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LEM ENGINEERING MEMO LMO-370-16
May 14, 1963

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370-16

MINUTES OF RADAR REQUIREMENTS

COORDINATION MEETING #1

BETWEEN

GRUMMAN AIRCRAFT ENGINEERING CORPORATION (GAEC)

AND

MASSACHUSETTS INSTITUTE OF TECHNOLOGY (MIT)

LOCATION: GAEC

DATE: March 21-22, 1963

[U]

MINUTES APPROVED:

George Henderson
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Navigation and Guidance, Code 370
GAEC

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LEM Subsystems Project Engineer, GAEC

FF No. 602(A)

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(NASA-CR-118534) MINUTES OF RADAR
REQUIREMENTS COORDINATION MEETING NO. 1
BETWEEN GRUMMAN AIRCRAFT ENGINEERING
CORPORATION /GAEC/ AND MASSACHUSETTS
INSTITUTE OF TECHNOLOGY (Grumman Aircraft

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LIST OF ATTENDEES

MIT

M. Traegeser
D. Hoag
J. Dahlen
P. Bowditch
J. Nevins
E. Duggan
E. Hickey
P. Felleman
W. Tanner
J. Nugent
A. Boyce

GRUMMAN ATTENDEES

J. Gavin	G. Spinelli
C. Rathke	J. Rigsby
T. Kelly	G. Sullivan
A. Whitaker	J. Milligan
R. Carbee	W. Bischoff
G. Henderson	M. Olstad
W. Smith	R. Souave
K. Ratner	F. Kratachvil
H. Sheprow	R. Kunnves
E. Stern	P. Ellis
R. Flesig	L. Armani
F. Doennebrink	H. Sherman
J. Russell	S. Glasser
J. Cook	A. Tomanek
	L. Cipani

MSC

R. Lewis
P. Kurten
W. Rhine

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AGENDA

1. LEM Primary Landing Mode
 2. Rendezvous Operations
 3. Mechanical Installation of Sensing System
 4. Display Interface
 5. Computer and PSA Installation
 6. IMU and System Thermal Requirements
 7. Electrical and Functional Interfaces
 - *8. Radar Requirements Study
- * Minutes on this agenda item are covered in a separate document.

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GENERAL

Grumman/MIT Coordination Meeting # 1 was held at Bethpage, New York on March 21 and March 22, 1963. The objective of this initial meeting was to provide an exchange of information on system functional concepts and equipment installation requirements. The first day's meeting was devoted to a general group discussion on the agenda items. Because of the diversity of the agenda and the general interest, it was deemed necessary to plan working group meetings on March 22, 1963. These meetings were devoted to detailed discussions on the agenda items. The second day's panel meetings were grouped into the following areas:

Meeting # 1

Mechanical Installation of Sensing Systems
Display Interfaces
Computer and Power Servo-Assembly Installation
Howard Sherman, Grumman Chairman
MIT: P. Bowditch, J. Nevins, J. Nugent, A. Boyce

Meeting # 2

System Electrical and Functional Interface
Fred Doennebrink, Grumman Chairman
MIT: J. Dahlen MSC: P. Kurten

Meeting # 3

Computer and PSA Installation
Ben Gaylo, Grumman Chairman
MIT: E. Duggan
(This was a splinter group from meeting # 1)

The specific action items generated in these group meetings are included in the minutes. General agreements were reached in several areas. In meeting # 1, it was mutually agreed that MIT and Grumman will plan discussions on future simulation plans to avoid overlap. In meeting # 2, it was mutually agreed that there is a need for meetings to be arranged, on the designer level, for the exchange of information relating to specific interface areas and system functional details involving the IMU, CDU, Computer, OMU and Stabilization Control Subsystem.

A reference list of documents presented at these meetings is included. Copies of some of the references are incorporated into the minutes, as indicated on the list.

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AGENDA ITEM 1

Subject: LEM PRIMARY LANDING MODE OF OPERATION

J. Dahlen of MIT discussed the LEM primary landing mode from the separation to terminal let-down. (Reference 1, copy included with minutes).

1. The inertial powered descent was described as a fully automatic all inertial mode up to 20 miles from the landing site. At this distance, the radar altitude information would be used to update the AGC.

2. At 15 miles from the selected land site, the SCT pointed by the AGC, would be used to survey the landing area. It was proposed that the astronaut in the right hand seat perform the monitoring. If desired, an alternate landing point would be selected by overriding the AGC and using the SCT to insert the bearing to the new point. Pilot permission would be required to select the new site.

3. The resolved doppler velocities would be continuously displayed. At 10 miles from the landing point the doppler velocity information would be introduced into the guidance computations.

4. An automatic flare-out maneuver would level the vehicle out to a predetermined altitude - proposed as two hundred feet. Prior to the automatic flare-out, an altitude differing from the predetermined value could be selected and manually inserted into the computer.

5. After flare-out, the vehicle would be in ALTITUDE HOLD mode; at constant altitude and a constant velocity of 50 ft/sec. with vertical attitude.

6. An automatic let-down mode would follow. The vehicle would be pitched up; then returned to vertical attitude when the horizontal velocity reached zero. From an altitude of 100 feet, with vertical velocity of 10 ft/sec., the LEM would begin a vertical descent.

7. Between the flare-out and terminal let-down modes, the pilot would have override options depending on the conditions of the landing area.

a) The telescope could be used to select a new landing site if suitable conditions for landing are not in the immediate area.

b) If the immediate landing area is acceptable but certain obstacles must be avoided, the pilot would be able to postpone initiating the automatic letdown until these obstacles presented no danger.

c) The pilot would be able to change the crafts' heading if no suitable landing areas were directly ahead.

8. If small translations were required during the automatic terminal let-down, it was proposed that the RCS thrusters be used in the manual translation mode of the SCS. With the over-ride button depressed during this mode, the altitude would be held constant during the translation.

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A. Whitaker asked about the use of the man to effect the terminal let-down. J. Dahlen stated that the automatic primary mode was more desirable from considerations of fuel economy and man's reaction time. A. Whitaker felt that training could provide man with the capability to control the vehicle during this phase.

G. Sullivan questioned if the 20 mile point was the first time the telescope would be used to survey the landing site. J. Dahlen stated that it would be; a complete synchronous orbit was not considered a requirement for visual sighting of the landing area. M. Traegeser pointed out that the CM sextant could give better landmark definition at orbital altitudes, than the LEM telescope could give at pericynthion. The initial conditions for landing would be established by CM landmark sightings.

The vibration levels exiting during telescope sightings was mentioned as a problem area. It was agreed to discuss this in detail later in the meeting.

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AGENDA ITEM # 2

Subject: RENDEZVOUS OPERATION

N. Sears discussed the primary system rendezvous operations. The phases of rendezvous were defined as (1) long-range (mid-course) corrections, (2) initial rendezvous and (3) terminal rendezvous.

The bulk of MIT's work to date was defined in phase 1, investigating the corrections, using radar data, for both nominal and abort ascents. These investigations examined Radar and Scanning Telescope parameters vs ΔV criteria for correction. (The SCT would be used to point the radar). For normal ascents, two to three corrections are required in the first hour. The last correction is made approximately 20 N.M. from the CM.

Abort from hover was described as the worst condition for rendezvous. Five or six corrections would be required in 90 minutes.

Position and velocity updating would be performed every 50 to 60 seconds. The required parameters for the mid-course corrections were stated to be angle, range and range rate; with best accuracy required for angle and range rate.

A. Whitaker asked what miss would result with no terminal rendezvous corrections. N. Sears estimated an error of 2000 ft. The abort errors, with no corrections, would yield a 40 N.M. miss. With one correction for the abort case, approximately a 1.3 N.M. miss results.

The nominal rendezvous trajectory would have a central angle of 140 to 180 degrees, depending on the out-of-plane distance. No separate out-of-plane correction is used -- just a change in azimuth and burn time.

E. Stern pointed out that establishing a clear pericynthion parking orbit was sensitive to flight path angle at ascent burnout. Attitude and velocity might have to be biased, depending on the magnitude of flight path angle. A discussion concluded that the angle would be $\pm \frac{1}{2}$ degree. Further discussion was held on the value of parking orbit altitude. A. Whitaker stated that agreement should be reached on this value.

J. Russell questioned the magnitude of IMU drift during thrusting accelerations, and the IMU errors to be expected for abort from hover. N. Sears stated that with no IMU updating during coasting descent, the errors existing at abort from hover would be 8 ft/sec. velocity error and $2-\frac{1}{2}$ m.r. attitude error.

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AGENDA ITEM # 3

Subject: MECHANICAL INSTALLATION OF SENSING SYSTEMS

J. Rigsby presented charts showing the evolution of the LEM vehicle configuration. Four vehicle configurations were discussed in terms of visibility and equipment locations. The most likely final configuration was identified as configuration #3 shown in Reference 2. (Copies included with minutes).

P. Bowditch discussed general installation considerations for the OMU and IMU. Pressure stresses, loads, and vibration were defined as the major sources of misalignment. General installation problems for the OMU are:

- a) Requirement to keep the OMU sufficiently clear of the RCS jets to prevent vapor coating the optics.
- b) Attachment of the OMU to the structural skin (at point of projection).

The present CM installation has the IMU and OMU mounted to a Navigation Base isolated from the vehicle structure. The vibration isolation characteristics were described as having a transmissibility of 2 at a resonant frequency of 22 cps.

A general description was given for the OMU:

- a) One power and three power capability.
- b) Uses an articulated double dove prism.
- c) Angle readout is mechanical and electrical with inputs to the AGC.
- d) Manual operation is possible.

The telescope's eye relief was described and H. Sherman questioned the use of the OMU under conditions of face plate down. Consideration must be given to how closely the man can approach the eye piece, under this condition, and the resulting degradation of resolution.

P. Bowditch presented a drawing showing a proposed installation for LEM G & N equipment. The OMU, IMU and Rendezvous Radar antenna were shown installed to a common navigation base. Double concentric bellows would be used between the OMU and the pressure wall. The Rendezvous Radar antenna, as proposed, would be attached to the Navigation Base with a tripod mounting; the three mounting arms penetrating the pressure wall (Reference 3).

The navigation base and associated equipment would be installed on the right hand side of the cabin. The radar antenna would sweep out ± 30 degrees in the vehicle y-z plane, and have almost full 360° rotation in the vehicle x-y plane to give a toroidal swept volume.

It was proposed that the AGC be installed under the right hand seat. The PSA was located under the navigation base assembly.

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AGENDA ITEM # 3 (CONT.)

Subject: MECHANICAL INSTALLATION OF SENSING SYSTEMS (Cont.)

In answer to a question concerning installation alignment tolerances, P. Bowditch stated the OMU misalignment must be held to 1 arc minute maximum. IMU must be installed to have a maximum misalignment of 20 minutes static and 2 m.r. dynamic.

T. Kelly asked whether Grumman or MIT would have responsibility for the Navigation Base. M. Traegeser stated that if the base were an integrated part of the vehicle, Grumman should be responsible. If the base were isolated, it should be furnished by MIT as is now being done for the CM.

A. Shreeves gave a detailed discussion on LEM vibration and shock environment. He discussed the differences between these environments for LEM and CM, based on the results of Grumman's Common Usage Study. The LEM vibration regime during lunar landing was described as a superimposed sine and random components. The random component ranging from 5 cps to 2000 cps, would increase linearly to 100 cps, remain constant from 100-500 cps and then decrease linearly out to 2000 cps. The sine component would have a linear increase from 5 to 400 cps and remain constant out to 2000 cps. The maximum would be 7 g's.

The maximum shock for LEM would be 12 g on lunar landing. This is higher than any shock specified for CM equipment, with the exception of 100 g specified for crash earth landing -- this does not require equipment survival. The ensuing discussion pointed out that CM equipment was designed for 20 g shock resulting from earth re-entry. This is not an abrupt acceleration onslaught. The LEM 12 g shock on lunar landing was described by A. Shreeves as having a 15 milli-sec rise time with a maximum stroke of 15 inches.

J. Russell asked what specification was being used by MIT for present vibration tests on sub-assemblies. D. Hoag replied that a basic NAA specification was being used.

P. Bowditch pointed out that the CM navigation base mount was primarily for strain isolation.

The use of the reticle was suggested by T. Kelly as a possibility if landing phase vibrations precluded the use of the SCT. A discussion by M. Traegeser and D. Hoag concluded that:

- a) With the 90° down visibility proposed for the LEM vehicle configuration, the reticle was not necessary.
- b) The reticle has only 1 to 1 optical viewing.
- c) The SCT gives capability for landing site bearing inputs.

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AGENDA ITEM # 3

ACTION ITEMS

1. Grumman will define a preliminary vibration regime for LEM.
2. Grumman will provide an attitude profile of LEM during descent for present "Nominal" trajectory.
3. Grumman will provide a philosophy on the use of the scanning telescope.
4. MIT will submit constraints and form factors on primary G & N equipment.
5. MIT will provide criteria against which present G & N equipment is being qualified.

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AGENDA ITEM # 4

Subject: DISPLAY INTERFACE

J. Nevins presented two drawings Control and Display Panel and G & N Display - LEM. (References 4 and 5)

The panel groupings were shown as:

- System Engineers Display Panel
- Pilot's Display Panel
- Power Panel
- Center Man Panel

The following controls were identified:

- IMU Controls
- Radar/Optics Control Group
- Manual Attitude Controllers
- Manual Thrust Controllers
- Computer Over-Ride Control

The following displays were identified:

- Condition Lights
- Clock
- Attitude - Attitude Rate (FDAI)
- Range
- Range Rate
- Altitude
- Altitude Rate

(Documents on crew tasks related to the AGE were not discussed, but are incorporated into the minutes as references 6 and 7).

J. Russell questioned the reference used for the displayed attitude angles. D. Hoag stated that these angles were IMU gimbal derived. It was questioned whether this information would be meaningful to the pilot, particularly during landing. M. Traegeser suggested that the IMU be aligned with respect to local vertical at the landing site.

AGENDA ITEM # 4

ACTION ITEMS

1. Grumman will provide ground rules on controls and displays.
2. MIT will submit information on electro-luminescent panel displays.
3. MIT will submit information on "condition lights."

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AGENDA ITEM # 5

Subject: COMPUTER AND PSA (POWER AND SERVO ASSEMBLY) INSTALLATION

Slides showing the existing computer and PSA configurations were shown and discussed by E. Duggan.

The computer has five removable trays, four symmetrically arranged and the fifth located above the symmetrical array. The fifth tray was described as a spare. The outline dimensions of the computer are 20 x 7 x 24 $\frac{1}{2}$.

In response to question by R. Carbee it was stated that the computer trays require a clearance of 23 $\frac{1}{2}$ inches for removal.

The PSA presently has nine trays; this could possibly be reduced to eight trays for LEM. The PSA trays are 16 $\frac{1}{2}$ x 4 x 2.

The same form factor was proposed for the LEM assemblies.

E. Duggan proposed the trays be mounted directly to cold plates that would be an integral part of the frame and supplied by MIT. It was also proposed that MIT supply the cabling between the Computer, PSA and IMU.

R. Carbee questioned the weight savings resulting from integral cold plate design. E. Duggan stated that a 20 pound savings would result.

The rope core memory was described as consisting of three "sticks" with approximately 1000 cores (1024) per stick. C. Moore asked what program flexibility existed with the rope core memory. It was stated that up to two weeks would be required for program changes.

A sample logic stick (unpotted) was available and was circulated for general inspection.

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AGENDA ITEM # 5

ACTION ITEMS

MIT and Grumman will jointly study packaging concepts for the Apollo Guidance Computer and the Power and Servo Assembly. The study will consider:

1. The possibilities of mounting trays directly to cold plate thereby eliminating the frame used in the present CM package.

Possibilities include but should not be limited to:

- a) Integral tray and cold plate design.
 - b) Tray and separate cold plate with cold plate fabricated and integrated with tray by MIT.
 - c) Cold plate fabricated by GAEC as part of structure with tray mounting arrangement jointly determined by MIT/GAEC.
2. Grumman will furnish to MIT their present concept on equipment arrangement.
 3. MIT will supply the following information to Grumman:

AGC Thermal profile of C/M tray.
AGC Tray size and mounting for LEM.
AGC Module size and mounting.
PSA size and mounting for C/M.

AGENDA ITEM # 6

Subject: IMU AND SYSTEM THERMAL DESIGN

Thermal design considerations for the AGE were discussed by E. Hickey.

The following IMU thermal design data was given:

- a) Maximum component design temperature 180°F.
- b) Minimum component design temperature 50°F.
- c) Limits on component temperature variation $\pm \frac{1}{2}$ °F.
- d) Nominal inlet coolant temperature 45°F.
- e) Tolerance on inlet coolant temperature ± 3 °F.
- f) Coolant Flow Rate 33 lbs/Hr. ± 3 .
- g) Pressure Drop 1.5 PSI (@ 33 lbs/Hr and inlet temperature of 45°F).

For storage condition, a ± 15 °F spread in IMU temperature can be tolerated. If the temperature drops below 45°F, recalibration will be required.

The IMU will be pressure sealed with an internal pressure of approximately 15 psi. This pressure is expected to be a minimum of 3.5 psi after four days mission time.

The AGC thermal characteristics were presented:

- Power density 100 watts/cu. in.
- Heat sink temperature 90° to 110° F.
- Heat sink loading 0-3 watts/sq. inch.

Grumman's requirements were stated as 1 watt/sq.inch heat sink loading and cold plate temperature range of 0° to 130°F. E. Hickey agreed that the conflicting requirements would be a problem.

The power dissipations for each major assembly were presented as:

Computer	175 Watts
PSA	402 Watts
SCT	20 Watts
IMU	80 Watts
CDU's	30 Watts (total)

It was requested that a copy of the document showing these powers be left with Grumman. D. Hoag stated that system power requirements were given in the current revision of the Weight and Balance Report, previously submitted to Grumman. It was pointed out that this document did not explicitly show the power for each major assembly.

E. Hickey and A. Boyce discussed slides showing the IMU internal assembly. The IMU's general gimbal configuration and basic components were identified -

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gyros, accelerometers, blowers and ADA. The IMU has a total of 130 sliprings - 50,40, 40 proceeding from inner to outer gimbal. IMU mounting provisions were described. Four stainless steel inserts are used to establish a reference with respect to the navigation base mounting plane. Locating pins are used for alignment reference within the plane. (Reference 8; copies included with minutes).

ACTION ITEMS

1. Grumman will review present MIT equipment cooling requirements. Joint discussions will be held to resolve existing incompatibilities on IMU coolant inlet temperature and AGC cold plate flux densities.
2. Grumman will define the thermal environment for all LEM Navigation- Guidance equipment.

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AGENDA ITEM # 7

Subject: ELECTRICAL AND FUNCTIONAL INTERFACES

The electrical interfaces between primary G & N and other LEM systems were defined by D. Hoag. Mr. Hoag suggested that within the next month, the following interfaces be defined and ICD's issued:

1. Steering Errors - existing signal is 800 cps, scale 0.3 to 0.5 Volts/degree.
2. 8 - Ball display. NAA presently takes 800 cps sin and cos outputs from each IMU axis and converts to 400 cps to drive 8 - ball.
3. Electric Power - MIT/GAEC determine:
 - a) Who is responsible for the power switching.
 - b) Use of separate turn-offs for IMU, AGC, OMU.
4. Computer interfaces to be resolved.
 - a) Throttling command - MIT prefers a pulse train command with pulse rate proportional to desired thrust rate of change.
 - b) Engine start/stop commands.
 - c) Computer clock.
5. Failure lights - a decision is required on who will supply these.
6. Computer programming - (operational procedures must be established).
7. Cabling - MIT proposes to supply cabling internal to the primary N & G equipment. The cabling requirements for connection to external equipment must be mutually defined.

P. Felleman discussed slides showing the radar, computer and optics interfaces. It was proposed that the rendezvous radar gimballed antenna be slaved to the Scanning Telescope (SCT) during search mode. The interface between the SCT and the gimbal axes readout was shown as a two-speed synchro system. 1 x, 64 x synchro receivers on the antenna trunnion (x) axis and $\frac{1}{2}x$, 16x receivers on the antenna shaft (y) axis would be matched to transmitters on respective shaft axes of the SCT. It was proposed that these matching synchros be specified by MIT entirely (mechanically and electrically). P. Felleman stated that these would be standard synchros -- size 8 or size 11. (Reference 9, copies included with the minutes).

A relay closure on rendezvous radar lock-on would give a 102.4 kc input to the AGC to indicate the end of search mode. After lock-on, antenna gimbal angle inputs to the computer would be through the SCT shaft and trunnion axes encoders.

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Rendezvous radar outputs (range, range rate) and landing radar outputs (altitude and x,y,z velocities) would be read into the computer through a time-shared high speed counter. Details are shown in Figure 2 of Reference 8. The additional proposed interfaces between the radar and computer are shown in Reference 9, Figure 3.

ACTION ITEMS

1. Grumman will establish Interface Control Document format and procedure.
2. MIT will furnish to Grumman complete drawings of all primary Guidance and Navigation equipment planned for use in LEM down to the lowest replaceable assembly level. (Details on primary G & N as now configured for CM in addition to layouts of modifications proposed for LEM.)
3. MIT will provide a list of on-board spares, level and method of maintenance for each major assembly of the primary G & N equipment.
4. MIT will provide information of facility requirements at Grumman, with detailed justification for the working area requirement (cleanliness standards, etc.). A schedule for this facility will be established and a list of equipment to be installed will be furnished.
5. Grumman will provide information on preliminary design and installation data for descent and ascent engines and RCS; details to include:
 - Characteristics of start and cut-off transients.
 - Ullage requirements
 - Dynamic response of throttling mode (descent)
 - Minimum impulse
 - Duration
 - Moment arms
 - Description of modes of operation of RCS, to include SCS logic
6. Grumman will supply vehicle information as available.
7. Grumman will submit to MIT information on SCS modes of operation with block diagrams.
8. Grumman will furnish a definition back-up guidance concept (inertial) and Grumman definition of interface with primary N & G system.
9. Grumman will define the electrical interface between CSM and LEM when docked. (any umbilical on launch pad).
10. MIT will furnish Grumman detailed and complete description on primary G & N interfaces with the LEM FCS/SCS:
 - a) Written description of attitude error signals, whole angle signals and thrust control signals for each mode of operation (functional writeup).

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- b) Interface list of inputs and outputs and type of signal (digital, analog, syncho, resolver, etc.). Is 16 speed-signal available?
 - c) Scaling, carrier and modulation technique, resolution, expected noise levels, etc., for attitude, attitude error, accelerometer output, thrust command signals, etc.
11. MIT will define the programming techniques or parameters controlled during various flight phases. (For example, define transient problems that might occur when switching between programs, guidance modes, etc.).
 12. MIT will submit an outline of ~~IM~~ alignment procedures for each mission phase, if different. (e.g., lunar orbit, parked on lunar surface).
 13. Parts failure effects analysis - (what portions of equipment in primary G & N is disabled and/or still available for partial use) to be provided by MIT.
 14. A functional block diagram of primary G & N system (flat-schematic) will be submitted to Grumman.
 15. MIT will define standby power requirements for AGC and major assemblies during all mission phases.
 16. MIT will submit midcourse and rendezvous ΔV requirements.
 17. Grumman and MIT will mutually define the interfaces between LEM radar equipment and other N & G equipment.
 18. Grumman and MIT will jointly establish the handling procedures for N & G equipment at GAEC.

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REFERENCES

- * (1) LEM Landing Radar Operation, John Dahlen, MIT Instrumentation Laboratory, 18 March 1963.
- * (2) LEM Vehicle Configuration (Grumman Charts - no ref. no.)
- (3) Drawing - Proposal - Guidance and Navigation Equipment LEM: MIT Instrumentation Laboratory. Drawing No. 100126.
- (4) Drawing - Control and Display Panel. MIT Instrumentation Laboratory Drawing No. D 101437.
- (5) Drawing - G & N Display - LEM, MIT Instrumentation Laboratory Drawing No. J 101436.
- (6) Navigator's General Task Sequence for Apollo AGE, MIT Instrumentation Laboratory. DG Memo No. 10, J. Nevins, L. Dunbar, A. Wooden, 12 March 1963.
- (7) MIT/IL Drawing 101300-H. Crew Tasks for:
 - a) Earth or Lunar Orbit Navigation Measurement
 - b) IMU Coarse Alignment
 - c) IMU Fine Alignment
 - d) Midcourse Navigation Measurement
 - e) Thrusting Program (Non-Launch)
- * (8) MIT/IL Slides No. 24329 thru 24334, IMU - 3 for Apollo G & N Equipment.
- * (9) MIT/IL Slides TP 8003-1,2,3; LEM Radar - Optics-Computer Interface.

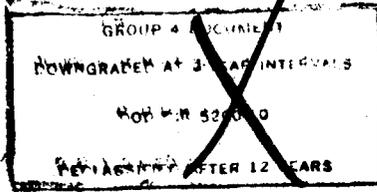
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(REF 1)

Massachusetts Institute of Technology
Instrumentation Laboratory
Cambridge 39, Massachusetts



John Dahlen
18 March 1963

LEM Primary Landing Mode of Operation

NOTE: By primary mode of operation we mean the recommended mode when all systems are GO. Refer to Fig. 1 for picture of events.

1. Prior to separation of the LEM from the mother spacecraft, the G&N system is checked out and aligned.
2. The LEM separates from the mother spacecraft using its reaction control system jets, operated in the manual translation mode.
3. The LEM is injected into the equal-period transfer orbit by applying approximately 460 feet per second velocity increment with the descent engine. Guidance is via the fully automatic thrust vector control mode. This maneuver lasts about 30 seconds.
4. During the approximately 30 minute coast period to pericyynthion the crew monitors system operation and prepares for the landing maneuver. Both the LEM and the C-SM rendezvous radars may be checked during this phase by tracking the transponder on the other vehicle. The landing radar can also be checked shortly before pericynthion by having it radiate toward the lunar surface and monitoring the return.
5. At pericynthion the descent engine is started by the G&N system. The initial descent is a fully automatic all-inertial mode, and lasts until the LEM is approximately 20 miles from the landing point. Velocity and altitude are displayed on the AGC display unit. Doppler inputs resolved by the AGC are also displayed, even though they are not yet introduced into the guidance equations.

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6. At a distance of about 20 miles from the landing point the radar altitude information begins to become more accurate than the inertial altitude. At this point it is used by AGC to update the altitude coordinate in a smooth manner.
7. At 15 miles the astronaut can begin to use his telescope in order to monitor the landing area. The telescope is placed in the AGC mode of operation which accomplishes the following: The telescope is pointed by the AGC at the landing point for which the guidance system is steering the vehicle. Let us refer to the astronaut in the right seat as being the navigator. The navigator looking in the telescope eye-piece will see the landing point in the center of the field with the crosshairs directly over the predicted landing point. The magnification of the telescope permits the navigator to judge more accurately the suitability of the landing spot than can the pilot. Also at this point the ability of the pilot to see the landing area is somewhat questionable, depending on the visibility permitted from his seat. The dynamics of this telescope mode are such that large angular accelerations of the vehicle will cause motion of the landing area in the field. However, it is not felt that this will be a serious problem.

If the navigator does not like the landing area he so informs the pilot. The pilot has an approximate indication of where the spacecraft is headed because the computer controls the yaw degree of freedom of the vehicle so as to place the landing area in the Xsc Zsc (pitch) plane. Refer to Fig. 2 for axis definitions. With the pilot's permission, then, the navigator can change landing site by momentarily disengaging the AGC mode with the toggle switch at his left hand. Then, using the optics stick, the navigator points the telescope at a desirable landing point. When he has the crosshairs on the desired landing point he releases the toggle switch. The computer then reads out the angles of the

telescope and the IMU with respect to the navigation base, thereby determining the bearing of the new landing point.

The computer then steers the bug for this point. The telescope is now back in the AGC mode of operation so that it will follow the new landing point. It is possible for the navigator to change the landing point several times before the flare is initiated.

8. At a distance of about 10 miles from the landing point, the doppler velocity information also begins to become useful to the computer and so it is assimilated into the guidance equations with a gradually increasing weighting function.
9. Next will be an automatic flare maneuver which levels the flight path. Before this happens the pilot has the ability to select the altitude to which the LEM will flare out. Therefore, prior to the flare the pilot will instruct the navigator to punch into the computer through the keyboard the altitude at which he desires to flare out. If he does not do anything, the computer will flare the vehicle out to a predetermined altitude, say two hundred feet. Now it is going to cost fuel to flare out at a high altitude, consequently the pilot will only choose an altitude higher than the one stored in the program when he has reason to be apprehensive about the suitability of the terrain.
10. The flare-outs puts the craft into a level path with a constant velocity of 50 feet per second.* The attitude of the vehicle is constant and vertical. This will be referred to as the ALTITUDE HOLD mode of operation. Normally, the vehicle would continue in this condition for a very few seconds, followed by an automatic let down phase which places the LEM on the intended landing point.

*While it does not seem advisable at this time, the provision does exist for the pilot to change this velocity by so instructing the AGC prior to flare out.

11. The automatic let down phase has as initial condition the LEM travelling horizontally in the vertical attitude at a speed of 50 feet per second. The let down phase starts by pitching up so as to reduce the velocity. The vehicle returns to the vertical attitude when the horizontal velocity goes to zero. The throttle has been regulated by the AGC to attain an altitude of 100 feet and a sinking speed of 10 feet per second at this point. Now the LEM descends vertically* to the lunar surface, while sinking speed is gradually reduced to 5 feet per second or less. If there exists an altitude below which the radar can no longer be trusted, the descent can be completed in an all-inertial constant velocity mode. The all-inertial constant velocity let down does not require visibility from the cockpit, nor does it require functioning of the altimeter. It only requires proper functioning of the inertial guidance system which, of course, is no problem.
12. Now, if after the flare-out and before the terminal let-down, the pilot did not like the looks of the terrain, he has two alternatives available to him for selecting a new landing point. First he hits the OVER-RIDE button to prevent the terminal let-down. So long as he holds this button down the LEM will remain in ALTITUDE HOLD. When this button is released, the let-down will start.
13. If the new landing point should be some distance away because of a gross misjudgment on the part of the pilot or the navigator in selecting this area earlier in the trajectory, the navigator can then select a new point using the telescope mode of operation already described.

*The terminal descent need not be vertical. Later information may indicate the need for a slant approach which can be programmed into the AGC as readily as a vertical approach.

14. If, however, the landing area is generally suitable but has certain obstacles to be avoided, which is probably the most realistic case, then small changes in the intended landing point can be accomplished as follows: The pilot has overridden the terminal let-down maneuver so that the LEM is now proceeding at constant altitude 50 feet per second in a vertical attitude. The pilot can see the surface ahead of him. The pilot also has good judgment based upon his experience in training that when he releases the OVER-RIDE button to initiate the let-down maneuver he knows about how much forward travel will be accomplished during the time it takes the forward velocity to be arrested. So, if there appears ahead of him a suitable landing area, the pilot waits until he is at known distance in advance of the desired landing point and then releases the OVER-RIDE button which initiates the automatic terminal let-down maneuver.
15. If there are not suitable landing areas directly ahead of the spacecraft then the pilot can change his heading as follows: Remember now the spacecraft is travelling at constant altitude and 50 feet per second over the lunar surface. The OVER-RIDE button is being held down. The pilot now uses his control stick to roll the ship over to some roll angle in the same manner he would bank an aircraft. The G&N system automatically controls the throttle to maintain the HOLD altitude. The system controls spacecraft yaw attitude to hold the velocity vector in the XscZsc (pitch) plane and controls pitch attitude to hold constant speed. Note, then, that OVER-RIDE during ALTITUDE HOLD not only delays the automatic let down but it takes control of roll attitude away from the AGC and gives it to the pilot. From the cockpit this looks and feels like a conventional coordinated aircraft turn. When the craft is headed in the desired new direction the bank angle is returned to zero. The OVER-RIDE button is released when the pilot wishes to initiate the automatic let-down.

- 16 The need may exist for small translations on the order of 50 feet or less during the terminal descent. It is proposed that these translations be accomplished with the RCS thrusters in the manual translation mode already provided in the control system. The automatic terminal descent would be interrupted by the OVER-RIDE button. Depressing this button during terminal descent causes the AGC to relinquish attitude command authority by switching the control system to manual translation mode. The AGC retains control of the throttle to maintain the altitude existing when the OVER-RIDE was depressed. Releasing the button would tell the AGC to resume control of the terminal descent from the new position.
17. Also during the terminal descent the AGC will correct the yaw angle (rotation about Xsc) so that the LEM will set down in the proper azimuth orientation to permit tracking the mother ship from the lunar surface.
18. Note that the AGC Display will indicate time remaining before the next mode so that the pilot will know how much time he has to change his mind.

Specifically, we will display:

TIME-TO-GO TO:

- a. separation
- b. descent engine start
- c. flare out
- d. automatic let down
- e. latest possible let down (when in over-ride mode)
- f. touch down

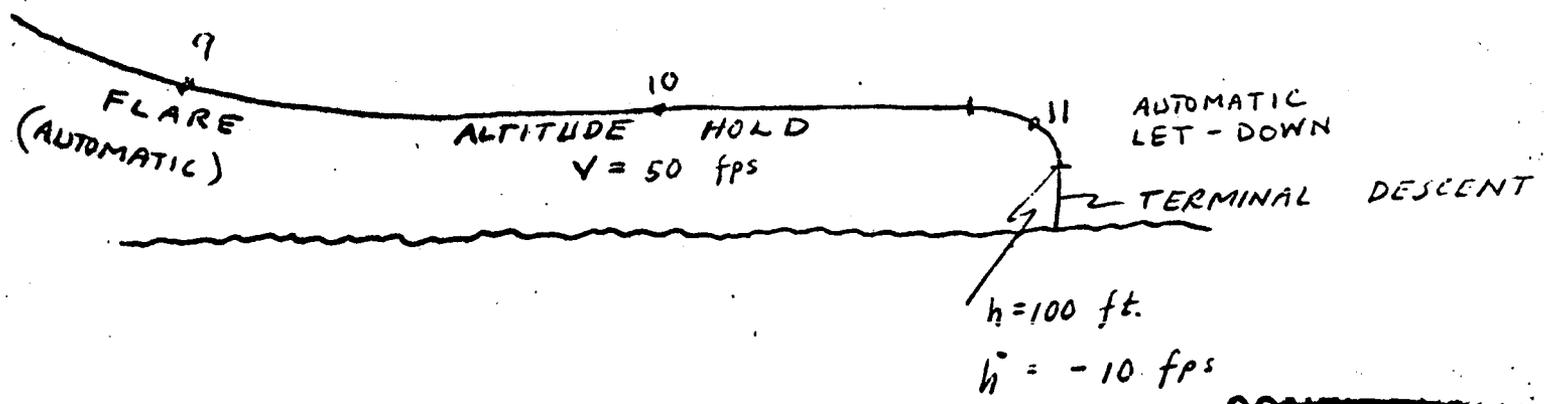
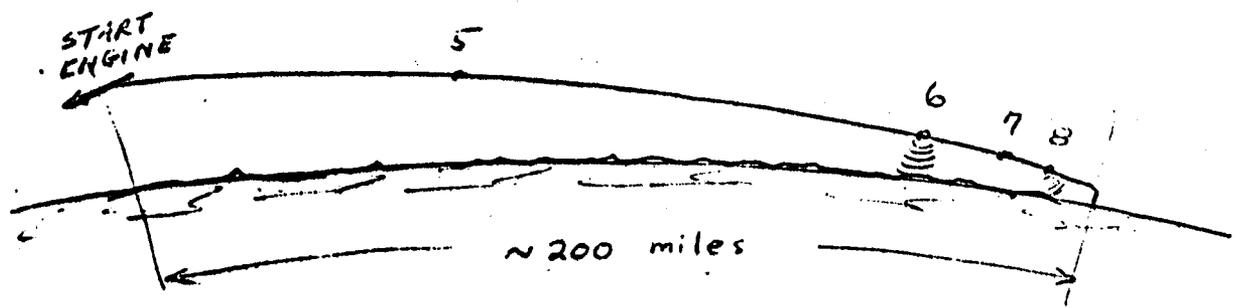
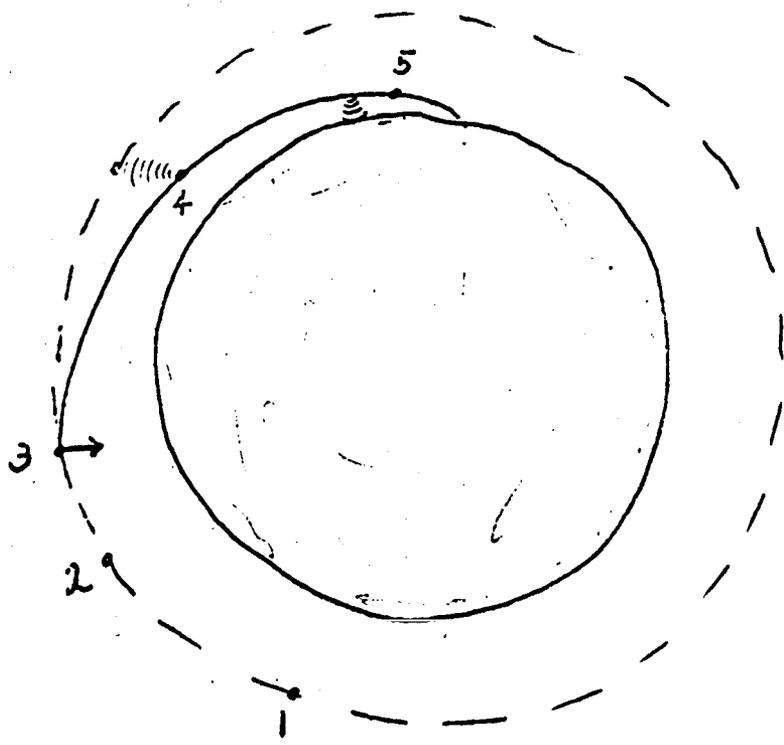
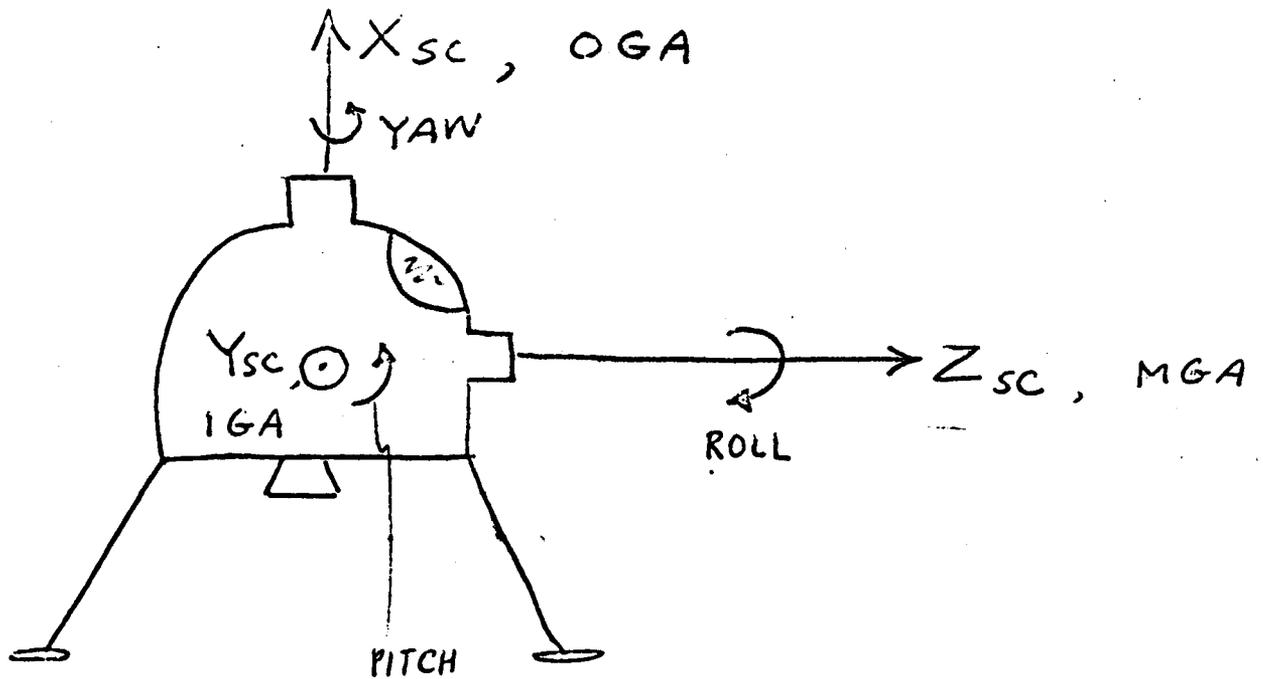


FIG 1. EVENTS

(KEYED TO PARAGRAPH NOS.)
1-7

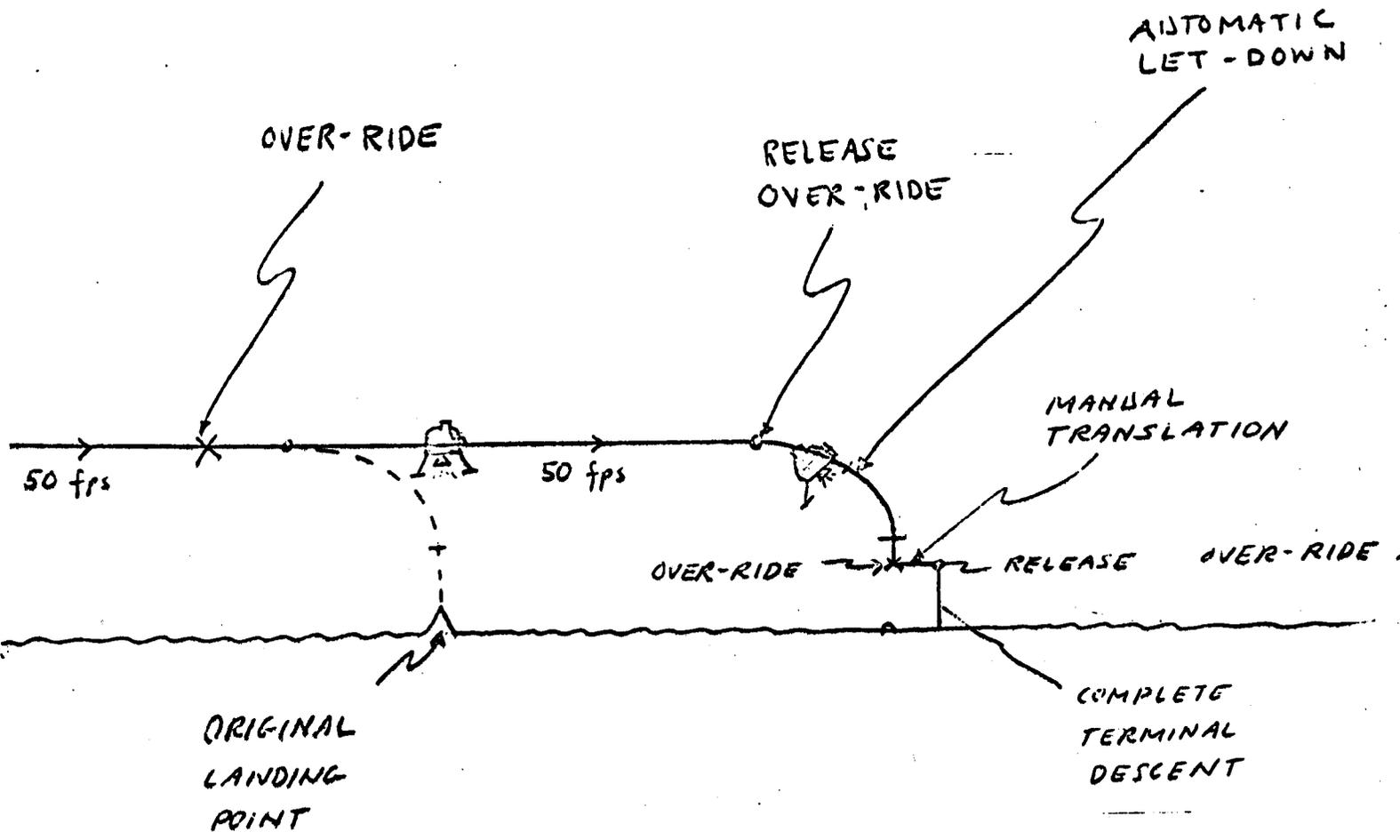


(IMU AXES SHOWN IN ORTHOGONAL CONDITION ,

$$A_{OG} = A_{IG} = A_{MG} = 0)$$

FIG 2. 1-8 AXIS DEFINITIONS

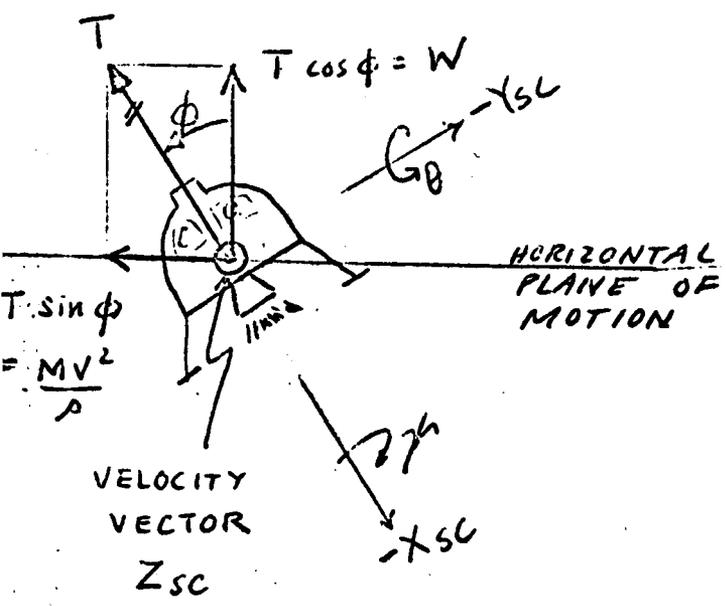
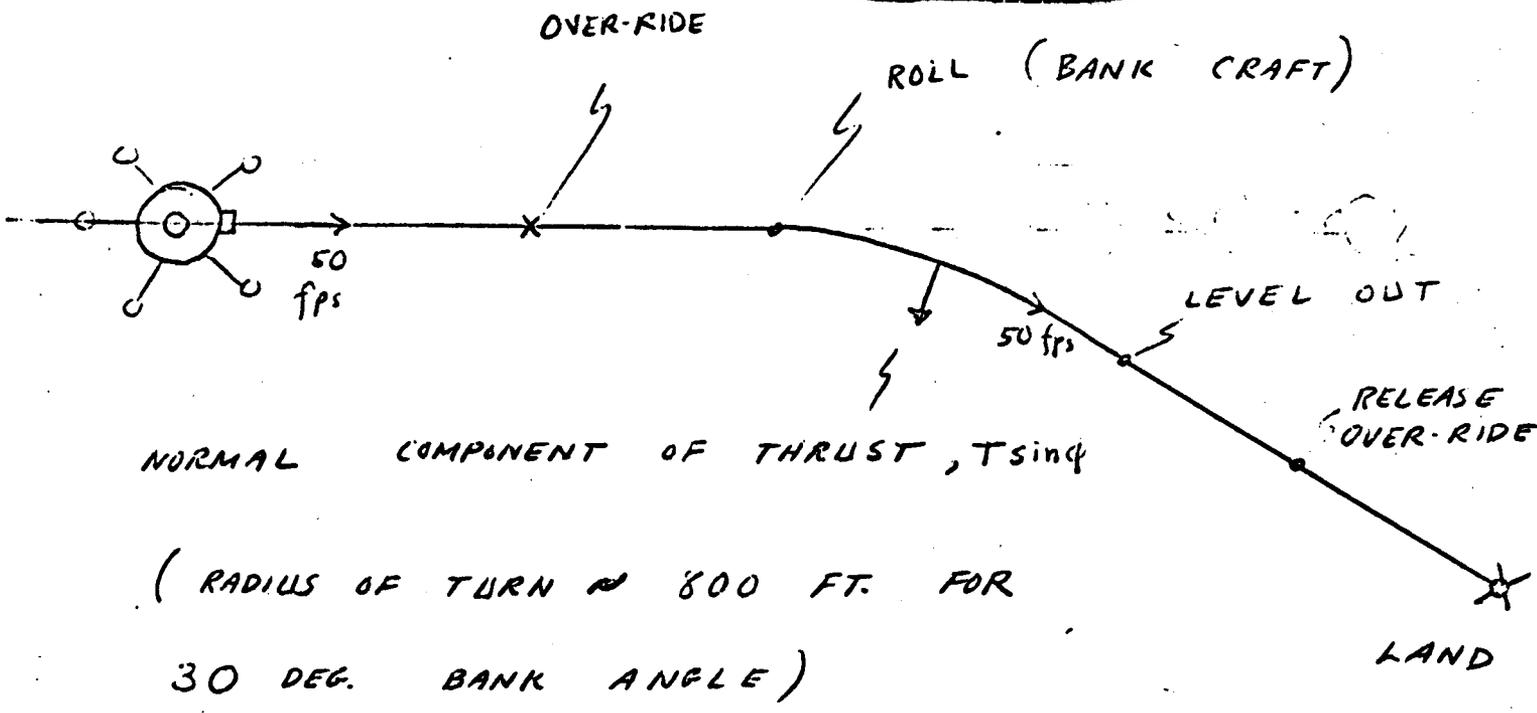
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FIG. 3. RANGE CONTROL AFTER FLARE 1-9

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PILOT CONTROLS ϕ

AGC CONTROLS :

T, θ, ψ TO

HOLD ALTITUDE,

SPEED AND VELOCITY

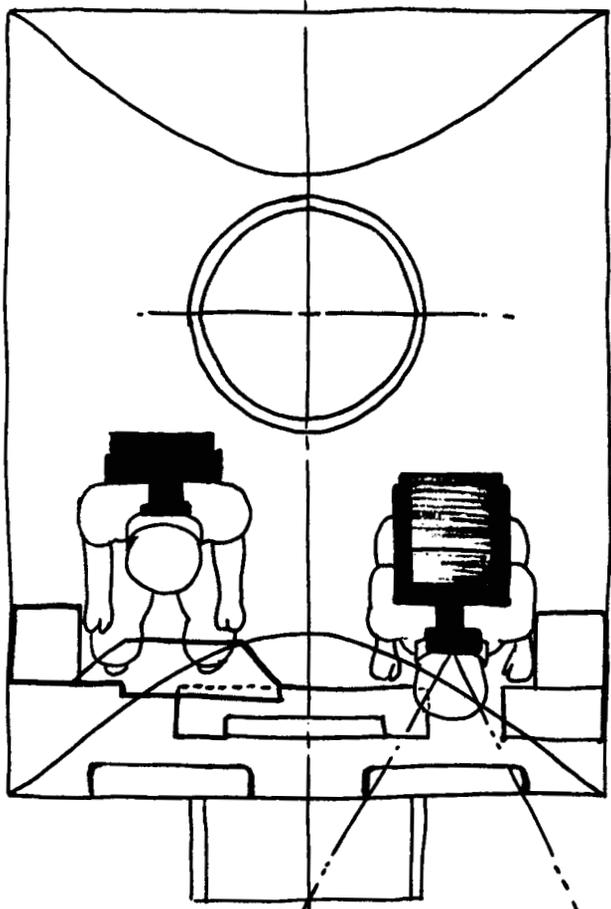
VECTOR IN $X_{sc} Z_{sc}$ PLANE

RESPECTIVELY

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FIG 4 - HEADING CONTROL AFTER FLARE

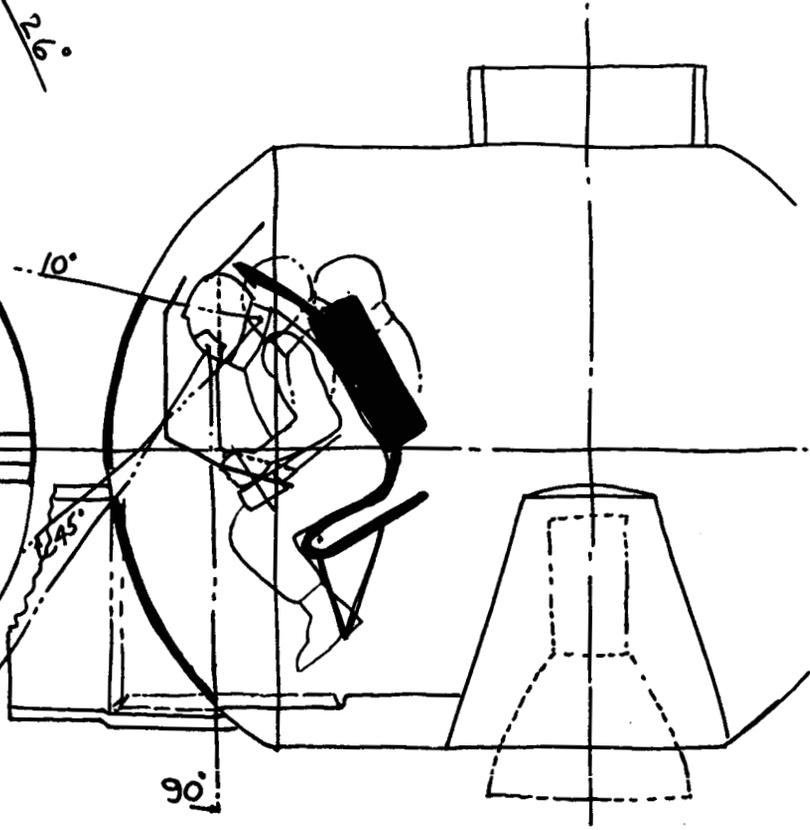
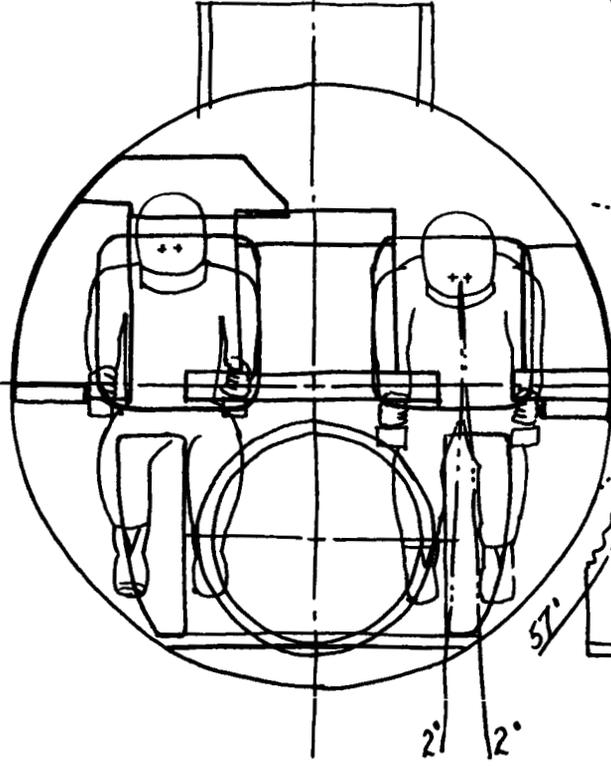
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CONFIG # 1

HD.RM. 86"
SEAT \angle s
 0° - 15° - 30°

30° 30°



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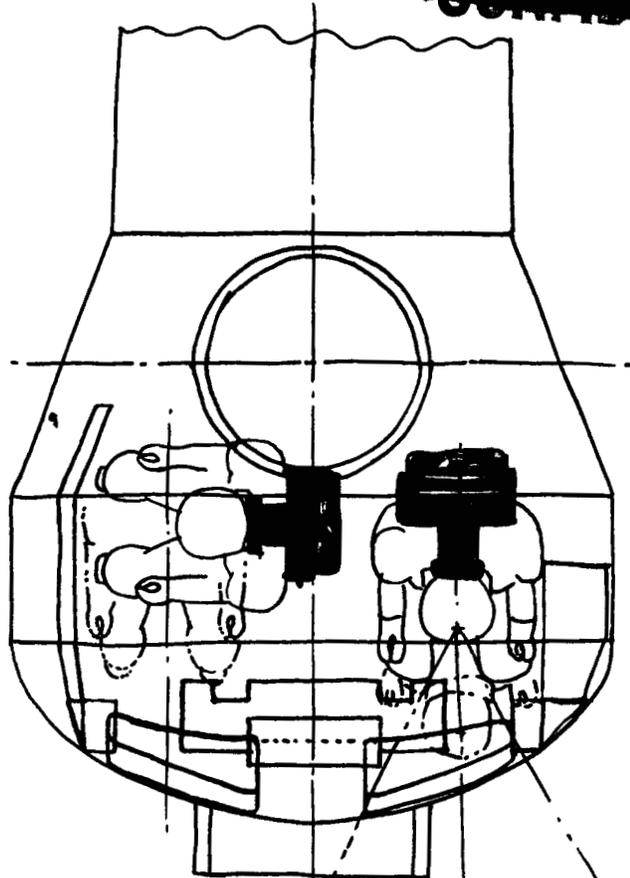
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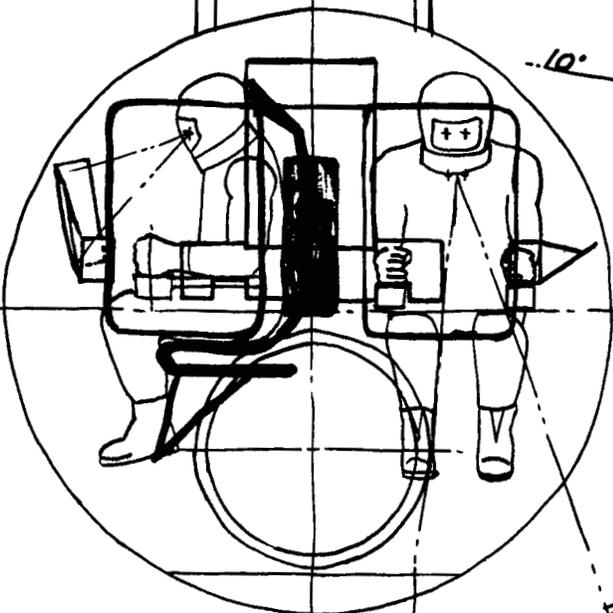
SEAT \angle s

$0^{\circ} 10^{\circ} 38^{\circ}$

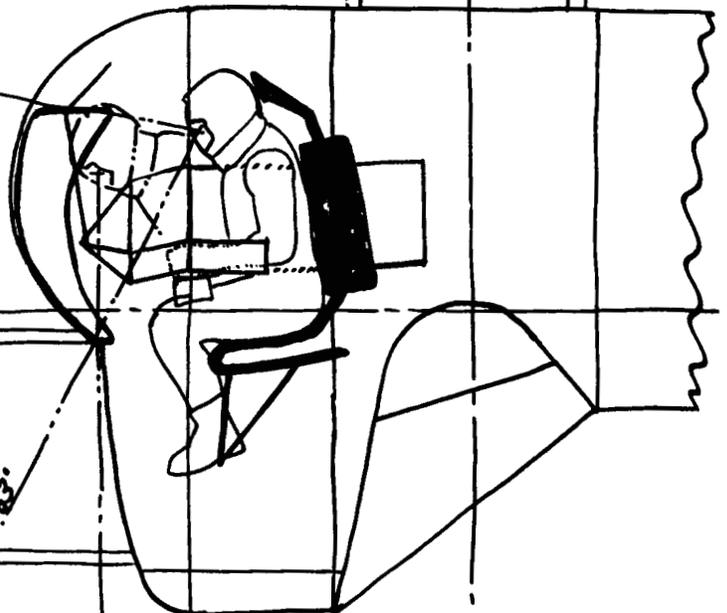


27°

28°



10°



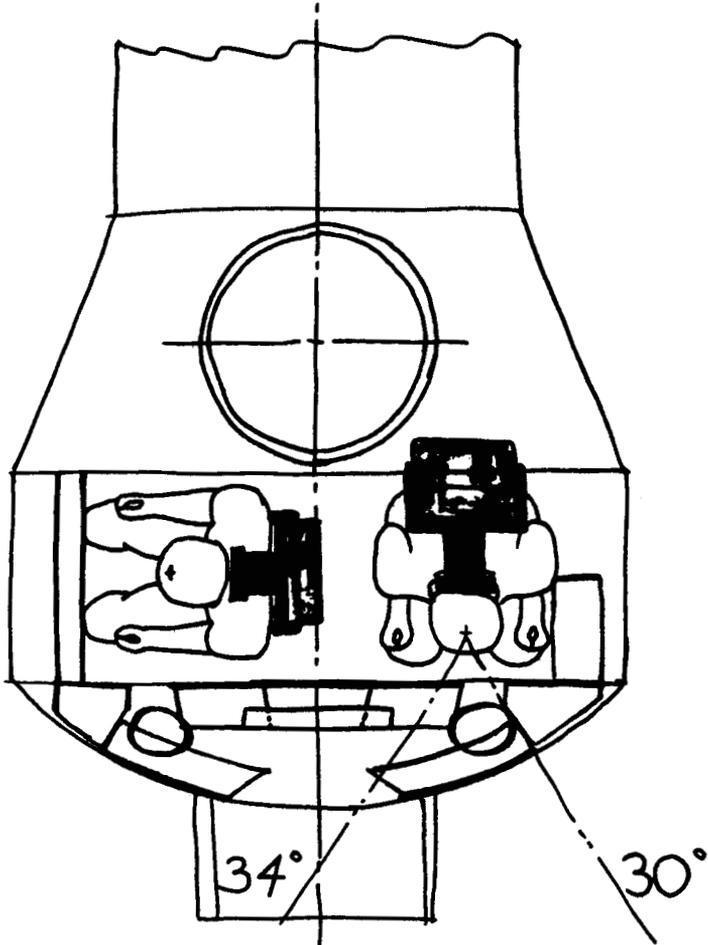
6°

90°

5 1/2°

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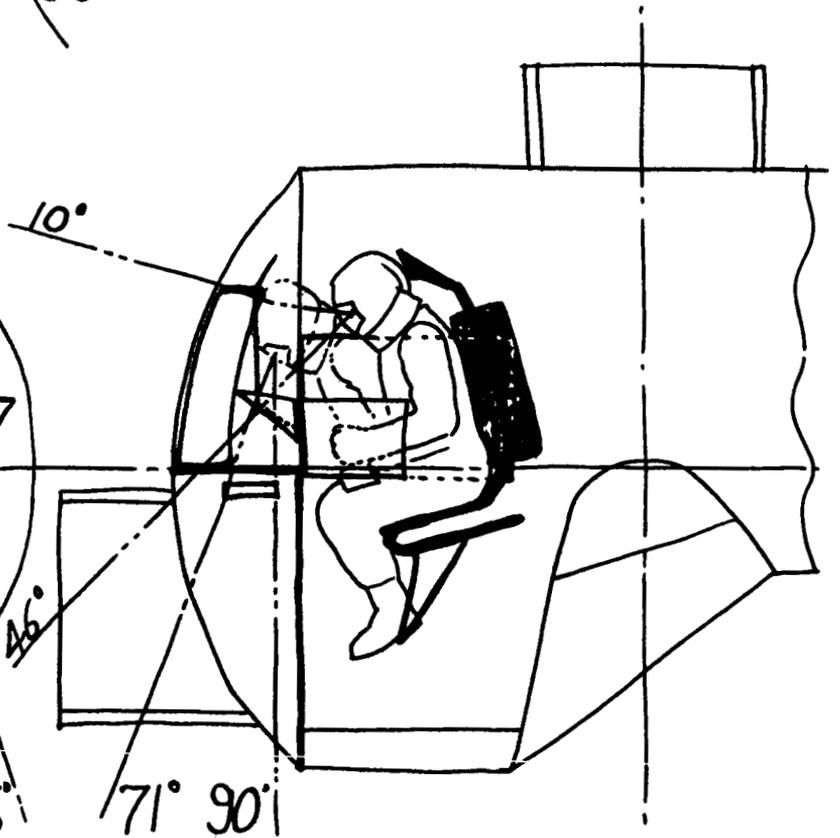
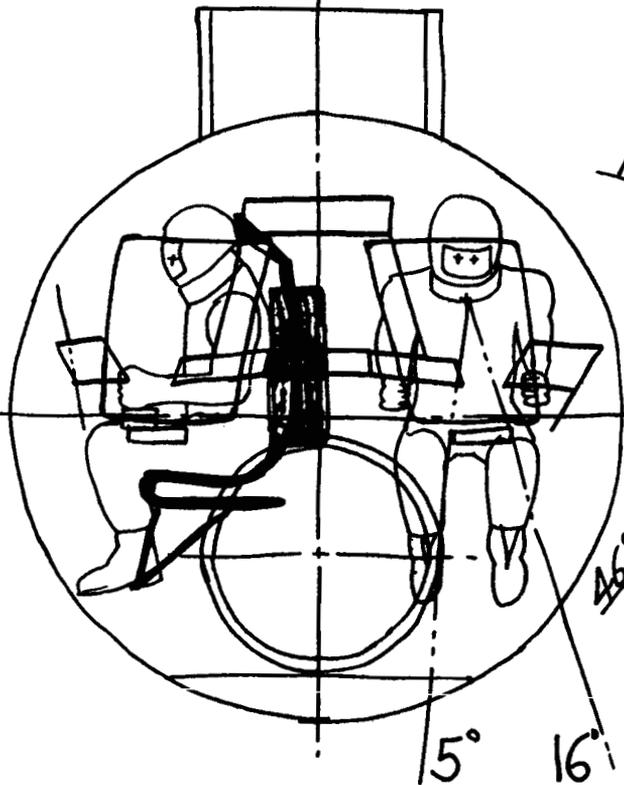


CONFIG # 3

HD. RM. 86"

SEAT \angle s

$0^{\circ} 15^{\circ} 36^{\circ}$



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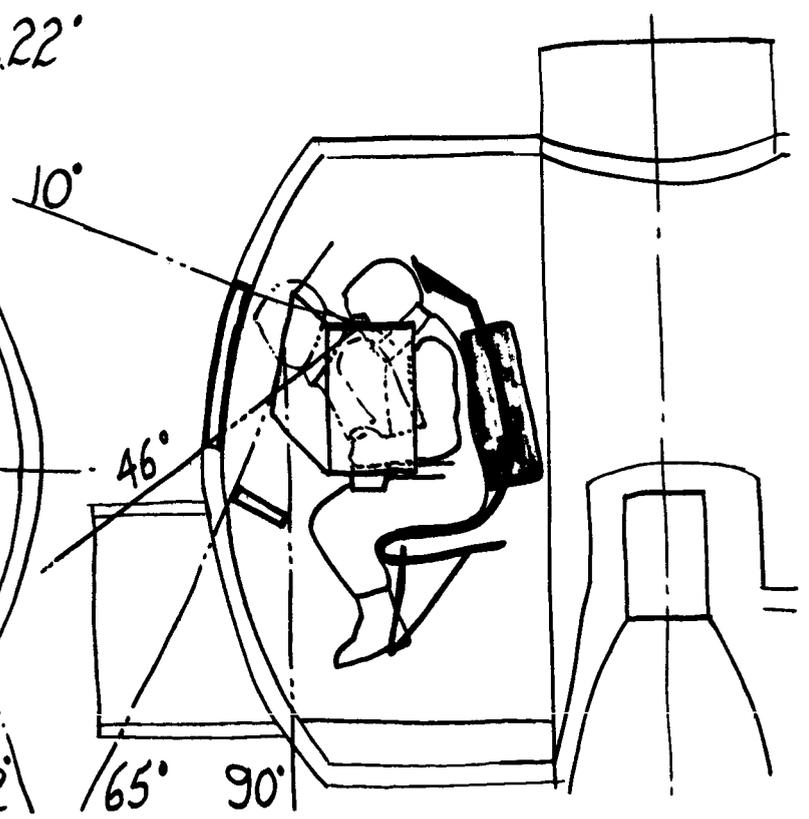
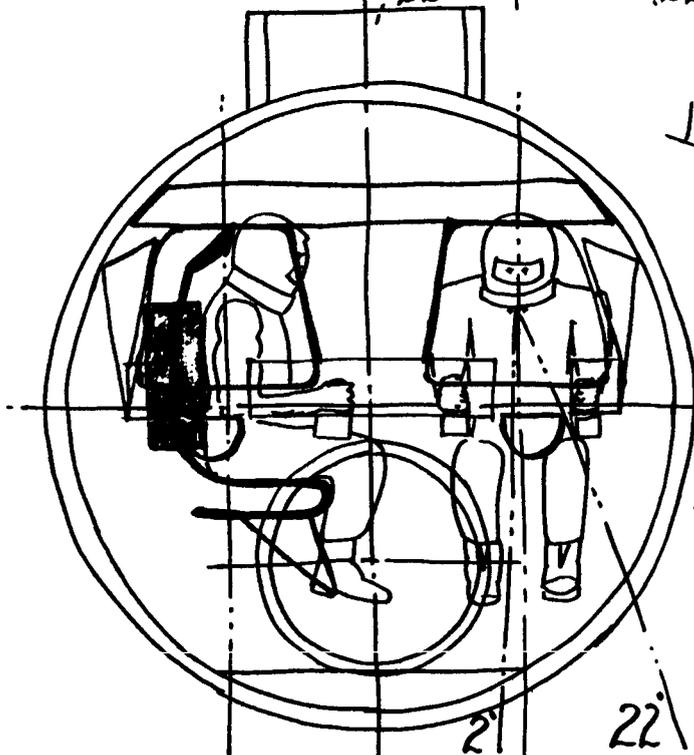
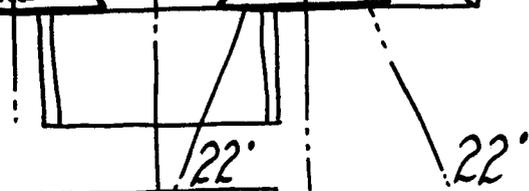
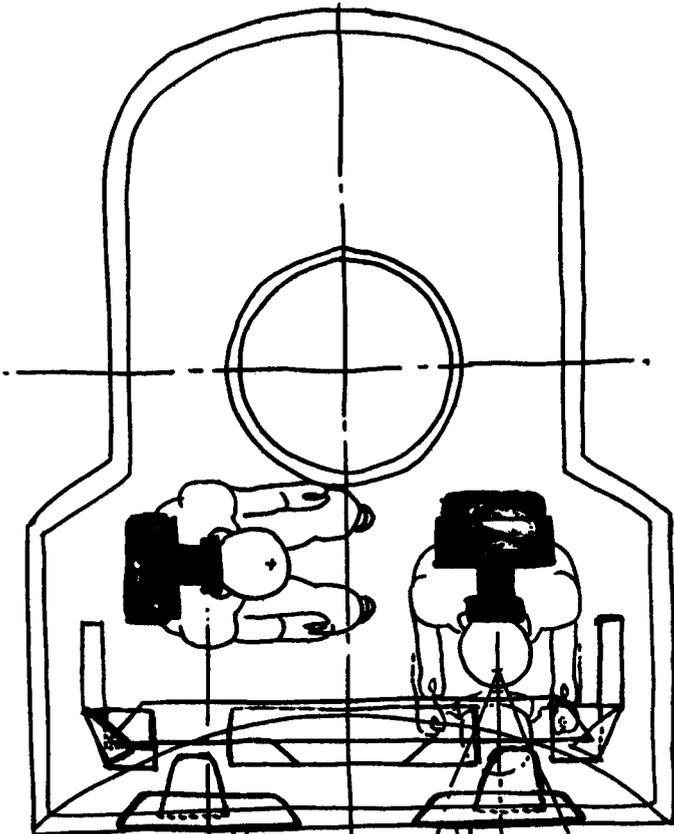


CONFIG # 4

HD. RM. 86"

SEAT \angle s

0° 10° 40°



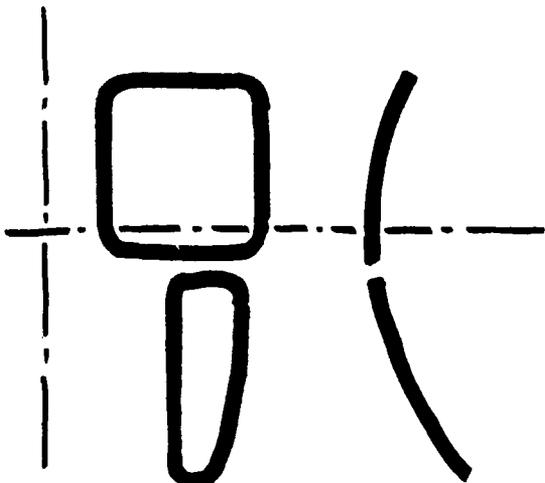
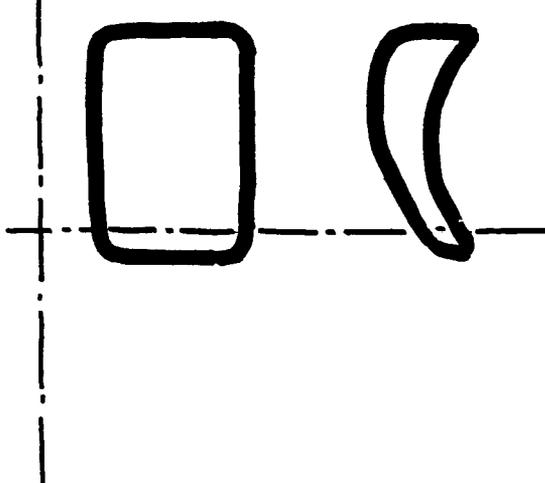
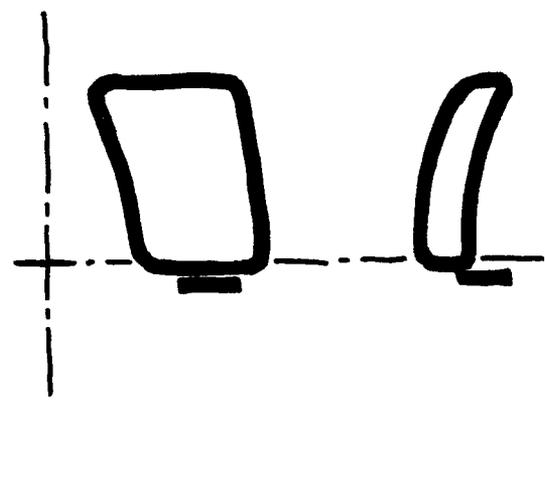
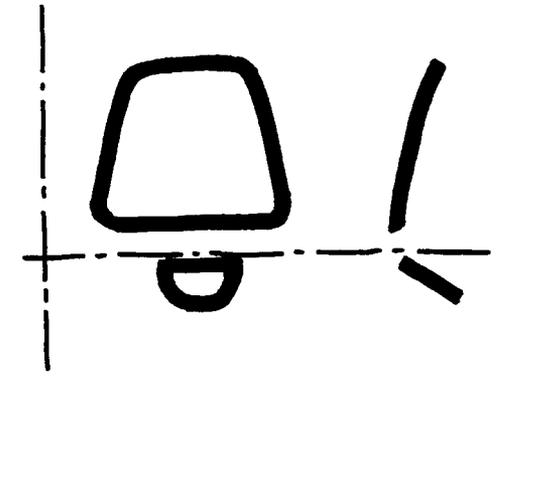
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VIEW ANGLES (DEGREES)				
CONFIG	EYE POSITION			
	NORMAL (Z'S IN Y-Z PLANE)			FWD (Y-X)
	10° UP	HOR	30° DN	90° DN
① INBD OUTBD	34°	33°	30°	2°
	30°	29°	25°	2°
② INBD OUTBD	27°	27°	26°	5½°
	28°	28°	23°	19°
③ INBD OUTBD	35°	34°	25°	5°
	30°	30°	30°	16°
④ INBD OUTBD	20°	22°	26°	2°
	20°	22°	26°	22°

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FWD GLASS AREA (FT²)

 <p>① 12.4</p>	 <p>② 12.6</p>
 <p>③ 9.5</p>	 <p>④ 9.1</p>

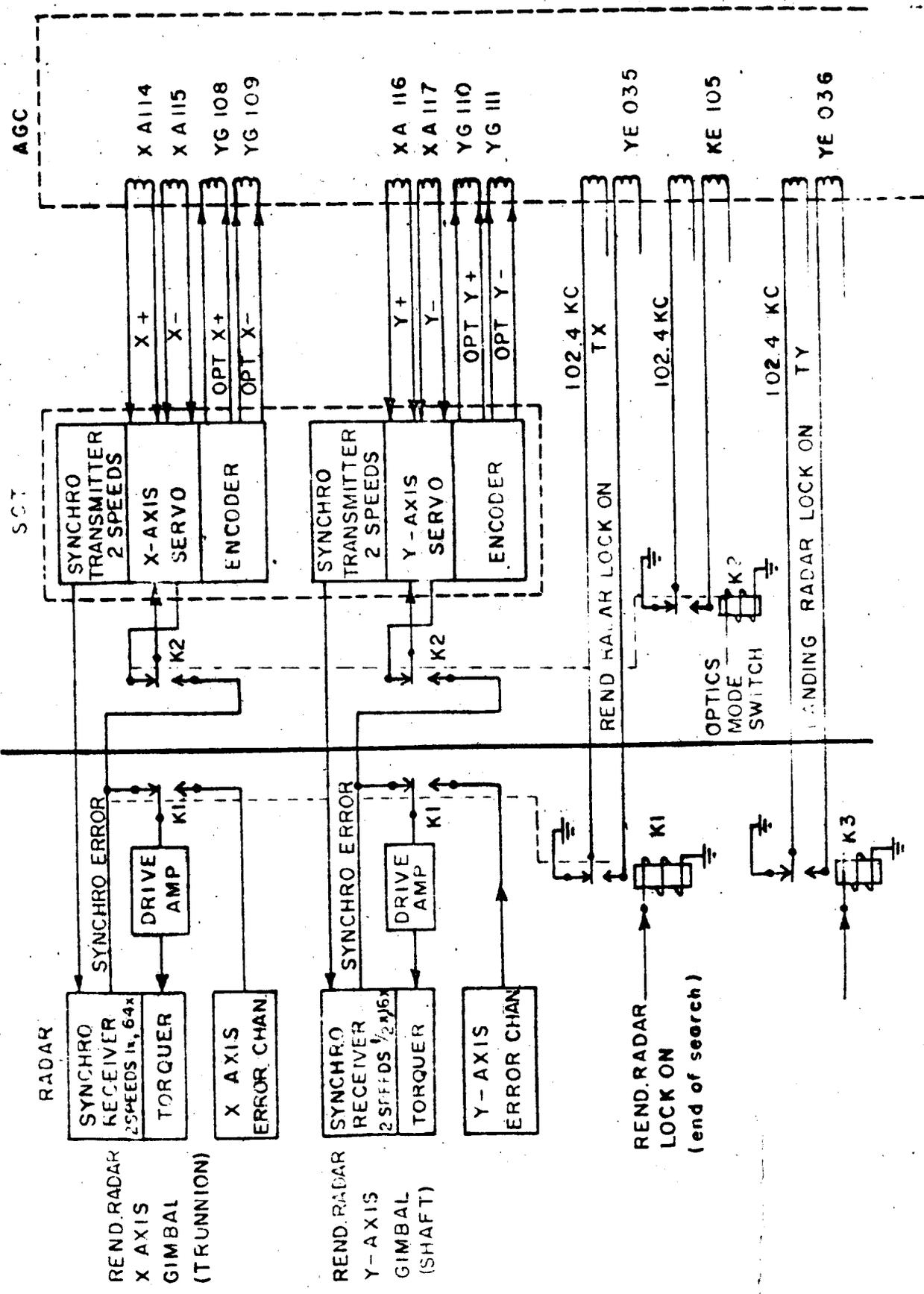
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REF. 8,
FIG. 1

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REV. 10-62

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LEM RADAR - OPTICS COMPUTER INTERFACE



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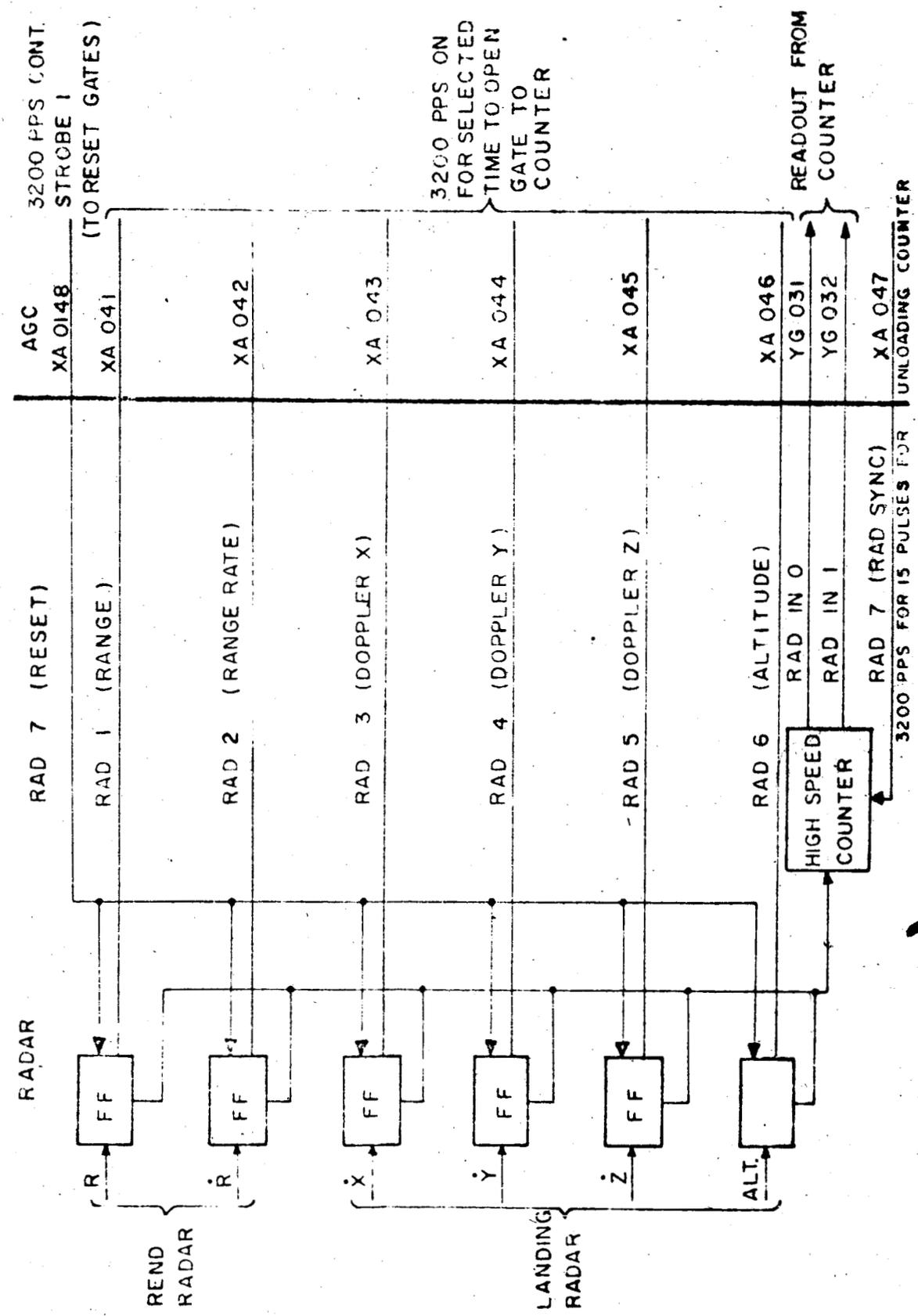
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Rev 8
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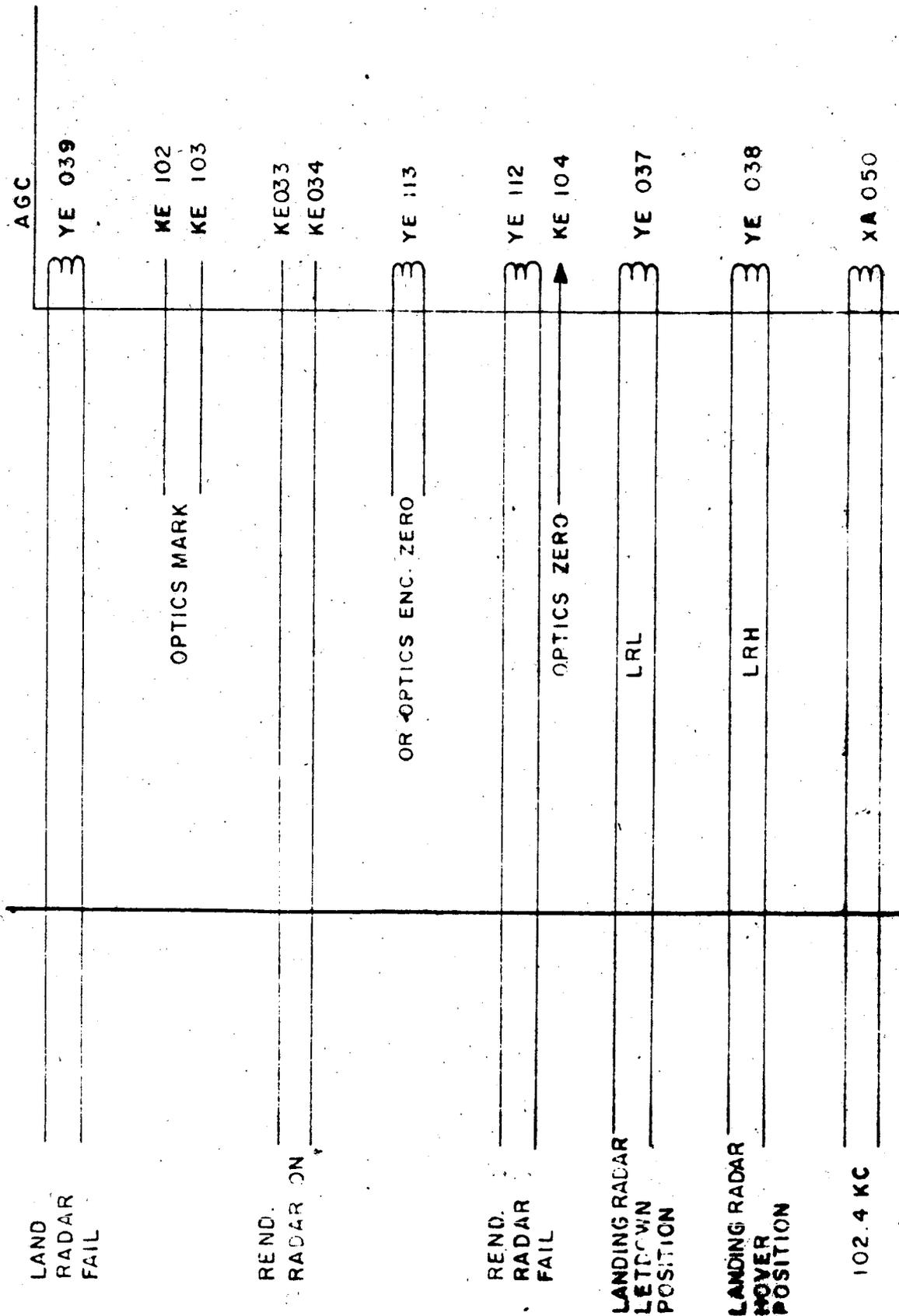
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 PROJ # _____
 FIG. NO. _____
 CLASS _____
 DATE _____

MAR 20 1963

LEM RADAR-OPTICS-COMPUTER INTERFACE



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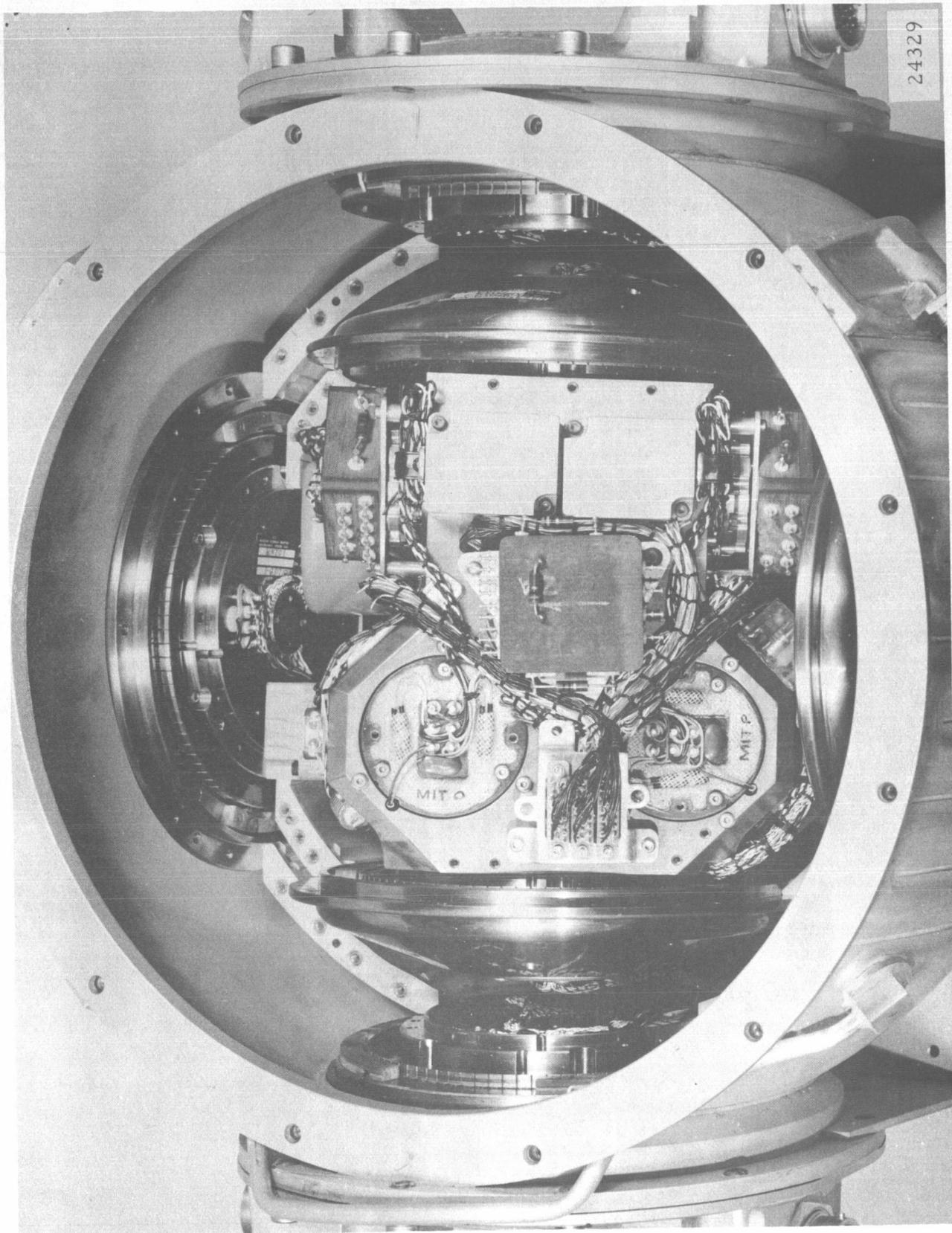


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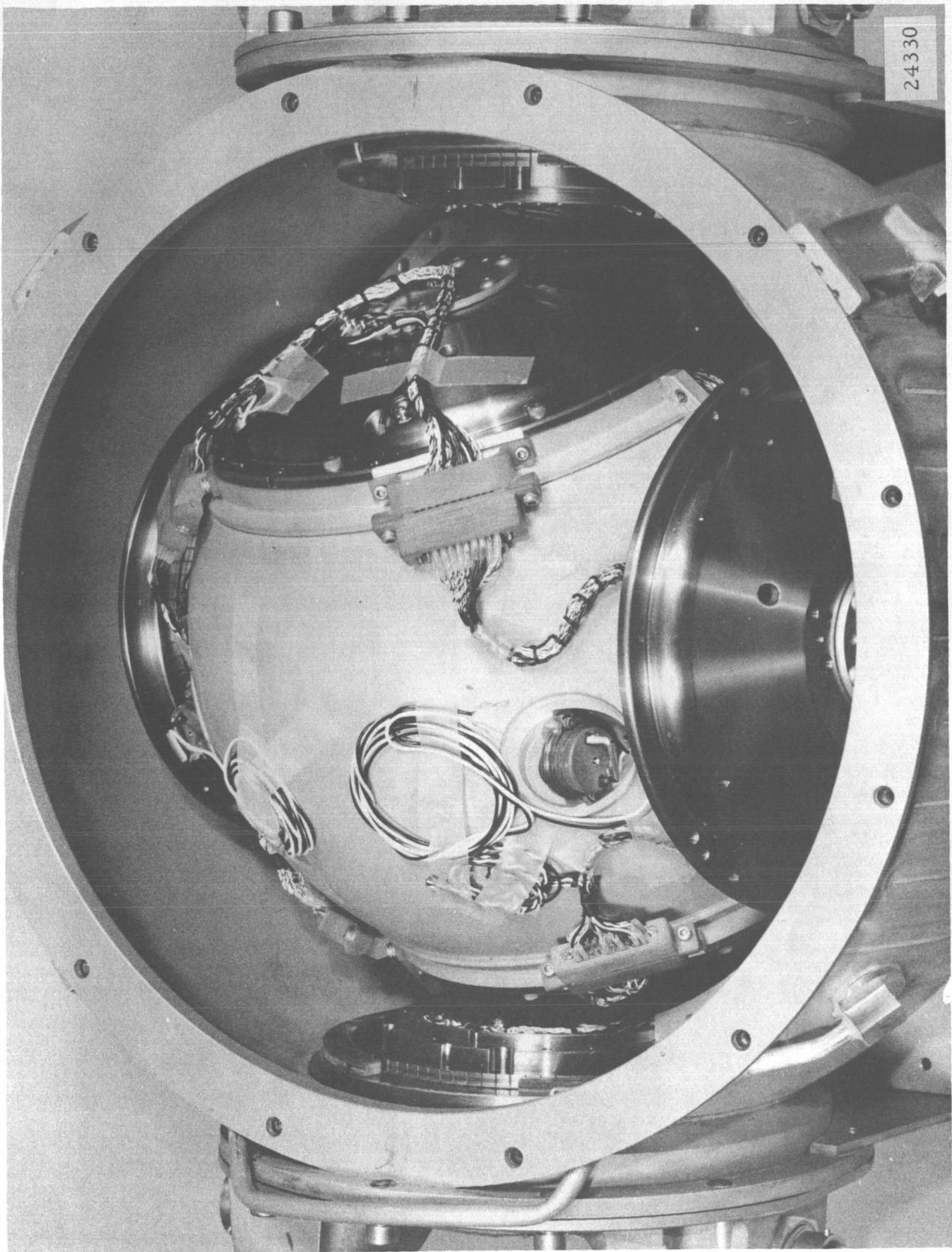
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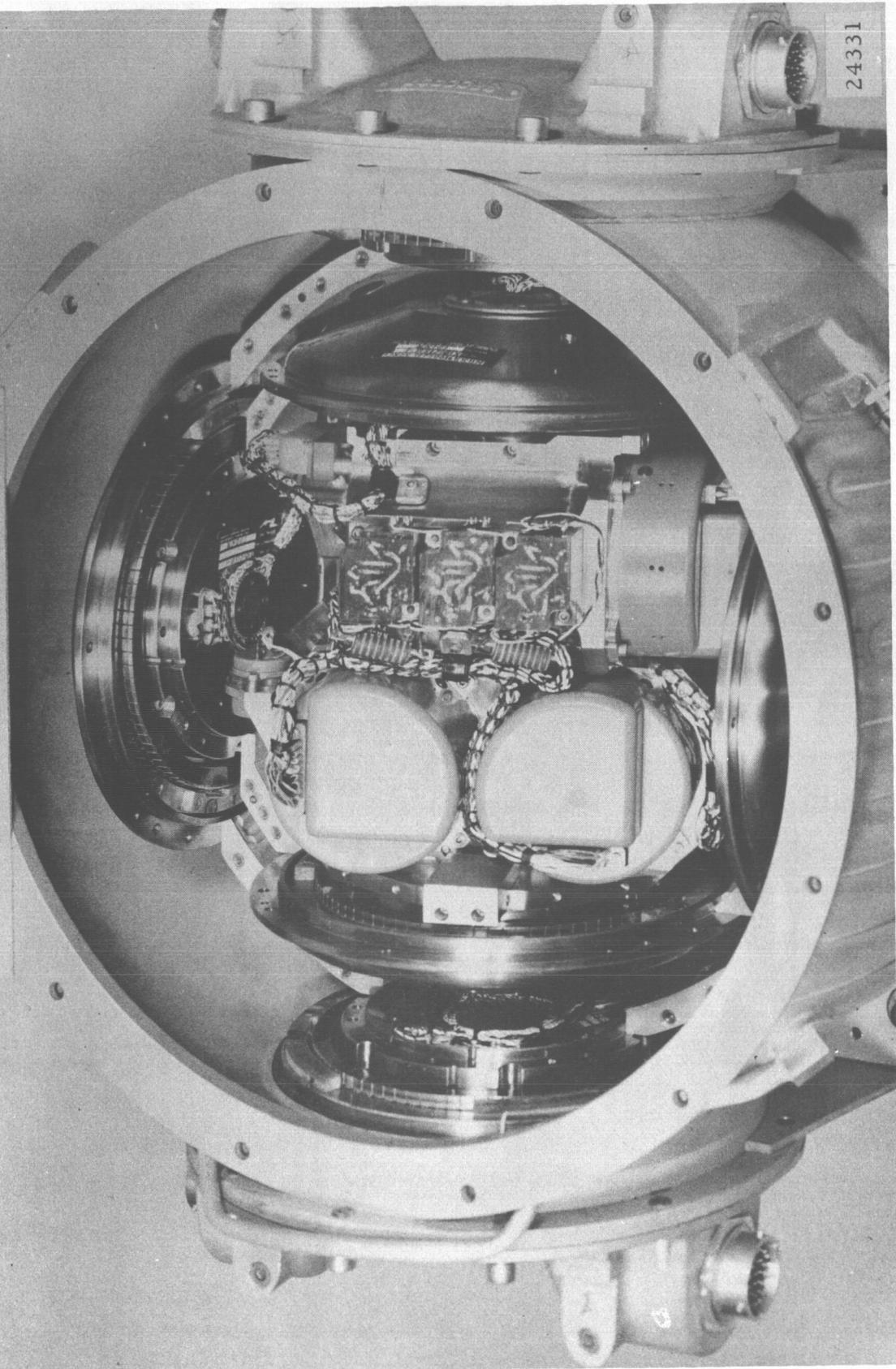
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FEBRUARY 1963

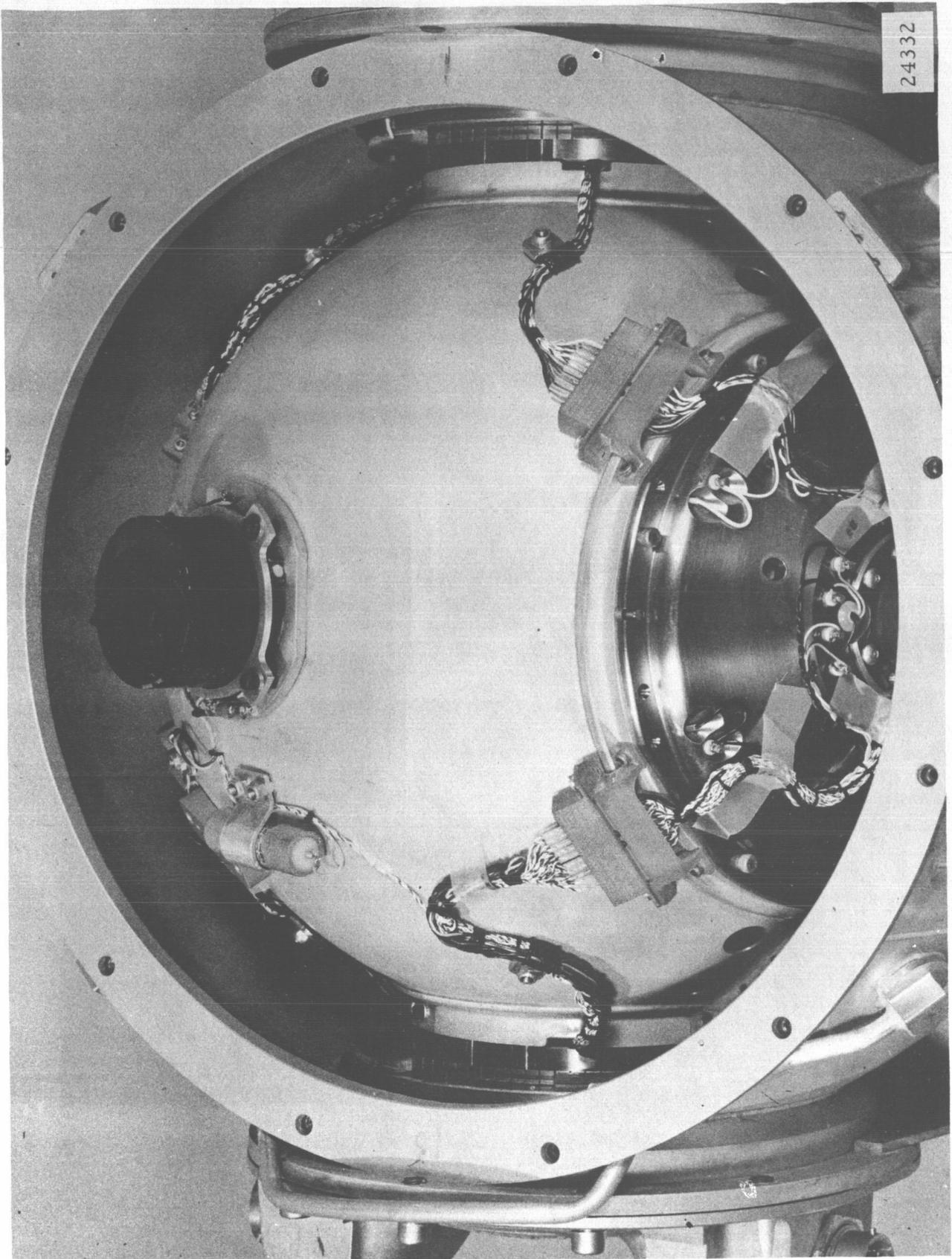
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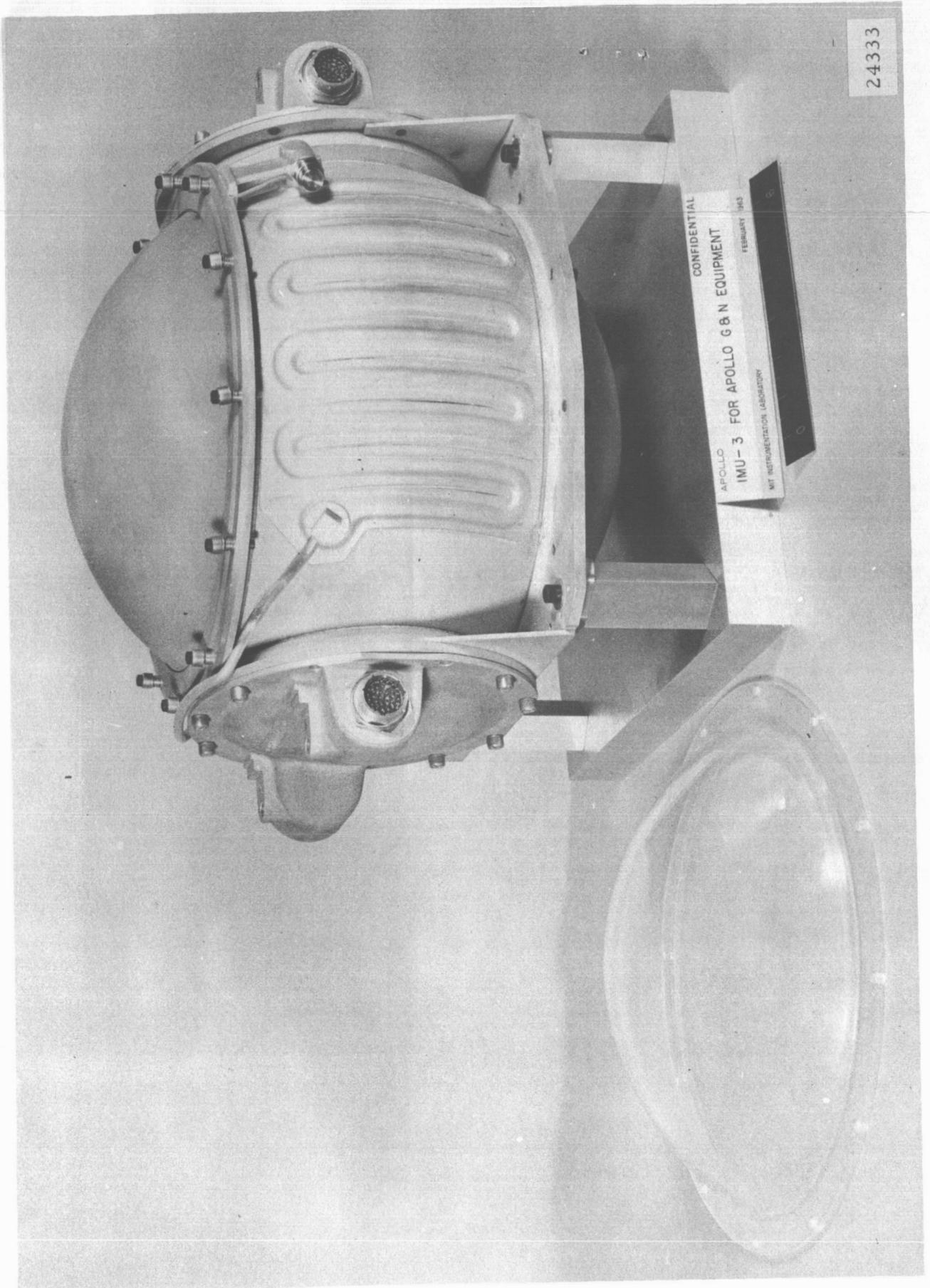
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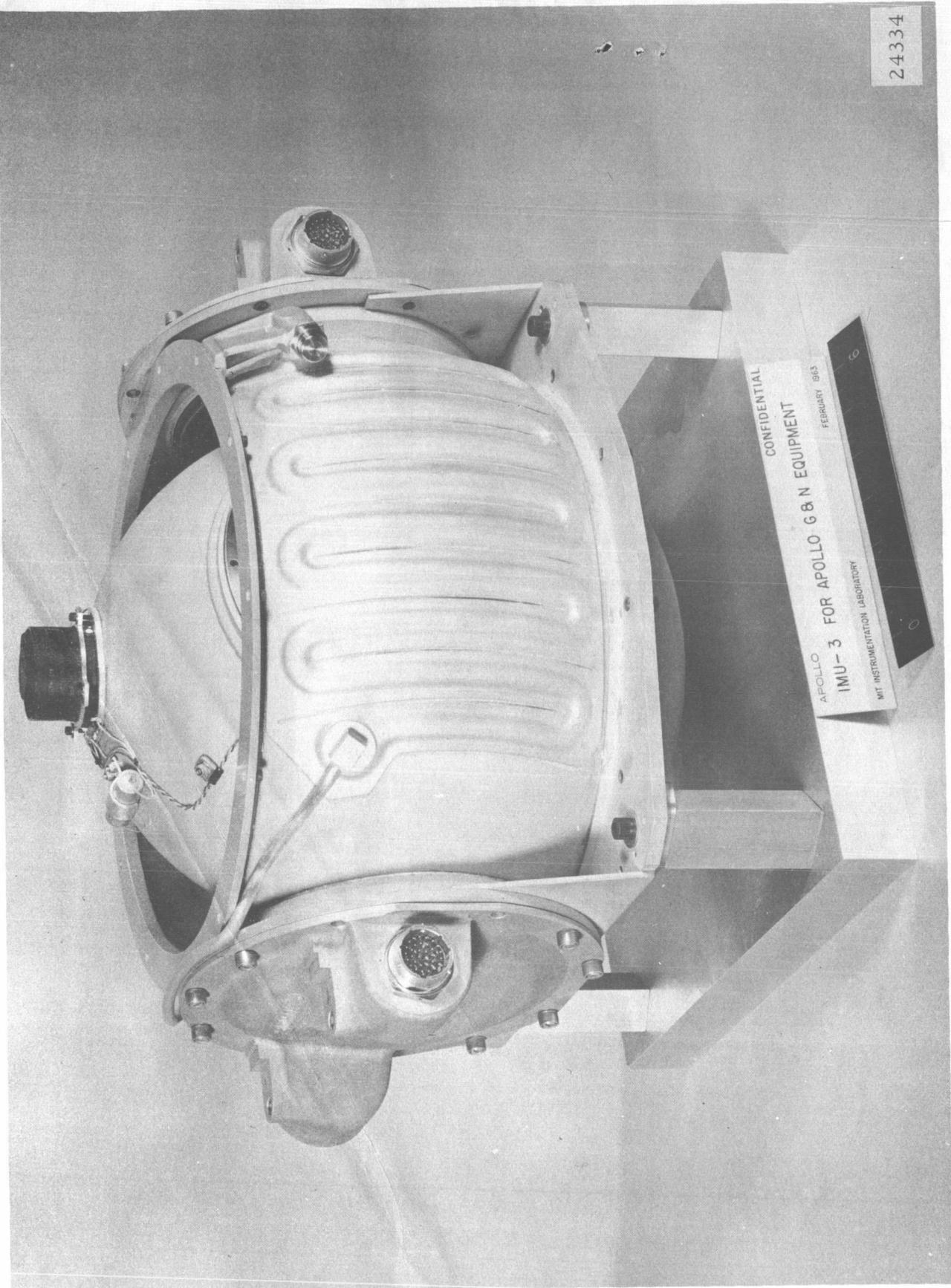
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