This was the Poseidon missile, which has much greater effectiveness, and its installation began in fleet ballistic missile submarines in late 1970.

The largest single undertaking of the Laboratory began in 1961, when the Laboratory was entrusted with design and development of the guidance-navigation systems for the Command and Lunar Modules of the Apollo program. The spectacular success of the Apollo lunar missions is well known and in every one the guidance system has been accurate and reliable. In fact on the Apollo 13 mission, which had to be aborted because of an explosion

that rendered a large part of the command module temporarily useless, the guidance system completed its task perfectly and brought the command module back to splash-down on target. A problem developed on Apollo 14 when a defective switch began sending spurious abort signals to the Lunar Module's on-board computer. In the very short time allowable before cancellation of the lunar landing might become mandatory, the Laboratory staff devised effective "work around" procedures that enabled the crew to by-pass the faulty switch and permitted the mission to continue. This newsworthy event attracted attention in the international press.

Because the Laboratory is basically mission-oriented, the original purpose of teaching-by-doing has always been, and is still, paramount. During the years of its existence, the Laboratory has consistently welcomed students of promise, capable of original thought, for exposure to "real world" situations at the pioneering edge of technology, and its graduates have become leaders in industry, in research, and in teaching. It is gratifying to Dr. Draper and to the perman-

ent staff that so many who passed through the Lab have become key figures capable of accepting the responsibilities of

successful continuance of the nation's scientific effort — a "capital gain" in think-power, our greatest national resource.



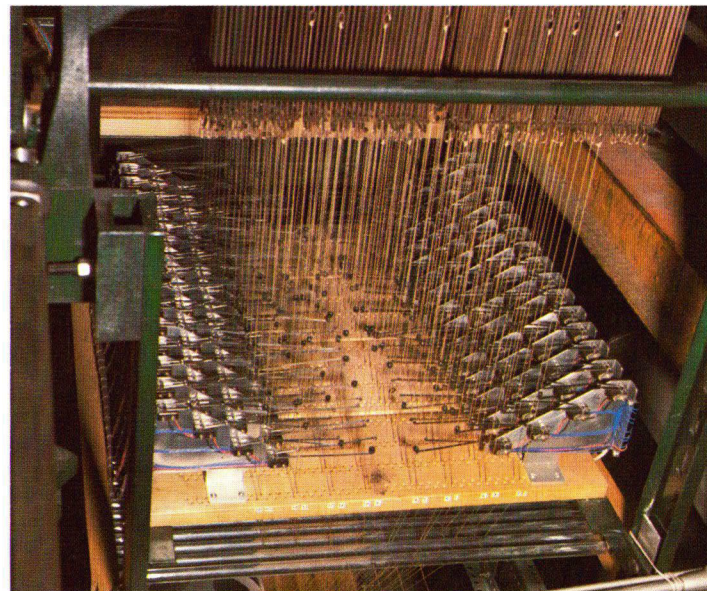
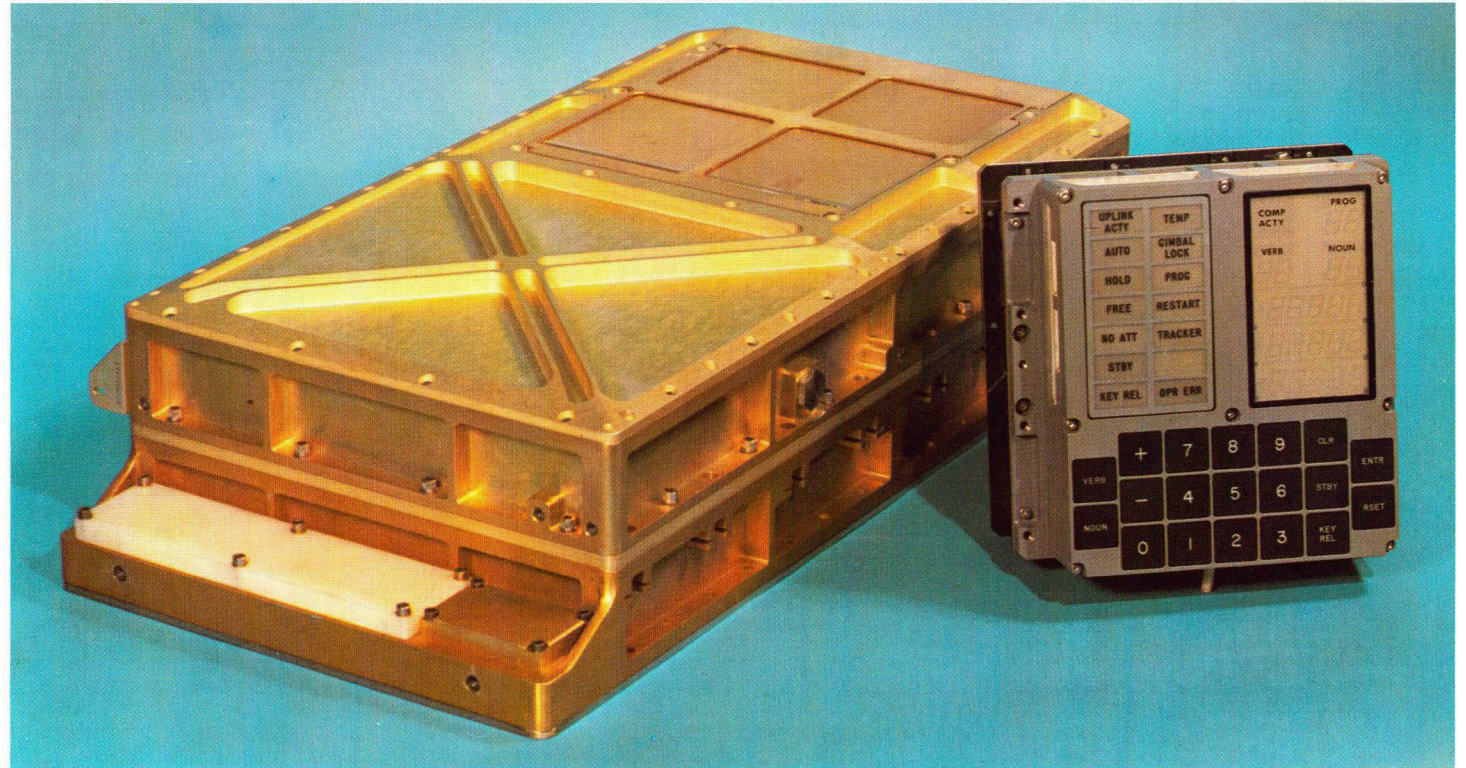
Apollo, Command Module primary Guidance and Navigation system

Objectives

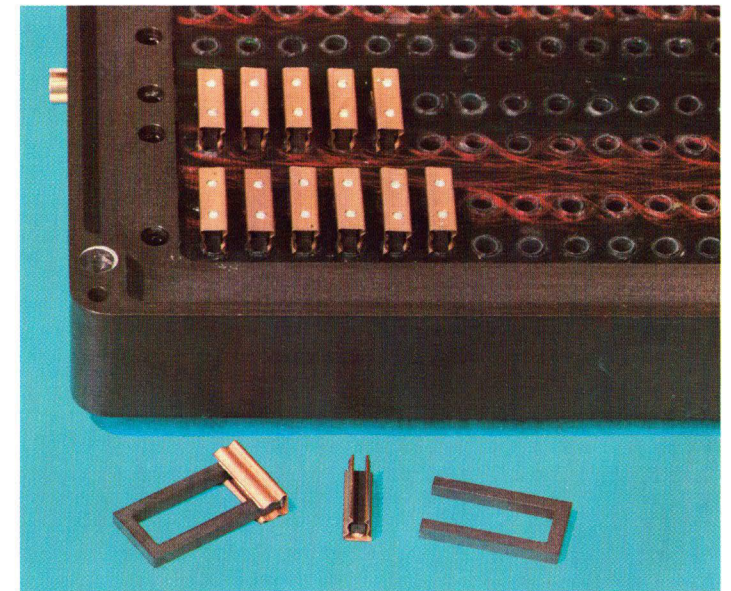
The Laboratory continues to serve the nation and society by application of its resources and talents for:

1. The advancement of scientific and technological education in general, particularly at the interface of formal academic education and professional practice, in an environment conducive to the greatest possible personal development.
2. Contributions to the knowledge and techniques of science, applied science and technology.
3. Creation of operational components, complete systems and subsystems, producible by industry, with performance characteristics that represent pioneering capabilities for the nation, our society, and humanity generally.

The Apollo flight computer occupying less than 1 cubic foot of space, with a fixed memory of 36,000 words and an erasable memory of 2,000 words



A Laboratory breakthrough — use of loom to braid the memory of the Apollo computer



Braided memory section of Apollo computer with its ferrite core elements

Policies

To be acceptable to the Laboratory a project must fit into the framework of intents and purposes stated generally as objectives and tailored by specific governing policies. The boundaries of acceptability are set as follows:

1. Sponsored research projects must enable the continuance of the educational two-way flow. Opportunities must be inherent for the achievement of academic credit for the student and advancement of professional standing for members of the staff of the Laboratory who are to be involved.

2. Projects must:

a) Require research at the frontier of science or technology involved.

b) Lie in the field of competence of this Laboratory, and within the framework of background and interest of the members of the Laboratory.

c) Be characterized by pursuit of the highest standards of performance and reliability.

d) Have the potential for improving the national life or, better still, for improving the environment of world life generally.

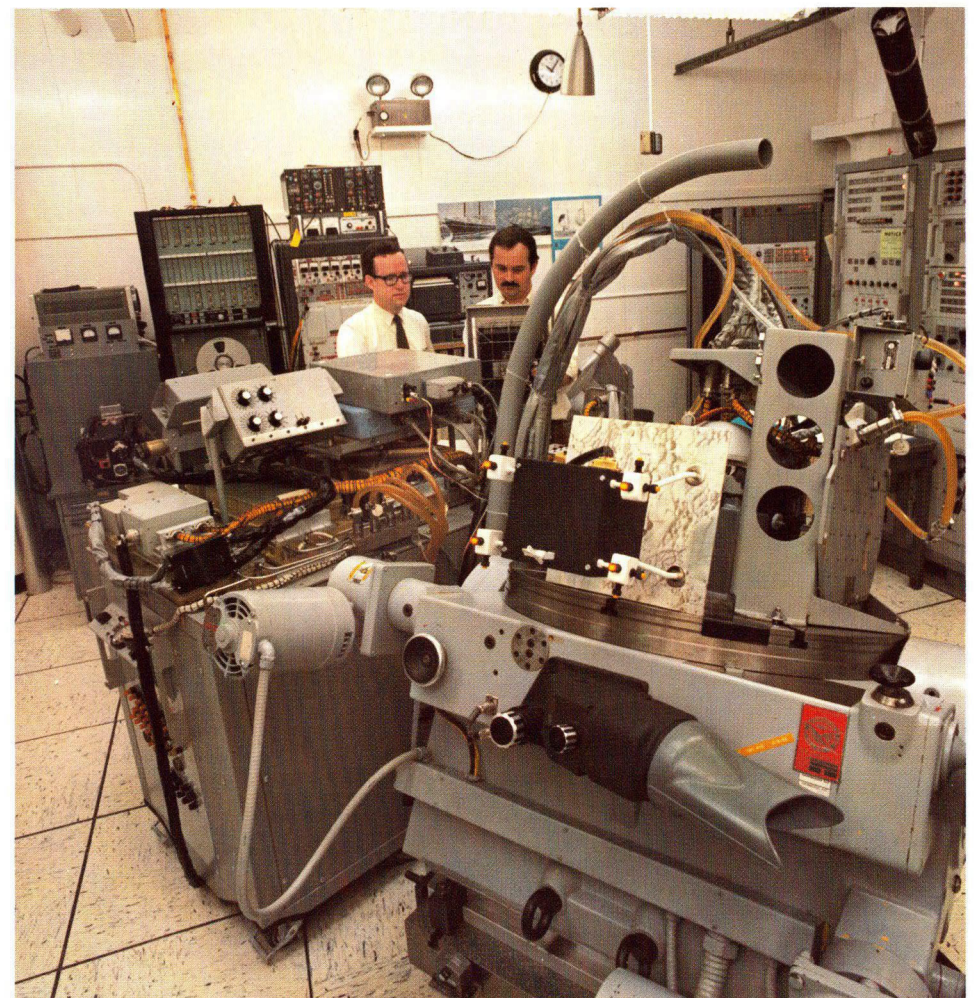
3. Exceptions may be made. Tasks of a routine or "production in quantity" nature may be accepted if they point up improved industrial methodology, stimulate industrial development, or meet an imperative need of the sponsor.

4. The general field of interest of the Laboratory deals with sensing, processing and applying information essential to improved performance of systems or of processes. During the past two decades special attention has been directed towards the application of dynamic geometry in stabilization, control, guidance and navigation of flight vehicles carrying out missions of accurate transportation to fixed or moving destinations. Beyond this, Laboratory interest embraces the progress of scientific, engineering, and technological endeavors directed toward better living for humans, the intelligent use of natural resources and the conservation of the environment within which life continues.

5. The Laboratory seeks authority and responsibility needed to conceive, design, construct, test, generate manufacturing documentation for, and finally super-

vise production of whole systems, from gleam-in-eye to full maturity. This sort of responsibility is essential to the creative environment of the Lab, in which professional achievement for Laboratory staff and Institute faculty, and personal achievement for students are realizable goals.

6. In summary, the overriding policy of the Lab is to pursue a course by which material benefits to the national good accrue from the efforts of all participants in its projects.

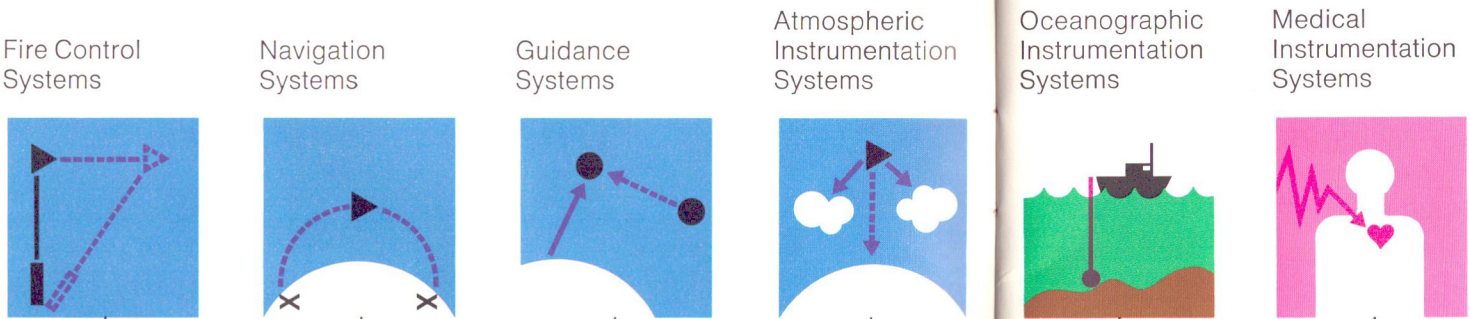
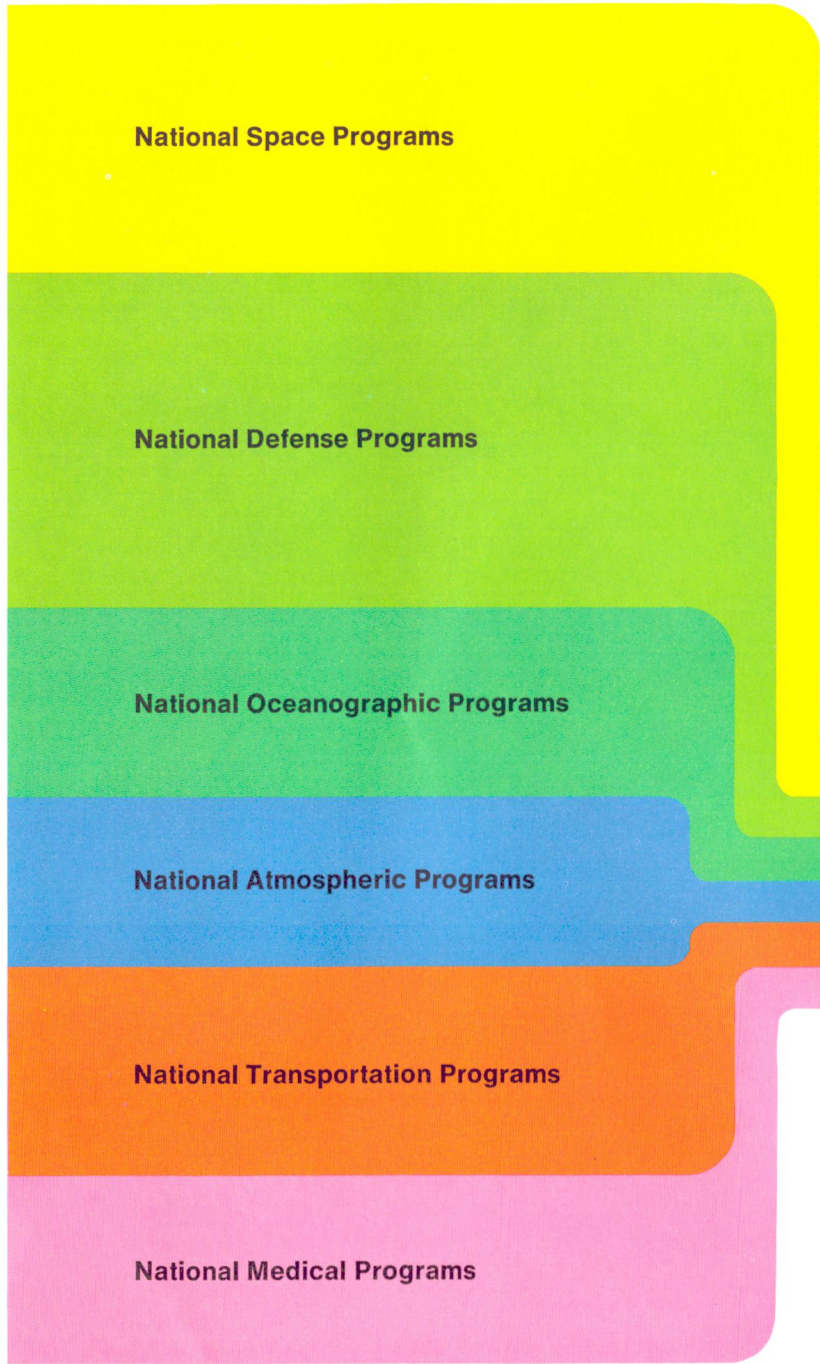


Testing of Lunar Module's Guidance, Navigation and Control System

The General Framework

The parts of these programs that require precision instrumentation are directed to Draper Laboratory. The Laboratory responds in development, design and fabrication of advanced hardware prototypes essential to:

The U.S. Government expresses its needs in the field of science through:



Specifically:

- For NASA:**
 - Apollo Guidance
 - Mission Simulation
 - Mission Analysis
 - Space Shuttle Guidance
 - Satellite Attitude Control
 - Remote Manipulation
 - Lunar Gravimetry Development
- For D.O.D.:**
 - Air Force Air Navigation Systems
 - Air Force Aircraft Fire Control
 - Air Force and Army Aircraft Flight Control Systems
 - Air Force and Navy Missile Guidance Systems
 - Navy Submarine Navigation Systems
 - Navy Deep-submergence Control Systems
 - Navy Hydrofoil Control System
- For N.O.A.A., W.H.O.I. and N.S.F.**
 - Data Buoy Systems
 - Oceanographic Computer Modeling
 - Instrumentation for Real-Time Monitoring of Oceanographic Efforts
- For NASA:**
 - Aeronomy Studies and Experiments
- For F.A.A.:**
 - Navigational Aids Inspection System
 - Aircraft Strokes System
 - Optimum Aircraft Traffic Control Systems
- For N.I.H., NASA:**
 - Medical Instrumentation
 - Medical Computer

National need for Scientists

Education

In response to a National need for more and better trained scientists and technologists, the Laboratory conducts courses for degree credit at undergraduate and graduate levels in the fields of its special competence. It also undertakes to add to the competence of its sponsoring organizations, users of its products and services, and industrial concerns that accept contracts for production models.

Activities

Currently the Laboratory is engaged in applying inertial reference toward perfection in the science of guidance and navigation, and it has several projects in work that apply this principle in vehicles that will operate on land, on sea, below the surface, in the air, and in space. Submarines, surface ships, helicopters, manned and unmanned aircraft, aerodynamic missiles, ballistic missiles, orbiting craft and vehicles for extraterrestrial flight share a common need for accurate guidance. The Laboratory's approach to guidance and navigation problems places emphasis on precision as the best avenue to high performance and reliability, but with recognition that cost, time and functional requirements are important considerations.

Accomplishments of the recent past and a reasonably definitive list of current activities include the following:

Inertial Sensor developments for a third generation of instruments have reached the stage of extended tests on engineering prototype units. First results indicate that design performance objectives can be achieved or exceeded for both the gyro units and the specific-force integrating

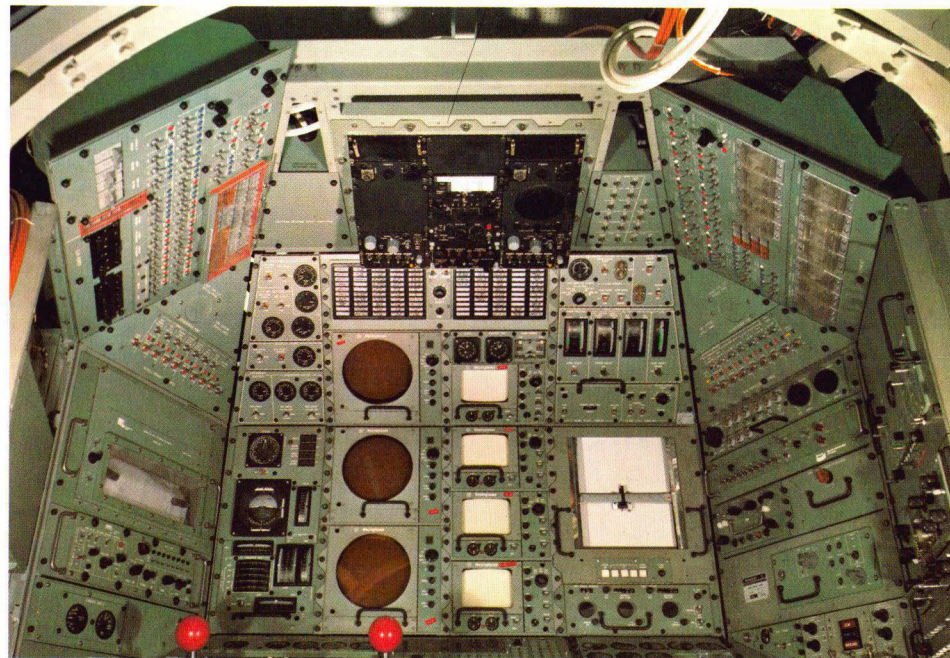
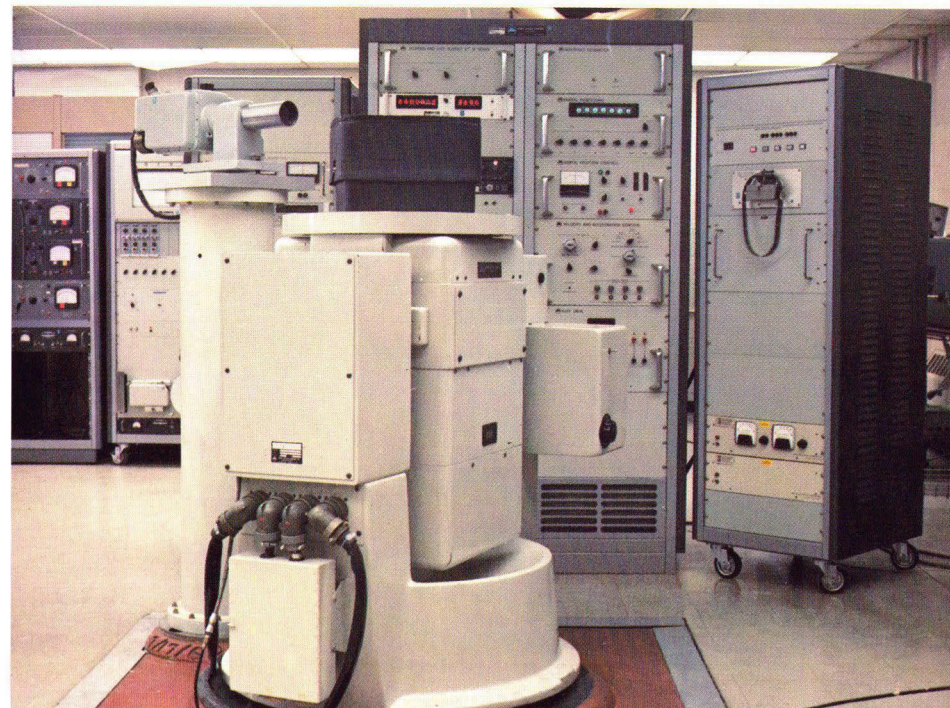
receivers. System designs incorporating these new sensors will occupy the attention of the Laboratory for several years.

Operational tests of the Poseidon Fleet Ballistic Missile have confirmed performance goals set for its guidance and control systems.

In support of the Navy's Deep Submergence Systems Rescue Program, two complete suits of equipment and spares of the sensors, navigation and control equipment, and operational software have been designed, built, integrated and delivered for the Deep Submergence Rescue Vehicles. These equipments are being supported by field test, configuration management and engineering personnel. The crews for the vehicles have been trained at the Laboratory utilizing a hybrid computer simulation with a complete house model of control equipments. Initial results from test dives of the DSRV-1 have been highly satisfactory, and a successful undersea transfer of personnel from submarine to rescue vehicle has been accomplished.

Tests of a hydraulically-supported inertial measurement platform, already built for the

Fully automated inertial test station



Integrated control and display console of the Deep Submergence Rescue Vehicle

Pre-flight checkout of VTOL
experimental control system



Air Force, prove that the concepts involved are sound. Components and subsystems for incorporation into the guidance or precision range measurement systems are now in development stage. This new equipment will be smaller and lighter, with higher performance and greater reliability than existing hardware.

SEAL, a geometrical reference system for navigation and landing aids calibration, designed and built for the Federal Aviation Administration, has completed the required series of tests and a final report has been delivered to FAA.

Three Stabilization and Angular Control Systems for NASA's Orbiting Astronomical Observatory (OAO) have been built and delivered. The systems have passed acceptance tests and have been made available for installation in vehicles.

Control for vertical take-off and landing aircraft (VTOL) has been the subject of continued research and development in the Laboratory, under Army sponsorship. Engineering models have been satisfactorily tested in helicopters. As the work continues the application of improved sensors and advanced mechanizations can be expected

to realize very significant technological progress during the foreseeable future. Logical extensions of the program are expected in the area of civilian short-haul VTOL transportation, where application of the technology can lead to much improved safety and ability to conduct scheduled operations without interference by weather conditions. The circumvention of these limiting factors is essential to the successful development of VTOL transportation, a much-desired goal of commercial aviation generally.

The Apollo program continues. The expertise resulting from this long and rewarding program can be credited with important contributions to its success in an essential and critical area. NASA projects continue to represent an important part of the support of the Laboratory. Sky Lab and Space Shuttle are current activities of Apollo-related interest.

A major scientific lunar-surface gravity experiment, proposed by the Department of Earth and Planetary Sciences (E&PS) of M.I.T., the Lamont Doherty Laboratory of Columbia University, and the Draper Laboratory has been accepted



and funded by NASA. This Lunar Traverse Gravimeter is currently in the design and fabrication stage at the Laboratory and is scheduled to go along on the Apollo 17 lunar mission.

In company with the E&PS Department, under National Science Foundation sponsorship, the Laboratory is designing a major array of oceanographic sensors for an international mid-ocean dynamics experiment, involving several U.S. universities and oceanographic centers as well as British, Canadian, and other foreign participants. The equipment is scheduled for completion and deployment in 1973.

The Laboratory is always pleased when its expertise can be applied to programs resulting in human betterment. Significant growth of the Laboratory's involvement in bio-medical engineering can be reported. Collaborating with M.I.T.'s Clinical Research Center, the Lab has extended its role in automating clinical chemistry and in developing the interactive use of computers with bio-medicine.

Applications of modern control theory are of great interest to the Lab, and it would welcome opportunities to broaden its activities in this area. One effort

involving industrial sponsorship is worthy of note. During 1970 the Laboratory accepted a contract with Fiat SpA Corporation of Turin, Italy, to explore the incorporation of modern control theory into industrial processing. This activity has identified an approach-to-failure diagnosis that promises significant improvements in efficiency for automated manufacturing processes.

An example of Laboratory academic interaction with M.I.T. is a fully accredited Freshman seminar offered in both the Spring and Fall terms. These seminars center around the Lab's Scientific Technology Division and involve many members of the Laboratory staff in teaching roles. The seminar program has expanded to accommodate increasing student interest.

Faculty members from Aeronautics and from other Departments of M.I.T. continue to provide a bridge between academic science and the extremely practical atmosphere of the Laboratory, lending their support to Laboratory activities and deriving empirical information from the advanced technology developed in the Lab. for incorporation into modern engineering

curricula. Dr. Draper was for many years Head of the Department of Aeronautics and Astronautics as well as Director of the Laboratory. His continued interest in the educational aspects of the Laboratory has

brought members of the M.I.T. faculty into the Laboratory's specialized sphere. Additionally he has always encouraged members of the Laboratory's professional staff to participate in academic programs.

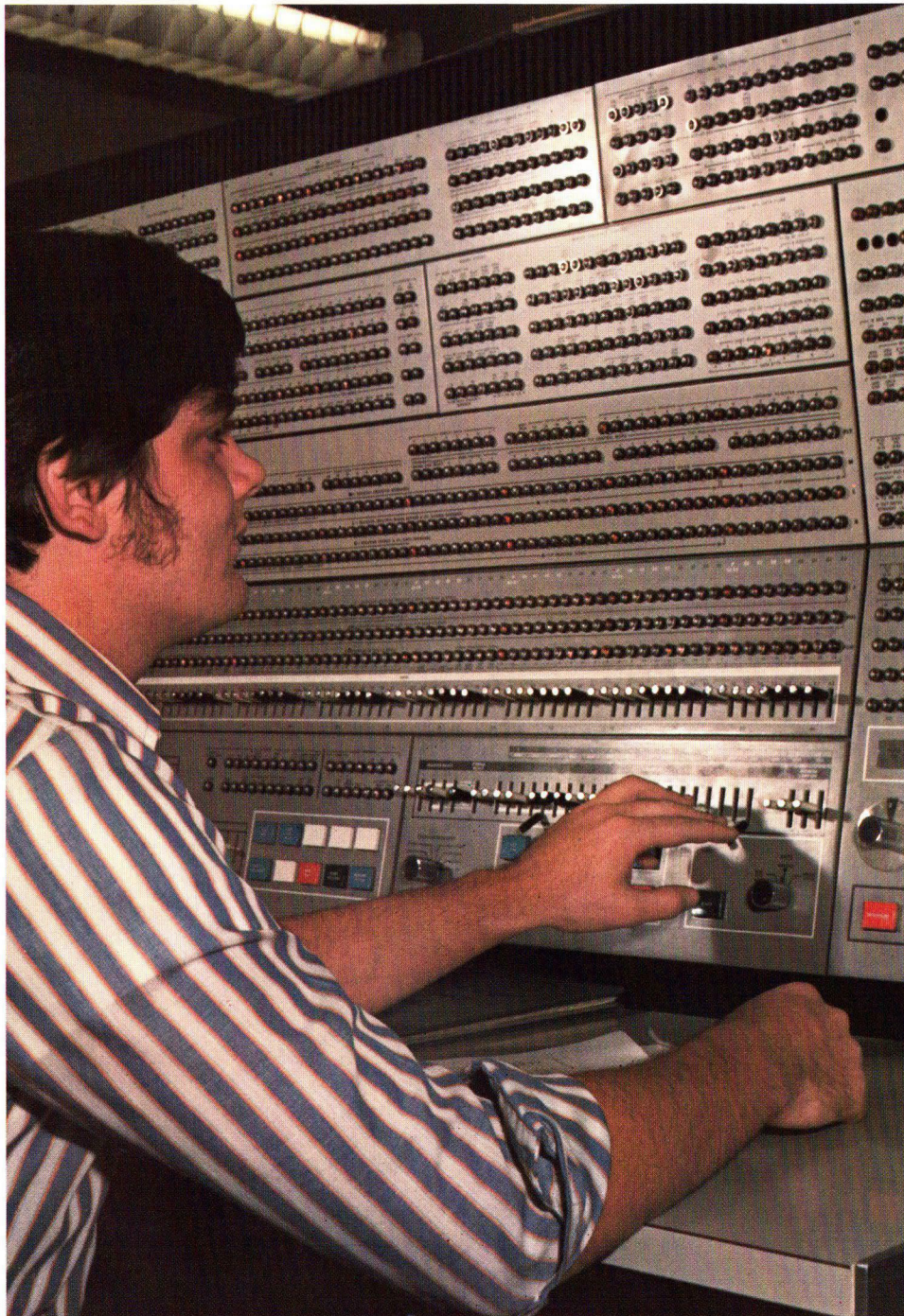


Laboratory instrumentation for oceanographic research

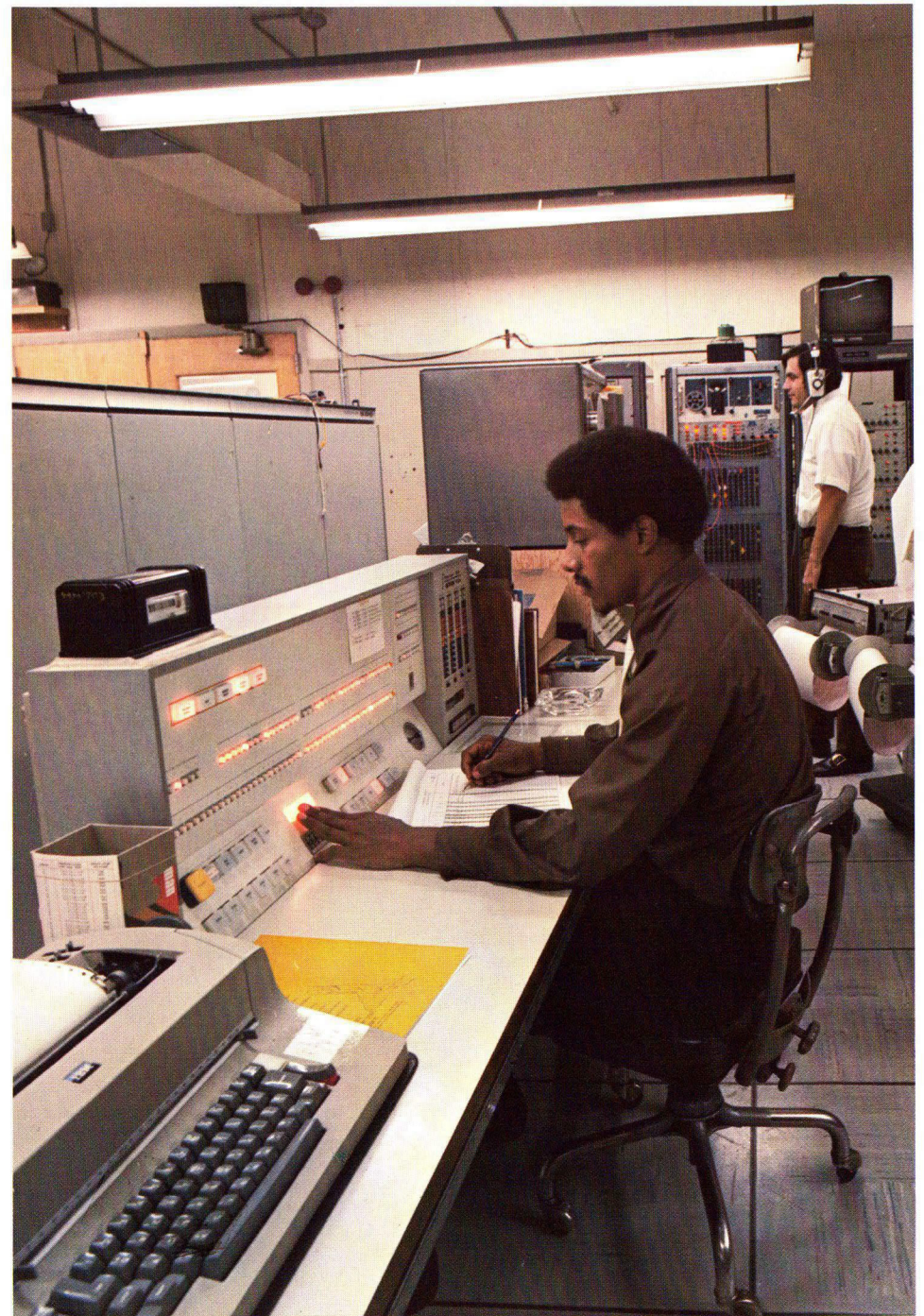
Programs of the Laboratory

Name or Symbol	Sponsor	Requirement
Gyro Research	Air Force (ASD)	Basic and applied research related to the development and test of advanced inertial sensing instruments including exploratory development and test of new sensors, materials research, and transmission of developments to industry.
Test and Test Instrumentation	Air Force (SWC)	Improve the testing machinery and operational methodology of an advanced gyro test station at the Central Inertial Guidance Test Facility at the Air Force Missile Development Center.
IR and UV Radiometers	Air Force (SAMSO)	Modify and improve infrared and ultraviolet radiometers developed by Draper Laboratory under previous contracts to deliver flight-qualified units.
AIRS (Advanced Inertial Reference System)	Air Force (SAMSO)	Develop Third-Generation Inertial Instruments, Gravity Gradiometers, and Inertial Measurement Units to advance the state-of-the-art in IMU technology, accuracy, reliability and environmental survivability.
SAMSO Support	Air Force (SAMSO)	Provide technical support of the Minuteman 16 PIGA Program and the Minuteman III Guidance and Control Program.
SIGHT	Air Force (SAMSO)	Conduct research and development toward higher performance and reliability in Small Inertial Guidance Hardware Technology.
Advanced Interactive Display System	Air Force (RADDC)	Extend the capability of the Anagraph Computer Display System developed for Data Disc Inc. to a generalized display system to reduce cost and increase capability and flexibility of an intelligence data handling system at Rome Air Development Center.
Reticular Model	Air Force (ASD)	Design a new model of the reticular formation (H-RETIC).

The largest of the Laboratory's many computers is the IBM 360/75



The hybrid analog-digital computer control console



Name or Symbol	Sponsor	Requirement
Holloman Centrifuge	Air Force (SWC)	Make a detailed study and diagnostic tests of the precision centrifuge machine at the Air Force Central Inertial Guidance Test Facility at Holloman Air Force Base, and provide redesign plans, working drawings, specifications, and prototype components to upgrade the centrifuge.
LES 8/9	Air Force (SAMSO)	Develop, fabricate, test and deliver three strapped-down, single-axis third generation gyro systems for experimental satellites under development by Lincoln Laboratory of M.I.T.
DSRV (Deep Submergence Rescue Vehicle)	Navy (DSSP)	Conduct research and studies of vehicle ship control and develop, design, fabricate, test and deliver the Navigation and Sensor Subsystem for the Deep Submergence Rescue Vehicle and associated software and support equipment.
Poseidon	Navy (SSP)	Design and develop the Poseidon Missile Guidance System, including new and advanced inertial components and advanced electronics.
ULMS	Navy (SSP)	Engineering services and studies related to advanced guidance of the Underwater Launched Missile System.
SSTTP	Navy (SSP)	Provide special engineering studies associated with general guidance problems; provide Safeguard System Target Test Program flight support, evaluation and data analysis; correlate actual performance to Polaris tactical program reports, as indicated by flight test data.
FBM	Navy (SSP)	Analysis of field test performance and evaluation of producer-initiated changes for the Polaris Missile Guidance System. This program, begun in 1957, resulted in the development of two generations of this guidance system.

Deep Submergence Rescue Vehicle
riding "piggyback" on mother
submarine

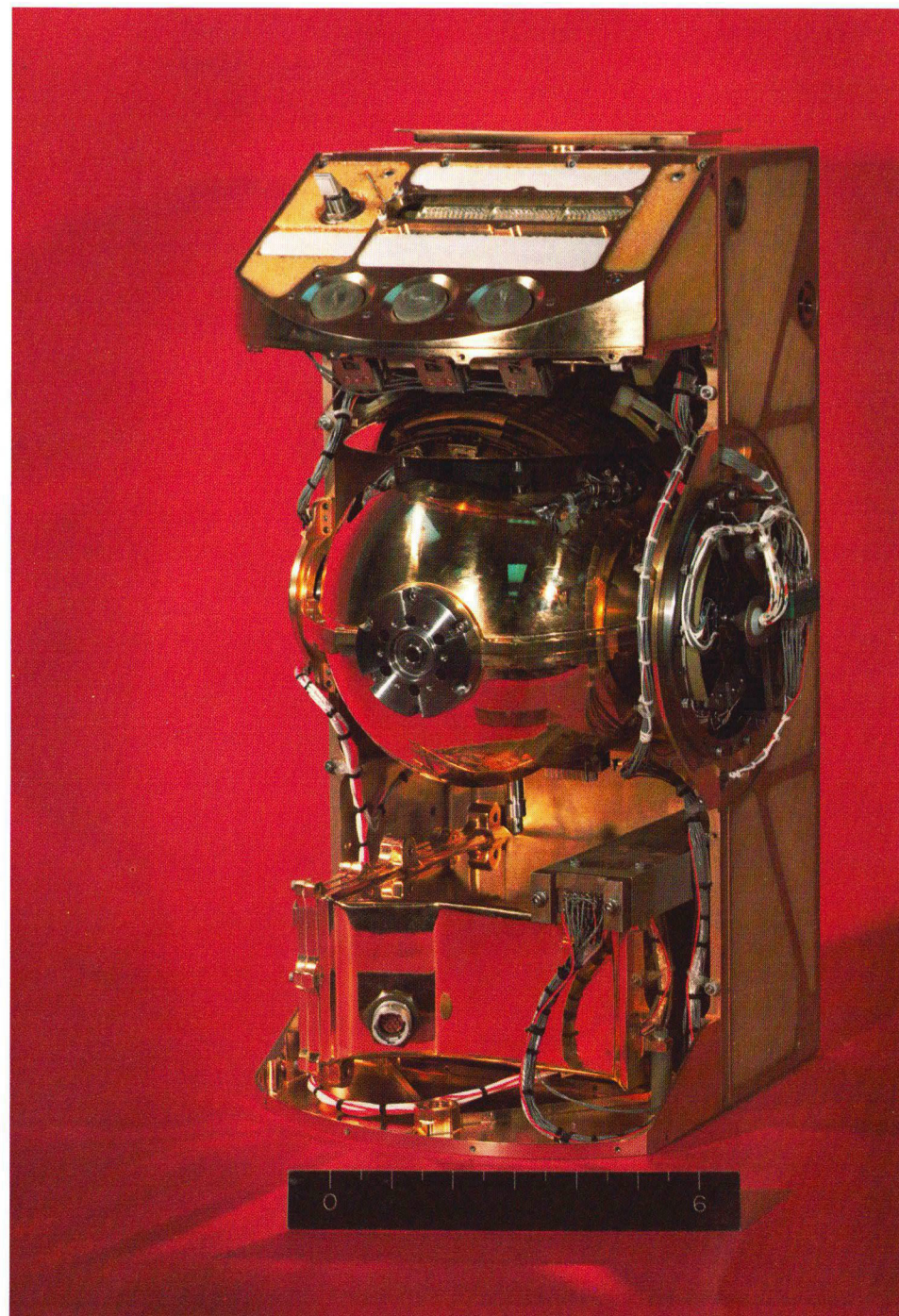


Name or Symbol	Sponsor	Requirement
Damping Fluid	Navy (SSP)	Develop an alternate source for an inertial component damping fluid.
HELIOS	Navy (SSP)	Application of the unusual properties of low temperature liquid helium to the development of high accuracy inertial instruments.
Ocean Telescope	Navy (ONR)	Develop and deploy an array of thermistors and pressure transducers to measure spectral and synoptic characteristics of oceanic internal waves in the main thermocline.
Hydrofoil Digital Autopilot	Navy (NSRDC)	Design and develop a universal digital autopilot for the prime controller of hydrofoil craft.
Tactile Communication	Navy (NSRDC)	Develop a tactile sensor to enhance the operator communications for control of vehicles such as DSRV.
Apollo Guidance, Navigation & Control System	NASA (MSC)	Design, develop, test, and provide operational support for the on-board primary guidance, navigation and control systems for the Apollo spacecrafts, the Command Module, and the Lunar Module.
GN&C Software Equations Definitions	NASA (MSC)	Identify and document the GN&C software requirements and base-line equations for space shuttle missions to which Apollo knowledge and technology may be applied.
NEW NAV	NASA (MSC)	Continue the effort to produce new techniques for the guidance and navigation of space vehicles for economical orbit-keeping over long durations.
TGE	NASA (MSC)	Design, develop, fabricate, test and deliver a flight-qualified Lunar Traverse Gravimeter, including associated software and documentation.

Exterior view of Lunar Gravimeter,
an Apollo 17 experiment

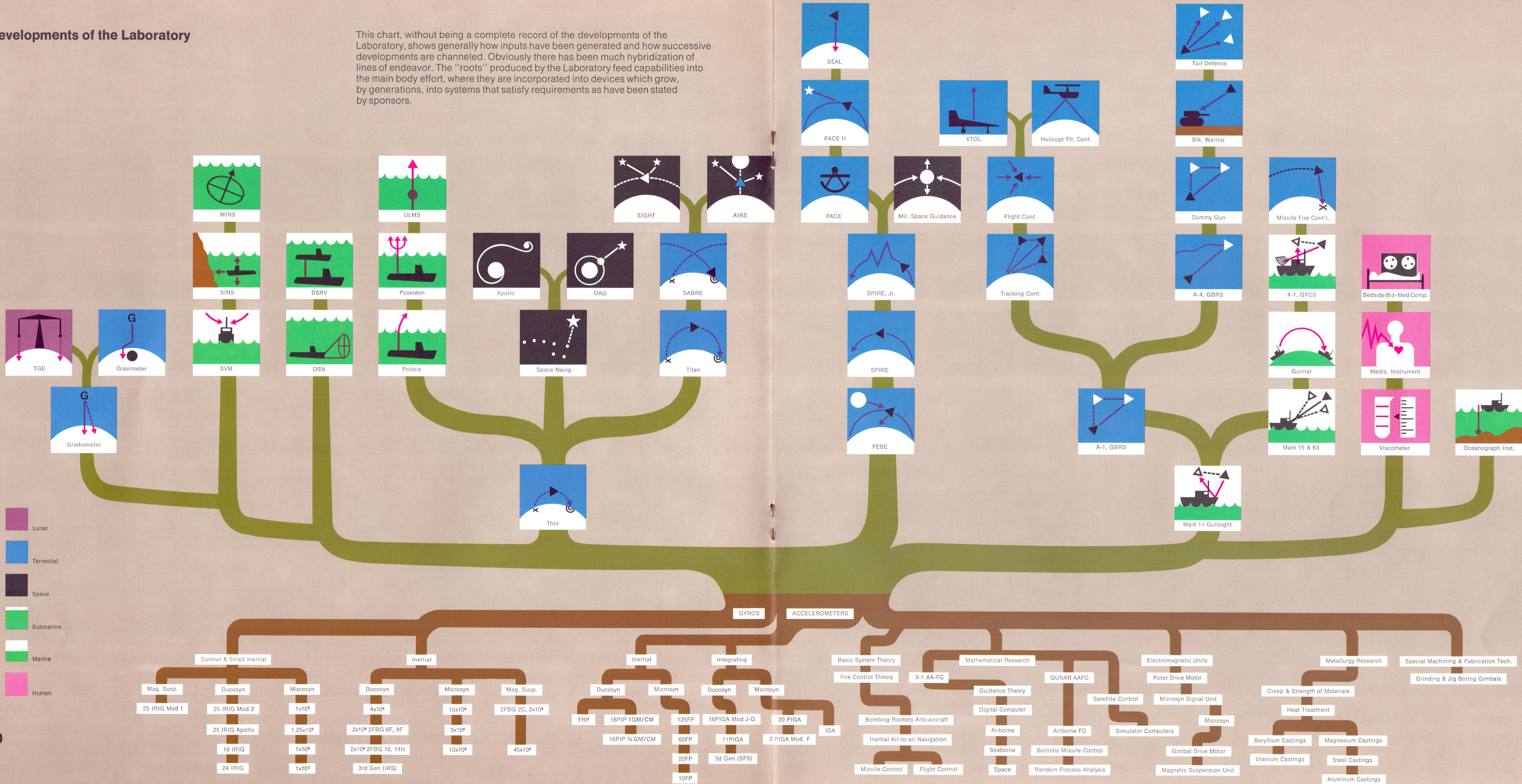


Lunar Gravimeter without protective
covering



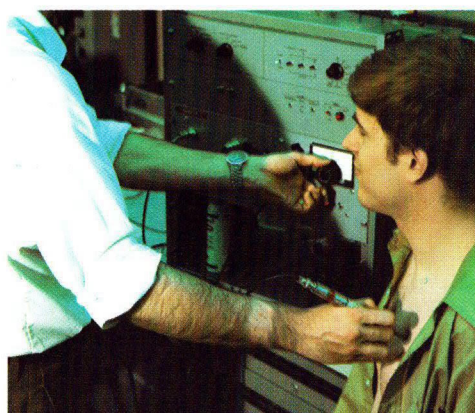
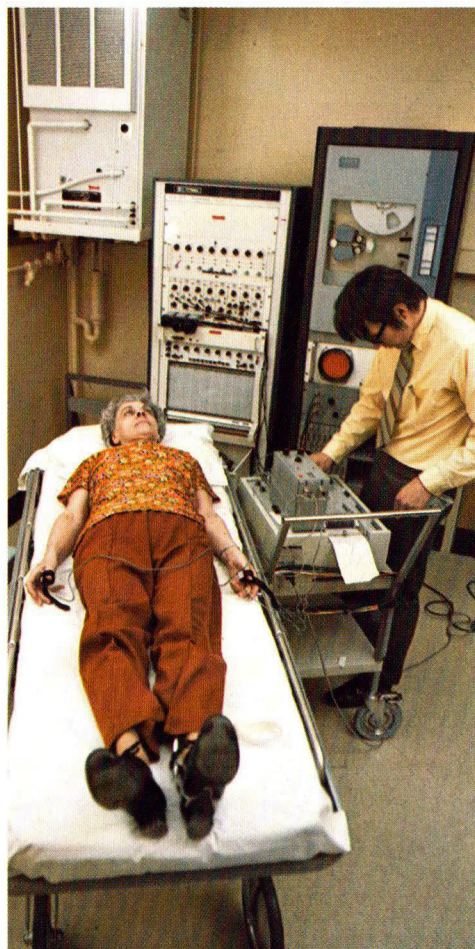
Developments of the Laboratory

This chart, without being a complete record of the developments of the Laboratory, shows generally how inputs have been generated and how successive developments are channeled. Obviously there has been much hybridization of lines of endeavor. The "roots" produced by the Laboratory feed capabilities into the main body effort, where they are incorporated into devices which grow, by generations, into systems that satisfy requirements as have been stated by sponsors.



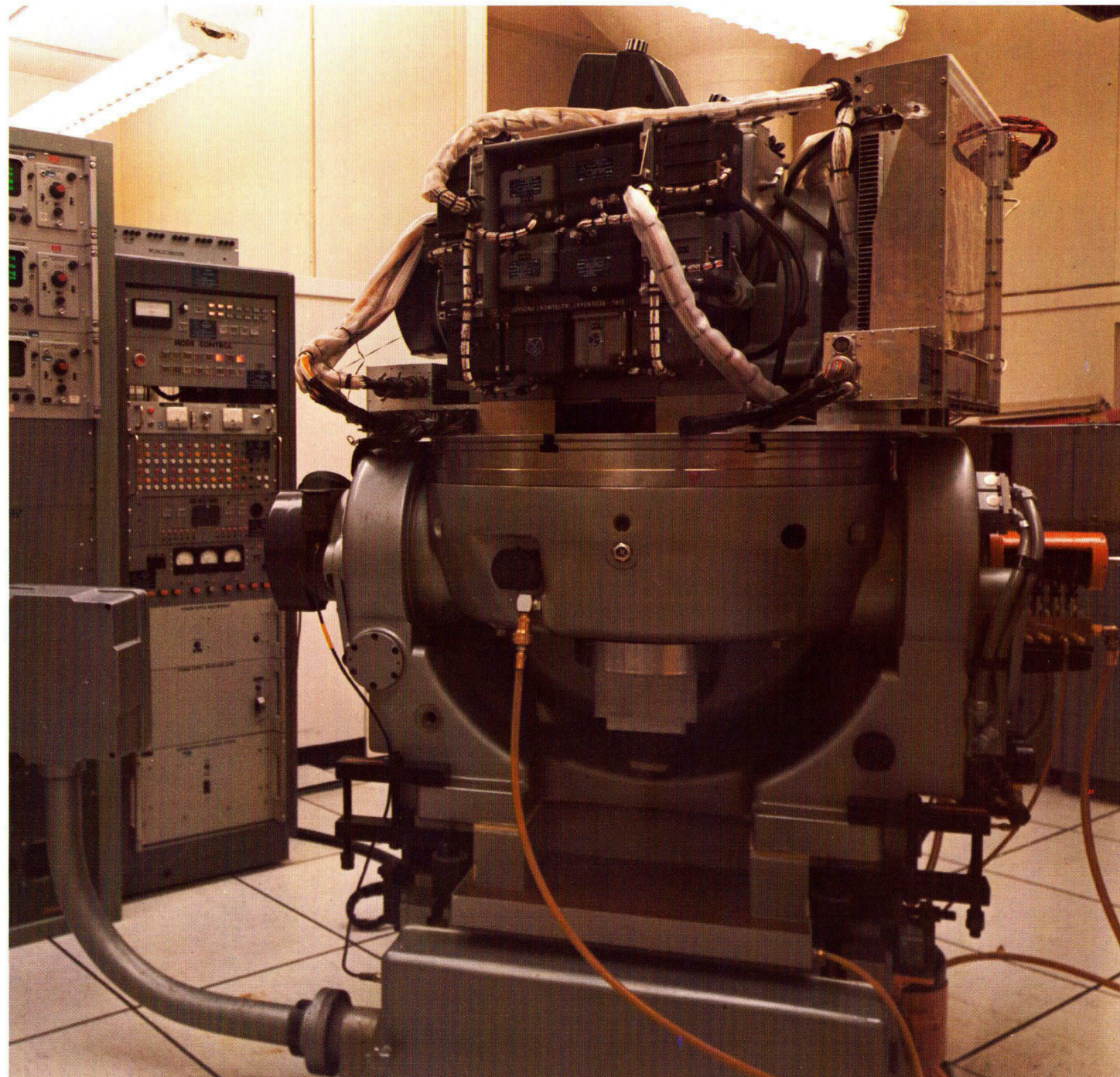
Name or Symbol	Sponsor	Requirement
SEPS (Lunar Surface Electrical Properties)	NASA (MSC)	Provide support to the M.I.T. Center for Space Research in developing hardware for an experiment to determine electrical characteristics of the lunar regolith to determine layering in the lunar subsurface, and to search for water at depth.
SIMS (Stellar Inertial Measurement System)	NASA (MSC)	A trade study of candidate configurations of a Stellar Inertial Measurement System for use on one of the proposed Earth Observation Satellites (EOS).
SIRU (Structure-Mounted Inertial Reference Unit)	NASA (MSC)	Develop a modular inertial reference unit employing structure-mounted (as differentiated from gimballed) inertial components using a redundancy concept on a non-orthogonal six axis array to achieve high fail-operational reliability for long-term space flight.
Strapdown Performance Observation Test	NASA (MSC)	Develop and evaluate techniques for digital compensation of dynamic errors in a three-axis strapdown system.
Gyro Dynamics Evaluation Test	NASA (MSC)	Develop a dynamic error model of the single-degree-of-freedom gyroscope in a strapdown system application.
STS Analysis (Space Transportation Systems)	NASA (MSC)	Define advanced manned mission guidance, navigation, and control system requirements for the space shuttle vehicle and space base missions. SNCS (Space Navigation Control System) configuration, sensor performance requirement, and base-line equations are the major objectives of this effort.
Bedside Biomedical Computer	NASA (MSC)	This is a joint project with the M.I.T. Clinical Research Center for the development of computer programs for improved care of cardiovascular patients.

Bedside Biomedical Computer, for improved care of cardiovascular patients



The Laboratory's ultrasonic probe for non-invasive examination of internal body structure.

Structure-mounted Inertial Reference Unit testing



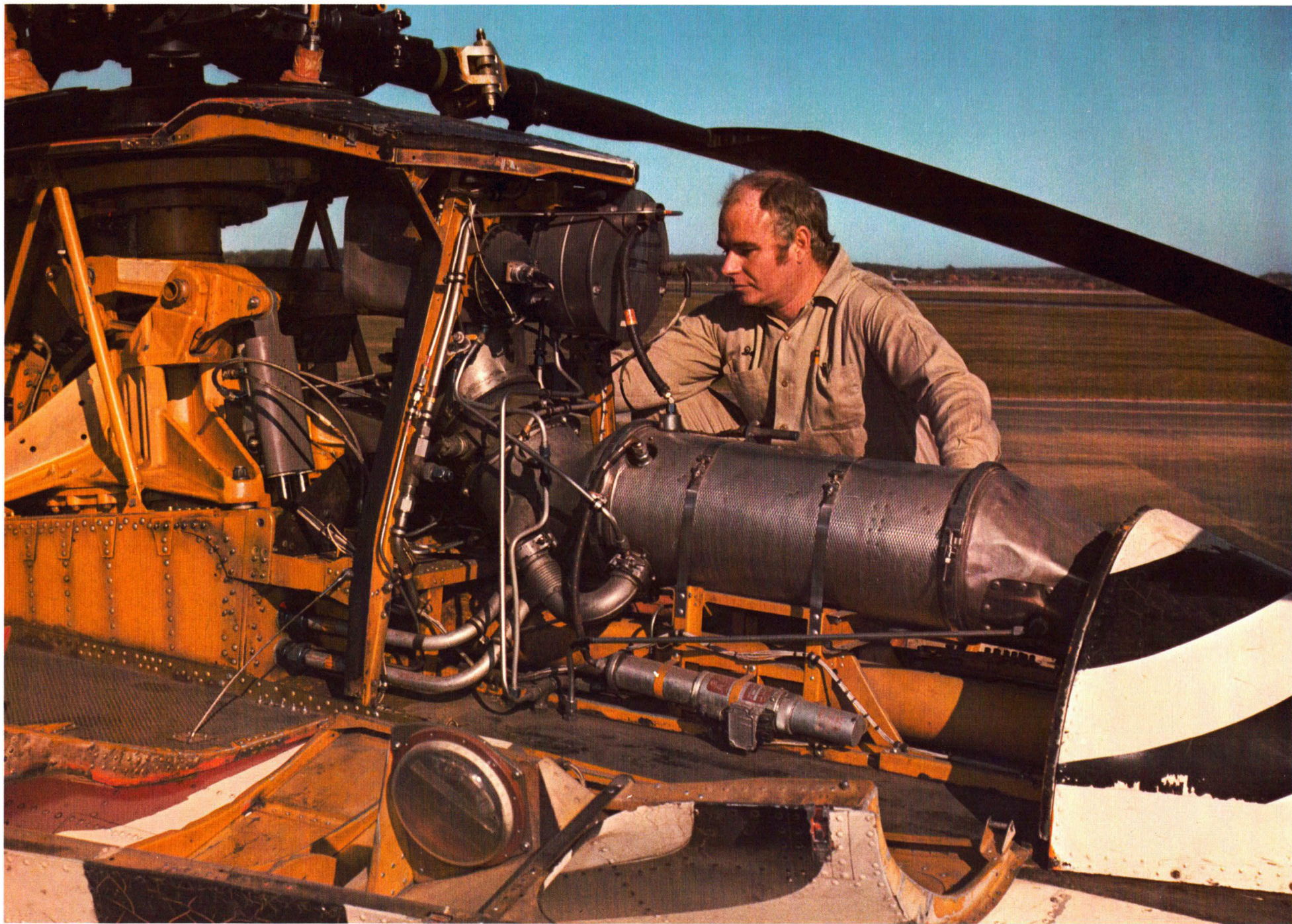
Name or Symbol	Sponsor	Requirement
GAUSS (Guidance Advanced Unmanned Space Mission)	NASA (MSC)	Assess in a general way (with no specific spacecraft) whether or not guidance and navigation will be accurate enough with the technology that exists, or is projected to exist by the time of possible future unmanned probes to the outer planets and short-period comets, to meet the requirements of those flights.
Ion Detector	NASA (ARC)	A study directed at the development of an implantable bio-telemetry ion detector for the measurement of ions in body fluids.
STOL Avionics	NASA (MSC)	Conduct a study to define the air traffic environment and operational procedures representative of STOL transportation systems in the 1970-1990 time period.
Respirator Study	NASA (MSC)	Design a respiratory support system for a space station as well as for use by municipal fire departments for fire and rescue work.
Respiratory Support System for a Space Shuttle	NASA (MSC)	Apply control system technology to the design and development of a respiratory system for a space station.
Aeronomy Experiment	NASA (LRC)	Measurement of neutral atmospheric density and ozone concentration by both stellar occultation and Rayleigh scattering techniques and measurement of atomic oxygen by airglow techniques.
NERVA	NASA (SNPO)	Develop a baseline navigation, guidance, and control system for the NERVA (Nuclear Engine for Rocket Vehicle Application) engine.
Remote Manipulator	NASA (SNPO)	Develop a general purpose space radiation-hardened remote manipulator (teleoperator) system for maintaining, assembling, and repairing space vehicles.

In-flight checkout of VTOL
experimental control system



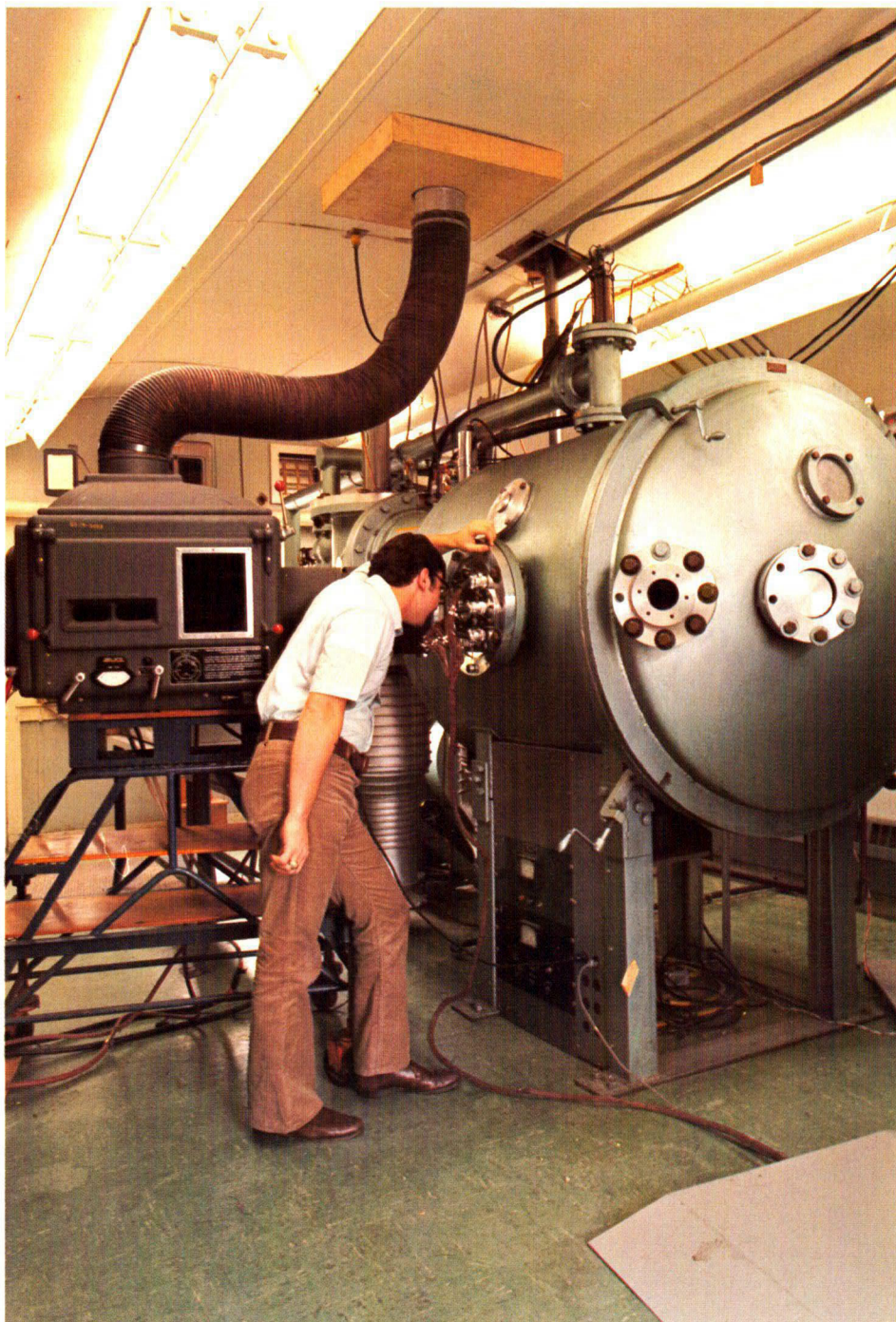
Name or Symbol	Sponsor	Requirement
Space Shuttle Avionics	NASA (MSFC)	Define an on-board checkout and redundant management system for space shuttle avionics.
Mirror Configuration	NASA (MSFC)	Support an in-house research program for active figure control of large telescope mirrors.
Minimum-Fuel 3-Body Trajectory	NASA (OUA)	To develop efficient analytical and numerical methods of determining minimum-fuel orbital transfers in the restricted three-body problem.
OAQ (Orbiting Astronomical Observatory)	NASA (GSFC)	Design, develop, fabricate and test a strapped-down inertial stabilization unit to provide OAQ spacecraft stabilization and to provide the ability to slew precisely the OAQ spacecraft from one position to another.
SATT (Space Astronomical Telescope Technology)	NASA (GSFC)	Conduct analytical studies to determine the optimum structural parameters for large thin mirrors (active and passive) for use in orbiting astronomical telescopes and analytically develop the necessary active figure control configurations.
Army VTOL	Army (AVLAB)	Develop a flight control system providing optimum control characteristics for VTOL aircraft under all operating conditions and to provide engineering and technical support to the Army for a demonstrator program.
ILS Scanning Rate	Department of Transportation (TRC)	Perform studies, aircraft simulation and analysis in an effort to determine the scanning-rate requirements for Microwave Instrument Landing Systems.
Aircraft Strobes	Department of Transportation (TRC)	Measure operating characteristics of flare lamp strobes for use in a Pilot Warning Indicator.

An aspect of the Lab's Flight Facility activities



Name or Symbol	Sponsor	Requirement
Transportation Info System	Department of Transportation	Aid the Department of Transportation in the development of a Transportation Data Management System.
Bureau of Commercial Fisheries Engineering	Department of Interior (BCF)	Support development of the Bureau's fishery resource assessment program. Conduct preliminary tests of existing remote sensor systems, including acoustic devices, lasers and other devices to evaluate their application for improving the resource assessment program. Develop model simulations of several commercial fisheries for the Bureau's use in management system analysis.
CAORF	Department of Commerce (NMRC)	Study the uses and applications for a Computer Aided Operational Research Facility for the National Maritime Research Center.
Miner's Helmet	Allegheny River Mining Co.	Develop an improved miner's helmet with a self-contained air supply providing head, eye, ear and respiratory tract protection.
Ultrasonic Probe Design	National Institutes of Health	Develop an electronically-steered scanning ultrasonic probe system to allow remote examination and observation of the internal structure of a patient's body.
Pre-Mode Moored Thermal Array	National Science Foundation	Together with the Department of Earth and Planetary Sciences of M.I.T. provide temperature measurements for the Pre-Mode Experiment of the International Decade of Ocean Exploration.
LRL Position Locator	Lawrence Radiation Lab.	Develop a low-power, highly accurate geographic position locator.
WHOI (Buoy Engineering)	Woods Hole Oceanographic Institute	Support the Woods Hole Oceanographic Institute in its effort to develop reliable mooring arrays for purposes of oceanographic data acquisition.

The 48-inch space environment chamber with carbon-arc solar furnace



Miner's helmet with a self-contained air supply, developed to reduce the hazards of mining



Name or Symbol	Sponsor	Requirement
Optical Analysis Assistance	M.I.T.-Lincoln Lab	Design internal baffling for, and construct a prototype Cassegrain telescope for the Lincoln Experimental Satellite 8/9 Optical Transceiver. Design work is to be done in close consultation with Lincoln Laboratory. Drawings and other documentation will be delivered, as well as the hardware.
Boston Medical Laboratory	Boston Medical Lab., Inc.	Study the application of systems-engineering to the practical problems of operating a clinical laboratory.
Fiat System Study	Fiat Corporation, SpA	Study the applicability of modern control and computer methodology to specific production processes of interest to Fiat.
Data Disc	Data Disc, Inc.	Demonstrate an integrated software-supported display system, to be used as an interactive graphic terminal capable of acting as an independent free-standing system utilizing its own local data base or as a satellite to a central computer.



How the Laboratory Works

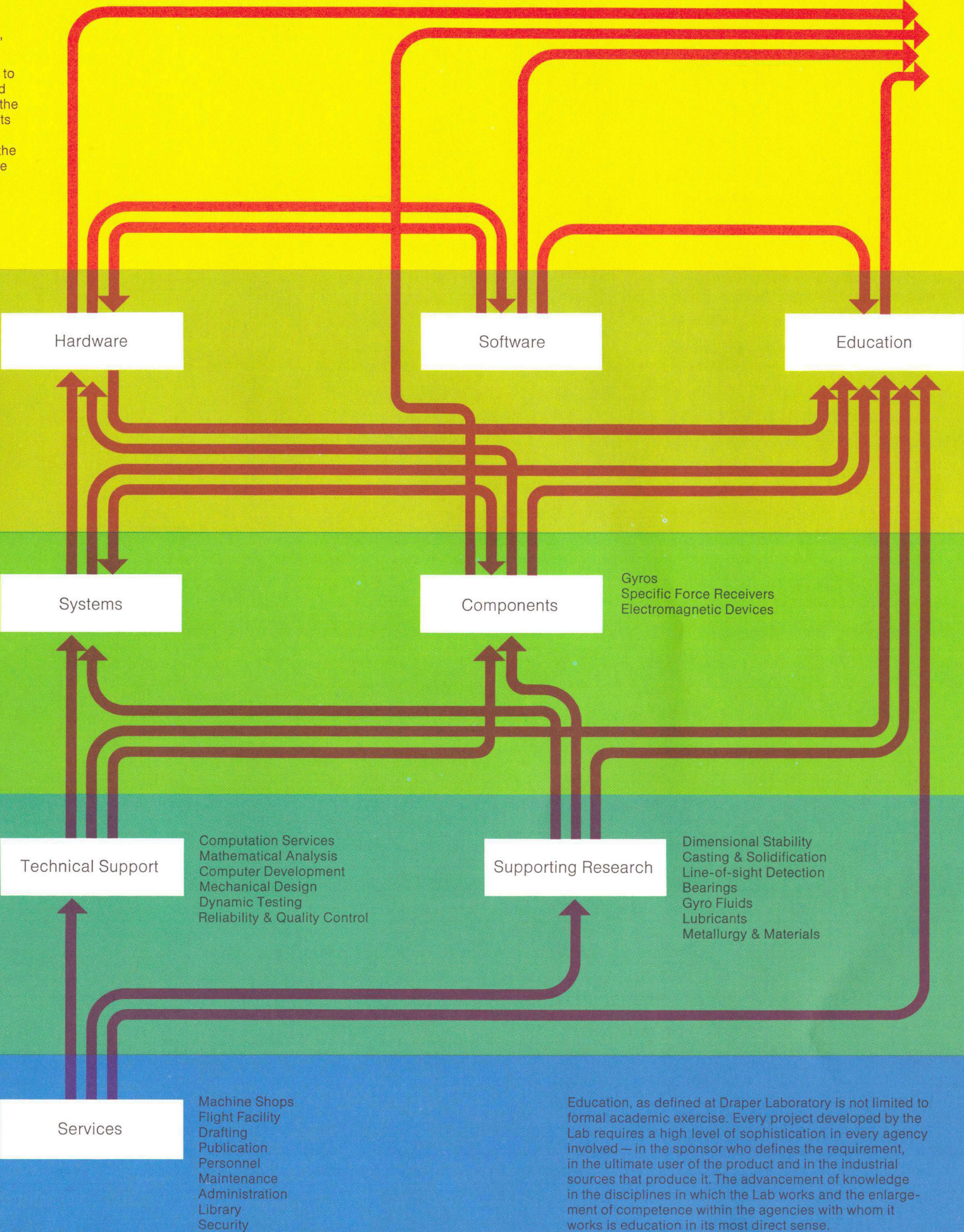
The Laboratory contributes to the "outside world" by offering three separate but related outputs, — hardware to satisfy stated requirements, software to make the hardware work, and information, derived from these developments, that becomes part of the world's body of scientific knowledge. The elements from which these outputs derive are systems and components, designed, developed and tested in the course of the Lab's endeavors, and made possible by technologic support and directed research. Available to all levels of work are basic services, common to all Lab pursuits.

Outputs of the Laboratory

Products of the Laboratory

Support

Basic Services



Pioneering

The Laboratory can point with pride at many inventions and innovations that have opened up new avenues, not only for the benefit of the immediate projects for which they were intended, but universally useful in follow-on projects throughout the technological world. *In toto* they represent a broad-front attack on the accepted horizons. The Laboratory has, during its history, not only peered into the conjectural world, but it has reached out to grab the future and bring it into the present tense. A partial list of significant pioneering efforts includes:

In Systems Hardware:

First inertial guidance system for underwater-launched missiles.

First inertial navigation system for ships and submarines (SINS).

First complete simulation of a submersible in its hydrodynamic, hydro-acoustic and optical environments.

First application of a digital computer for inertial guidance

First computer capable of operation in a nuclear environment

First successful all-inertial cross-country flight test.

First successful inertial star-tracking system flight test.

The Apollo computer, developed

in 1961, still compares favorably with the current generation of flight computers.

The entire Apollo guidance system, a unique requirement successfully met.

First concept of a fault-tolerant multi-processor.

First concept and execution of the principle of single-instruction re-start.

The controls, displays, navigation and ship control subsystems of the Deep Submergence Rescue Vehicle.

First application of "disturbed line-of-sight" fire control.

World's most sensitive seismic measuring device.

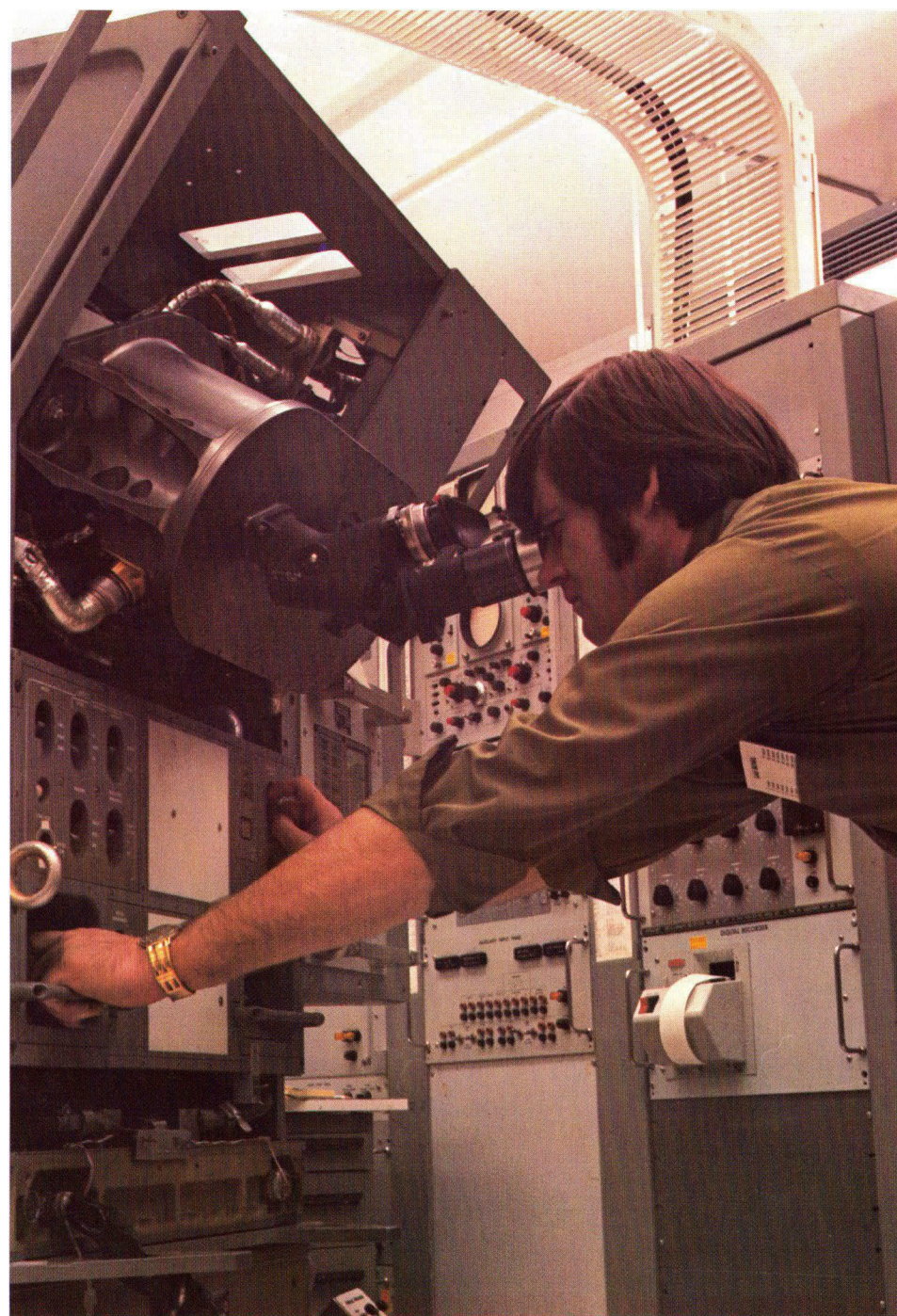
In Software:

First algebraic compiler, conceived and developed in 1952, implemented on the M.I.T. Whirlwind computer. Known as MAC, it is the precursor and enabler of Fortran.

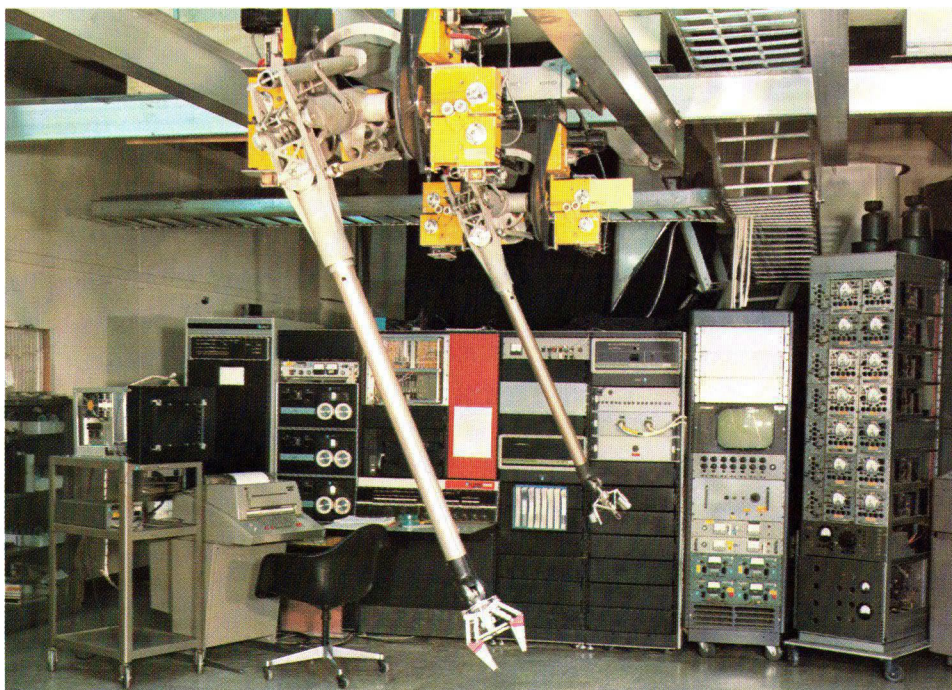
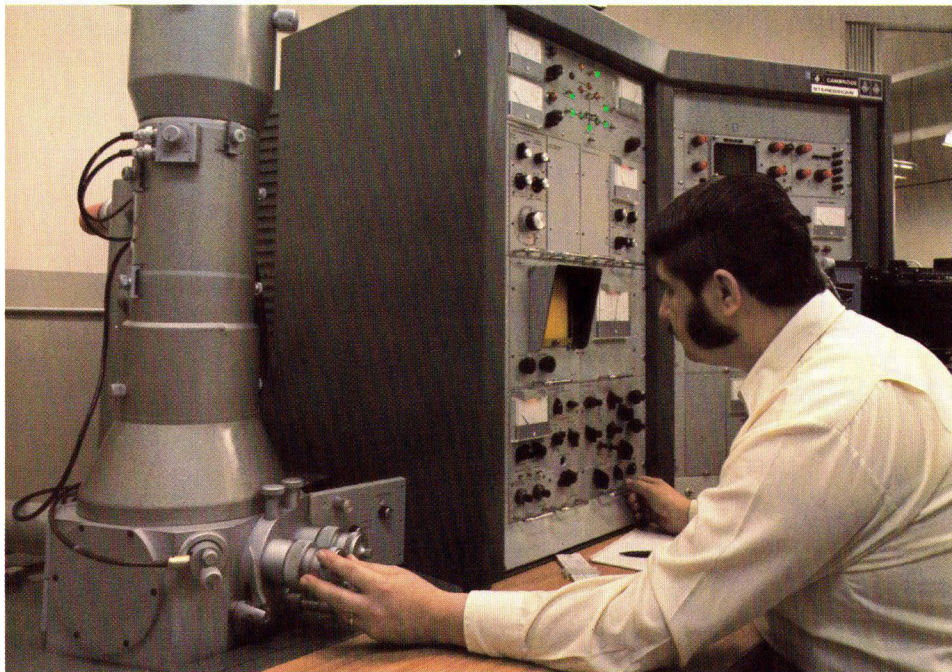
The so-called "Q-systems equations" not only improved accuracy of performance but permitted development of small computers for on-board guidance systems.

Digital systems architecture, allowing continuation of operation despite failure in circuitry, providing a reliability factor nec-

Testing the Apollo Command Module Guidance and Navigation system



Electron microscopic examination of bearing surfaces



A man-controlled, computer-operated remote manipulator for Space Station applications

essential to long-time space missions.

In Components:

First completely-enclosed floated gyros.

Application of Pendulous Integrating Gyro Accelerometer.

The Microsyn, an angle-sensor torque generator and angular-spring generator, requiring no wires to moving parts and thus eliminating friction.

The Ducosyn magnetic element combination, which packages in a common plane both the Microsyn and magnetic suspension.

The use of beryllium as a structural material in gyro development.

First application of braided wire memory.

Pioneered in plated wire technology.

First application of welded-wire cordwood electronic packaging.

First to use direct-drive torque motors in gimbals.

Introduced the flimbal — a floated ball within a ball, replacing gimbals.

First application of dielectrically isolated integrated circuits with film resistors (for nuclear hardening).

First practical transfer of gyro-wheel power from housing to

moving elements by electrostatic and magnetic coupling.

First to develop successful adhesives, potting compounds, hermetic sealing, through-porous polyimide materials and flotation fluids for high-precision instruments.

Pioneered and, by demonstration, led the U.S. bearing industry into micro-inch tolerances on all dimensions of metal parts, into pre-loading techniques, cleaning and precoating ball bearings and races, pre-running techniques, into through-porous sintered nylon and polyimide materials and improved lubricants.

Pioneered clean rooms and clean room techniques in manufacture of instruments.

First single-degree-of-freedom floated integrating gyros.

Pioneered in development of precision linear and angular shakers and high-G centrifuges.

Pioneered in precision 3-axis base motion stabilization and adequate testing techniques.

Dimensions and Capabilities

The through-put of the Laboratory, all derived from contracts, is in the neighborhood of \$50 million annually. Approximately 1700 people are required to create the outputs of the Lab, to continue its teaching aspects, and to conduct its business. About 700 of these are professional staff, and of this group approximately 300 hold advanced degrees. In the past 10 years approximately 1000 people have, by virtue of Laboratory experience, moved into important positions in industry, into government, or into teaching, to the great gratification of Dr. Draper and the Laboratory.

Operations of the Lab are housed in 12 buildings in Cambridge adjacent to the M.I.T. campus, with a total usable space of 275,000 square feet. In addition, the Laboratory is supported by a flight facility at Bedford, Mass., containing a 17,000-square-foot hangar and 22,000 square feet of other support facilities. An environmental test facility of some 12,000 square feet is also located in Bedford.

The Lab has developed, mostly in-house, a broad spectrum of capabilities to satisfy the unusual requirements of Laboratory

projects. Among its resources are:

A machining capability for a wide variety of material to tolerances in the low millionths of an inch; quality sheet metal fabrication with highly precise measurement and inspection techniques.

Facilities for the design and fabrication of printed-circuit, cordwood and thin film-hybrid electronics assemblies compatible with size, shape, weight, and environmental requirements.

Environmental testing equipment for subjecting components and assemblies to environments of high G, vibration, angular motion, mechanical shock, pressure or vacuum, humidity, temperature and solar-heat radiation, includes the largest precision centrifuge in the country, altitude-temperature-humidity test chambers, as well as vibration, shock and angular motion generators. Special configurations of these equipments are available for analysis and certification of components or complete systems for "real world" applications.

A calibration and standards laboratory provides for assuring test and measuring equipment accuracies by comparison against standards established by

the National Bureau of Standards. Standards capabilities of this laboratory involve both electrical and physical measurements.

A number of "clean rooms" permit critical assemblies to be made under rigidly controlled environmental conditions.

A specially equipped laboratory, staff and consulting service is available at the Draper Laboratory for the analysis and handling of optical problems, particularly those associated with precision angular measurement. This facility is experienced in solving many measurement problems encountered in the development, calibration and test of instruments and instrument systems.

A complete facility for the design, analysis, development, fabrication and test of specialized electromagnetic components. Fabrication capabilities include the bonding of laminations to make magnetic cores; the winding of these cores, either by hand or by form wound coils; and the assembly, connecting, and impregnation of the windings. Test capabilities are extensive and elaborate, and in the main rely on special test equipment

designed and built by Laboratory personnel.

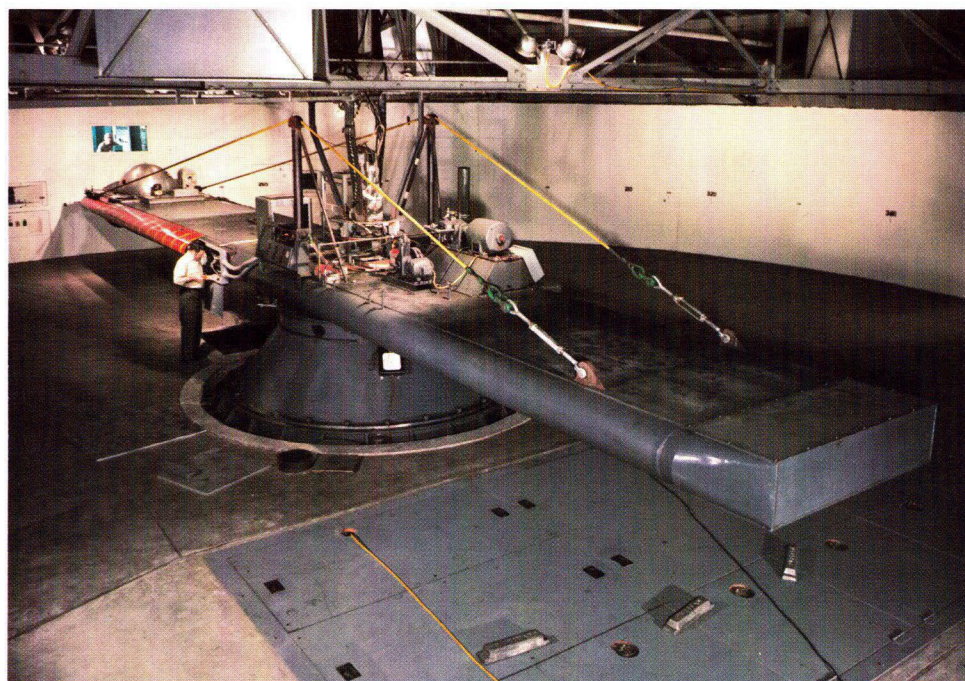
A central facility for materials research, process and test is equipped to solve materials problems and to investigate new areas of materials development. Other facilities exist for heat treatment, metallography, surface chemistry, and general metals testing.

A surface chemistry lab deals with problems associated with lubricated and various other surface finishes and treatments, and is equipped to perform glow discharge and other processes for removing recalcitrant coatings from critical metal surfaces, electrolytic and non-electrolytic plating, electropolishing and chemical surface treatments.

A flight facility at Hanscom Field for ground and flight testing of vehicle-borne instrument systems is equipped to perform installation and maintenance of test instrumentation, ground checkout, flight operations, and maintenance and storage of aircraft. The flight facility staff includes fully-qualified engineering test pilots.

Draper Laboratory provides extensive computational support over a wide range of scientific disciplines. Central to this capa-

Inertial component assembly in a laboratory clean room



100g-32 foot radius Precision Centrifuge, the country's largest

bility is the IBM 360/75 digital computer, which provides programming and operation seven days per week, twenty-four hours a day. Conversational Remote Batch Entry (CRBE) has been implemented, by which programmers using a teletype device create and edit files remotely and then enter those files to be run in the normal batch stream.

The Laboratory also maintains a hybrid computing facility providing a real-time computing environment that permits extensive math modelling, interface communications, simulation and design verification associated with engineering and software design problems. This facility includes two SDS 9300 general purpose computers, four Beckman analog computers, complete hybrid interfaces, comprehensive monitor systems, and on-line interactive displays, with interfaces at the facility to provide access to the digital computer. Other special purpose computers provide support to specific Laboratory programs.

Participation in major defense and space programs has created in the Laboratory a highly experienced and innovative capability in the design,

development and utilization of special-purpose computers and complete software systems. These talents have been applied successfully to industrial process control problems, to the delivery of health care services, and in the design of an interactive computer display system with a myriad of potential users.

The ability of the Lab to produce highly accurate and reliable inertial sensors and navigation systems is due in large part to some of the most advanced facilities in the country for performance testing. These facilities, developed by the Lab, measure instrument performance far beyond normal systems requirements.



Systems Programmer at work

Management

The Laboratory is organized to encourage creative independence and to facilitate the cross-flow of ideas and information at every level. Ease of communication has enabled hybridization of concepts, theory and practical applications and mutual assistance in performance of tasks.

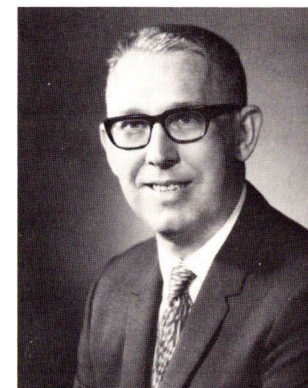
The broad policies under which the Lab pursues its objectives are determined by a Board of Directors, consisting of:

Albert G. Hill, Chairman
Professor of Physics and
Vice President for Research, M.I.T.



1949-52: Director, Research Laboratory of Electronics, M.I.T.
1952-55: Director, Lincoln Laboratory.
1956-58: Director of Research and Deputy Director, Weapons Systems Evaluation Group, D.O.D.
1952-59: Vice President and Director of Research, Institute for Defense Analyses

Robert A. Charpie
President, Cabot Corporation



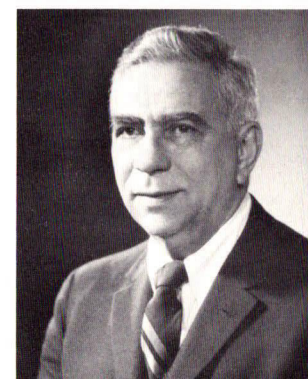
1950-61: Oak Ridge National Laboratory Director
1958-61: Reactor Division
1961-68: Manager of Development; President, Electronics Division, Union Carbide Corp.
1968-69: President, Bell and Howell Company

1948-53: Executive Secretary, U.S. Educational Commission in United Kingdom
Advisory Committee on Higher Education, Department of Health, Education and Welfare



Alan Pifer
President, Carnegie Corporation of N.Y. and
President, Carnegie Foundation for the Advancement of Teaching

1949-55: Chief Scientist and Deputy Director, Office of Naval Research
1955-56 Vice President, AVCO Manufacturing Corporation
1956-71: Director of Research, Vice President for Research and Engineering, Chief Scientist, IBM Corporation



Emanuel R. Piore
Director, International Business Machines Corporation

Charles Stark Draper
President, Draper Laboratory



Institute Professor Emeritus, M.I.T.
President, International Academy of
Astronautics
Chairman, National Inventors Council

Robert A. Duffy
Vice President, Draper Laboratory



Brigadier General (retired), U.S.A.F.
Major Air Force assignments included
Special Assistant in the Office of the
Director of Defense Research and
Engineering, and Vice Commander,
Space and Missile Systems
Organization

James McCormack
Chairman, Aerospace Corporation



Major General (retired), U.S.A.F.
Air Force assignments included that
of Military Liaison to Atomic Energy
Commission
1955-64: Vice President, M.I.T.
1965-70: Chairman and Chief Execu-
tive Officer, Communications Satel-
lite Corporation

Charles L. Miller
Professor of Civil Engineering and
Director, Urban Systems Laboratory,



1961-69: Head, Department of Civil
Engineering, M.I.T.
Chairman, CLM Systems, Inc.

Early 1940's: General Manager,
SKF Industries
1945-1971: General Manager,
Vice President and Vice Chairman of
Board, Polaroid Corporation



David W. Skinner
Director, Polaroid Corporation

1926-1971: President, Chairman,
Chief Executive Officer, Sprague
Electric Company
Life Member, M.I.T. Corporation



Robert C. Sprague
Chairman, Executive Committee,
Sprague Electric Company

1946-49: Director, Research Labora-
tory of Electronics, M.I.T.
1949-59: Provost, Vice President,
Chancellor, M.I.T.
1959-66: President, M.I.T.
1966-71: Chairman, Ford Foundation



Julius A. Stratton
President Emeritus and Life Member
of Corporation, M.I.T.

Director, Trustee or Corporation
Member of numerous financial,
educational and civic organizations.
1936-52: Estabrook & Company

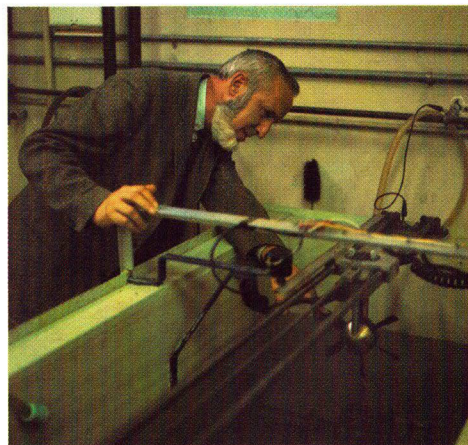


Mark C. Wheeler
President, Chairman, Chief Executive
Officer, New England Merchants
National Bank

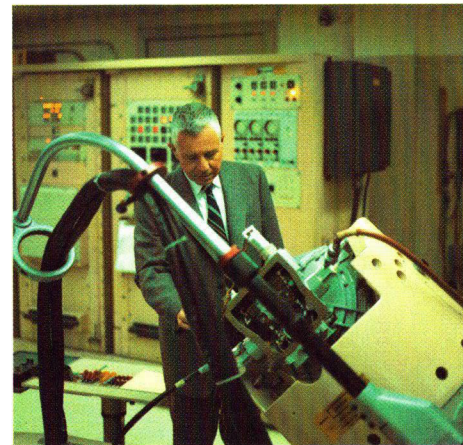
Operations of the Laboratory are conducted by a group of Officers, as follows:

C. Stark Draper, President
 Robert A. Duffy, Vice President
 John E. Kirk, Assistant to the President
 Forrest E. Houston, Director for Navy Programs
 Ralph R. Ragan, Director for NASA Programs
 Roger B. Woodbury, Director for Air Force Programs
 Walter Wrigley, Educational Director
 J. Bernard Feldman, Executive Officer
 Paul V. Cusick, Treasurer
 David C. Driscoll, Assistant Treasurer
 Frederick J. Robbins, Secretary
 Joseph F. O'Connor, Assistant Secretary

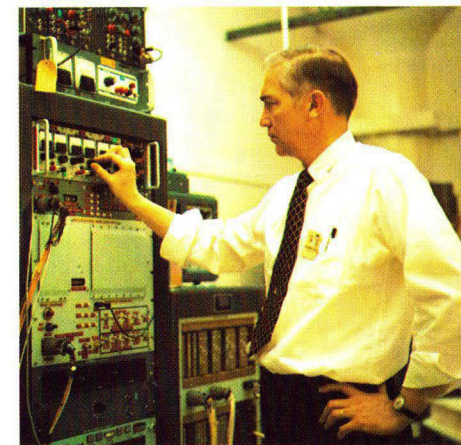
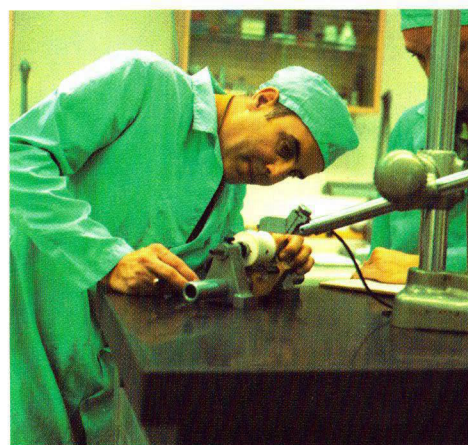
Phil Bowditch
 Dick Battin
 Ed Hall



Sam Fortner
 Roger Woodbury
 Brian Cuevas



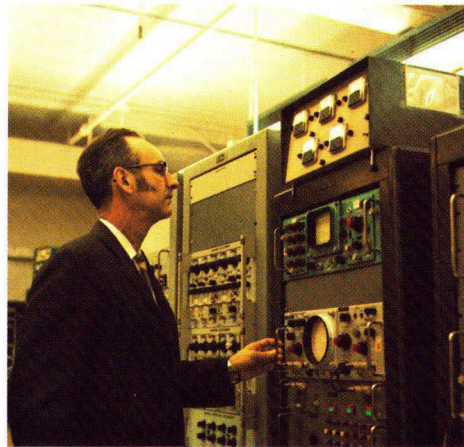
Bob Duffy
 Milt Trageser
 Norm Sears



John Kirk
Eldon Hall
Ken Fertig



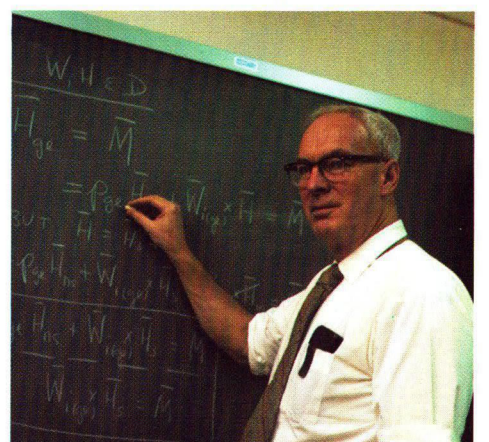
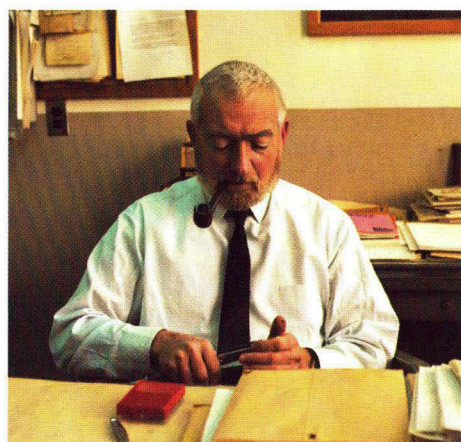
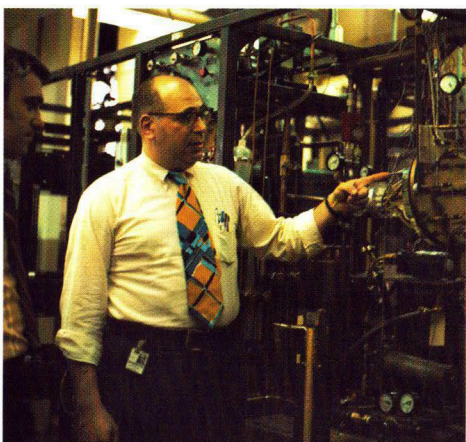
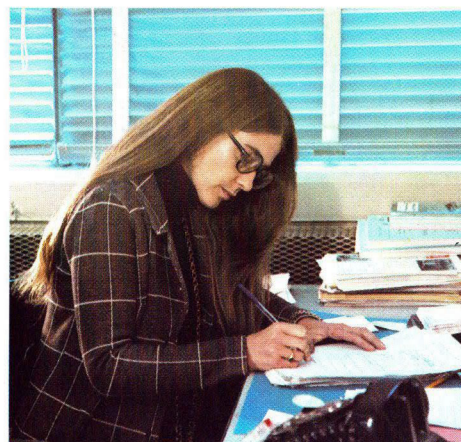
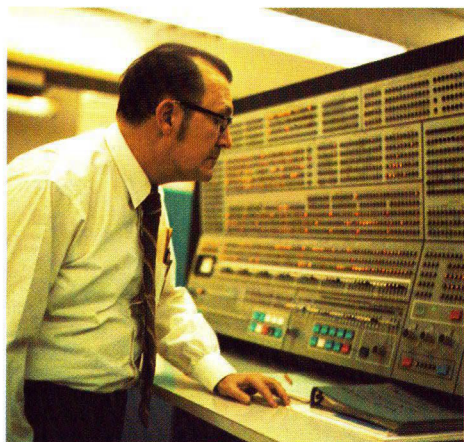
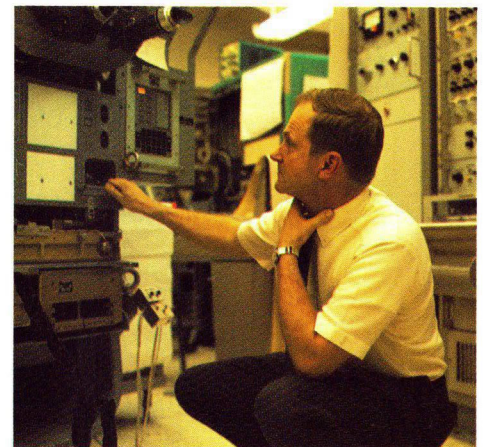
Ralph Ragan
Hal Laning
Mike Sapuppo



Bill Denhard
Margaret Hamilton
Bernie Feldman



Dave Hoag
Forrey Houston
Walt Wrigley



Apopemptic

The Greeks, who had a word for everything, defined happiness as “the exercise of vital powers along lines of excellence in a life affording them scope.” Our somewhat less articulate generation would call it “doing your own Thing.” If either definition is tenable, Draper Laboratory is indeed a happy place, witness this list of indelible and undeniable assets:

- It stands high among the knowledgeable practitioners of the aeronautical and astronautical sciences, with an impressive record of accomplishments in the advanced reaches of guidance, navigation and control, and in the pursuit of precision in instrumentation.
- It has contributed materially to National programs essential to our society.
- It has added significantly to the world’s body of scientific knowledge.
- It has fed a steady stream of meritorious people into the National reservoir of scientific talent.
- Last, but by no means least, it has raised the level of scientific education in this country by contributing its expertise to the academic scientific world, to the enhancement of the profession of teaching, which is as it should be.

Annuity Coeptis





The Charles Stark Draper Laboratory

68 Albany Street, Cambridge, Massachusetts 02139