

UNCLASSIFIED

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

APOLLO

GUIDANCE AND NAVIGATION

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FACILITY FORM 602

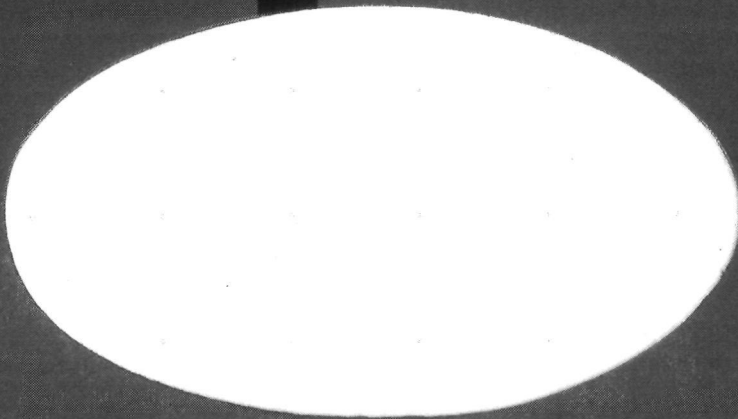
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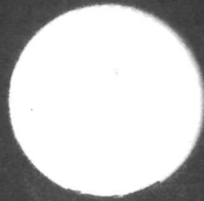
MIT

INSTRUMENTATION LABORATORY

(NASA-CR-154596) REPRINTS OF PRESENTATION
 TO NORTHEAST EXECUTIVES VISIST AT
 INSTRUMENTATION LABORATORY, MASSACHUSETTS
 INSTITUTE OF TECHNOLOGY (Massachusetts Inst.
 of Tech.) 81 p

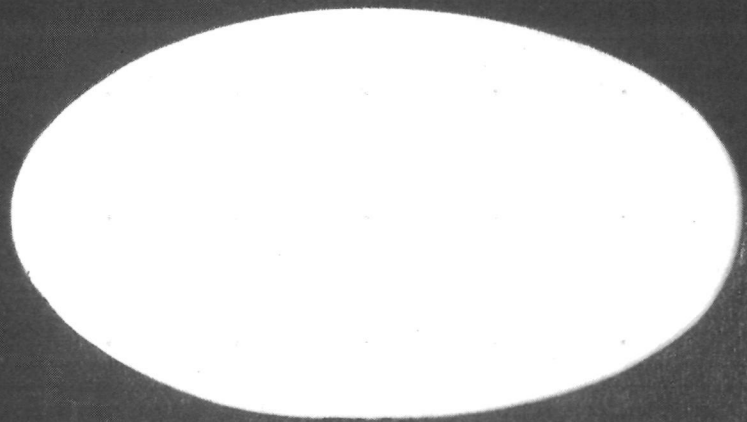
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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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APOLLO

GUIDANCE AND NAVIGATION

~~AVAILABLE TO NASA HEADQUARTERS ONLY~~

R-443

Reprints of Presentation to
Northeast Executive's Visit

at

Instrumentation Laboratory
Massachusetts Institute of Technology

13 March 1964

by: Dr. C. S. Draper
M. B. Trageser
D. G. Hoag
P. K. Bryant
R. H. Battin

MIT

**INSTRUMENTATION
LABORATORY**

CAMBRIDGE 39, MASSACHUSETTS

COPY # 41

ACKNOWLEDGMENT

This report was prepared under DSR Project 55-191, sponsored by the Manned Spacecraft Center of the National Aeronautics and Space Administration through Contract NAS 9-153.

The publication of this report does not constitute approval by the National Aeronautics and Space Administration of the findings or the conclusions contained therein. It is published only for the exchange and stimulation of ideas.

DR. C. STARK DRAPER

INTRODUCTION TO THE MIT APOLLO G&N PROGRAM

BACKGROUND ON APOLLO WORK AT INSTRUMENTATION LABORATORY

General

In a three-story building at 75 Cambridge Parkway overlooking the Charles River in Cambridge, Mass., more than 300 engineers and scientists are teamed in an extensive mingling of government, industry and university talent to help send American explorers to the moon.

The team is engaged in designing the guidance and navigation system three U. S. astronauts will use to steer their National Aeronautics and Space Administration Project APOLLO spacecraft to the moon and back to earth.

More than 200 of the professional force are staff members at Massachusetts Institute of Technology's Instrumentation Laboratory, which -- as NASA's Associate Contractor for APOLLO Guidance and Navigation -- holds primary responsibility for system design, development, test and operational support.

Others on the team are on-site representatives of the Guidance and Control Division of the APOLLO Project Office at NASA's Manned Spacecraft Center at Houston, Texas, which directs the program, and on-site representatives of the APOLLO Participating Contractors for Guidance and Navigation which NASA selected to support Instrumentation Laboratory and eventually manufacture systems.

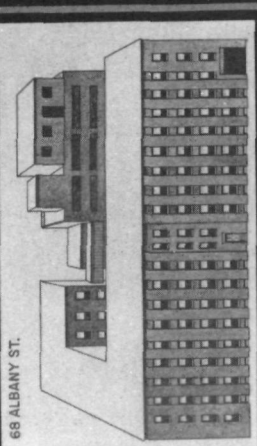
Participating Contractors and their responsibilities are:

AC Spark Plug Division of General Motors Corporation, Milwaukee, Wisconsin, and Wakefield, Mass., for inertial measurement units and associated displays and controls, for

INSTRUMENTATION LABORATORY FACILITIES

FACILITIES

IL-1, 2, 3 & 4



68 ALBANY ST.

62,640 SQ. FT. NET (ALL FLOORS)

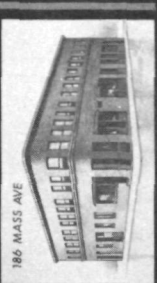
IL-7



BROWN-DURRELL BLDG.
(SUB-LEASED FROM ITEK)

NET 70,000 SQ. FT. NET (ALL FLOORS)
75 CAMBRIDGE PKWY.

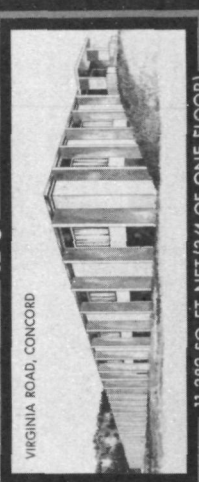
IL-9



186 MASS AVE

4,475 SQ. FT. NET (TOP FLOOR ONLY)

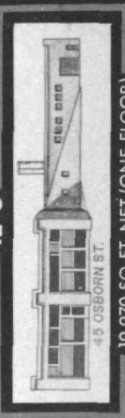
IL-8



VIRGINIA ROAD, CONCORD

11,382 SQ. FT. NET (3/4 OF ONE FLOOR)

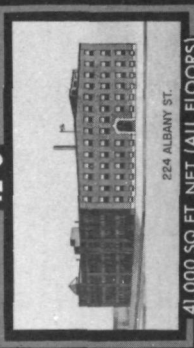
IL-5



45 OSBORN ST.

19,970 SQ. FT. NET (ONE FLOOR)

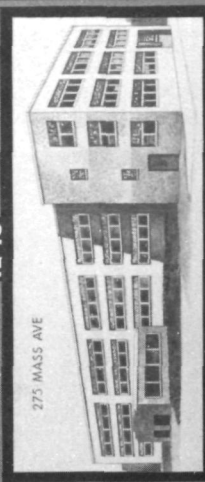
IL-6



224 ALBANY ST.

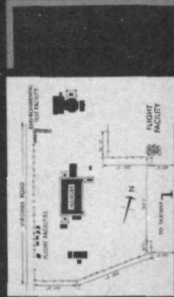
41,000 SQ. FT. NET (ALL FLOORS)

IL-10



275 MASS AVE

18,960 SQ. FT. NET (1ST. & 2ND. FLOORS ONLY)



BEDFORD FLIGHT FACILITY

18,600 SQ. FT. (HANGAR)
16,600 SQ. FT. (FACILITIES LESS HANGAR)
9,000 SQ. FT. (ENVIRONMENT TEST FACILITY)

TOTAL: 47,106 SQ. FT. NET FLIGHT & TEST FACILITIES

gyroscopes in the IMU, for total system integration and integration of all displays and controls, and for ground support equipment.

Kollsman Instrument Corporation, a subsidiary of Standard Kollsman Industries, Inc., Elmhurst, N.Y., and Syosset, N.Y., for the optical subsystem, the map and data viewer, and associated ground support equipment.

Raytheon Company's Space and Information Systems Division, Bedford, Mass., and Sudbury, Mass., for the G & N digital computer and associated displays and controls.

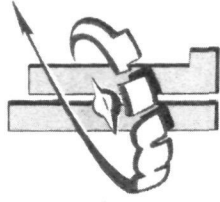
Sperry Gyroscope Company division of Sperry Rand Corporation, Great Neck, N.Y., for pulsed integrating accelerometers used in the IMU.

Also on hand are engineering liaison representatives of other APOLLO contractors, including Space and Information Systems Division, North American Aviation, Inc., Downey, California, NASA's Principal Contractor for the APOLLO spacecraft, and Grumman Aircraft Engineering Corporation, Bethpage, N.Y., NASA's Associate Contractor for the APOLLO Lunar Excursion Module which will carry two of the three APOLLO astronauts from the orbiting main spacecraft to the moon surface and back.

The guidance and navigation system for the Lunar Excursion Module (LEM), the vehicle which makes the actual lunar descent, is expected to have many elements in common with the main spacecraft system. This common usage will provide substantial advantages in inflight repairs, astronaut familiarization and training, pre-launch logistics, and reduced development costs.

Supporting this fully-integrated government-industry-university design team are another 300 Instrumentation Laboratory technicians, machinists and administrative personnel assigned to the APOLLO program.

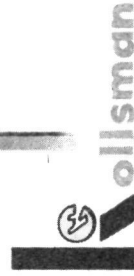
apollo team • relative funding



MATERIALS
&
SERVICES

SUBCONTRACTORS

SPERRY



T.P. NO. 11214

DATE 3/64

M.I.T. INSTRUMENTATION LABORATORY

The building that houses the design center is one of seven used by the Instrumentation Laboratory in Cambridge and was leased for the APOLLO program in late 1961 when the Laboratory accepted NASA's assignment to design the G & N system.

Laboratory History

The Laboratory's founder and director is Dr. Charles Stark Draper, Professor and Head of the Department of Aeronautics and Astronautics at MIT and a pioneer in the development of inertial guidance, inertial navigation and inertial control systems for ships, submarines, airplanes, missiles and satellites.

Dr. Draper started the Laboratory just prior to World War II to develop lead-computing gyroscopic gunsights for Navy anti-aircraft guns. His Mark 14 gunsight was the first of its kind to reach the fleet and played an important role in naval engagements of World War II.

Toward the end of World War II, Dr. Draper and his associates developed gyro-stabilized gun-bomb-rocket sights for Air Force fighter planes and one of these saw extensive service in the Korean War aboard F-86 fighters.

Following World War II, Dr. Draper began applying knowledge of gyroscopic stabilization and feedback control to the original work done in this country on inertial navigation and guidance.

Essentially, these are systems that have a gyro-stabilized inner member on which force-measuring accelerometers are mounted. Information from the accelerometers, isolated from the vehicle by gyro and gimbal stabilization, is then computed into information about changes in speed, position and direction of movement, all without reliance on any information from outside the vehicle. Navigation systems read out this information, guidance systems control the vehicle automatically and guide it to a terminal or target.

Dr. Draper made his first inertial system transcontinental test in an airplane flight from Massachusetts to Los Angeles in 1953, demonstrating the feasibility of such systems. Since then from the Laboratory have come designs and design concepts for many now-operational systems. The Air Force THOR missile guidance system is based on Laboratory design concepts. The Laboratory designed and carried out engineering test of the inertial measuring unit in the Air Force TITAN missile guidance system. The Navy POLARIS missile guidance system also was designed, developed and tested by the Laboratory. And the first ship's inertial navigation system (SINS) was built, tested and demonstrated by the Laboratory. SINS are now used on nuclear submarines to enable them to remain submerged for long periods.

Laboratory research and development on advanced inertial guidance, navigation and control systems for military vehicles is continuing.

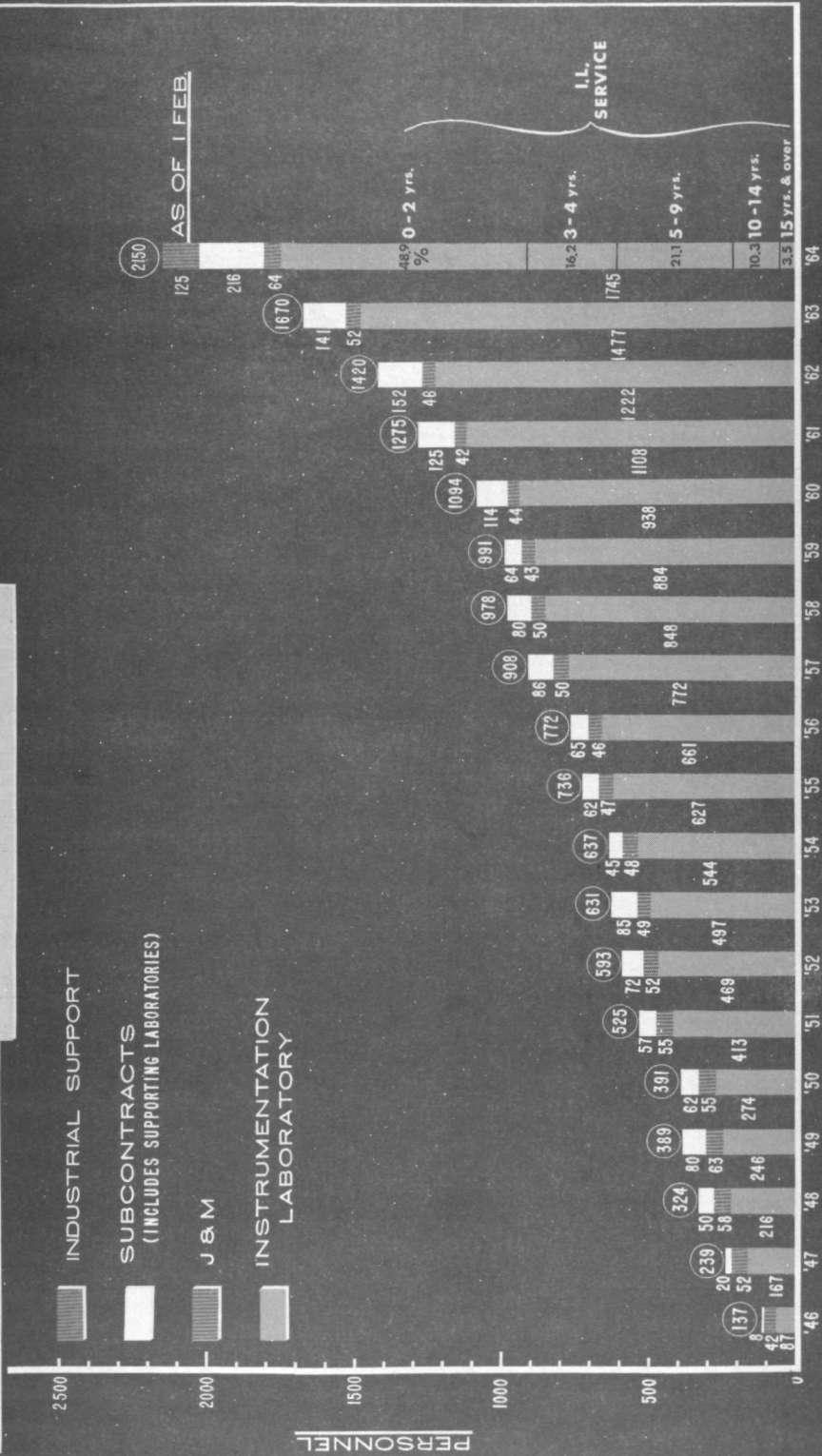
Many key Laboratory engineers now assigned to the APOLLO project worked earlier on such projects as TITAN and POLARIS.

Moreover, several Laboratory engineering groups now working on various phases of the APOLLO project are also working simultaneously on similar phases of other Laboratory projects.

In APOLLO, as in all of its programs, the Laboratory works closely with government-selected participating contractors in developing system designs, fabricating prototypes, carrying out engineering design tests and supporting operational use. System production and manufacturing, of course, is performed by industry. Of federal funds expended for design, development, test and procurement of these systems, the bulk goes to the participating industrial contractors for manufacture and fabrication, and only a small portion to support MIT's design, test and operational support efforts.

PERSONNEL

MANPOWER HISTORY



AS OF 30 JUNE

M.I.T.
FEBRUARY 1964
Instrumentation Laboratory

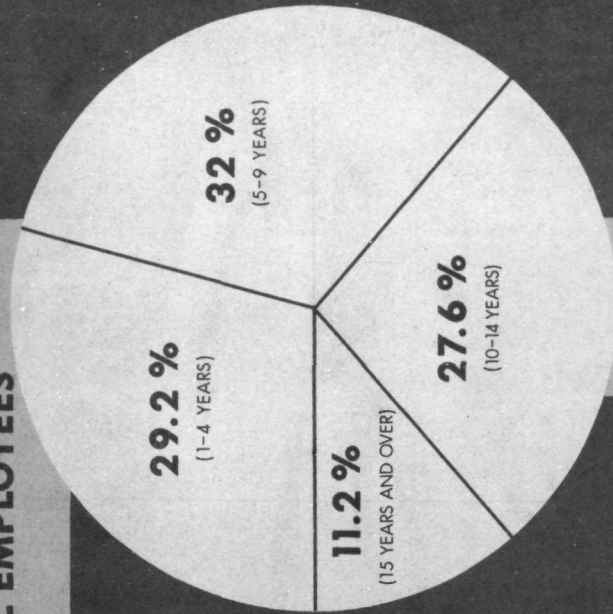
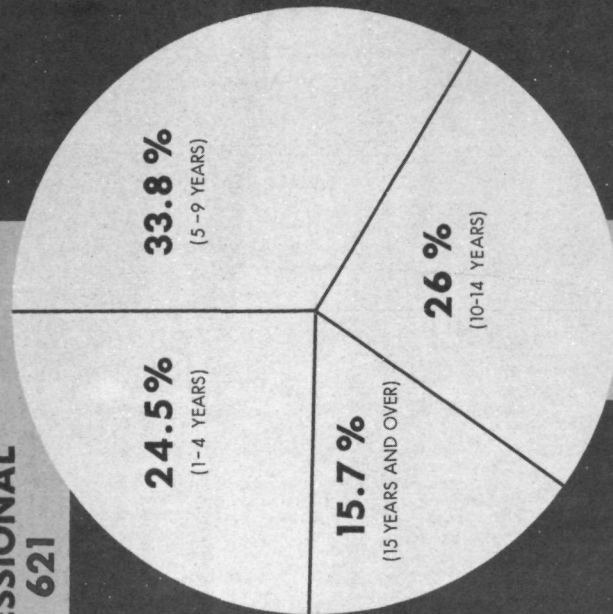
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INSTRUMENTATION LABORATORY

MAN-YEARS OF EXPERIENCE

PROFESSIONAL
STAFF 621

TOTAL EMPLOYEES
1745



4.9

4.5

3000

8000

AVERAGE EXPERIENCE (YEARS)

TOTAL EXPERIENCE (MAN-YEARS)

Laboratory APOLLO Organization

Assisting Dr. Draper in overall supervision of the Laboratory's design programs, including APOLLO, are the Laboratory's two deputy directors -- Roger B. Woodbury, who was a principal engineer in development of inertial guidance systems from their early beginnings at the Laboratory, and Forrest E. Houston, a Laboratory leader in development of inertial navigation systems and who is a co-holder of patents on SINS.

Directing the specific APOLLO program at the Laboratory is Milton B. Trageser, who joined the Laboratory staff in 1951 following graduation from MIT. Mr. Trageser participated in development of THOR and TITAN systems and later conducted space guidance studies for the Laboratory.

Technical director of the Laboratory's APOLLO project is David G. Hoag, who joined the Laboratory in 1946 following his graduation from MIT. Mr. Hoag worked on Navy anti-aircraft gun fire control systems and Navy TERRIER and TARTAR fire control systems. From 1956 to his appointment to the APOLLO project, Mr. Hoag was technical director of the Laboratory's POLARIS guidance system development.

Management director of the Laboratory's APOLLO project is Perry K. Bryant who joined the Laboratory in 1962 following retirement from the Air Force with the rank of Colonel. Mr. Bryant served with the Air Force Aeronautical Systems Division for several years with management assignments.

Key Laboratory officials leading important APOLLO development areas include:

Dr. Richard H. Battin in charge of space guidance analysis for the Laboratory.

Philip N. Bowditch in charge of mechanical design of the APOLLO optical system. (Mr. Bowditch, a 1946 graduate of MIT, is the great great grandson of Nathaniel Bowditch, the pioneer 19th century navigator whose classic book, The American Practical Navigator, is still used, in updated form, by seafarers.)

Eldon C. Hall in charge of development of the APOLLO digital computer.

Edward J. Hall in charge of development of the APOLLO gyros.

John R. McNeil in charge of electronics that make the Laboratory's pulsed integrating pendulum instrument into an accelerometer.

John B. Nugent in charge of mechanical design of the APOLLO inertial measurement unit.

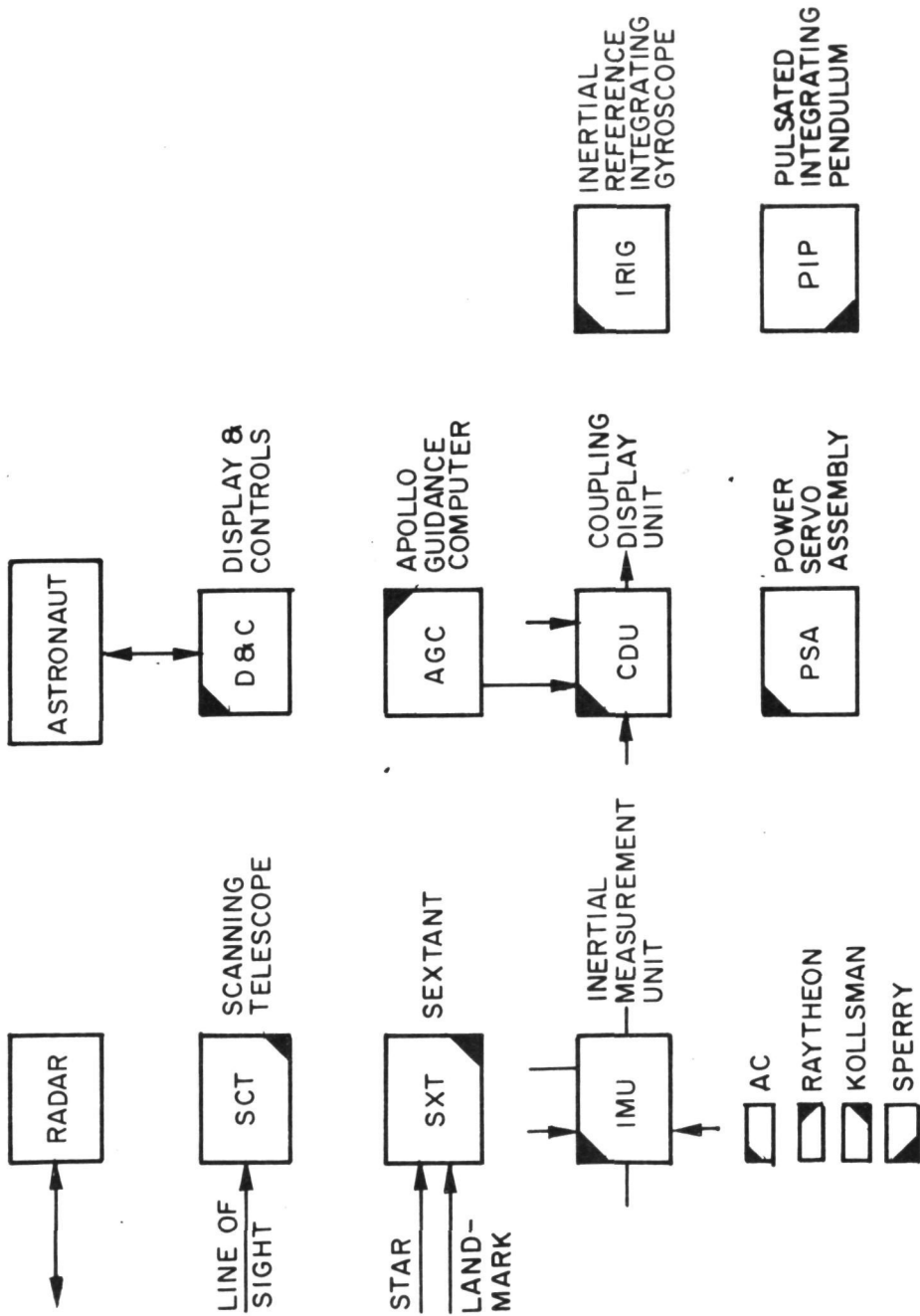
Michele Sappupo in charge of development of the pulsed integrating pendulum instrument that forms the heart of the APOLLO accelerometers.

John E. Miller in charge of APOLLO inertial measurement unit integration and calibration.

COL. PERRY K. BRYANT
PROGRAM MANAGEMENT PRESENTATION

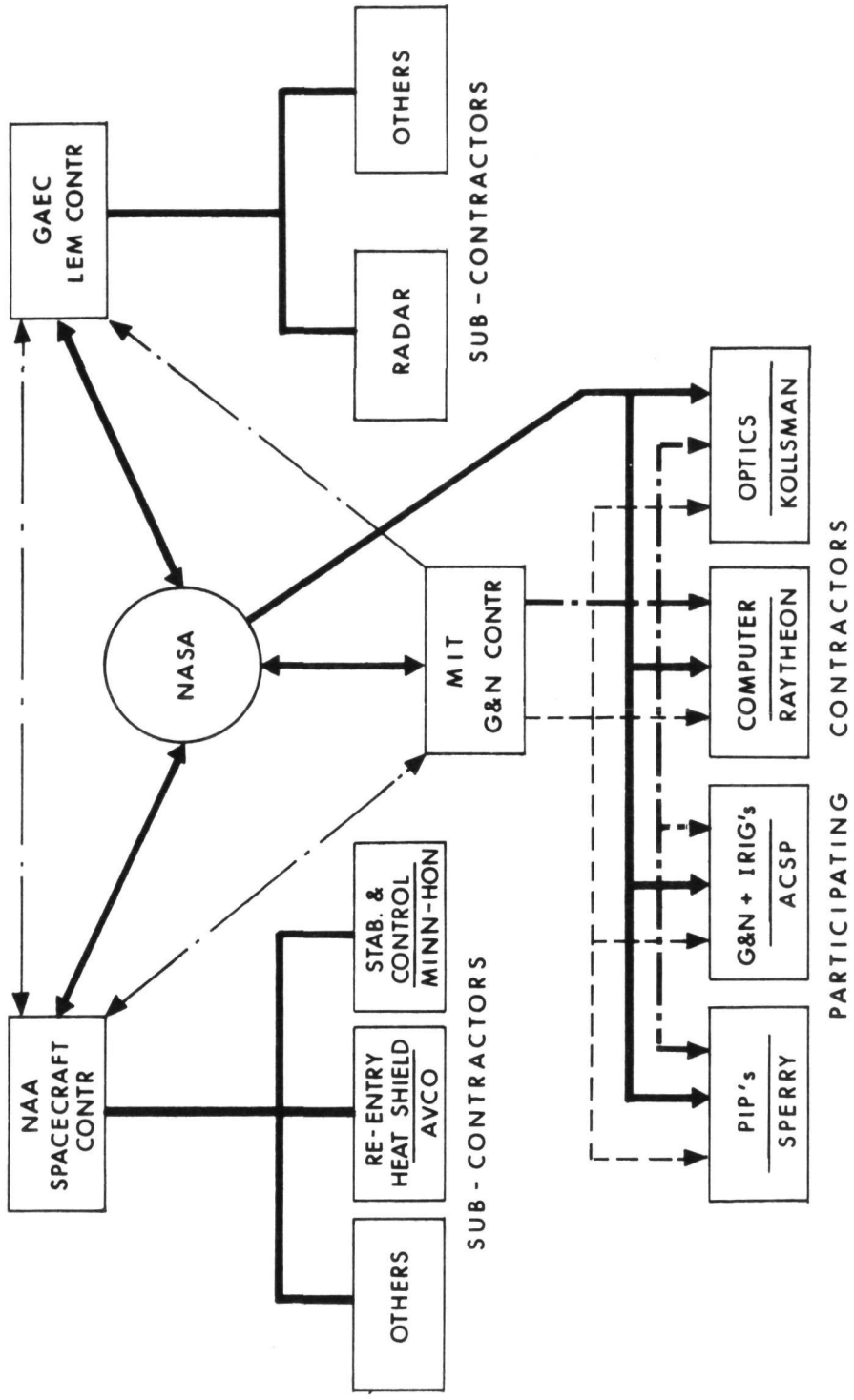
MAJOR SUBSYSTEM

GUIDANCE AND NAVIGATION

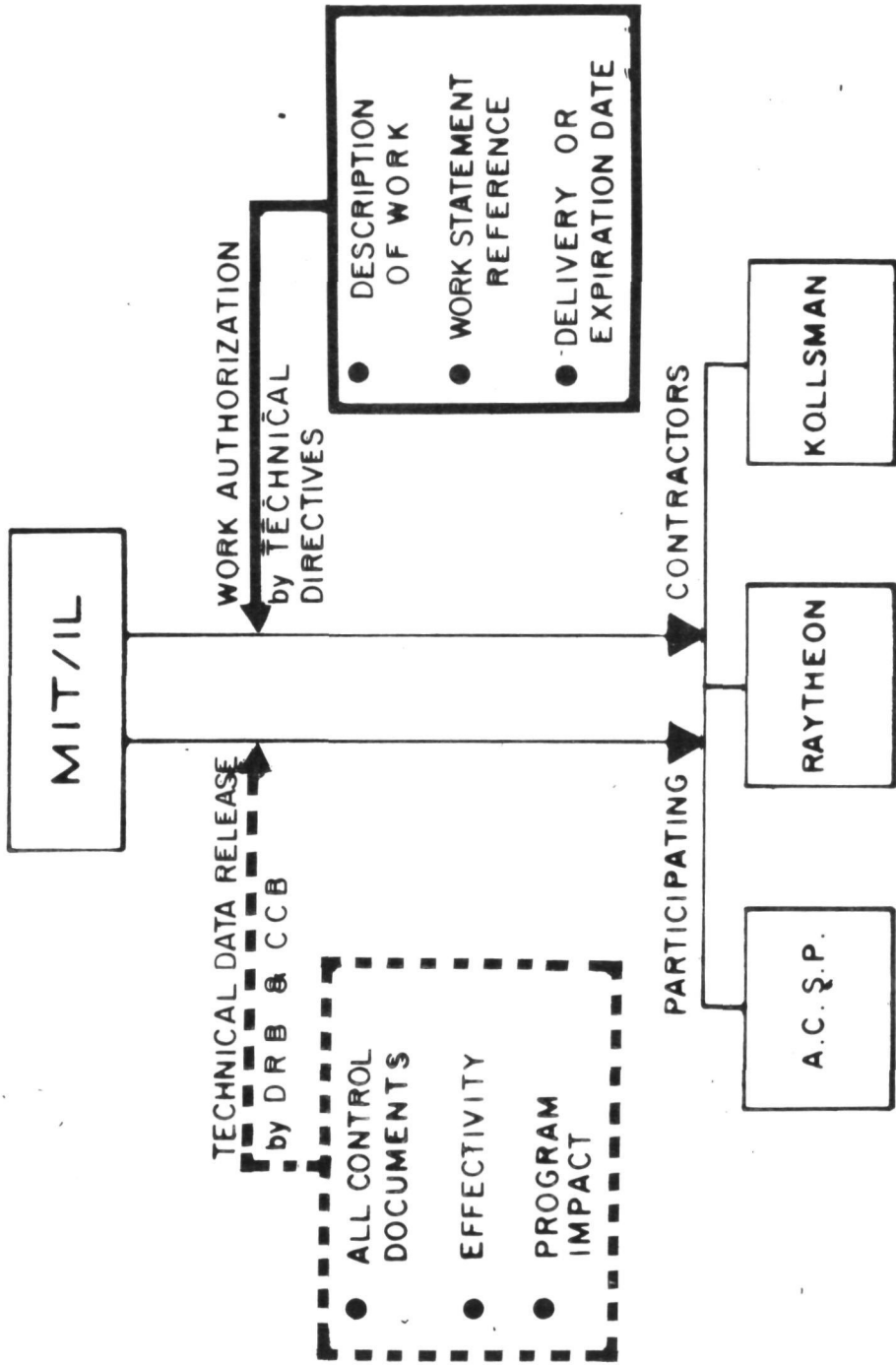


RELATIONSHIP BETWEEN ASSOCIATE & PARTICIPATING CONTRACTORS

- TECHNICAL COORDINATION
- - - DESIGN APPROVAL
- - - WORK AUTHORIZATION
- CONTRACTOR RELATIONSHIP



DESIGN CONTROL AND WORK AUTHORIZATION FLOW



INSTRUMENTATION LABORATORY
 MASSACHUSETTS INSTITUTE OF TECHNOLOGY
 TECHNICAL DIRECTIVE

Work to be accomplished by: Kollsman
 Contract No.: NAS9-499

Title: Procurement of Optical GSE Directive Number: K-74
 Engineering Contact: W. Schmidt Division Dir. Approved: W. Schmidt
 Instrumentation Lab: W. Schmidt/J. Gilmore Ext. 30-432
 Contractor: A. Ferraro Ext. 516-921-4843

Description of Effort

Reference: (1) NASA Statement of Work, SCG-100-133, Section 5.4.7(f)
 (2) MIT Letter AG 236-63, Definition of Optical GSE for
 KIC, ACSP, and MIT, dated April 22, 1963.

In accordance with the provisions of references (1) and (2), Kollsman is hereby directed to purchase eight (8) 5 inch coordinate autocollimators.* The supplier shall conform to Class 3 quality assurance requirements as contained in NASA Specification MD 1015404.

This T.D. is a partial release of equipment listed in reference (1) and (2).

This T.D. shall be considered complete upon delivery and acceptance of this equipment at locations which will be specified at a later date.

This T.D. expires March 1, 1964.

Engineering time to accomplish this T.D. shall not exceed 80 man-hours. Inspection Technician time to accomplish this T.D. shall not exceed 120 man-hours.

Delivery Date: _____ (if applicable) *per NASA Specification Drawing # 1017410

Manpower Estimate in Man Hours

Engineers	80 Hours	Other (Specify):	_____
Technicians	120 Hours		_____
Draftsmen	_____		_____
Manufacturing	_____		_____
Issued by:	<u>W. Schmidt</u>	Date:	<u>2-17-64</u>
NASA Technical Approval:	<u>W. Schmidt</u>	Date:	<u>2-17-64</u>
NASA C. O. Approval:	<u>W. Schmidt</u>	Date:	<u>2-17-64</u>
Accepted by:	<u>W. Schmidt</u>	Date:	<u>2-17-64</u>
Completed by:	_____	Date:	_____
Confirmed by:	_____	Date:	_____



INSTRUMENTATION LABORATORY
 MASSACHUSETTS INSTITUTE OF TECHNOLOGY
 TECHNICAL DIRECTIVE

Referenced in folder

Work to be accomplished by: A. C. Spark Plug
 Contract No.: MAS 9-497

Title: PSA Block I Hardware & Learning Model Directive Number: T.D. A-112
 Engineering Contact: Division Dir. Approved
 Instrumentation Lab: Dean Test Ext. 30453
 Contractor: R. Sparsino Ext. 202

Description of Effort

This technical directive authorizes the effort for the Block I PSA's.

1. Fabricate, procure, assemble, and test five (5) PSA's (PSA 5, 6, 7, 8, and 20). For ACE 5 PSA only, electronic parts may be procured to vendor catalog number and specifications where specifically indicated on the specification control drawings. In these instances, all other SCD requirements are waived except for lead material and physical dimensions. For ACE 6, 7, 8, and 20 PSA's, all parts shall be procured to NASA Class "A" drawings and specifications as they are released through the CCB. NOTE: ACE 5 PSA does not include Cold Plate or Junction box; Junction box is to be supplied by MIT four weeks prior to ACE-5 PSA delivery, for PSA level testing by ACSP.

REF: ACSP Statement of Work dated January 28, 1963, Section 5.2.4.

2. Fabricate, procure, assemble, and test one (1) PSA learning model to be built to less than Class "A" documents as they are released through the CCB.

REF: ACSP Statement of Work dated January 28, 1963, Section 5.1.4 (e).
 Milestones and deliveries are to be in accordance with the January 28, 1963 ACSP Statement of Work.

EXPIRATION DATE: July 30, 1964
 Delivery Date: _____ (if applicable)

Manpower Estimate in Man Hours	
Other (Specify):	Estimated Man Hours
Engineers	
Technicians	
Draftsmen	172,628
Manufacturing	
Total	
Issued by: <u>Raymond B. Bryant</u>	Date: <u>15 Feb 63</u>
NASA Technical Approval: <u>William J. Ahern</u>	Date: <u>2-20-63</u>
NASA C. O. Approval: <u>William J. Ahern</u>	Date: <u>2/20/63</u>
* Accepted by: <u>R. Sparsino</u>	Date: <u>3-6-63</u>
Completed by: _____	Date: _____
Confirmed by: _____	Date: _____

* Refer to AC Spark Plug letter of acceptance for exceptions to or clarification of this T. D.

CHANGE CONTROL BOARD PROCEDURE

CHAIRMAN - MIT MEMBERSHIP

NASA - 1 PERMANENT
MIT

- | PERMANENT (SYSTEMS INTEGRATION ENGR)
- | ROTATING (DESIGN GROUP LEADER)
- | DOCUMENTATION
- | RECORDER

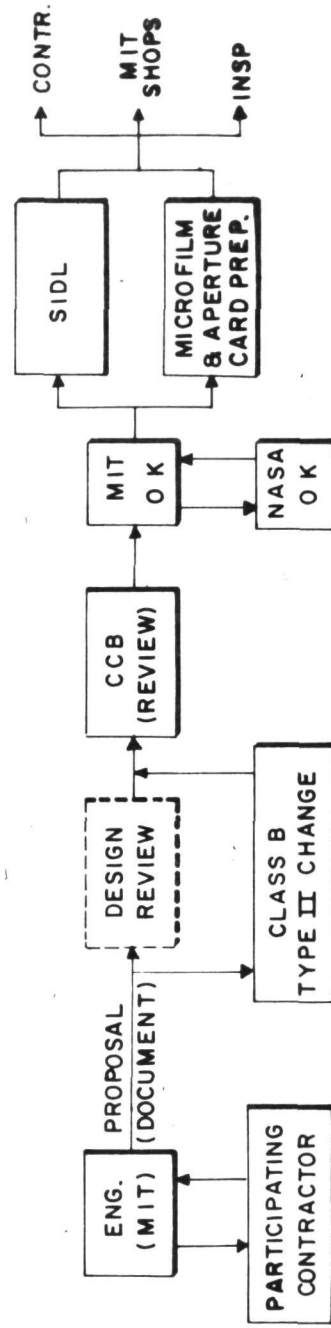
PARTICIPATING CONTRACTORS

- | EACH-PERMANENT
- | EACH-ROTATING

GOVERNMENT INSPECTORS

- | FOR EACH CONTRACTOR

PROCEDURES



Release on Return

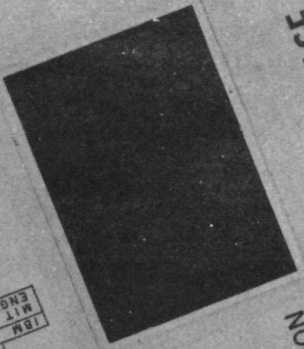
SAMPLE TDRR FORM

APOLLO COMMAND AND INVESTIGATION
TECHNICAL DATA RELEASE OR RETURN

1. NAME OF PROJECT	2. PART NO.	3. DRAWING NO.	4. TIME REL. 00493
MULTIPLE RELEASE - CLASS A		5. DATE	6. TIME REL. 00493
P.S.A. (INITIAL RELEASE - CLASS A)		7. DATE	8. TIME REL. 00493
9. DESCRIPTION OF SAMPLE			
1. 1007021: - PULSE TORQUE GYRO CALIBRATION ASSEMBLY.			
2. 1007020: - HEAVY DUTY PULSE TORQUE GYRO CALIBRATION.			
3. 1008023: - INSULATOR, PHOTO MASTER, GYRO CALIBRATION. (2 sheets)			
10. INITIAL RELEASE - CLASS A			
11. NAME OF PERSON			
12. SIGNATURE			
13. DATE			
14. TIME REL. 00493			
15. NAME OF PERSON			
16. SIGNATURE			
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ASSEMBLY
 WA. SYSTEM
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MIT INSTRUMENTATION
 LABORATORY

CLASS "A" RELEASE
 MASTER RELEASE

U.S. PAT. NOS. 2,511,859, 2,512,100, 2,587,072
 WASHINGTON
 GEORGES STENGLE

TRANSCAT BRAND APERTURE CARD PRODUCT OF 3M CO. ST. PAUL, MINNESOTA

DOCUMENT - DESCRIPTION
 COLLISION REPAIR ASSEMBLY DR

RELEASE CLASS
 TOTAL NO SHEETS & PAGES
 REVISION LETTER/NUMBER

DOCUMENT NO.
 EQUIPMENT CODE
 TYPE OF DOCUMENT
 FRAME NUMBER
 NUMBER OF FRAMES

FORM 1241

TYPICAL PAGE FOR APOLLO SYSTEM IDENTIFICATION DATA LIST (SIDL)

APOLLO SIDL															
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
EQ CD	DOC TYP	FRAME NO	DOC NO	TOT SHS PGS	REV LTR	REL TDR	CLS	DOCUMENT DESCRIPTION	RES MIT ENGR	MA-MECH NA-NXT HCHR NS-NEXT SIG	EFFECTIVITY SVT AGE	SYM CD	BT	CD	
35	01	A	A 1000069	001	A	00025	A	PIN, LOCATING ADA MT	26	NS1000001	05	05	3		
35	01	A	A 1000072	001	-	00072	A	GUSSET PLT CASE + HC	26	NS1000003	05	05	3		
35	01	A	A 1000074	001	-	00065	A	MID GIMBAL MSG ASSY	26	NS1000001	05	05	3		
35	01	A	A 1000075	001	-	00063	A	MOTOR, TORQUE, DC FRAMELESS.SCD	26	NS1000001	05	05	3		

Equipment Code	Document No. (self-explanatory)	Rev letter/number (when applicable)	Technical Data Release Number provided by the Change Control Board	Released Class - "A" Flight Units "B" Experimental, PreLetc. Units "O" Obsolete	"W" Waiver
Documentation Type	1. Drawings 2. Procurement Specs (PS) 3. Assembly and Test Proc. 4. Administrative Document	Frame No. A = 1, B = 2, C = 3	No. of Frames A = 1, B = 2, Ex: 2 Frames Microfilm 1st Card AB 2nd Card BB		
Document No. (or description of chg)	Responsible MIT Engr - Code No. of cognizant MIT engineer for reference of any technical question MIT APOLLO Engineer Code 1. R. Woodbury 2. F. Houston 3. M. B. Trageser 4. D. G. Rom				
MA - Next Higher Assembly NS - Significant Assembly MA - Mechanical Assembly	Cut-in and Cut-out by System AGE Serial No.				
	Cut-in and Cut-out by Component or Subsystem Serial No.				
	Document Status Code				
	0 = Obsolete 1 = Planned or under preparation 2 = MIT approved 3 = NASA approved				

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M.I.T. INSTRUMENTATION LABORATORY

Rev. 10/63
TR 7143-19

DOCUMENTATION TYPES LISTED IN SIDL

- 1 - Drawings
- 2 - Procurement Specs (PS)
- 3 - Assembly and Test Procedures (ATP)
- 4 - Final Test Methods (FTM)
- 5 - NASA Documents (ND)
- 6 - MIT Publications (E Notes)
- 7 - Coordination/Correlation Drawings
- 8 - Administrative Documents (Selected Documents)
- 9 - Job Description Cards (JDC)
- 10 - Spec. Control Drawings (SCD)
- 11 - Waivers
- 12 - Computer Programs



EQ CODE	ASSEMBLY	LEVEL	DOCUMENT	IDENT	DOCUMENT DESCRIPTION	# REQ	USED	ON
45	A05A04	Q09	ND1015402		GOLD PLATE		1010342	
45	A05A04	Q09	MIL-P-19491		SEMICOND PREP DELIVERY		1010342	
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45	A05A04	R01	MIL-R-26		RESISTOR FXD COMP W/W		1010389	
45	A05A04	R01	ND1015404		GAP FOR HI REL ITEMS		1010389	
45	A05A04	R01	ND1002034		QUAL STATUS LIST		1010387	
45	A05A04	R01	PS1015400		NI ALY 200 1/8 HARD		1010387	
45	A05A04	R02	QSCD1006750-039		RESISTOR FXD FILM 2K OHM	1	1007055	
45	A05A04	R03				1	1007055	
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SAMPLE AGARI PAGE

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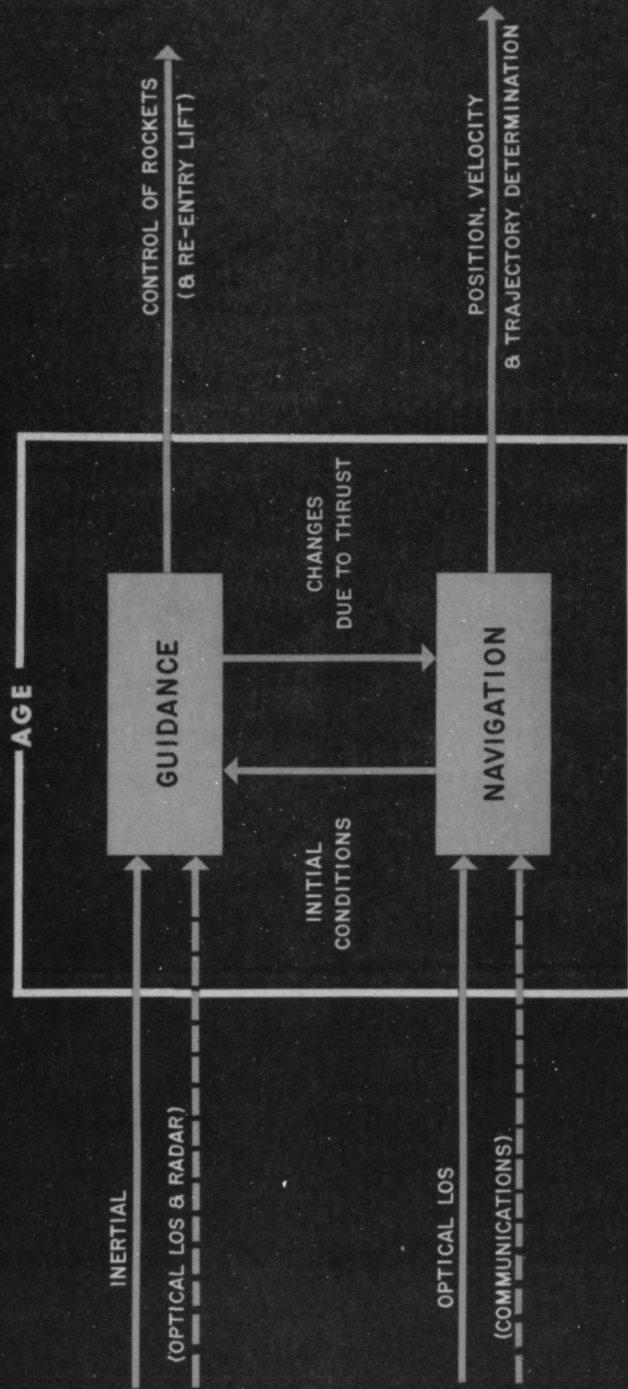


MR. DAVID G. HOAG
TECHNICAL DISCUSSION OF
THE CM AND LEM G&N SYSTEMS

GUIDANCE AND NAVIGATION

- **DETERMINE POSITION AND VELOCITY OF SPACECRAFT**
- **DETERMINE SPACECRAFT VELOCITY CHANGES NEEDED TO CORRECT TRAJECTORY**
- **MEASURE AND STEER VEHICLE IN REQUIRED MANEUVERS**

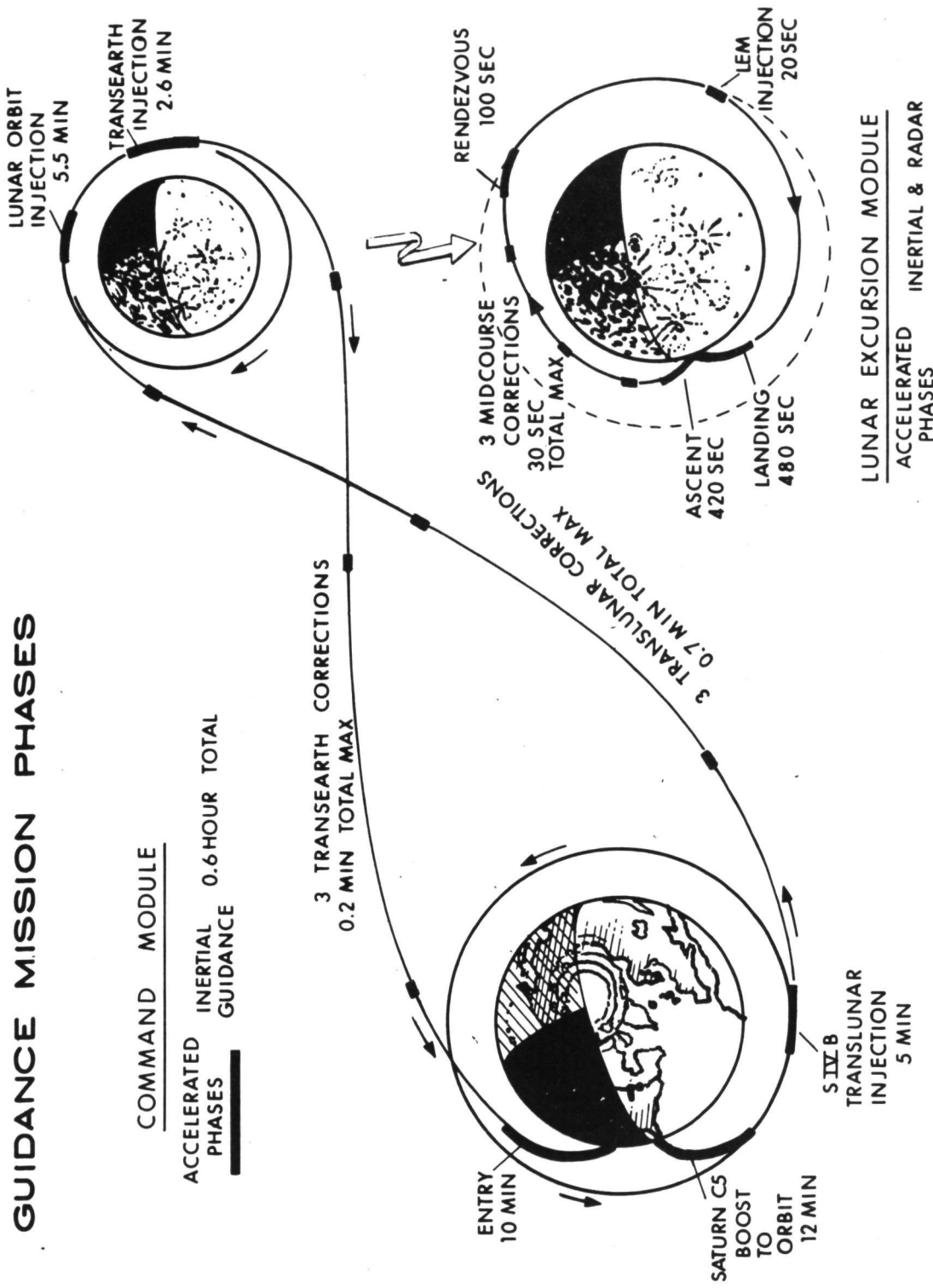
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June 1962

M.I.T. Instrumentation Laboratory

GUIDANCE MISSION PHASES



COMMAND MODULE

ACCELERATED PHASES
 INERTIAL GUIDANCE 0.6 HOUR TOTAL

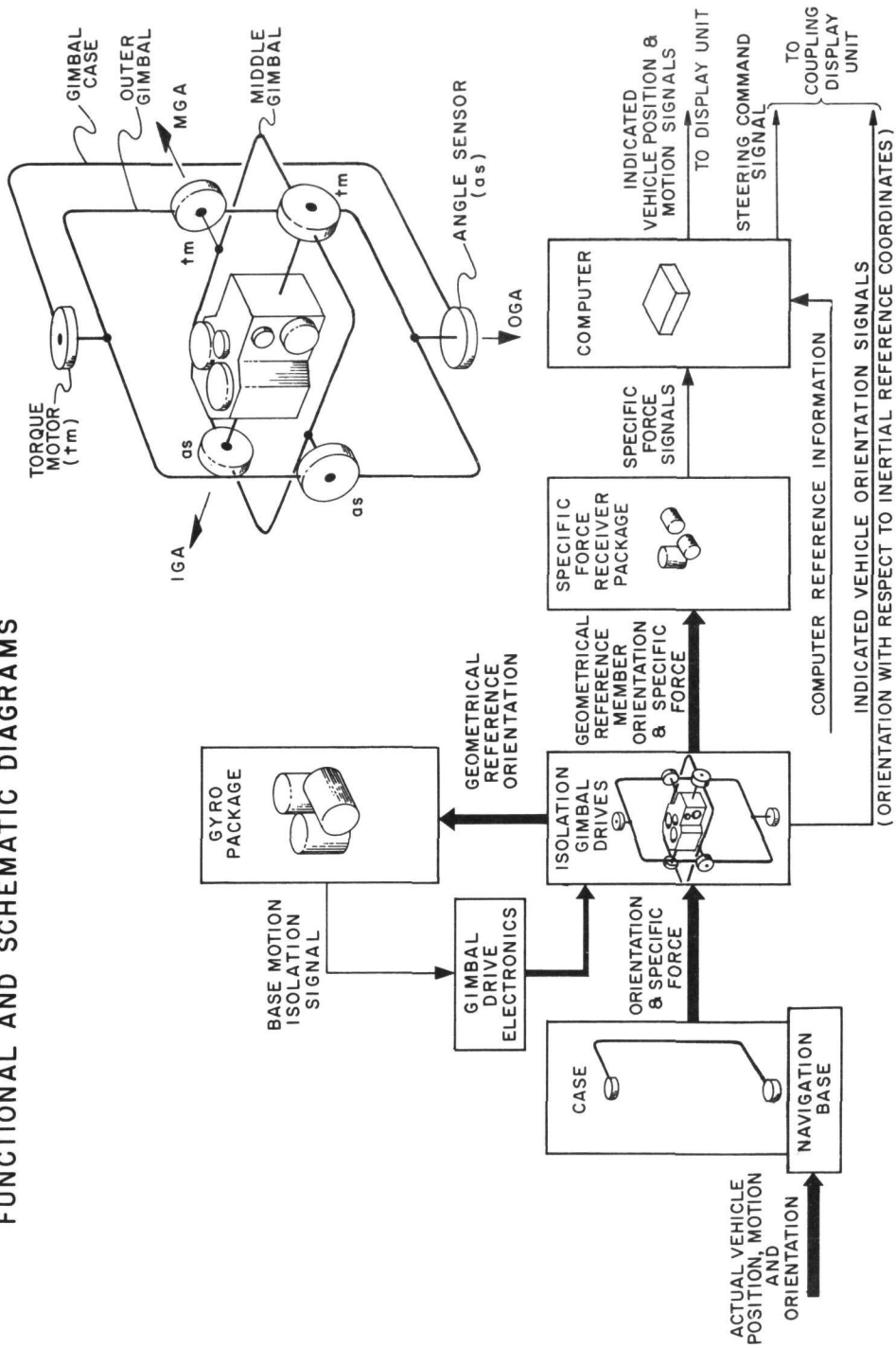
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ACCELERATED PHASES
 INERTIAL & RADAR



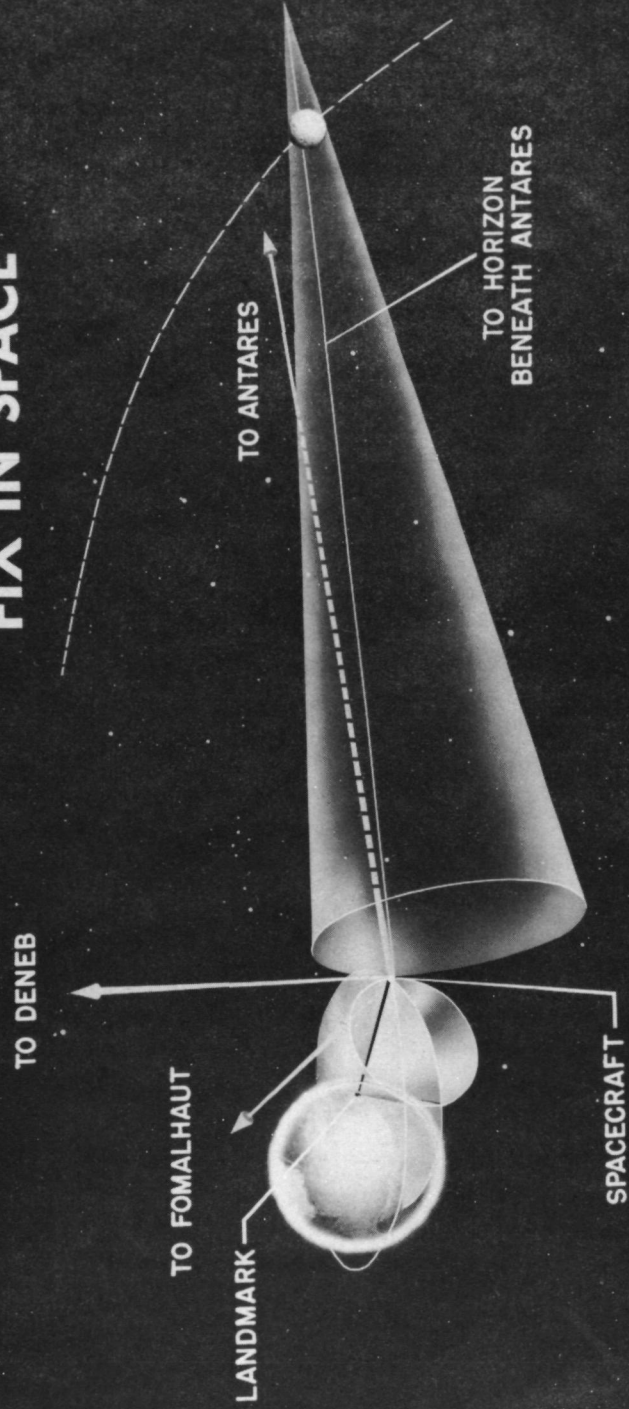
INERTIAL MEASUREMENT UNIT - IMU

FUNCTIONAL AND SCHEMATIC DIAGRAMS



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GEOMETRY OF NAVIGATIONAL FIX IN SPACE

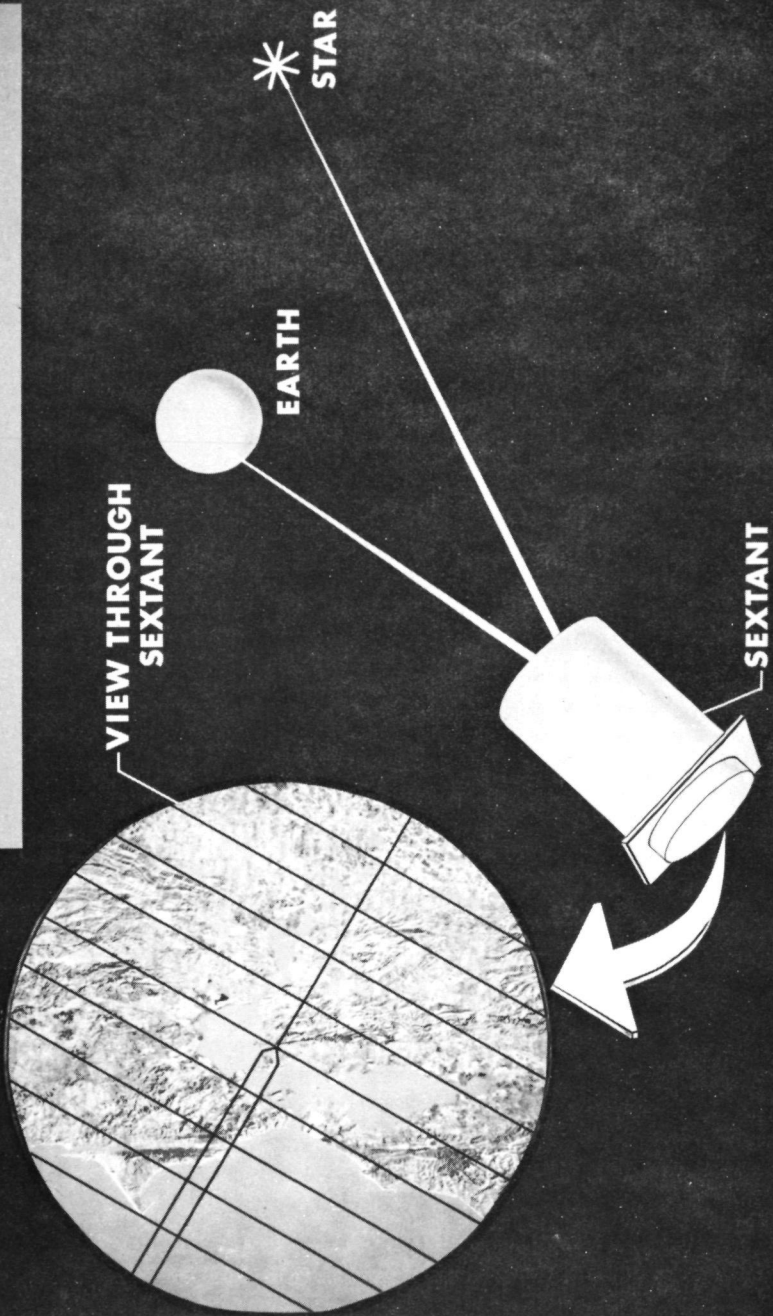


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June 1962
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EARTH LANDMARK NAVIGATION REFERENCE



M.I.T. March 1963
Instrumentation Laboratory

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STAR

ILLUMINATED EARTH HORIZON
NAVIGATION REFERENCE

NAVIGATION ANGLE

SEXTANT

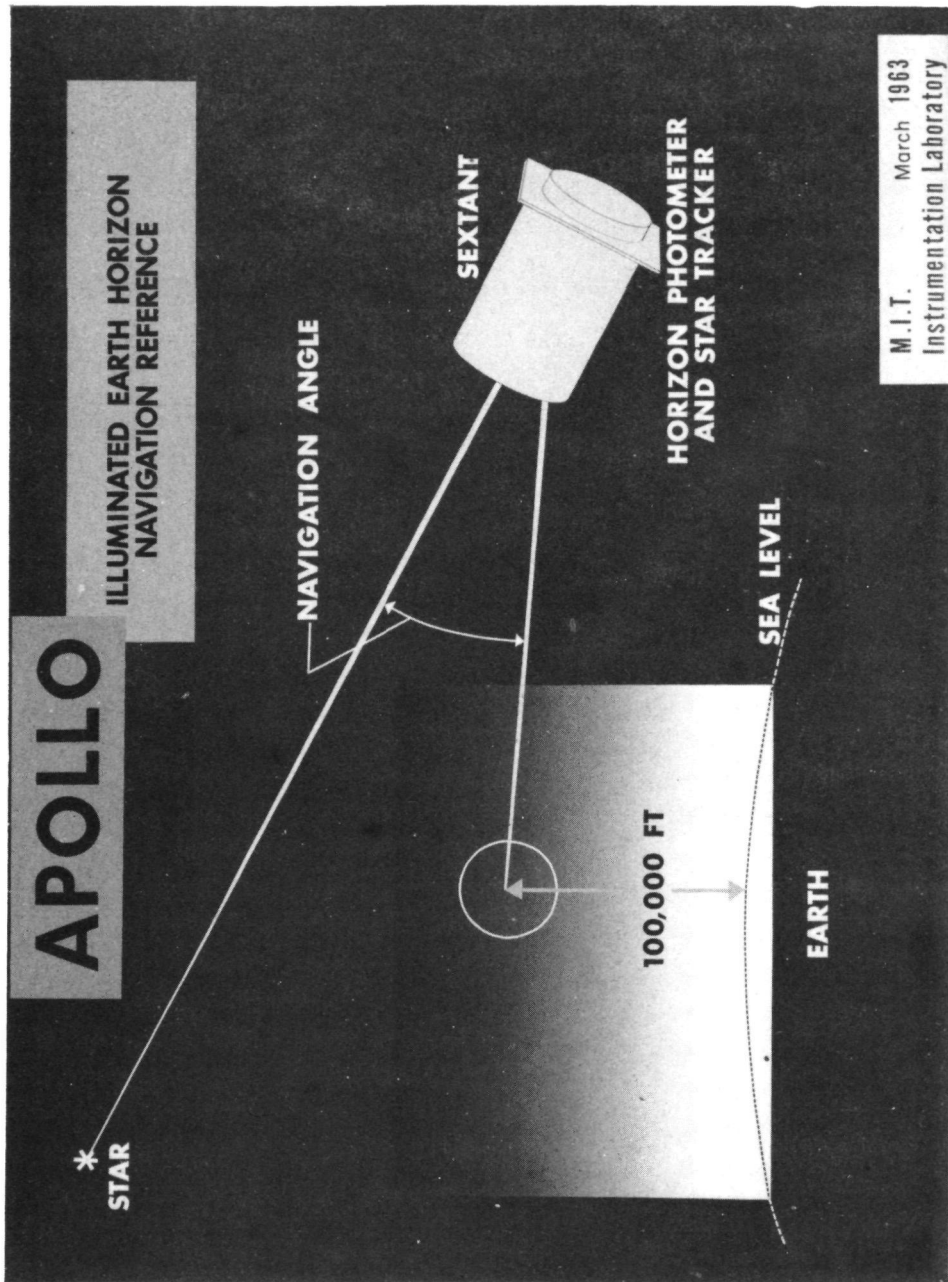
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AND STAR TRACKER

100,000 FT

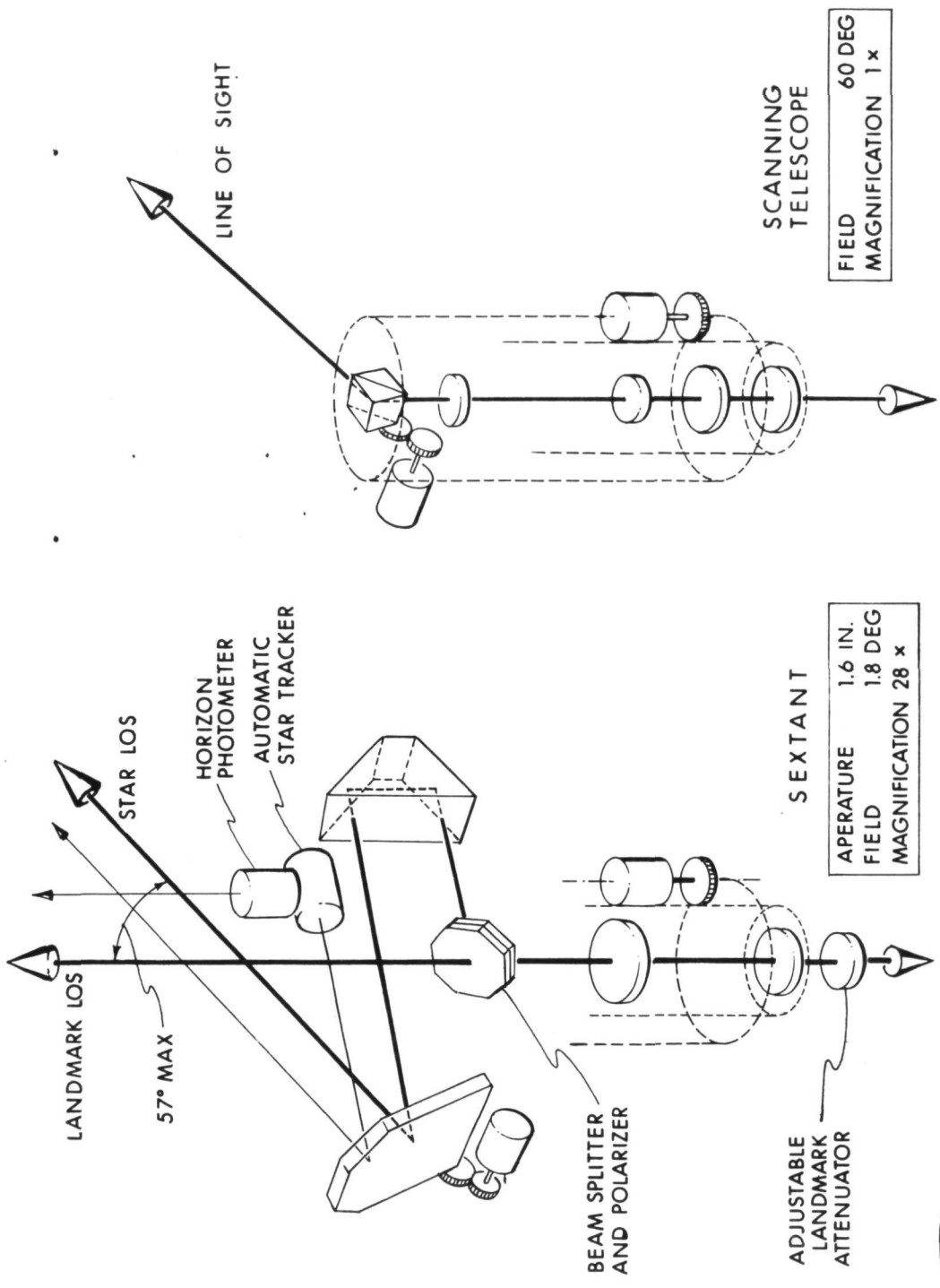
SEA LEVEL

EARTH

M.I.T. March 1963
Instrumentation Laboratory



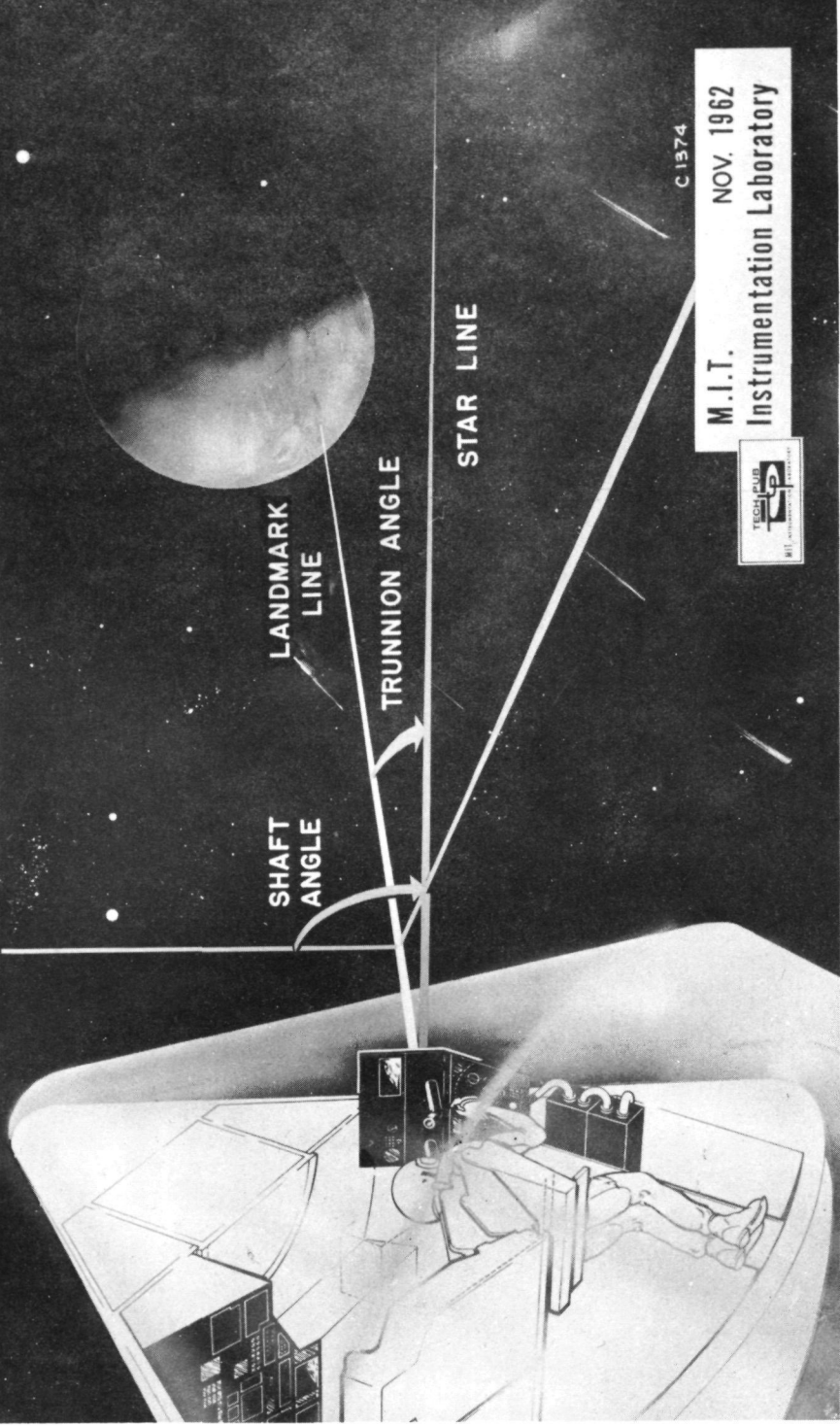
OPTICAL SCHEMATICS



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SPACECRAFT ORIENTATION MIDCOURSE NAVIGATION SIGHTING



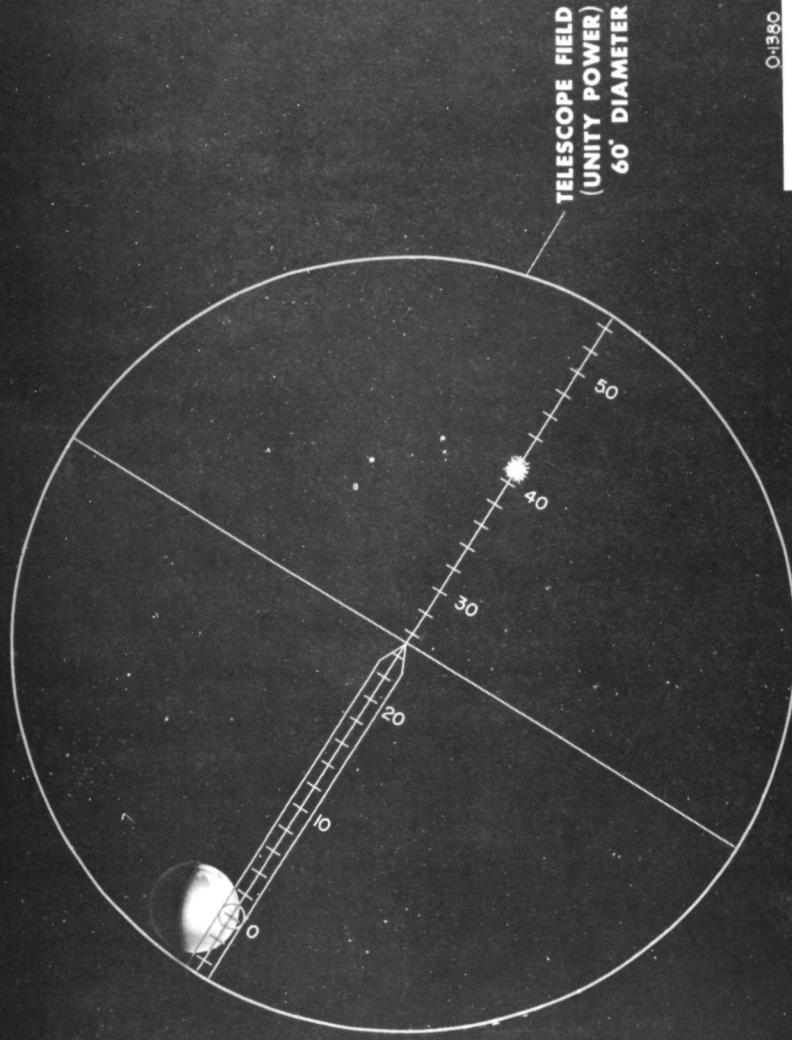
C 1374

M.I.T.
NOV. 1962
Instrumentation Laboratory



APOLLO

TELESCOPE VIEW - MIDCOURSE NAVIGATION

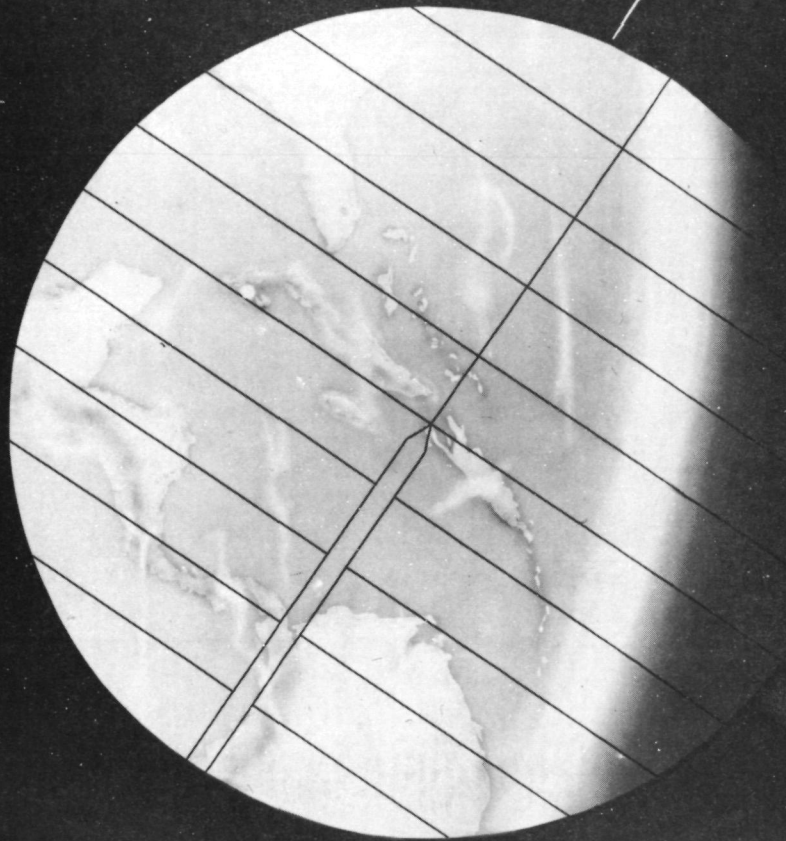


O-1360

M. I. T. NOV 1962
Instrumentation Laboratory

APOLLO

SEXTANT VIEW - MIDCOURSE NAVIGATION



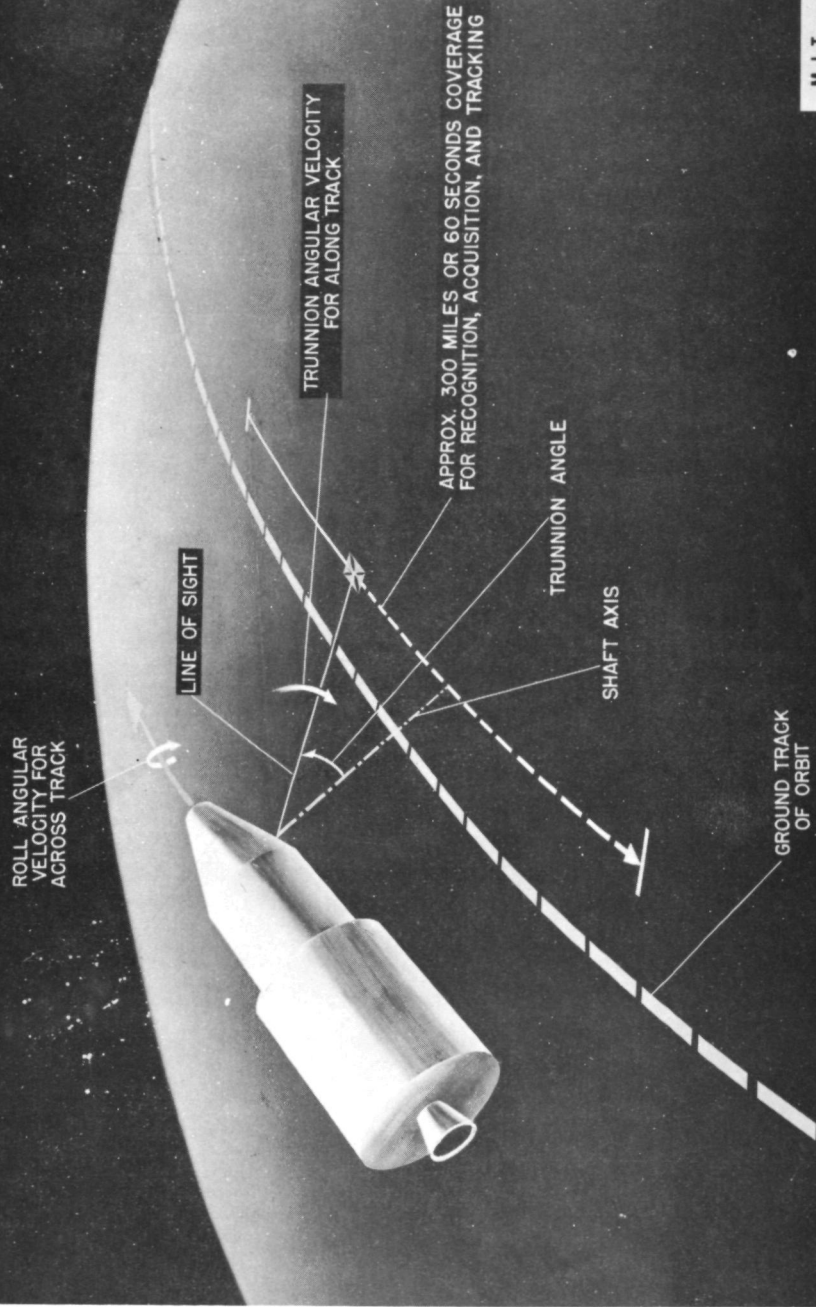
SEXTANT FIELD
1.9° DIAMETER

O-1377
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APOLLO

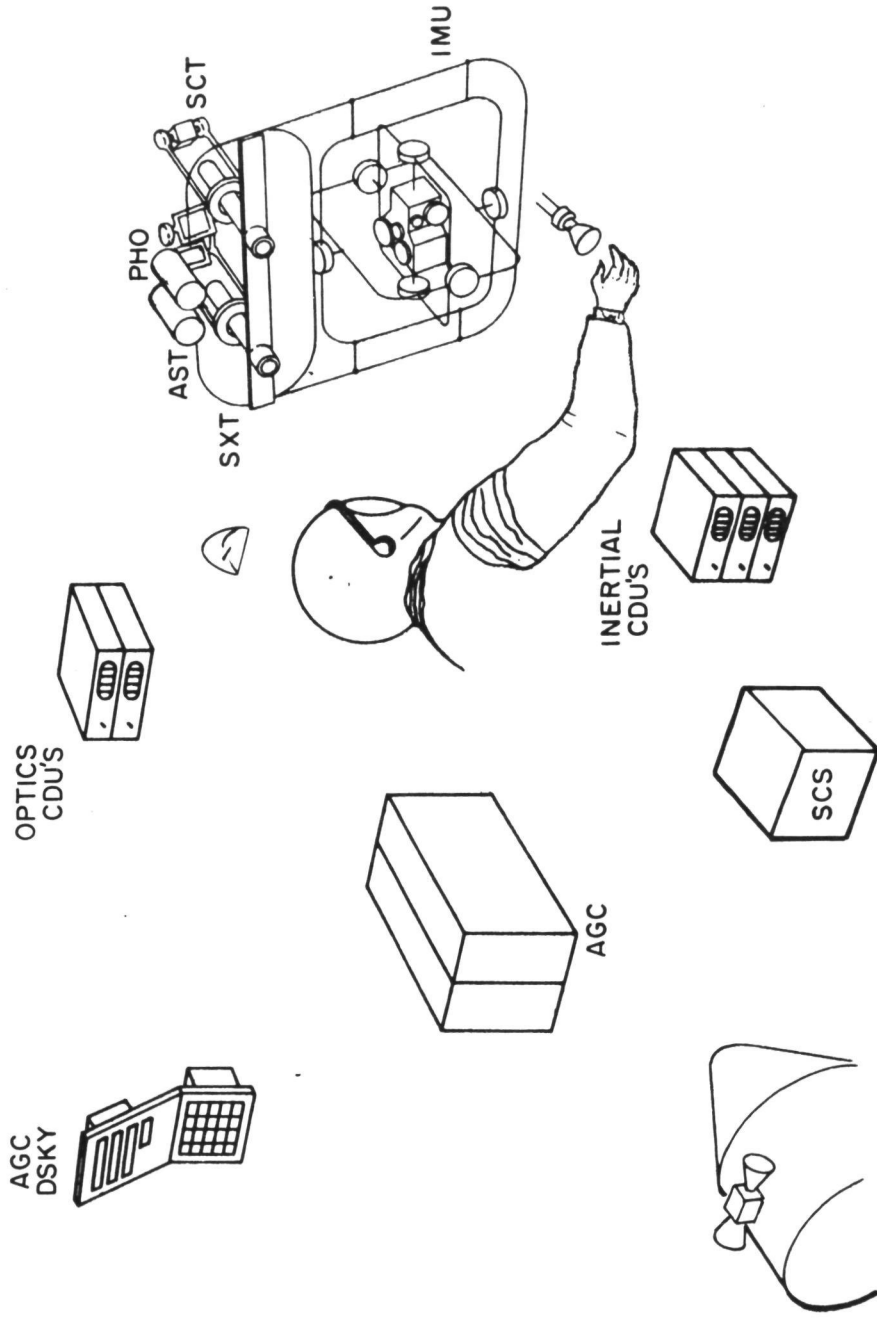
SPACECRAFT ORIENTATION-ORBITAL NAVIGATION SIGHTING



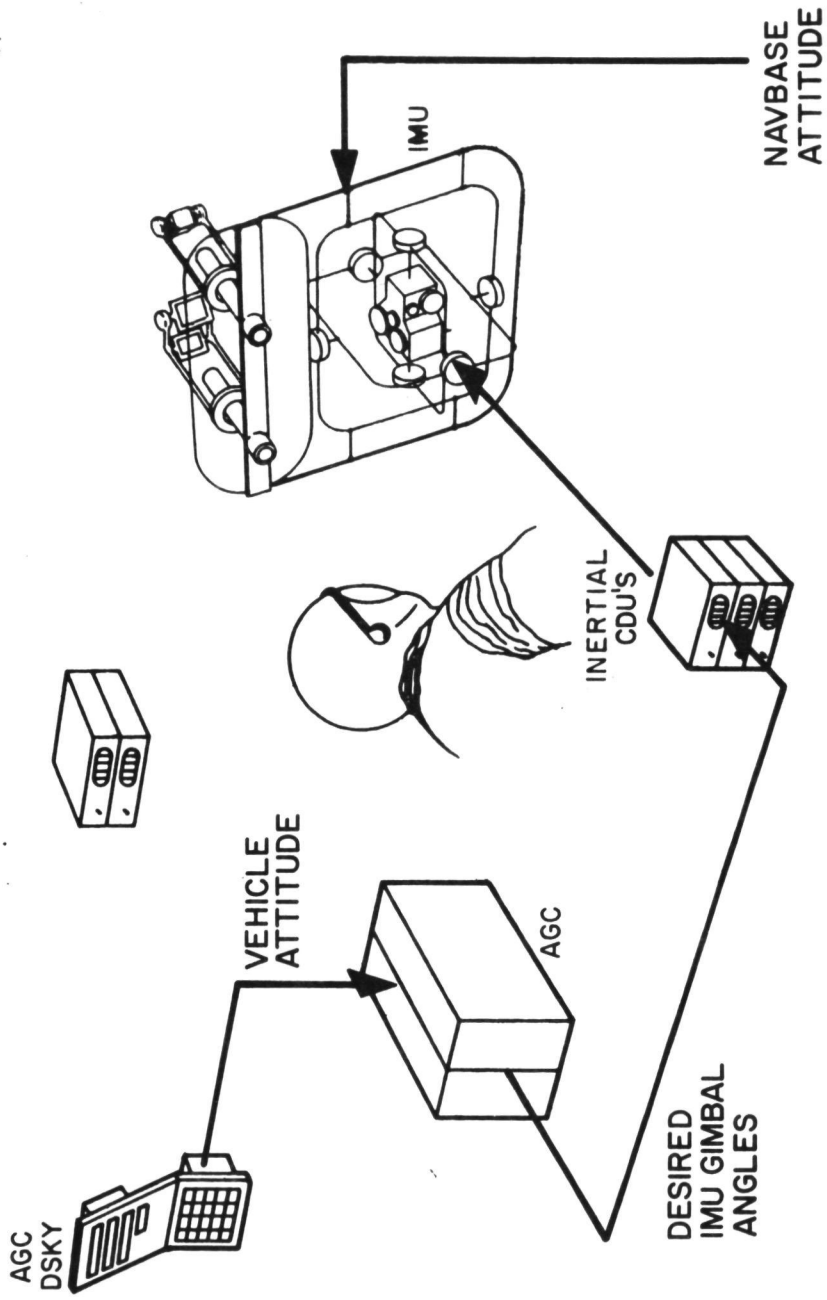
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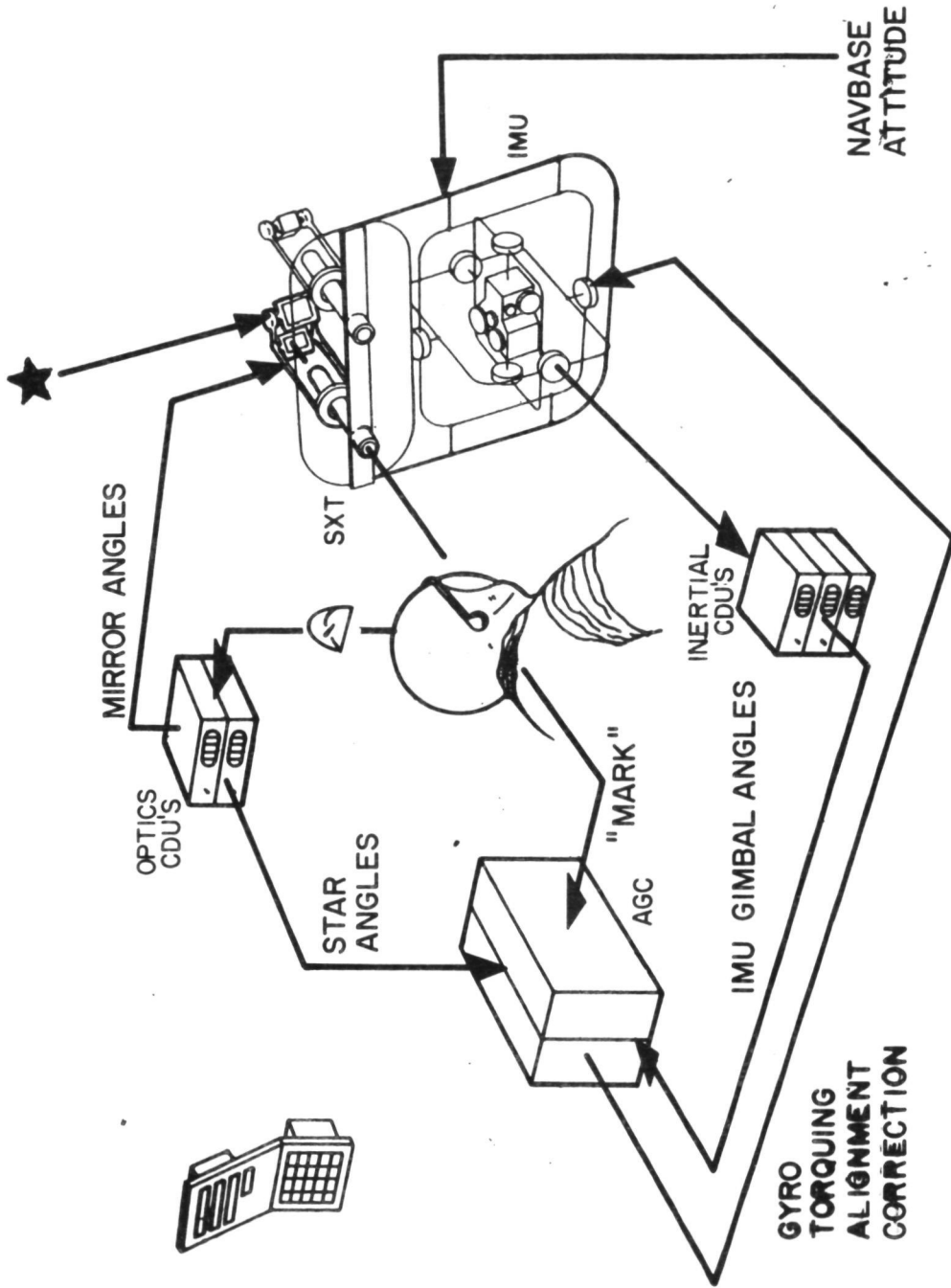
MAJOR SUBSYSTEMS



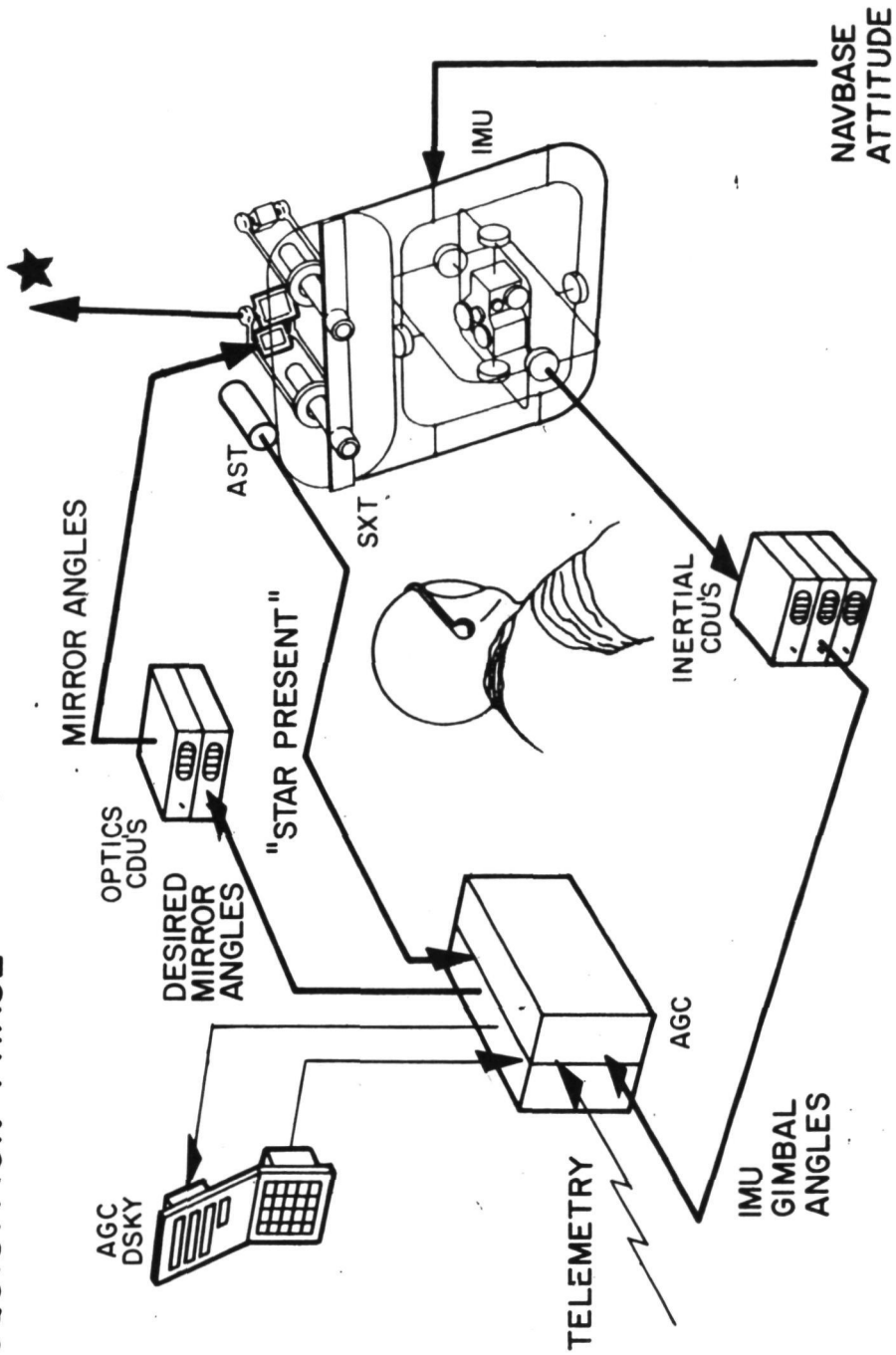
IMU COARSE ALIGNMENT - MANUAL



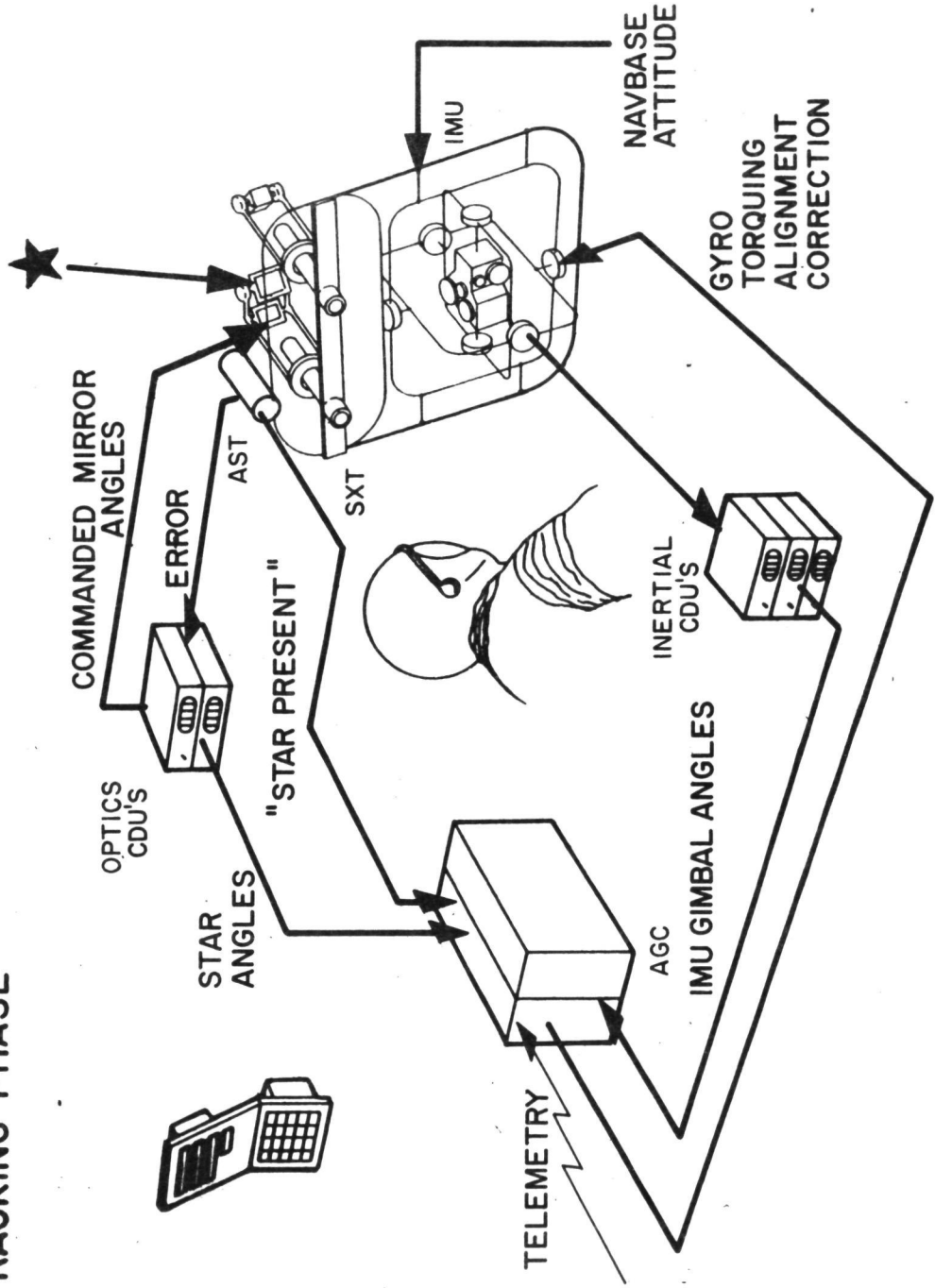
IMU FINE ALIGNMENT-MANUAL



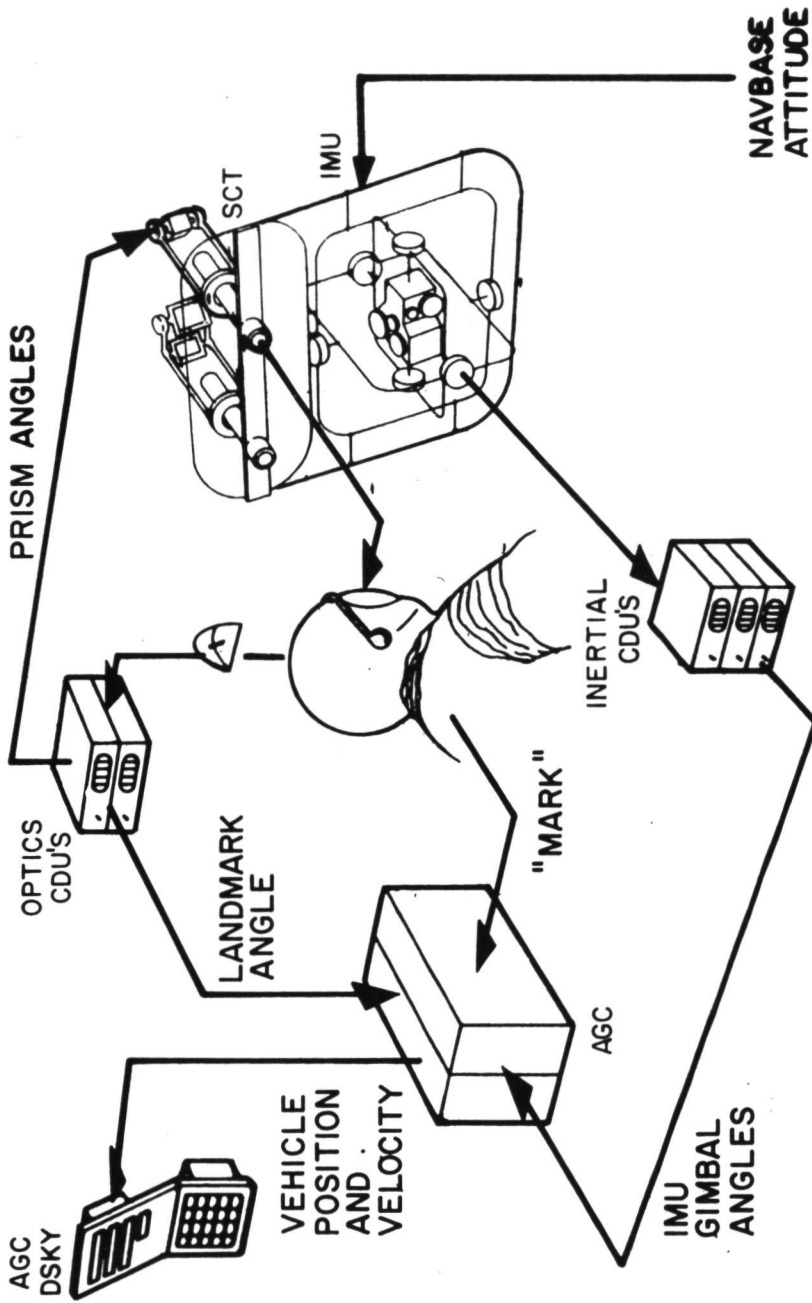
IMU ALIGNMENT - AUTOMATIC ACQUISITION PHASE



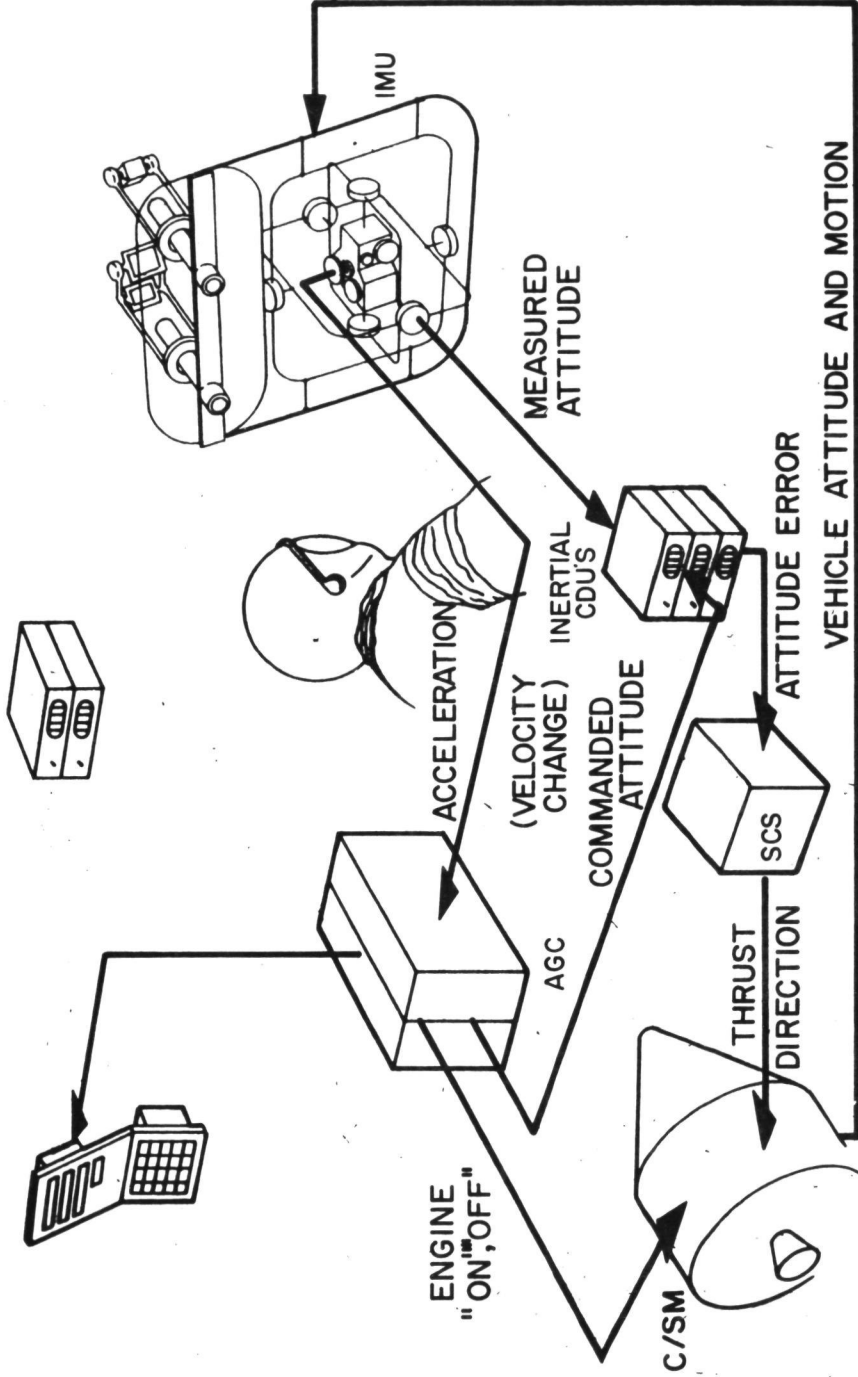
IMU ALIGNMENT - AUTOMATIC TRACKING PHASE



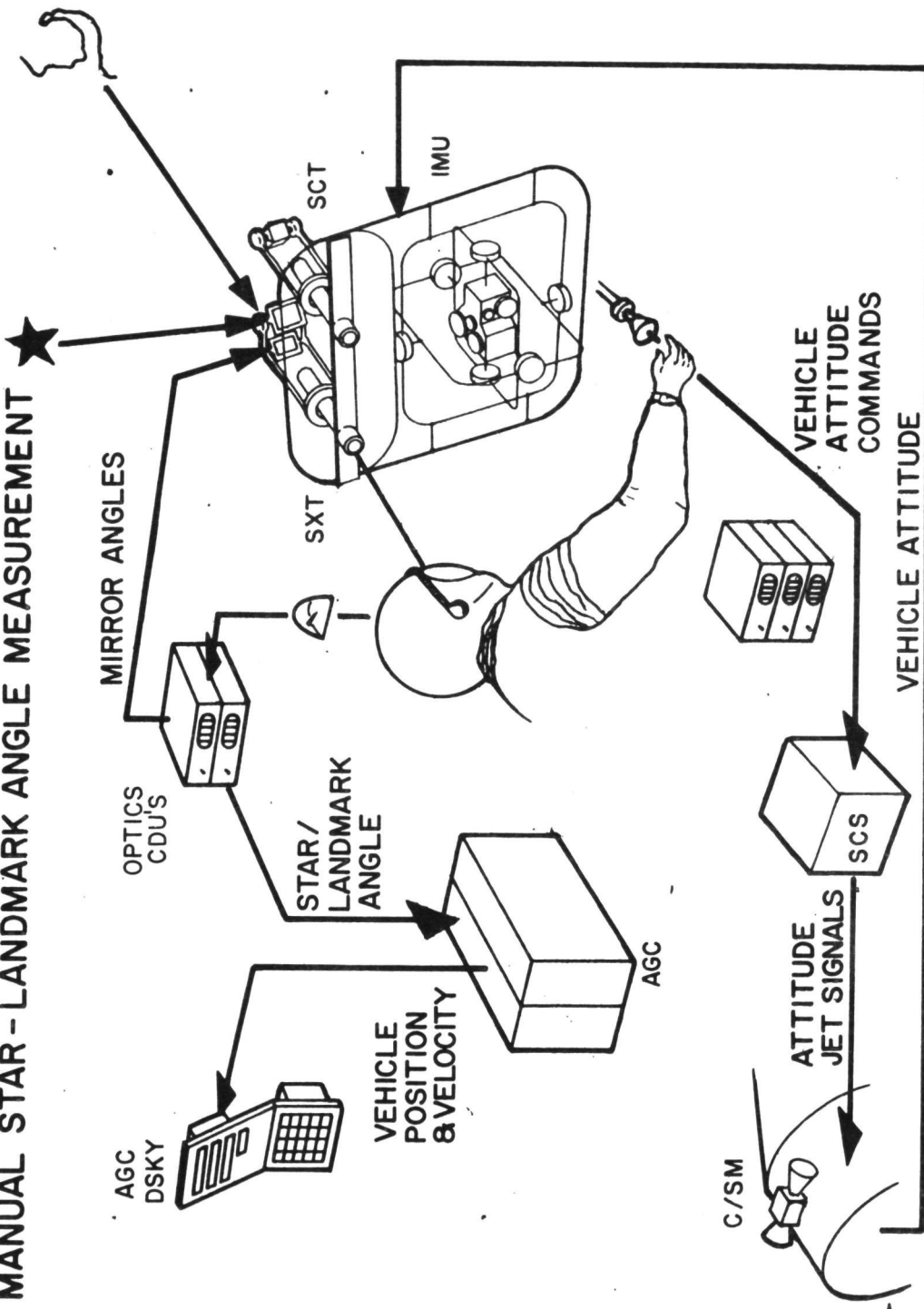
LOW ORBIT NAVIGATION LANDMARK TRACKING



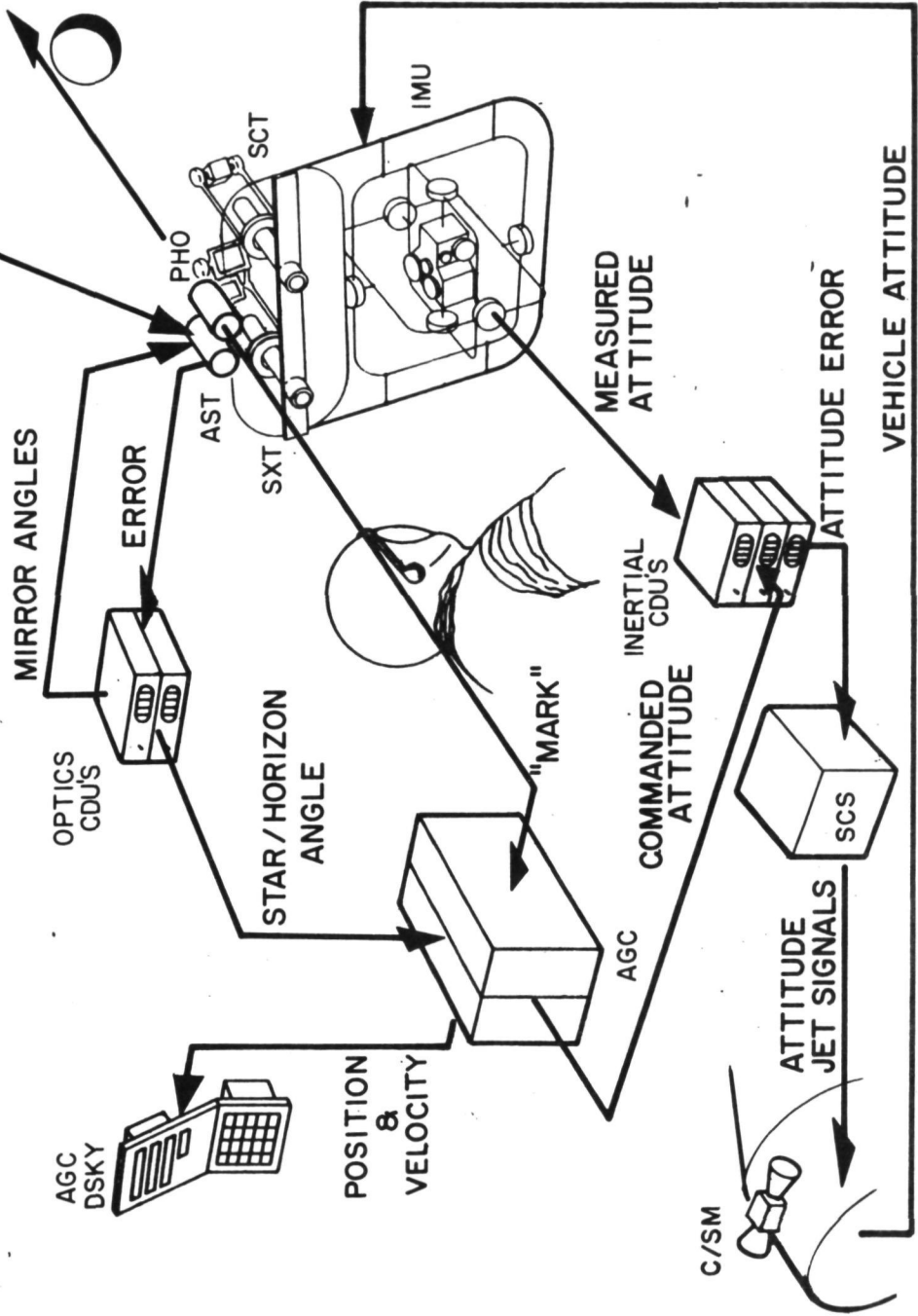
GUIDANCE THRUST CONTROL



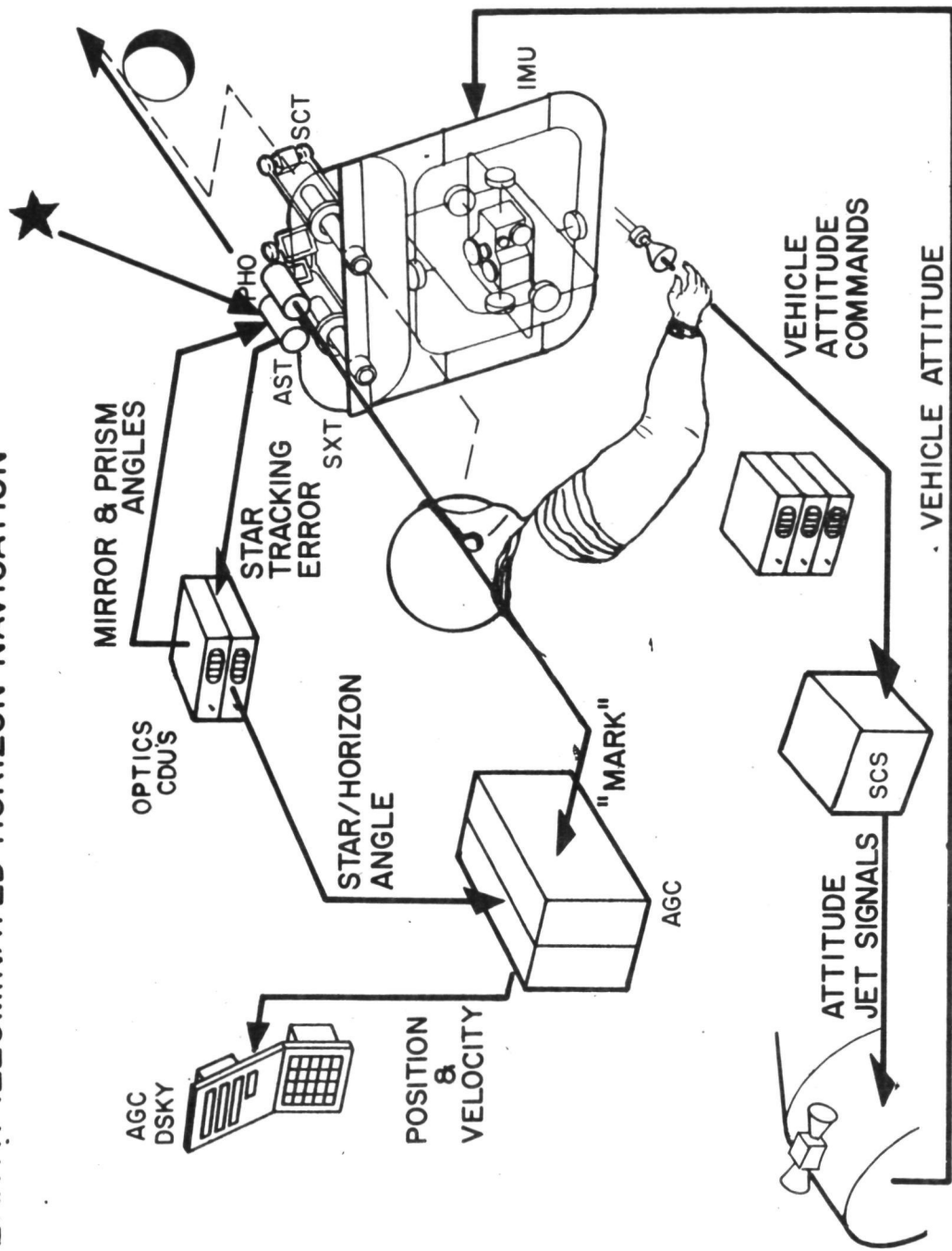
MIDCOURSE NAVIGATION MANUAL STAR - LANDMARK ANGLE MEASUREMENT



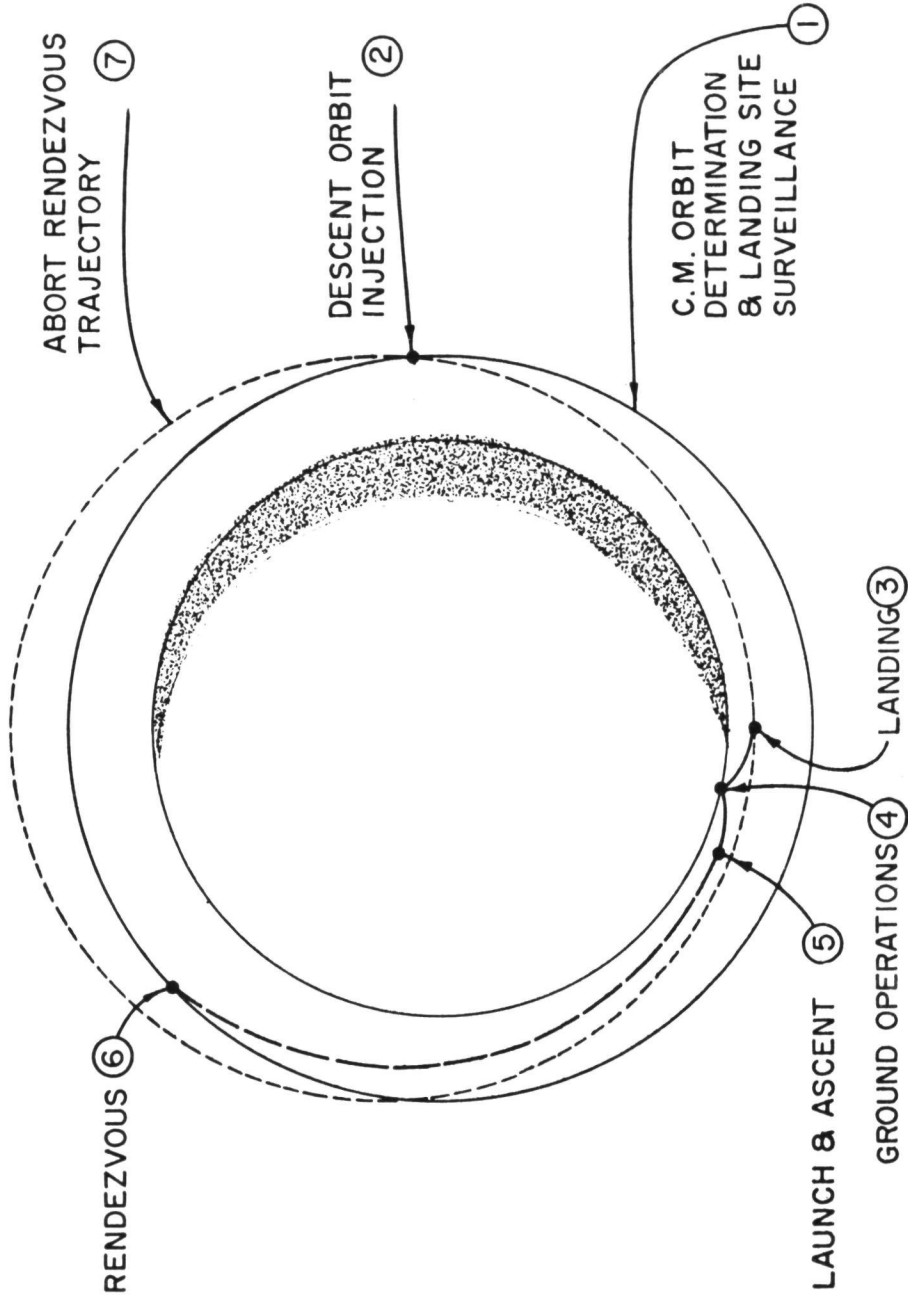
MIDCOURSE NAVIGATION AUTOMATIC STAR-EARTH HORIZON MEASUREMENT



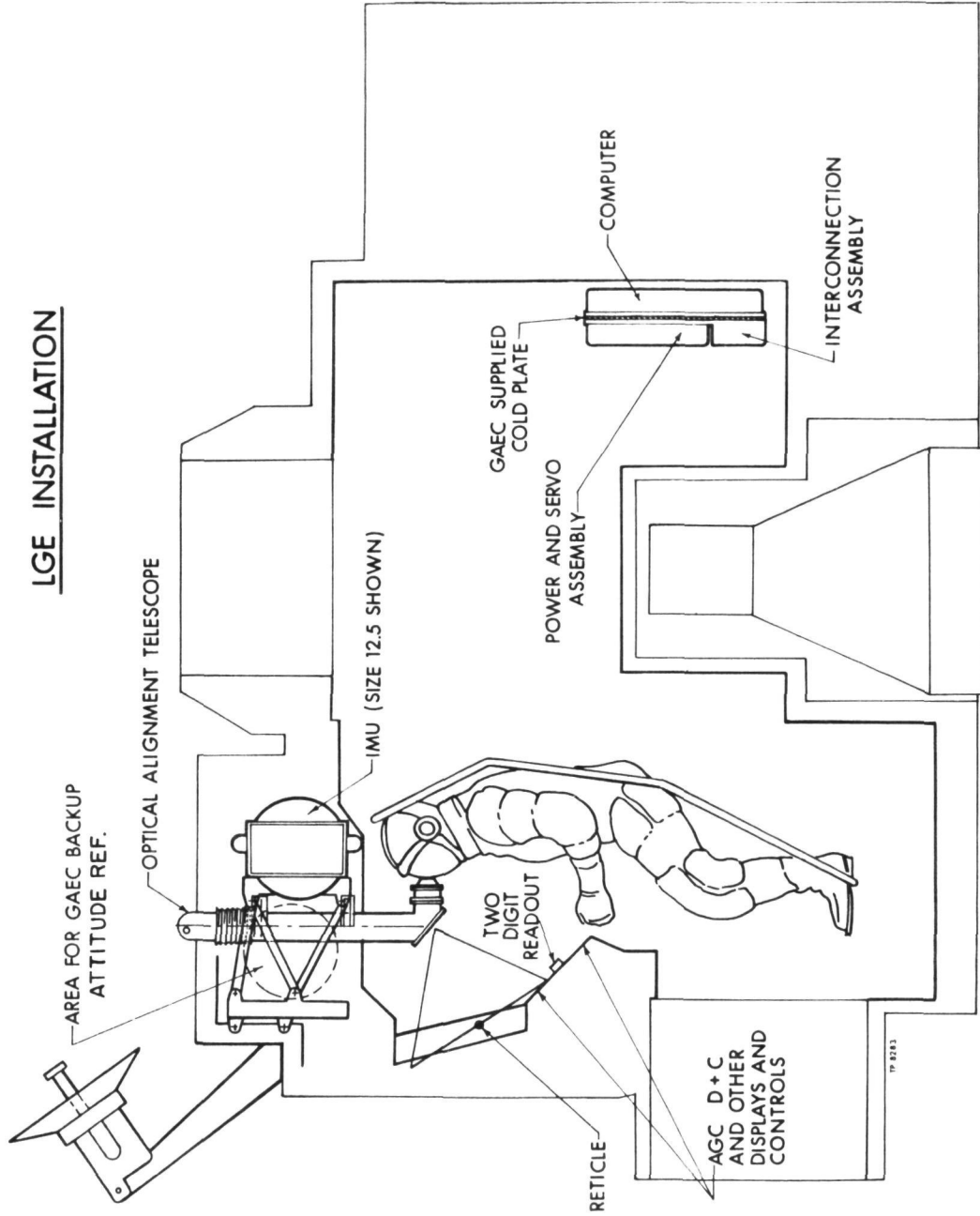
EARTH ILLUMINATED HORIZON NAVIGATION



LUNAR OPERATION PHASES



LGE INSTALLATION

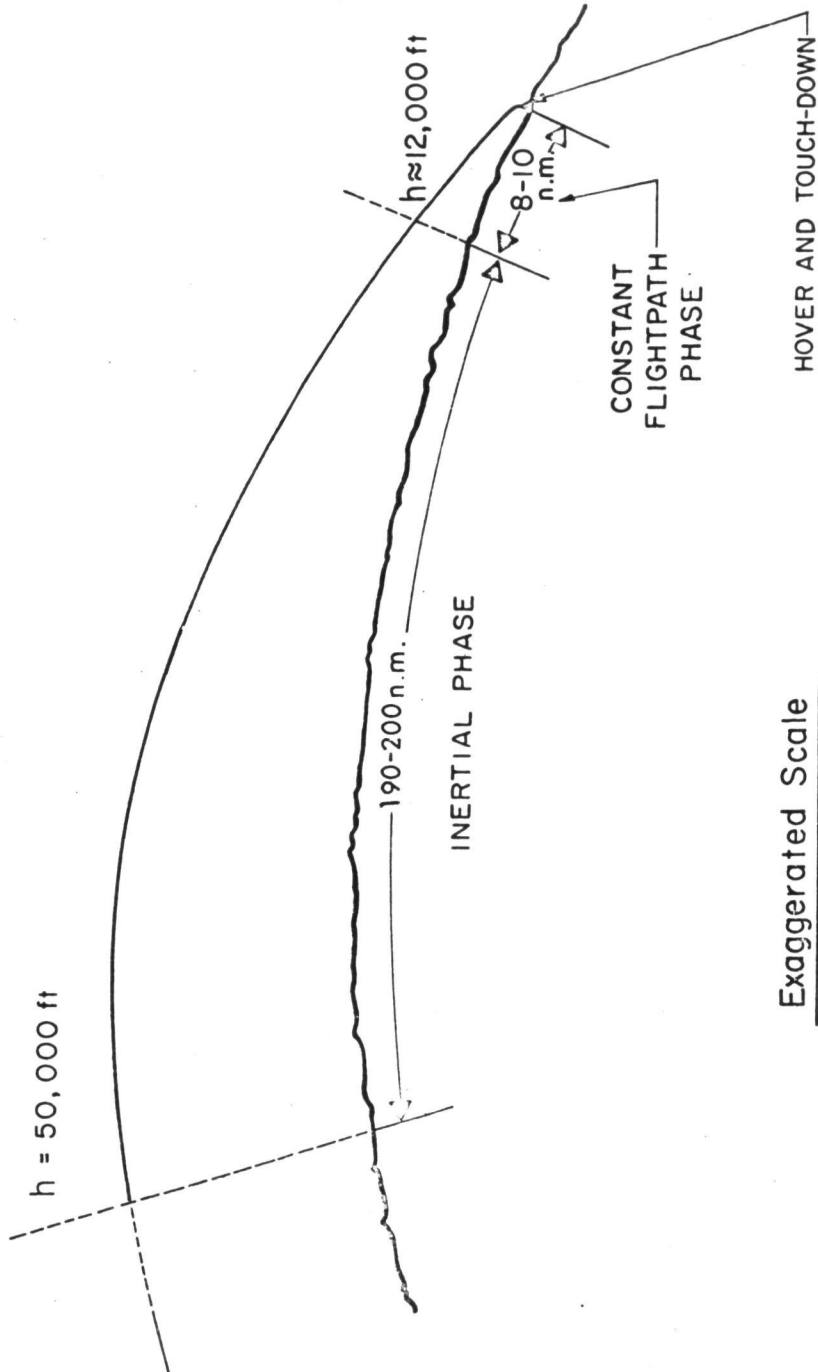


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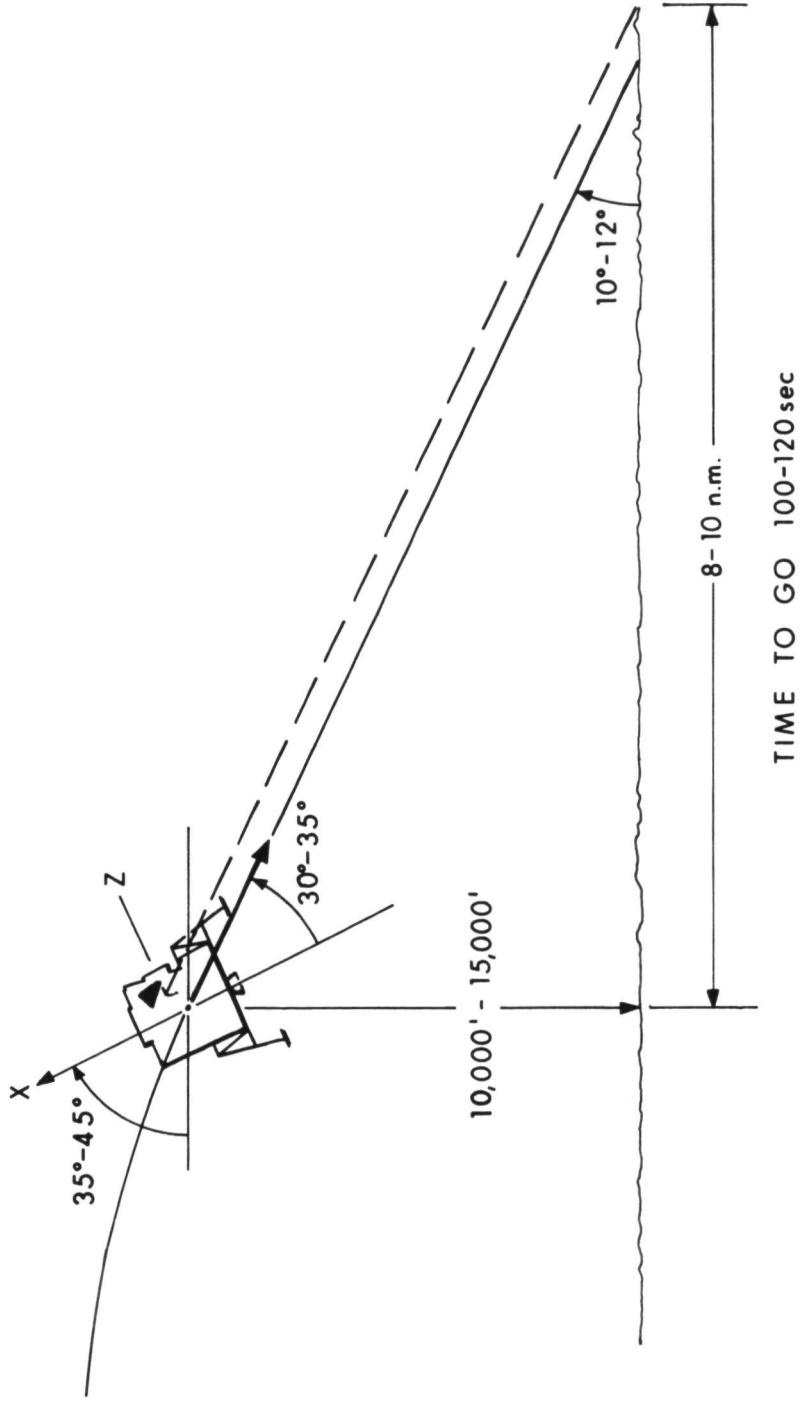
TP 8283-1

LUNAR LANDING MANEUVER PHASES



Exaggerated Scale

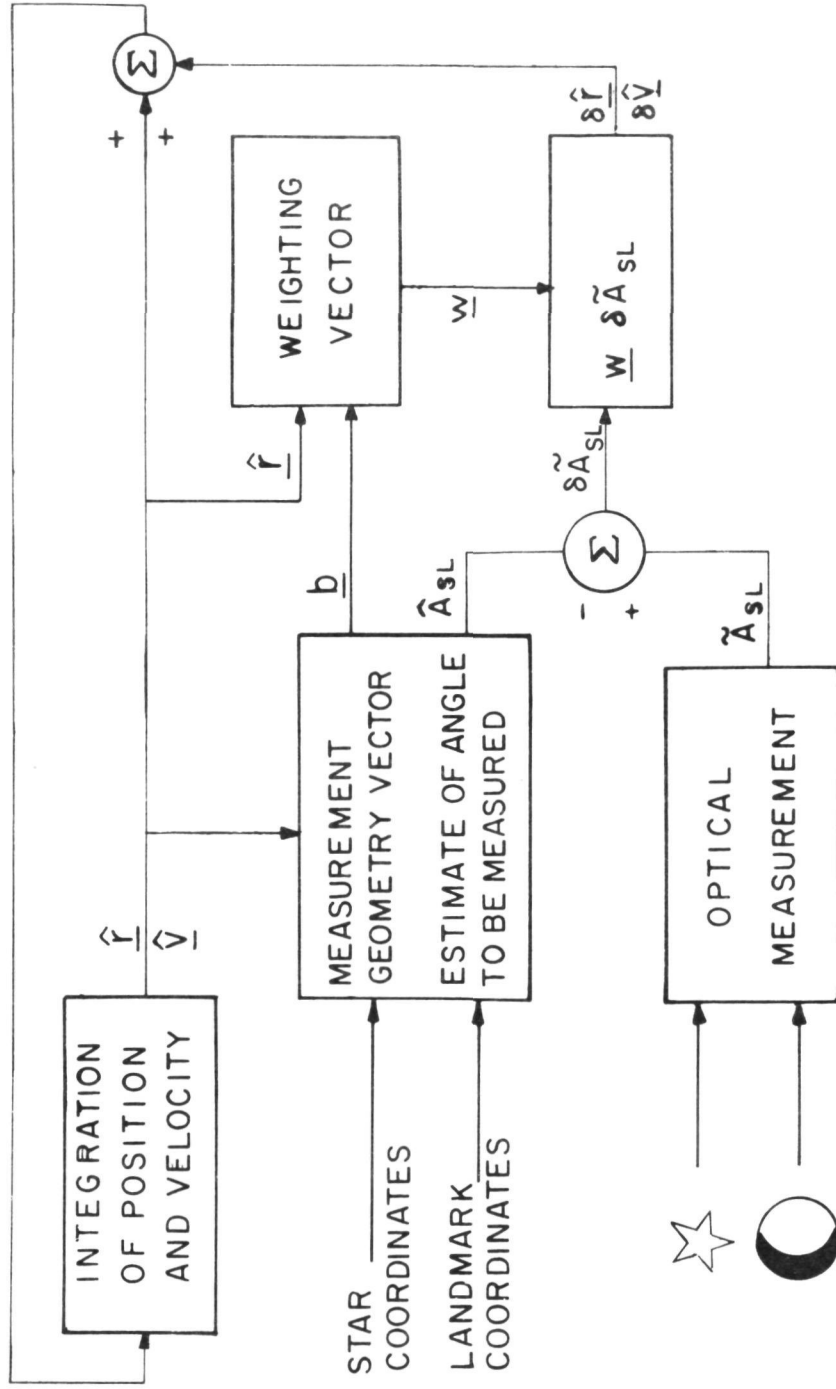
LUNAR LANDING MANEUVER - CONSTANT ATTITUDE PHASE



DR. RICHARD H. BATTIN

THE G&N COMPUTER

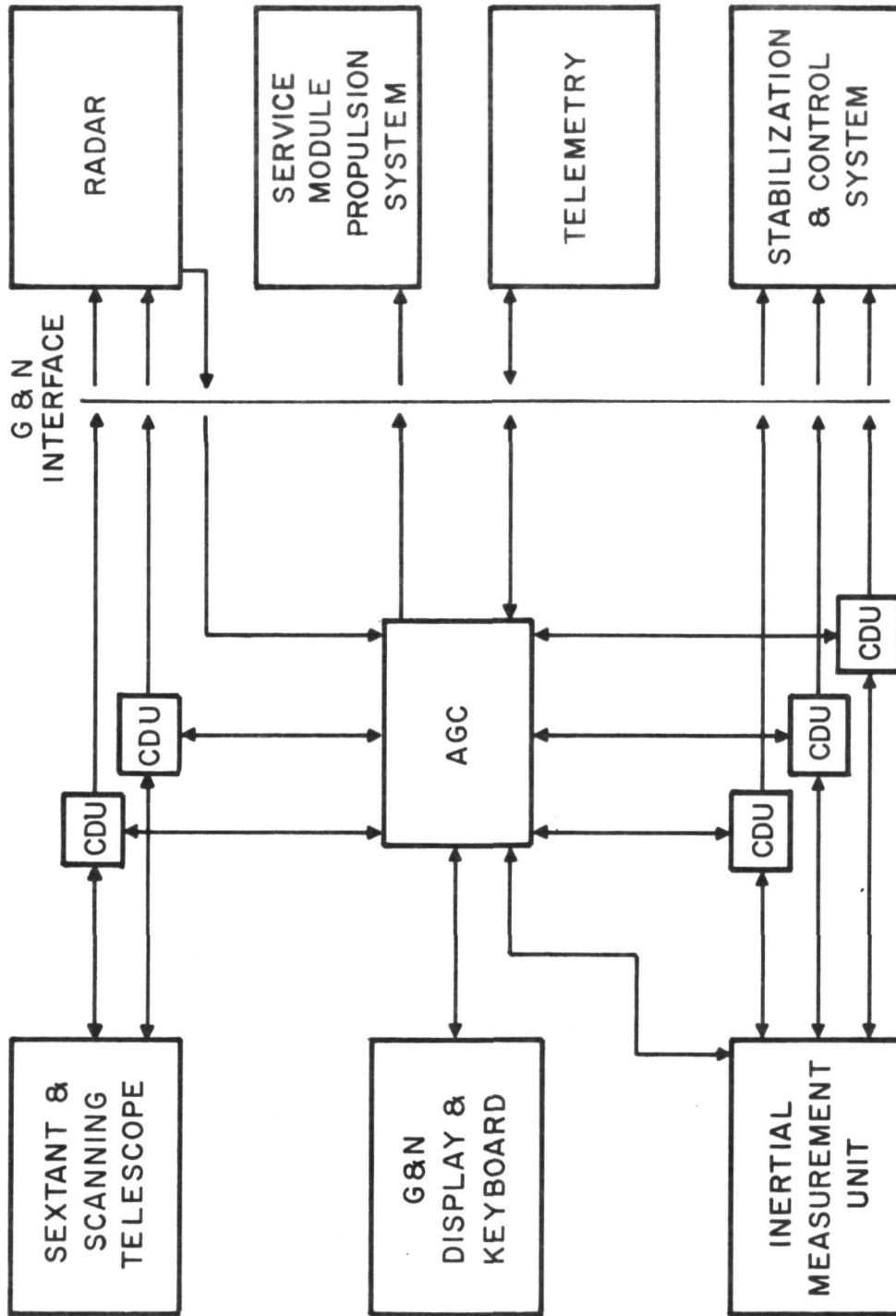
COAST PHASE NAVIGATION



\underline{b} : VARIATION IN MEASURED QUANTITY RESULTING FROM VARIATIONS IN COMPONENTS OF \underline{r} & \underline{y}



AGC INTERFACES



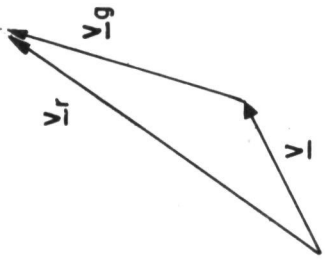
FEATURES OF THE AGC

1. SMALL WORD (16 BITS)
AUGMENTED BY
 - BANK SWITCHING TO INCREASE ADDRESS CAP.
 - INTERPRETER TO INCREASE OPERATION CODE.
 - INTERPRETER TO GIVE MULTIPLE PRECISION CAPABILITY.
2. PARITY TESTING AND SELF CHECKING FEATURES.
3. AUTOMATIC INTERRUPTION AND RESUMPTION OF PROCESSING TO ALLOW FOR SERVICING OF INCREMENTAL COUNTERS.
4. AUTOMATIC INTERRUPTION WITH SAVING OF REGISTERS TO FACILITATE:
 - a) INPUT/OUTPUT OPERATIONS.
 - b) TIMED FUNCTIONS.
 - c) EASE AND SPEED IN HANDLING KEYBOARD, DISPLAY, TELEMETRY.
 - d) ALTERATION OF PROGRAM FLOW BY ASTRONAUT OR EQUIPMENT.
5. THE KINDS OF MEMORY
 - a) FIXED - INEXPENSIVE, HIGHLY RELIABLE.
 - b) ERASABLE.
 - c) CENTRALS & SPECIALS - FOR PROGRAMMING EASE AND FLEXIBILITY.
6. OPERATION CODE FACILITATES MULTIPLE PRECISION ARITHMETIC.
7. INDEXING FEATURES.
8. EXTENDED OPERATION CODE.
9. SELF INTERRUPTION.



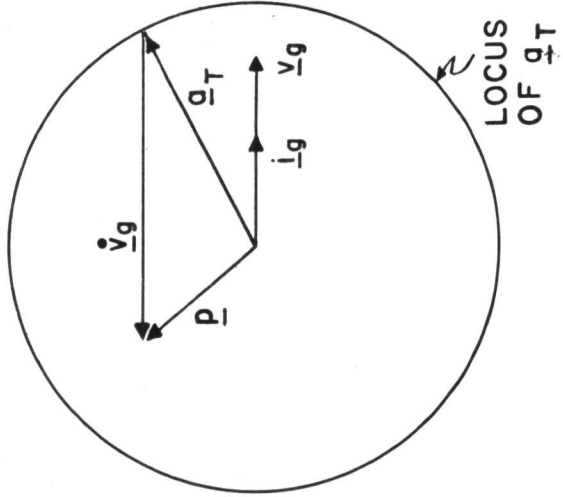
POWERED FLIGHT STEERING

- \underline{v}_r : REQUIRED IMPULSIVE VELOCITY
- \underline{v} : ACTUAL VEHICLE VELOCITY
- $\underline{v}_g = \underline{v}_r - \underline{v}$: VELOCITY-TO-BE-GAINED
- \underline{g} : LOCAL GRAVITY VECTOR
- \underline{a}_T : THRUST ACCELERATION VECTOR



$$\dot{\underline{v}}_g = \dot{\underline{v}}_r - \dot{\underline{g}} - \underline{a}_T = \underline{p} - \underline{a}_T$$

$$\underline{v}_g \times \dot{\underline{v}}_g = 0 \quad \text{STEERING LAW}$$



DIRECTION OF \underline{a}_T

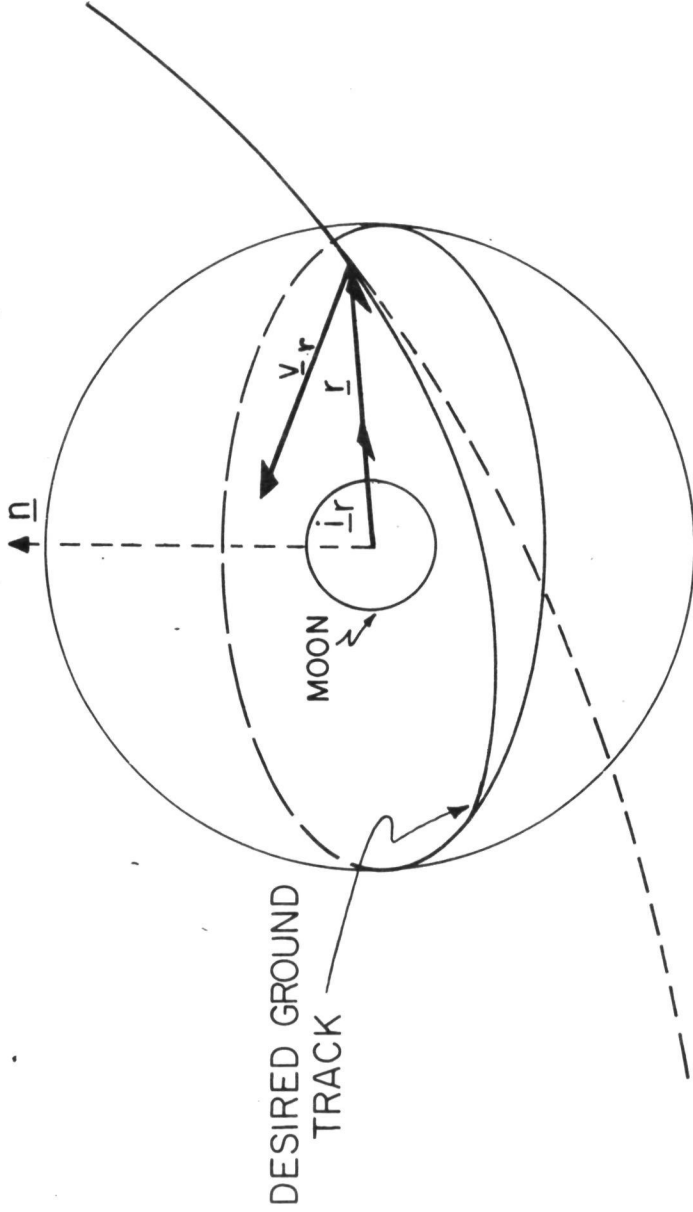
$$\underline{a}_T = \underline{p} + (q - \underline{i}_g \cdot \underline{p}) \underline{i}_g$$

$$q = \frac{\sqrt{a_T^2 - p^2 + (\underline{i}_g \cdot \underline{p})^2}}{2}$$

$$\underline{v}_g = 0 \Rightarrow \text{CUTOFF}$$



LUNAR ORBIT INSERTION



\hat{n} = UNIT NORMAL TO DESIRED PLANE

$$\underline{v}_r = \sqrt{\frac{\mu_M}{r}} \hat{i}_r \times \hat{n} \quad \underline{p} = \frac{\mu_M}{r^2} (\hat{i}_r \cdot \hat{n}) \hat{n} - \sqrt{\frac{\mu_M}{r}} \left[\hat{v}_g - \frac{3}{2} (\hat{i}_r \cdot \hat{v}_g) \hat{i}_r \right] \times \hat{n}$$



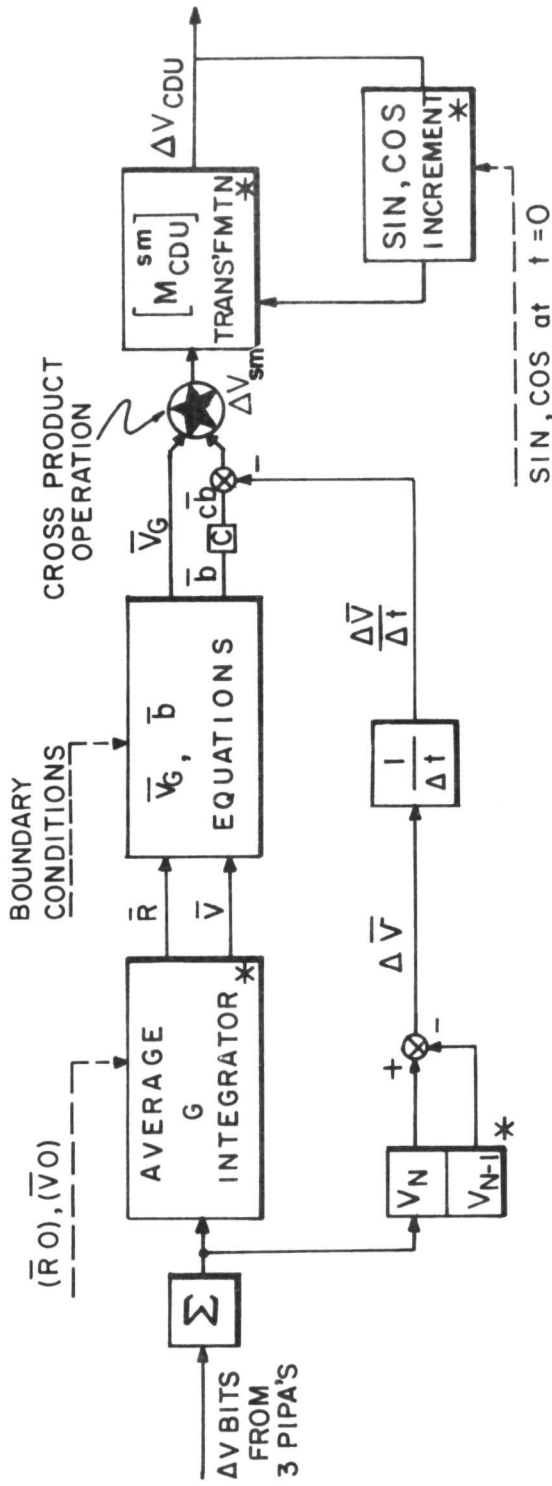
LUNAR ORBIT INSERTION PERTURBATIONS FROM NOMINAL
NO PLANE CHANGE.

CONDITIONS FOR $f = -13^\circ$	ALTITUDE PERIAPSE N.M.	ALTITUDE APOAPSE N.M	DURATION OF POWERED FL. SEC	TOTAL FUEL USED LB.	$\Delta Ft/sec$ INCR'T & VAR.
NOMINAL	99.16	99.23	326.67	22,393	$\Delta V =$ 3090
INIT. WEIGHT UP 1%	99.08	99.14	329.95	22,618	$\delta V =$ 103
INIT. WEIGHT DOWN 1%	99.25	99.32	323.39	22,168	$\delta V =$ -103
WEIGHT FLOW UP 3%	99.41	99.47	317.15	22,391	$\delta V =$ -92
WEIGHT FLOW DOWN 3%	98.92	98.98	336.80	22,397	$\delta V =$ 1.84
SPEC. IMPUL. DOWN 1%	99.08	99.16	329.57	22,592	$\delta V =$ 91.48

NOMINAL DATA = $I_{sp}320$, WT. FLOW = 68.546875 LB/SEC. INIT. WT. = 86000LBS.



THRUST VECTOR CONTROL, APOLLO CSM AGC INFORMATION FLOW



NOTE COMPUTATIONS MARKED WITH * ARE COMMON TO ALL POWERED MANEUVERS

BOUNDARY VALUES

1. TRANSLUNAR INJECTION — AIM POINT VECTOR
2. LUNAR DE-BOOST — CIRCULAR ORBIT
3. TRANSEARTH INJECTION — EXCESS HYPERBOLIC VELOCITY VECTOR
4. ABORT FROM MIDCOURSE — PERIGEE ALTITUDE, ECCENTRICITIES



AGC EXECUTIVE PROGRAM (1)

1. ALLOWS TIME-SHARING OF PORTIONS OF ERASABLE MEMORY BY DIFFERENT PROGRAMS.
2. ALLOWS SUSPENSION OF PROCESSING OF PRESENT PROGRAM AND INITIATION OF HIGHER PRIORITY PROGRAM AT BREAK-POINT.
3. ALLOWS SAVING OF SUFFICIENT INFORMATION AT TIME OF SUSPENSION OF A PROGRAM TO ENABLE RESUMPTION OF THAT PROGRAM AT A LATER TIME.
4. ALLOWS UP TO SEVEN PROGRAMS TO BE IN SUSPENDED ANIMATION.

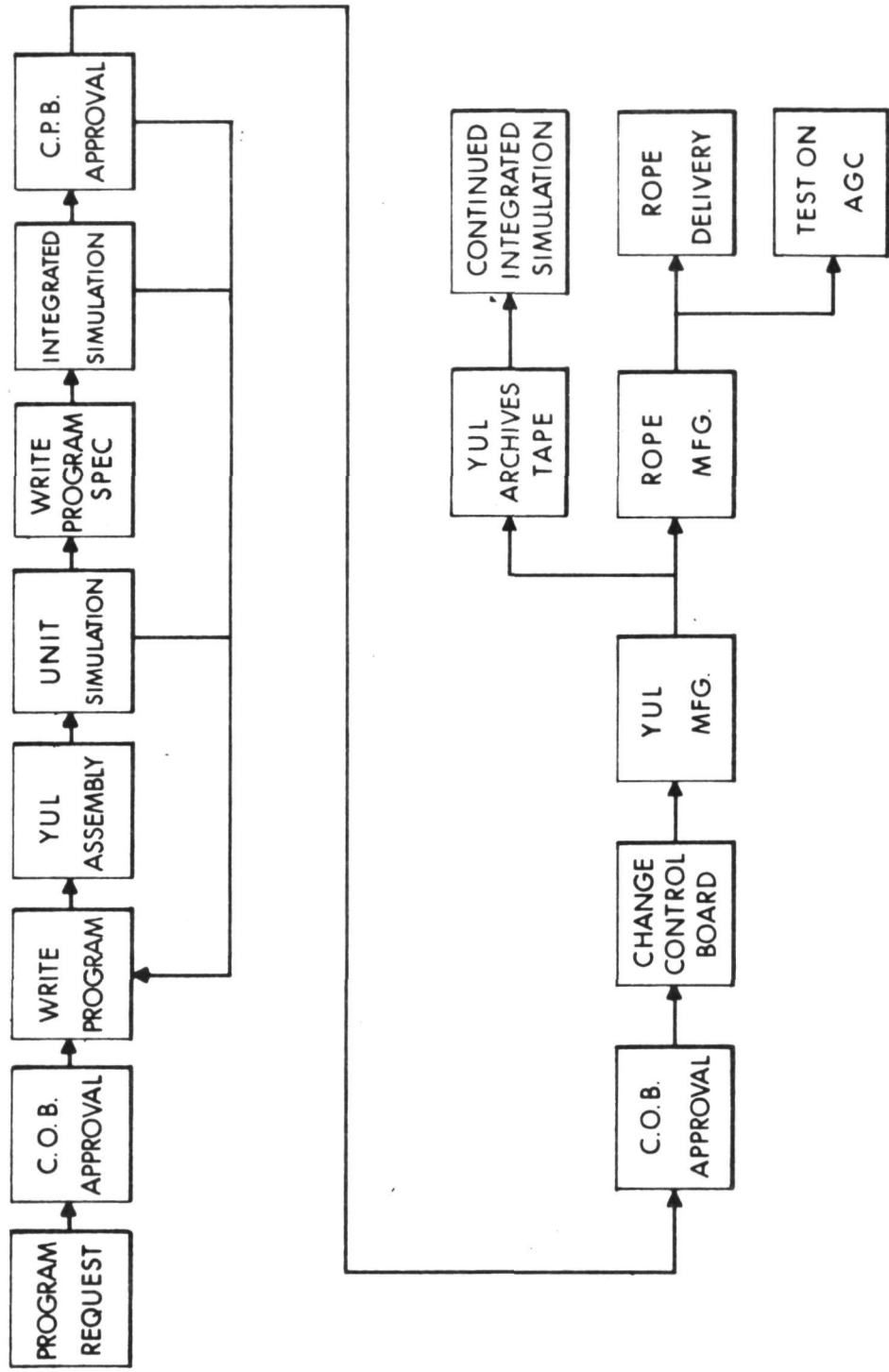


AGC WAITLIST PROGRAM

1. KEEPS TRACK OF ELAPSED TIME
2. EXECUTES SHORT JOBS ON TIME
3. FOR LONGER JOBS, CALLS TO EXECUTIVE
FOR EXECUTION



AGC PROGRAM GENERATION AND CHECKOUT



MR. MILTON B. TRAGESER

ACCOMPLISHMENTS

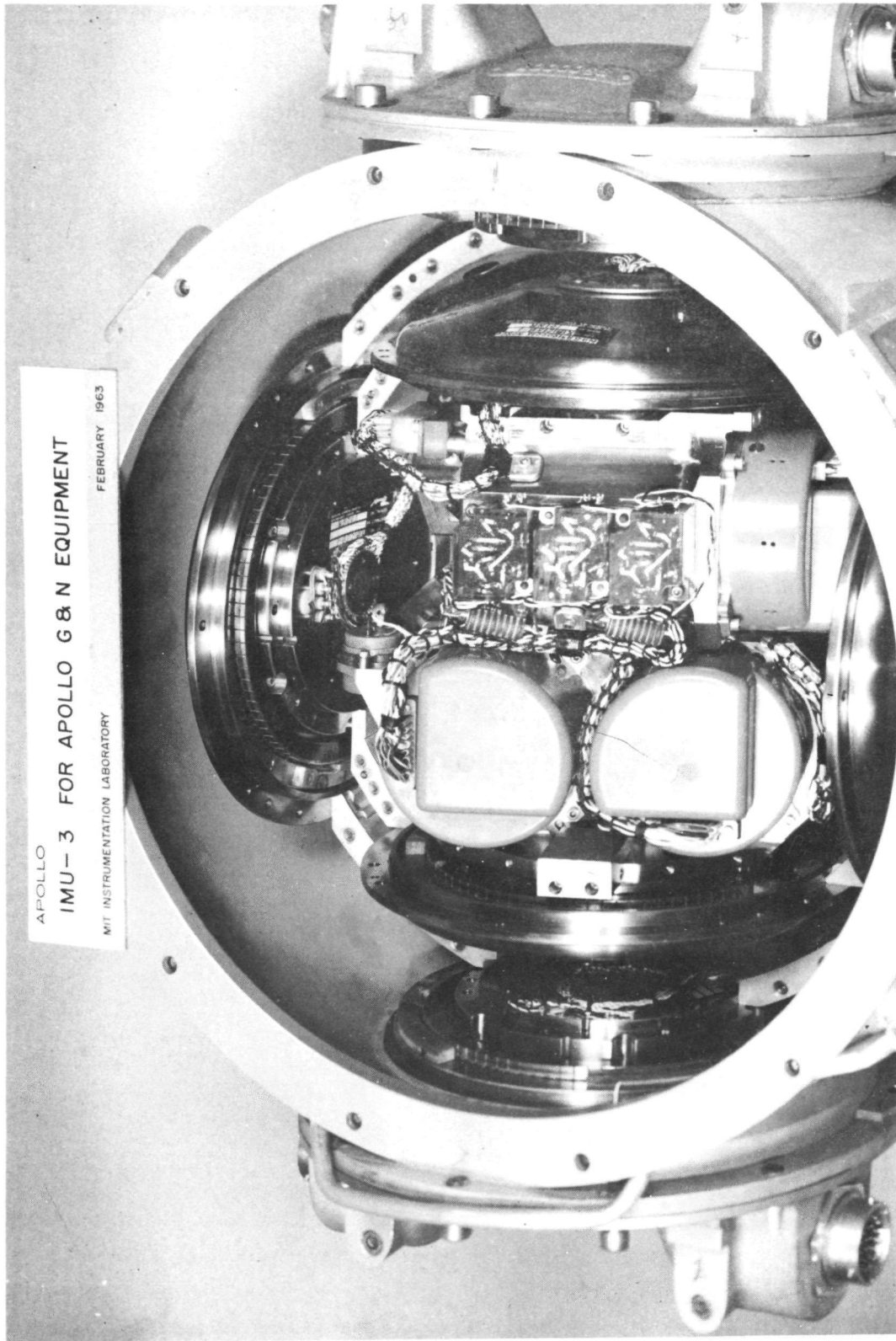
APOLLO GUIDANCE EQUIPMENT DEVELOPMENT PROGRAM

- AGE 0 DISPLAY MODEL - DETAILED MOCKUPS TO ILLUSTRATE FEATURES OF DESIGN.
- AGE 1 THERMAL MODEL - USED FOR EXPERIMENTATION ON THERMAL ASPECT OF DESIGN.
- AGE 2 MECHANICAL INTEGRITY MODEL
 - USED FOR EXPERIMENTATION ON VIBRATION & ACCELERATION ASPECTS OF DESIGN.
- AGE 3 FUNCTIONAL MODEL - WORKING SUBSYSTEMS USED TO PROVE OUT FUNCTIONAL ASPECTS OF DESIGN.
- AGE 5A INTERFACE & INSTALLATION GAUGE
 - AN ACCURATE MODEL WITH CORRECTLY TOLERANCED PARTS TO PROVE THE INTERFACE & INSTALLATION PROCEDURE HERE & AT NAA.
- AGE 4 FUNCTIONAL SYSTEM - WORKING SYSTEM TO PROVE FUNCTIONAL ASPECTS OF SYSTEM DESIGN.
- AGE 5 FLIGHT SYSTEM - FINAL FLIGHT CONFIGURATION.
- AGE 6 ET AL MANUFACTURED FLIGHT SYSTEMS FROM ACSP

BLOCK II

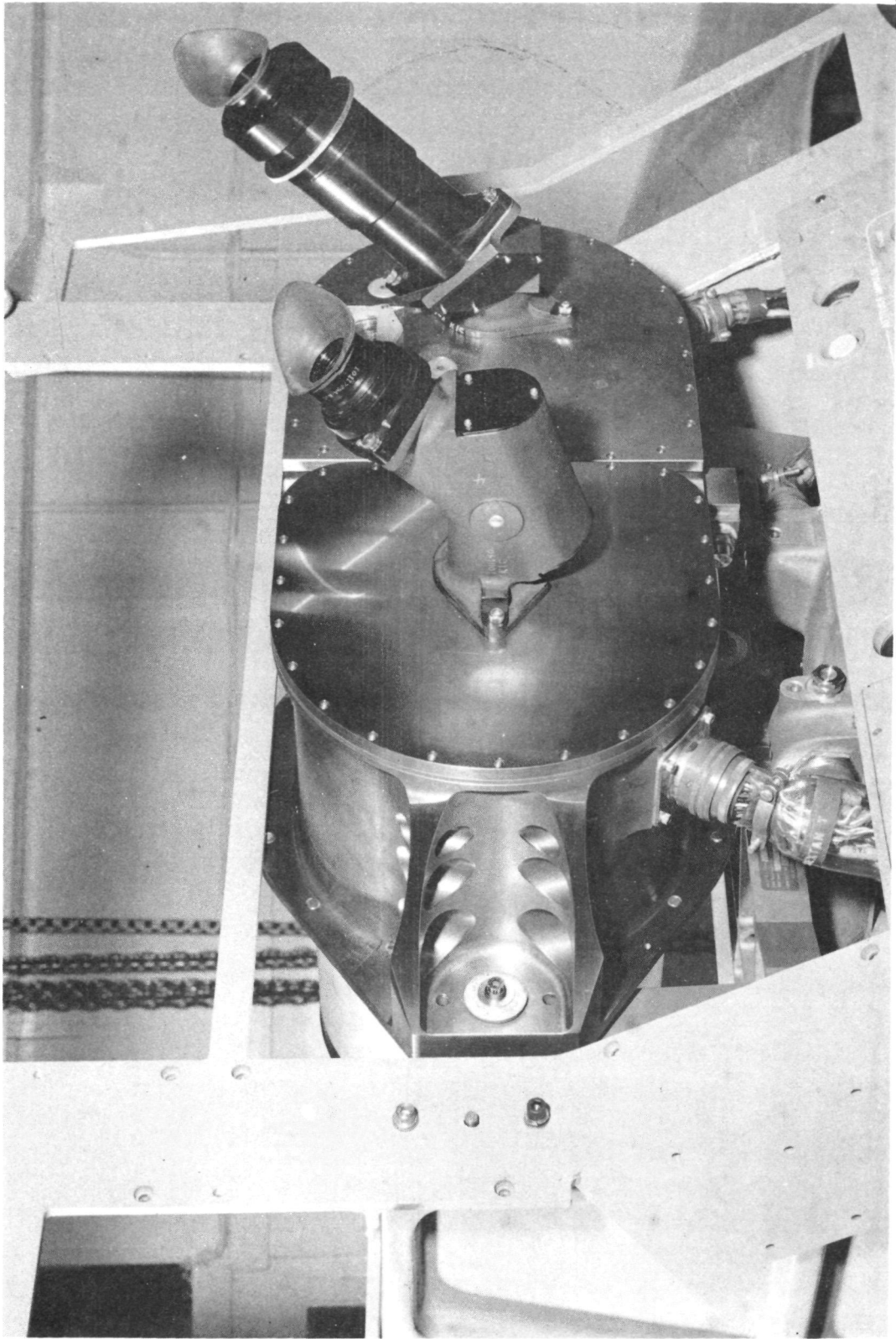
LEM G&N



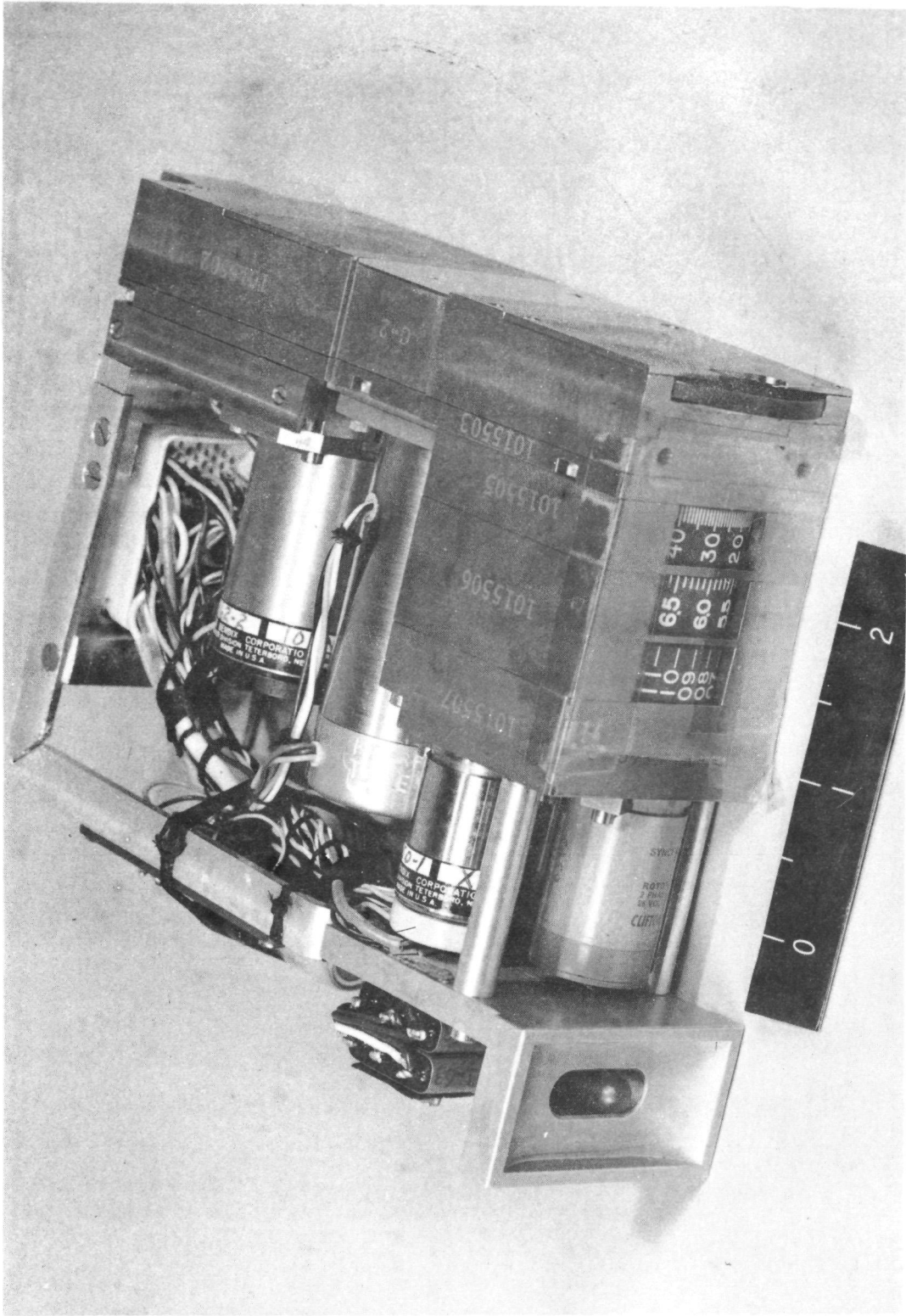


APOLLO
IMU-3 FOR APOLLO G & N EQUIPMENT
MIT INSTRUMENTATION LABORATORY
FEBRUARY 1963

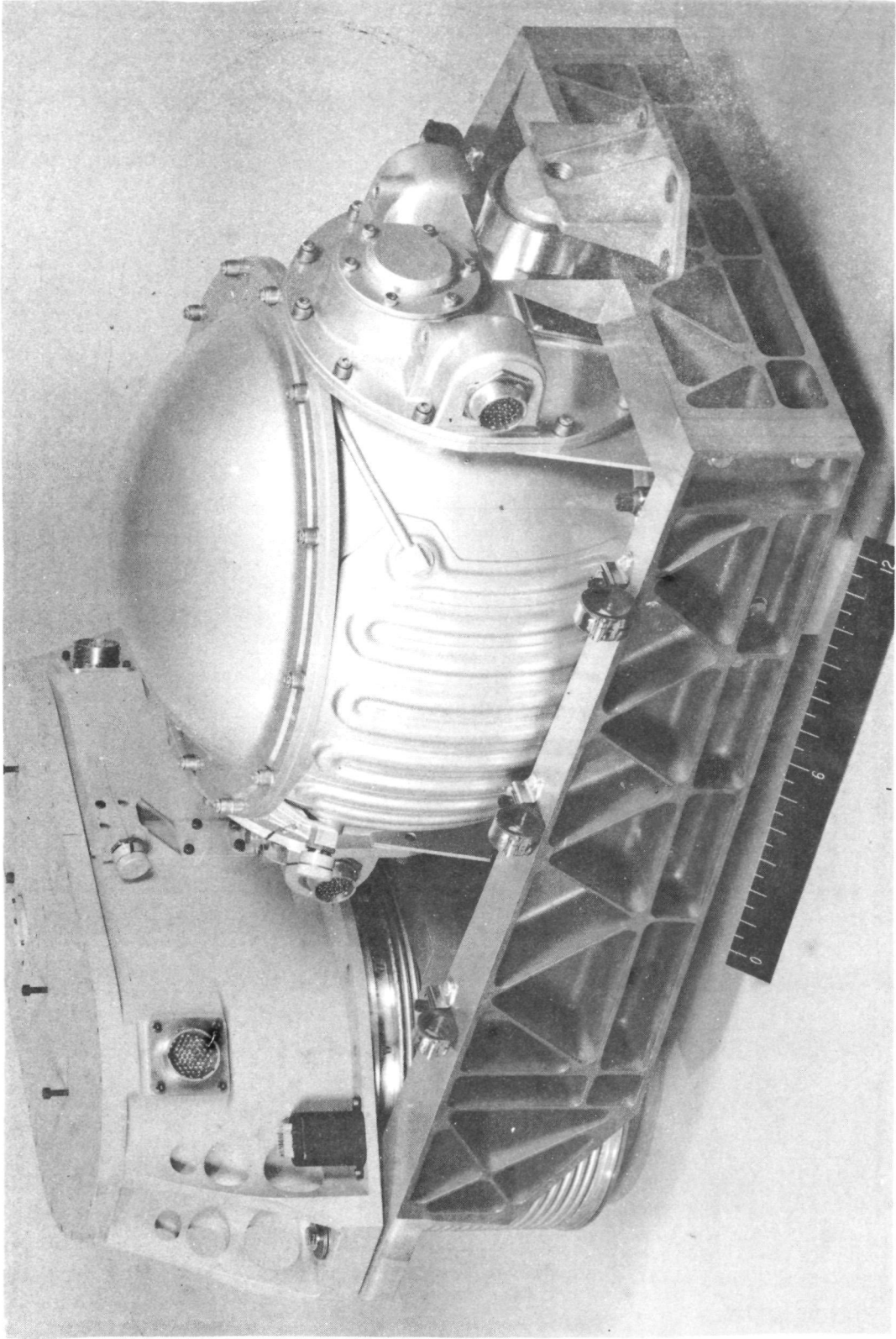
IMU 3



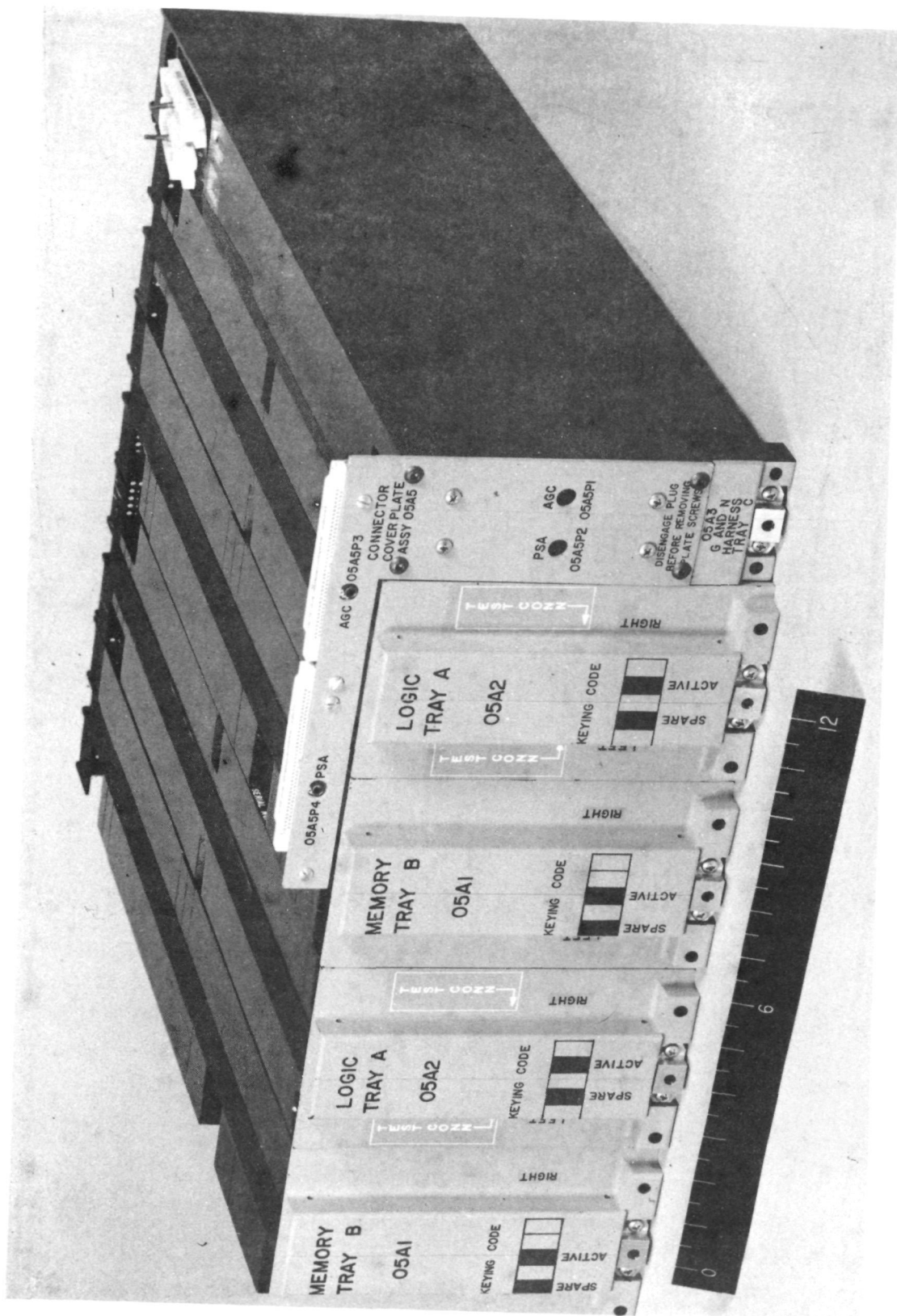
OPTICS 3



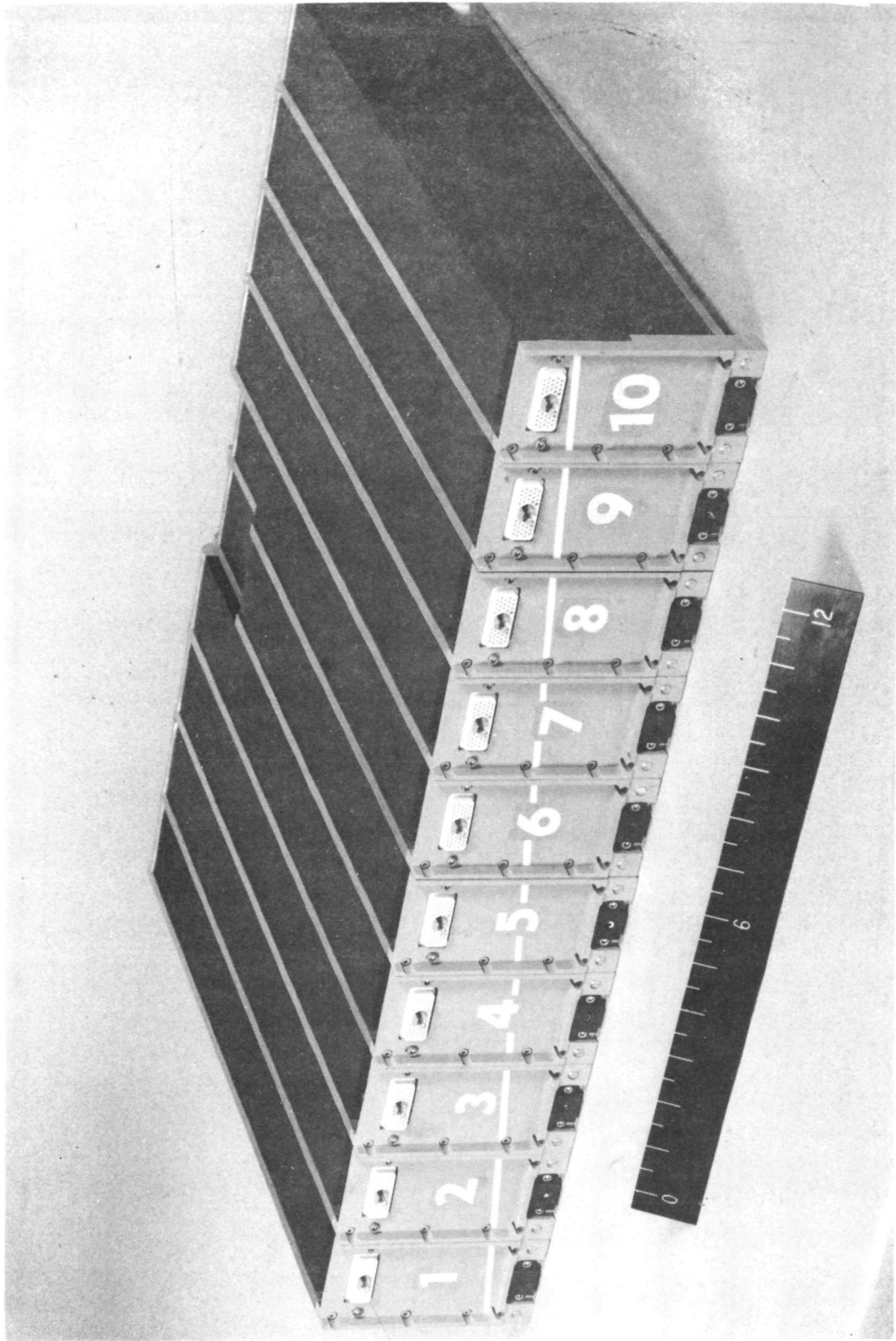
Prototype CDU



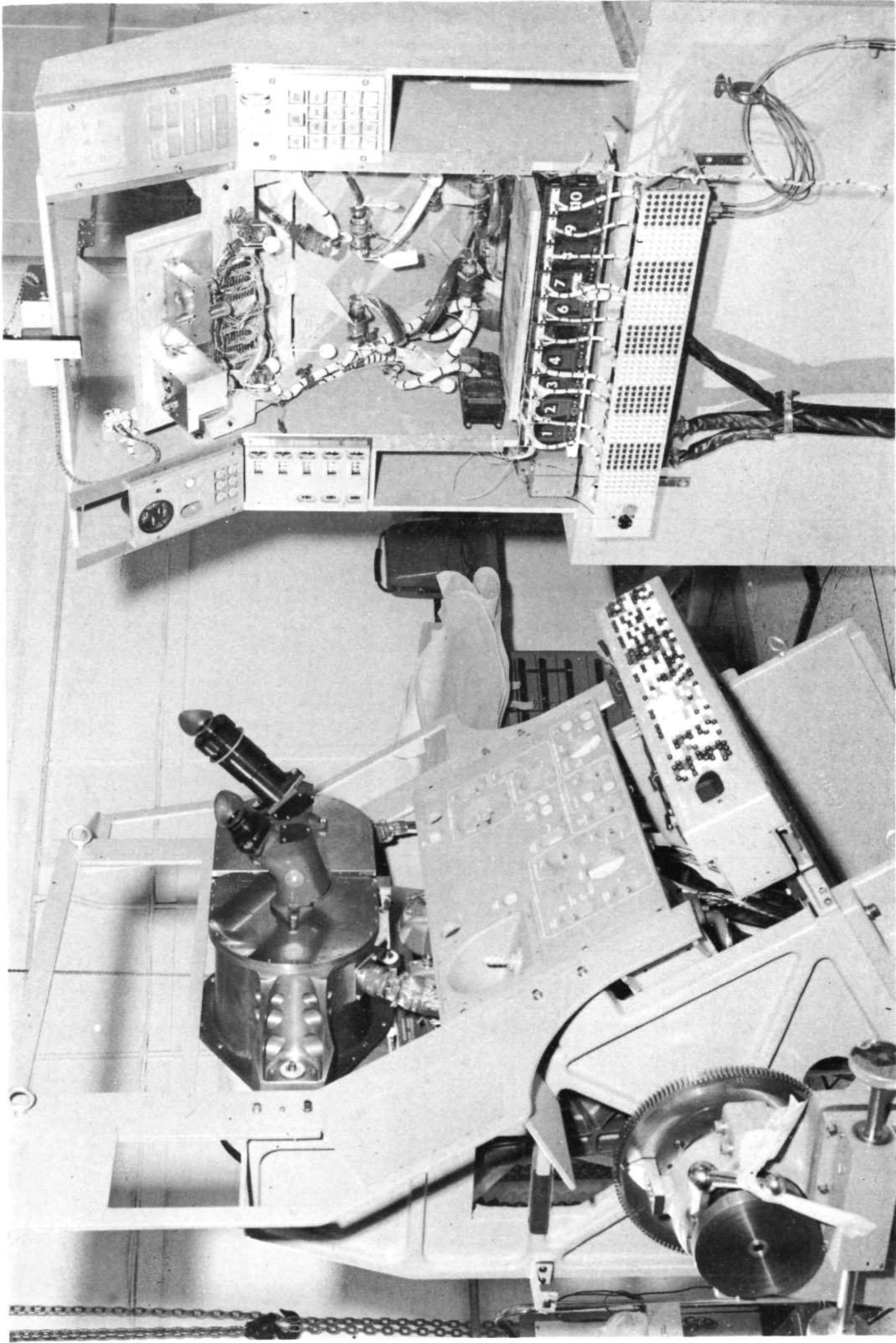
OPTICS and IMU on Navbase - AGE 5A



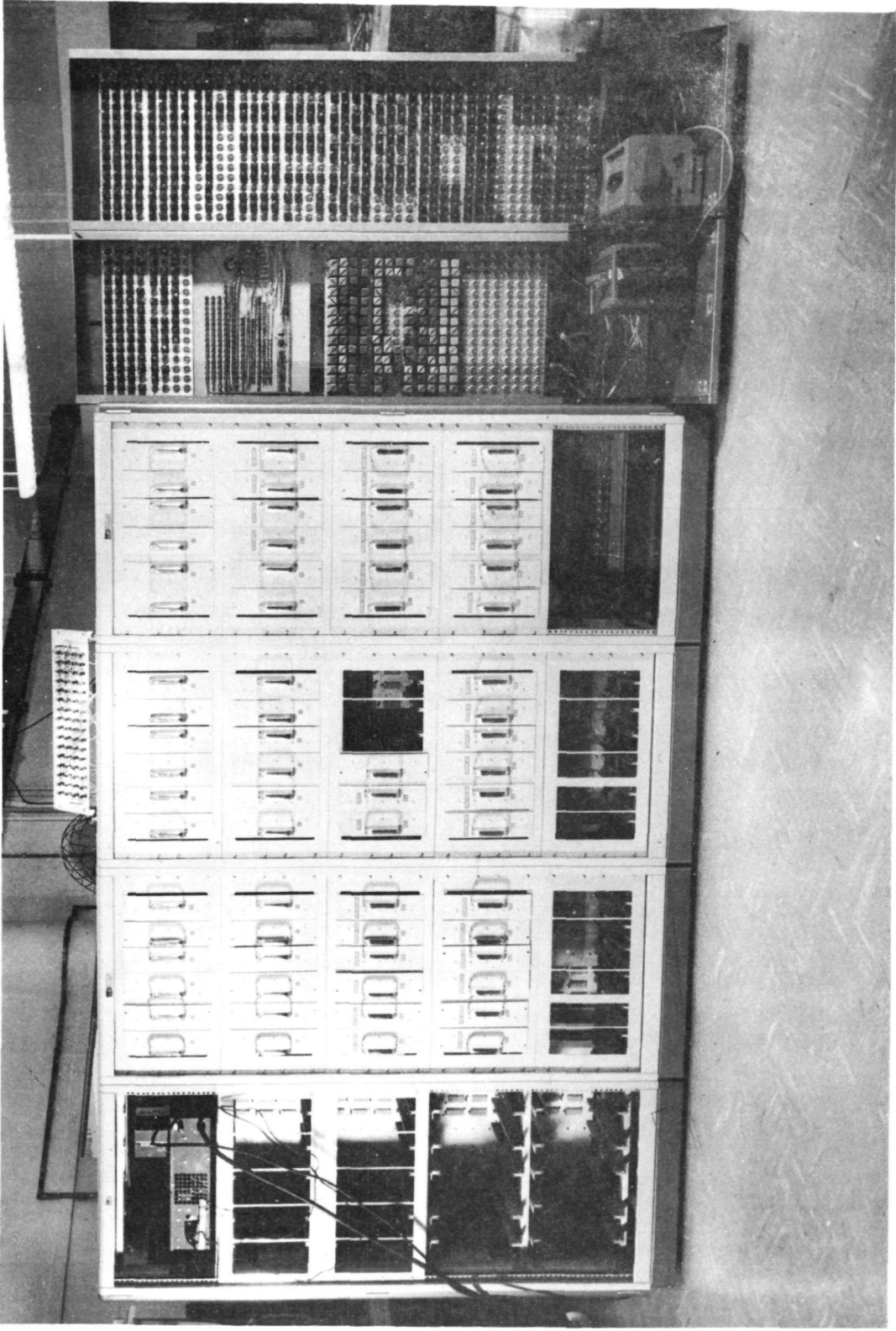
AGC 5A



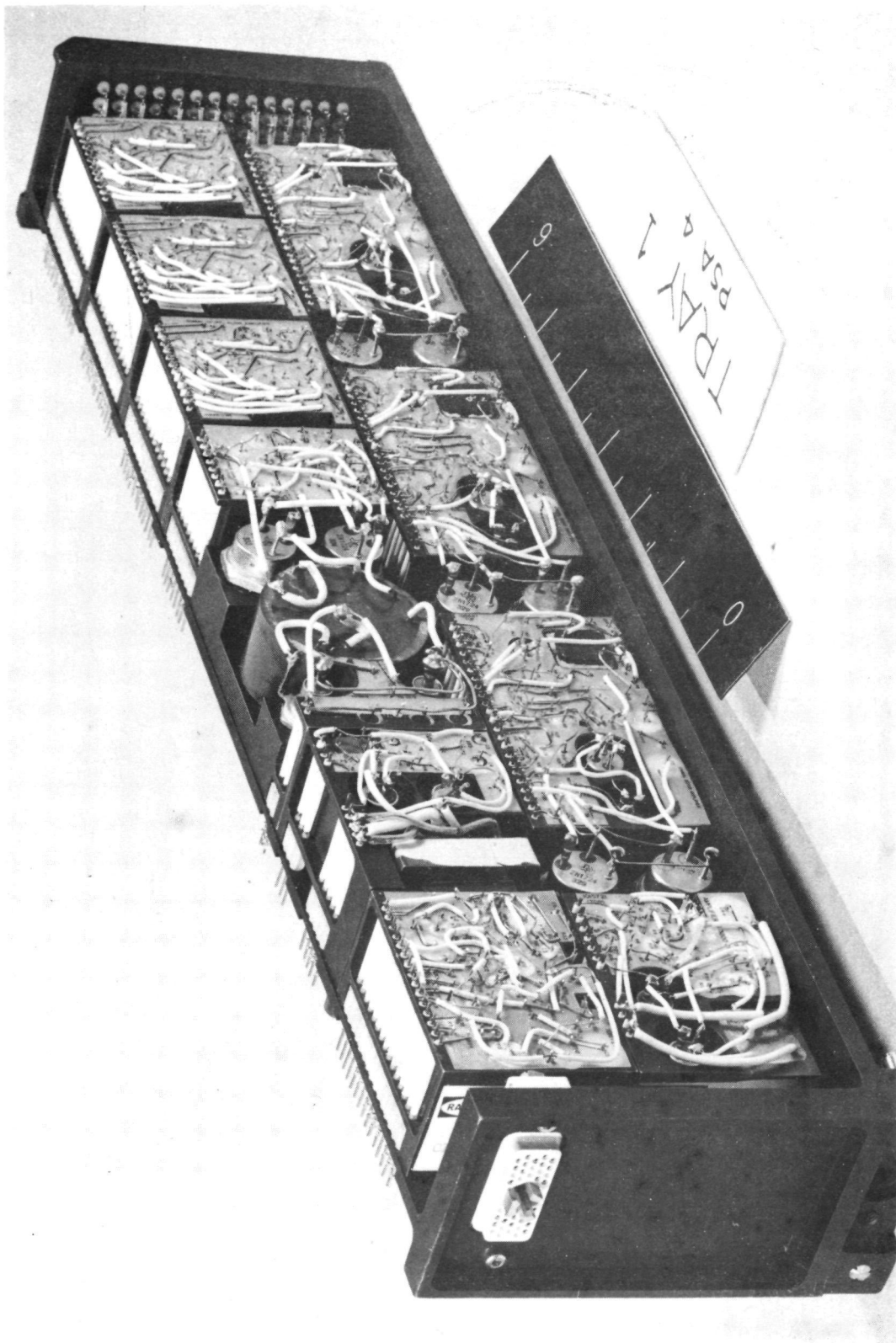
PSA 5A



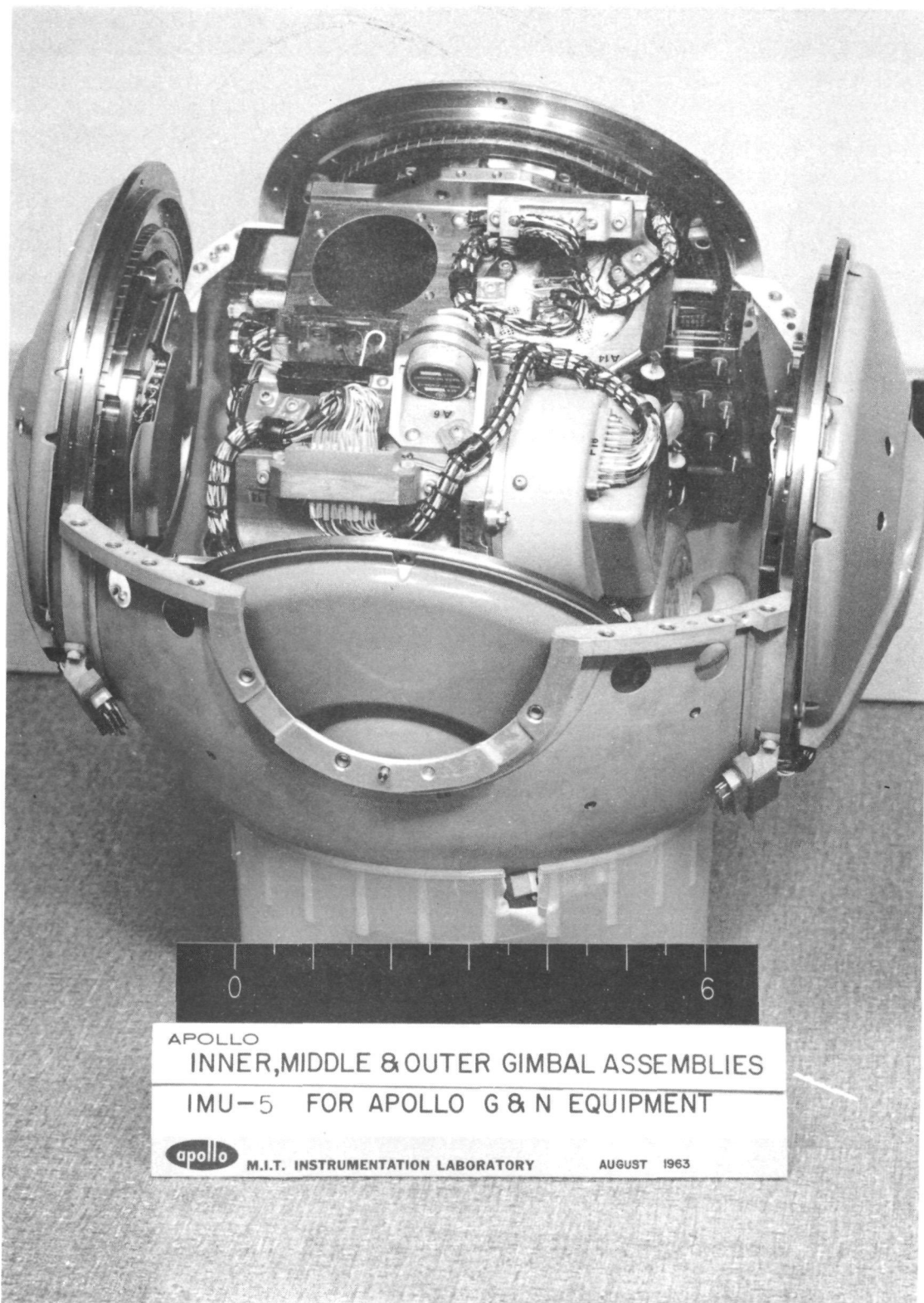
AGE 4



AGC 4



TRAY #1, PSA 4



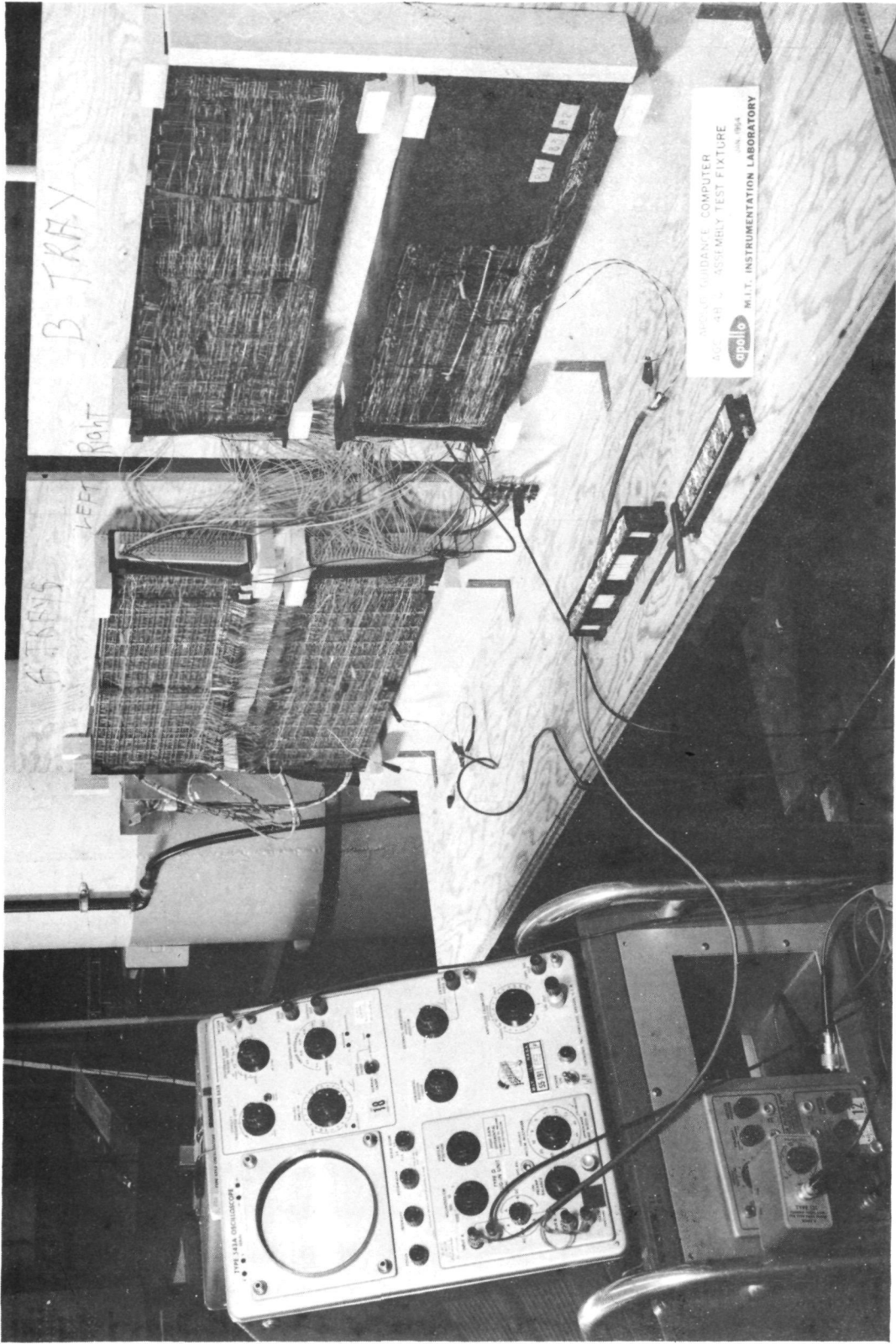
APOLLO
INNER, MIDDLE & OUTER GIMBAL ASSEMBLIES
IMU-5 FOR APOLLO G & N EQUIPMENT



M.I.T. INSTRUMENTATION LABORATORY

AUGUST 1963

IMU 5



AGC 4B

SUPPORTING ACTIVITIES

IMU OPTICS SIMULATION

THERMAL STUDIES	HARDWARE EFFORTS	DIGITAL
SYSTEMS LAB	1. ENVIRONMENT-THERMAL AND VACUUM	HUMAN FACTORS
GSE	2. PRECISION ANGLE MEAS. PHENOMENA	OPTICS
	1. OPTICS STUDIES	ANALOGUE
	2. COOPERATIVE LANDMARKS	
	3. LANDMARK SIMULATION	
	4. HORIZON RESEARCH	

FIELD SITES

NORTH AMERICAN (DOWNEY)
ATLANTIC MISSILE TEST RANGE (CANAVERAL)
MANNED SPACECRAFT CENTER (HOUSTON)
GRUMMAN AIRCRAFT (BETHPAGE)
WHITE SANDS MISSILE TEST RANGE (NEW MEXICO)
(TO BE DETERMINED)



UNCLASSIFIED

UNCLASSIFIED