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CLASSIFICATION CHANGE
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APOLLO

GUIDANCE AND NAVIGATION

SINGLE COPY ONLY

Approved Milton B. Trageser Date 1/8/62
MILTON B. TRAGESER, DIRECTOR
APOLLO GUIDANCE AND NAVIGATION PROGRAM

Approved Roger B Woodbury Date 1/8/62
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INSTRUMENTATION LABORATORY

PREPARED FOR NASA
by
MIT

(Unclassified Title)
E-1097

WORK STATEMENT FOR INDUSTRIAL SUPPORT

January 1962

[redacted]

INSTRUMENTATION LABORATORY
CAMBRIDGE 39, MASSACHUSETTS

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ACKNOWLEDGMENT

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LIST OF TABLES

Suggestions to Bidders for Preparation of Technical Proposals in Response to Request for Proposal No. 9-MIT/IS-3, "Navigation and Guidance System, Industrial Support"

Attachment "C" is titled General Instructions for Preparation of Proposal; Section I is a separately bound document, E-1097, Work Statement for Industrial Support. Paragraph 1.2.10 (page 1.2-3) of E-1097 lists Technical Proposal Requirements.

The following suggestions are proposed in an attempt to expedite the task of the proposal evaluation team:

1. Prepare the proposals as replies to each of the seven main subdivisions listed on page 1.2-3, using the same reference numbers as listed there.

i.e.	1.a.	System Support
	1.b.	IMU Subsystem Support
	1.c.	Coupling Display Unit
	2.	GSE
	3.	AGC
	4.	Optical Subsystem (a. SXT, b. M and VD, c. SFA)
	5.	PSA

2. It is preferred that each reply for a subdivision as indicated above be bound separately (no fancy bindings). Each of the separately bound replies could contain a reference to the other areas being answered by a particular bidder.

3. If the same information is required in two or more of your technical presentations, it should be stated in each place, and not cross-referenced, because in general the various sections will be evaluated by different teams.

4. If an overlap of information seems to be required between the technical proposals, business management proposals, and cost proposals (ex. scheduling as required in Sections II and III might be desired in Section I), the overlapping information should be stated in each proposal separately.

CLASSIFICATION CHANGE [redacted]

TO - UNCLASSIFIED

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Changed by D. H. Werkheiser Date 8/13/72

5. To simplify the task of comparison for the evaluation team, each bidder should number the proposal paragraphs to correspond to the numbers used in E-1097.

As an example, consider page 3.3-1, subdivision "Apollo Guidance Computer, Work Statement for Industrial Support" (AGC). Your response to this item should be numbered 3.3. In your introduction (numbered 3.3.1), item number 3.31B is your reply to the checklist.

Your response to Detail Requirements should be numbered 3.3.2, and your tabulated sub-headings should use the same designations as are shown in E-1097; such as 3.3.2D.2. to show your response to request to manufacture field service test equipment to supplement guidance GSE, and schedule delivery to conform with field service requirements.

6. If you desire to include more technical information than that outlined in E-1097, provide a technical appendix for that area, using the next number in the series. Example is shown on page 3.3-5 where 3.3.3 is titled Technical Appendices and items are tabulated through 3.3.3A.4 (p. 3.3-8).

The next technical appendix, if another one were desired would be numbered 3.3.4 "Additional Technical Appendices", with "3.3.4.A." used to state the title and introduction to the appendix.

[redacted]

Addendum to E-1097

DETAILED TECHNICAL AREA REQUIREMENTS

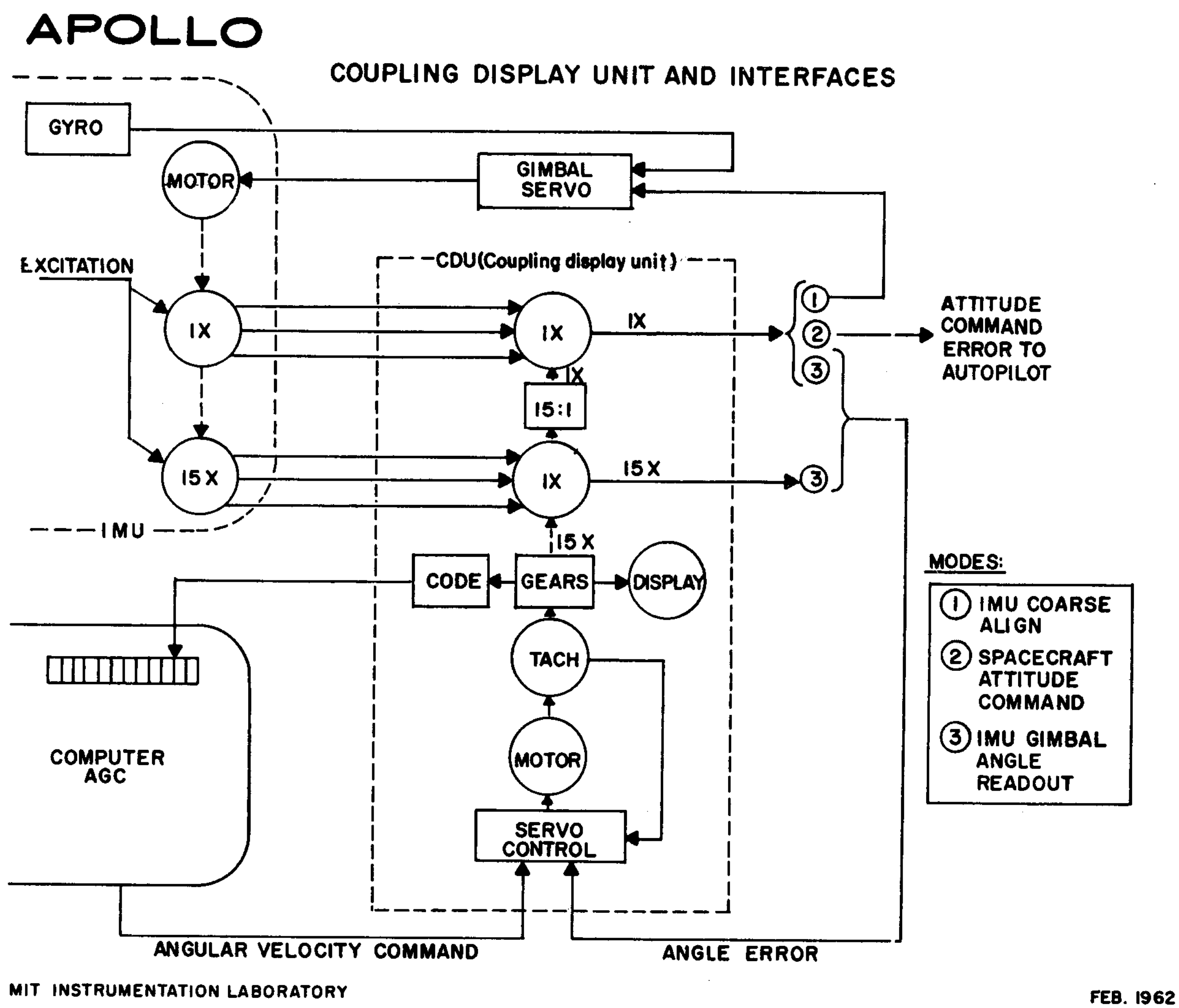
by D. Hoag

Page	
3.1-11	Change the last line on the page from 35 to 40 rings.
3.1-15	Change at the top of the page first line the 1 to 2 and add "or" after "speed" second line the 16 to 15 third } lines delete fourth } eighth line change 16 1/2" to 14 1/4"
3.1-22	Change by deleting the present page and insert attached sheet.

	SLIP RINGS	BEARINGS	RESOLVERS	TORQUERS	ANGULAR MOTIONS
INNER GIMBAL AXIS	2 ASSEMBLIES APPROX. 35 RINGS EACH	DUPLEX PAIRS 1-FIXED 1-FLOATING	2-SINGLE SPEED 1-16 SPEED	2-5.5" AIR GAP D.C.	UNLIMIT'D.
MIDDLE GIMBAL AXIS	2 ASSEMBLIES APPROX. 35 RINGS EACH	DUPLEX PAIRS 1-FIXED 1-FLOATING	1-SINGLE SPEED 1-16 SPEED	2-5.5" AIR GAP D.C.	±80°
OUTER GIMBAL AXIS	2 ASSEMBLIES APPROX. 35 RINGS EACH	DUPLEX PAIRS 1-FIXED 1-FLOATING	2-SINGLE SPEED 1-16 SPEED	2-5.5" AIR GAP D.C.	UNLIMIT'D.

	GYRO UNITS	ACCEL. UNITS	MATERIALS	MISC.
STABLE MEMBER	3-25 IRIG (APOLLO)	3-16 PIP	BERYLLIUM	GIMBAL MOUNTED ELECTRONICS
MIDDLE GIMBAL	NONE	NONE	HYDRO-FORMED ROLL-BONDED ALUMINUM HEMISPHERES	NONE
OUTER GIMBAL	NONE	NONE	HYDRO-FORMED ROLL-BONDED ALUMINUM HEMISPHERES	NONE
HERMETIC CASE	NONE	NONE	HYDRO-FORMED ROLL-BONDED ALUMINUM HEMISPHERES	COOLING TUBES ELECTRICAL & COOLANT CONNECTORS

Fig. 3.1-5 Mechanical Design Specification Summary For IMU


APOLLO
COUPLING DISPLAY UNIT AND INTERFACES
GYRO
MOTOR
GIMBAL SERVO
EXCITATION
IX
15 X
IMU
CDU(Coupling display unit)
IX
15:1
IX
15 X
CODE
GEARS
DISPLAY
TACH
MOTOR
SERVO CONTROL
COMPUTER AGC
ATTITUDE COMMAND ERROR TO AUTOPILOT
MODES:
① IMU COARSE ALIGN
② SPACECRAFT ATTITUDE COMMAND
③ IMU GIMBAL ANGLE READOUT
ANGULAR VELOCITY COMMAND
ANGLE ERROR
MIT INSTRUMENTATION LABORATORY
FEB. 1962

Addendum to E-1097

COUPLING DISPLAY UNIT

by

D. Hoag

3.1.6 Introduction (Coupling Display Unit)

A. The Coupling Display Unit, CDU, has been introduced as an AGE component since E-1097, "Work Statement for Industrial Support" was written. Support for the CDU will be considered as coming from the same offerer bidding on section 3.1 of E-1097. It becomes then support in addition to the "System Assembly and Test and Inertial Measurement Unit Manufacture".

B. Checklist of Type of Effort to be Furnished

Analysis	no
Design	no
Breadboard	no
Manufacture	yes
Assembly	yes
Test	yes
Field Service	yes
Documentation	yes
Level-of-Effort Assignment	yes

3.1.7 Detail Requirements (Coupling Display Unit)

A. ANALYSIS (Exclusive of Major System)

not applicable

B. DESIGN

not applicable

C. BREADBOARD

not applicable

D. MANUFACTURE

The CDU is too recent an addition to the AGE to provide detailed planning for manufacture. The manufacture schedule should be consistent with supporting the following program.

Use	Number of CDUs
Mechanical integrity	1
AGE 4 functional	3
AGE 5 flight passenger	3
AGE 6 flight passenger	3
AGE 7 flight passenger	6
AGE 8 flight passenger	6
AGE 9 flight manned	8 (plus 6 more)*
AGE 10 MSC test	8 (plus 6)*
AGE 11 reliability	8
AGE 12 flight	8 (plus 6)*
AGE 13 syst.lab.	8 (plus 6)*
AGE 14 spacecraft	8 (plus 6)*
AGE 15 lunar test	8 (plus 6)*
AGE 16 flight	8 (plus 6)*
	86 (plus 42)*

*The additional 6 units per system are not firm at this time. The extra units might be used to display other quantities in the computer. Offerers should indicate the effect of effort with and without the indicated extra CDUs.

E. ASSEMBLY

1. To support manufacture as necessary.

F. TEST

1. To support manufacture as necessary and assume complete system operation.

G. FIELD SERVICE

1. Conform to general requirements of paragraph 2.3 of E-1097.

H. DOCUMENTATON

1. Conform to general requirements listed in section 2.2 of E-1097.

I. LEVEL-OF-EFFORT ASSIGNMENT

1. One man from Industrial Support will be required to follow the design through first assembly and Test at MIT of the CDU. This will require approximately one month in residence. This same man should be liaison to his home company and provide the engineering help necessary to get the CDU in production.

3.1.8 Technical Appendices (Coupling Display Unit)

A. Function of Coupling Display Unit

During the many phases of the Apollo mission, the AGE equipment will provide navigation and guidance functions through the major subsystems: AGC, SXT, IMU, etc. Signals of wide dynamic range--particularly angle measurements--must flow among these subsystems. The CDUs provide a common element to tie together some of these interfaces. In each case the computer, AGC, would be one of the elements which is tied together with a variable of other subsystems. In addition this variable is displayed as a pointer or counter.

B. Description of a CDU.

It must be recognized that the concept of the CDU is too young to be accurately defined in much detail.

Figure 3.1-6 shows schematically in the dashed centerbox the elements of the CDU. It consists essentially of an assembly of electromagnetic transducers, and gears with a display readout:

1. 1X synchro receiver on 1X shaft
2. 1X synchro receiver on 15X shaft
3. Incremental or parallel encoding
4. Dial pointer or counter display
5. Servo tachometer
6. Servo motor
7. Associated gear train
8. Servo control

The unit should be small and light and configured so that an array can be stacked on a display panel so that minimum panel area is taken and yet can be easily removed individually.

C. Use of the CDU with IMU.

Figure 3.1-6 shows one of the uses of the CDU in coupling IMU gimbal angle, autopilot attitude command, and the computer together. The figure shows just one of the angles involved. Two others complete this function associated with the other two IMU gimbal angles.

The encoder keeps a computer register up to date with the actual state of the angle variable in the CDU. Depending upon the program status within the computer, this angle is inspected periodically and the computer may issue a new rate command to change the angle.

The IMU has one and 15 speed synchro transmitters on each gimbal axis. (The latter is a 30 pole unit on the single speed shaft.) These signals are transmitted to the corresponding units on the CDU. The one and 15 speed error signals are used in three possible different ways, depending upon the operating mode. They are identified on the figure and below:

1. Coarse IMU Alignment

   The computer sets desired IMU gimbal angle into the CDU. The one speed synchro error signals is driven to null by the IMU gimbal servo which during this phase ignores the visual gyro error signal.

2. Spacecraft Attitude Command

   The computer sets command spacecraft attitude into the CDU, based upon the aligned orientation of the IMU and the PIPA acceleration measurement. (This mode only during the rocket thrust phases or reentry.) The one speed synchro error signal is resolved as necessary to spacecraft coordinates and is used by the autopilot to achieve the desired spacecraft attitude. This constitutes the guidance steering function.

3. IMU Gimbal Angle Readout

   Instead of the computer driving the CDU, the one and 15 speed synchro error signals are brought to null by the CDU servo control. The register in the computer and the CDU display both are then holding the IMU gimbal angle. This is envisioned as a slow speed requirement phase--primarily during precision alignment of the IMU.

D. Other Uses of the CDU.

In a fashion similar to C above, the CDUs can be used for optical drive control through the computer.

Also, position and velocity variables within the computer could be displayed with more CDUs. The desirability of this use of the CDU is not fully evaluated at this time.

Addendum to E-1097
COMPUTER

by Eldon Hall
February 1962

The following group of photographs reflect the changes in the computer since the publication of E-1097. Probably the most significant change is that concerned with equipment deliveries as indicated in the revised milestone charts. As can be seen the computer delivery requirements start at one a month in August of 1963 and increase to two a month by the end of December 1963.

The organization diagram of the computer is shown in the next photograph. The expanded memory capability is indicated on the upper right side. The input and output is contained in the modified erasable section. On the upper left side of the diagram the registers for the instruction code (SQ) and the memory address registers (S and S*). On the lower left side is the control circuitry and clock with its scaler which is used to count down to provide the AGE power reference frequency and elapsed time counter in the computer.

The changes in the AGC General Characteristics are reflected in the following two photographs indicating the change in the memory size under the logic section Item 12 and parts count under electrical characteristics Item 6.

The remainder of the slides illustrate the thinking as far as package configuration and subassembly construction is concerned. The proposed control panel and artists' concept are as in E-1105 which has already been distributed. Packaging is planned to be similar to that used successfully in the Polaris guidance computer. The assembly technique is illustrated in the remaining group of photographs starting with the assembly of piece parts in an injection moulding which acts as a mechanical jig and concluding with photograph of the end connector. The last one shows the back panel wiring which is accomplished using wire wrap interconnections made on an automatic wire wrapping machine.

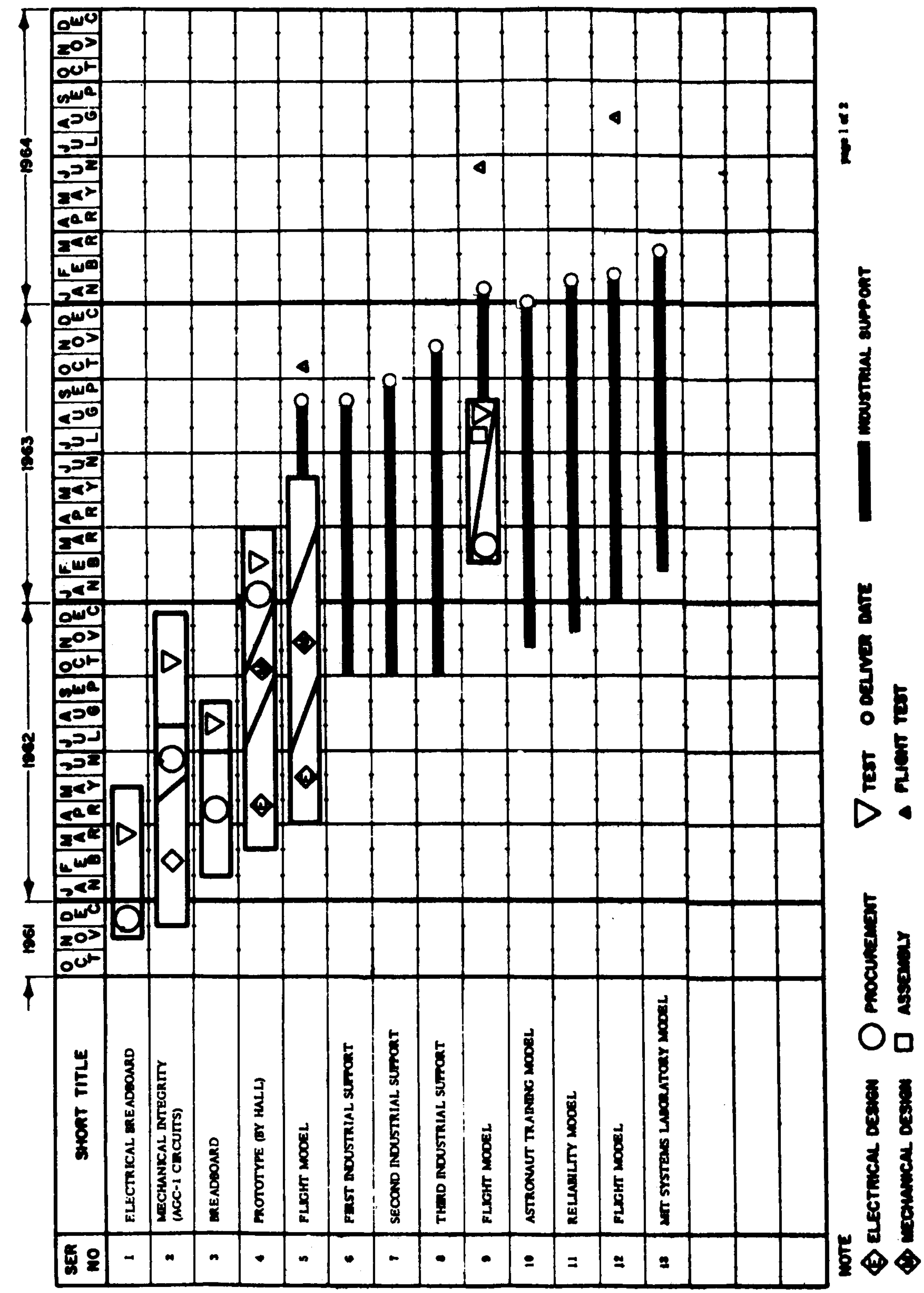


Chart 3.3-1. Milestone Chart for the AGC (Sheet 1 of 2).

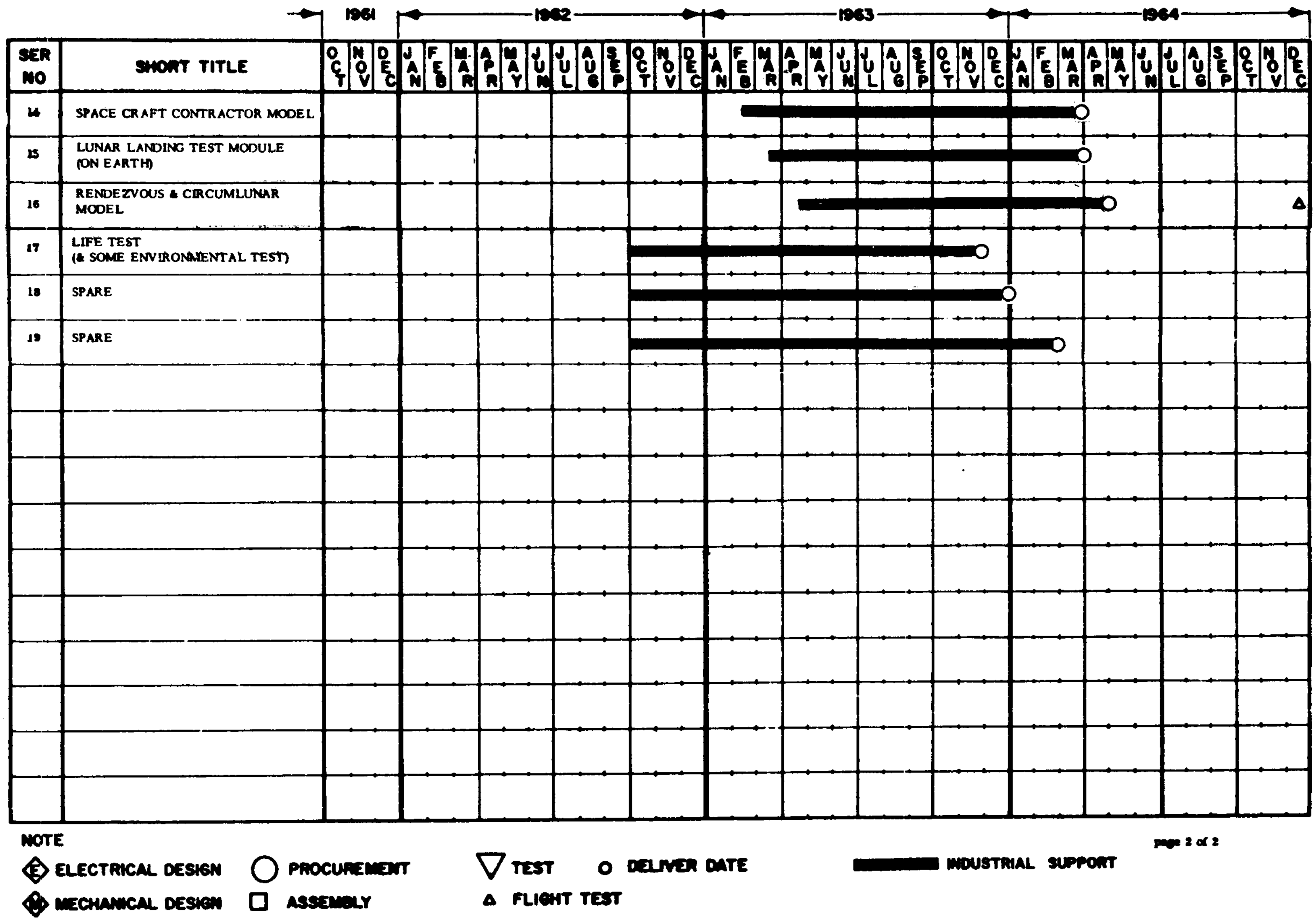
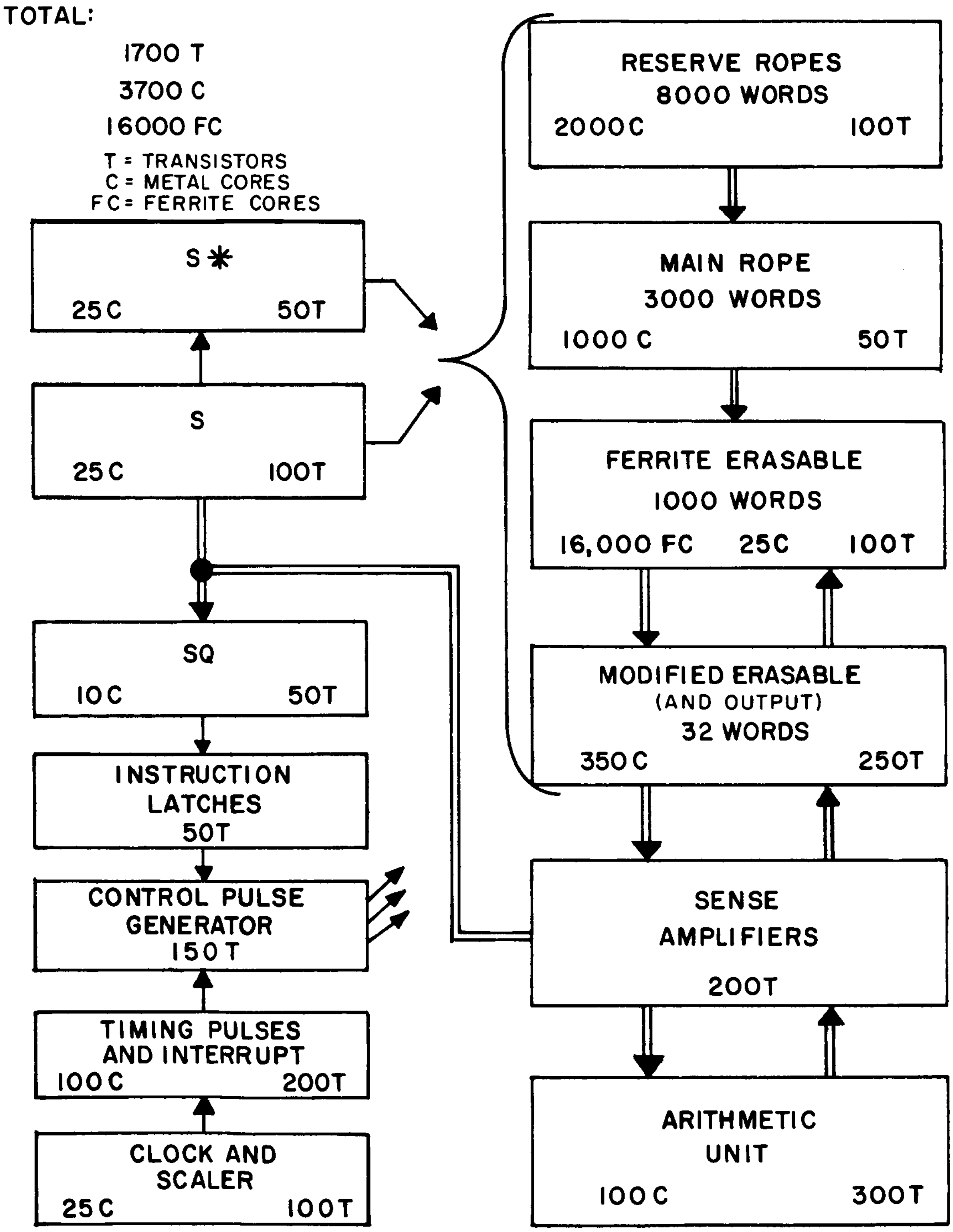


Chart 3.3-1. Milestone Chart for the AGC (Sheet 2 of 2).

ORGANIZATION DIAGRAM OF MOD 3C COMPUTER



PRELIMINARY
AGC GENERAL CHARACTERISTICS

I. Logical

1.	Word length and format	16 bits
	Data: Sign, 14 bits, parity. One's complement.	
	Instructions: Operation code (3 bits) Data address (12 bits), parity.	
2.	Parallel transfer of words	
3.	Bit rate	200 kc
4.	Normal Instruction Time	40 μsec
5.	Add Instruction Time	40 μsec
6.	Multiply Instruction Time	640 μsec
7.	Double Precision Add Time (subroutine)	400 μsec
8.	Double Precision Multiply Time (subroutine)	2 msec
9.	Variable Instruction rate	
10.	Counter Incrementing Time, per counter incremented (see item III).	20 μsec
11.	Interrupt Reaction Time (see item IV)	1 instruction time
12.	Storage	
	Erasable (volatile) storage	1024 words
	Fixed (wired-in) storage. In additive modules of 512 cores each (2048 words). Additional modules of 2048 words each may be added. Addressing is provided for up to 8 such additional units.	3072 words Min. 11264 words Max.
13.	Input Registers. Each has 15 input bits for 15 input lines. Used to sample the D. C. state of each line.	6 registers (90 lines)
14.	Input lines for pulse trains into addressable counters	20 lines
15.	Counter Registers (part of Erasable Storage)	20 registers
16.	Automatic Interruption Options (one input line per option).	8 options
17.	Output registers, 15 bits each. Each output bit can be either a D. C. level, or a pulse.	4 registers (60 lines)
18.	Outputs from counters - overflow, underflow pulses	20 lines

PRELIMINARY

AGC GENERAL CHARACTERISTICS

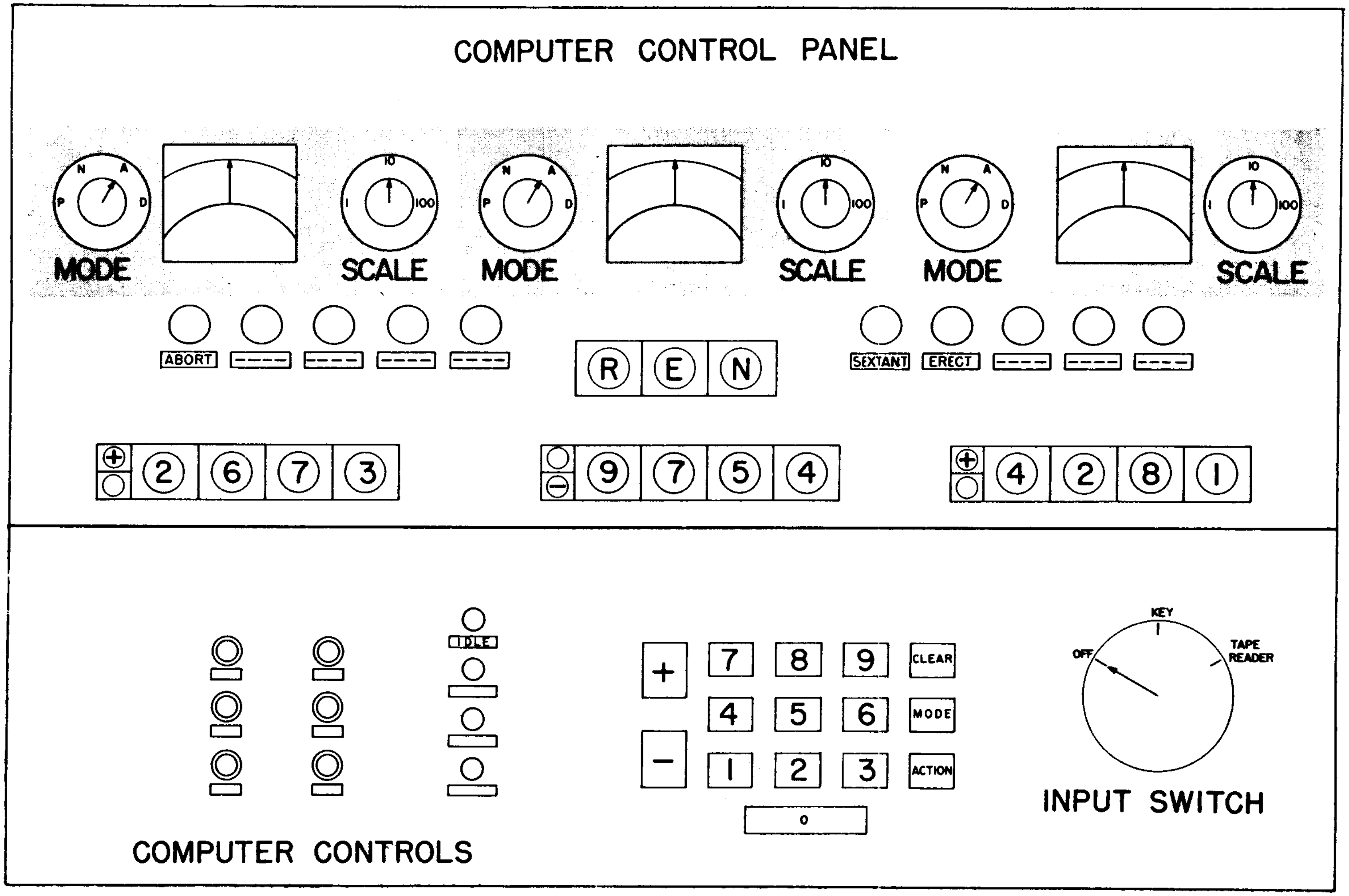
II. Electrical

1. Erasable Storage: Coincident Current Ferrite Matrix. The Ferrite Material is of a temperature insensitive kind.
2. Fixed Storage: 'Rope' type, one core per four words of 16 bits. (see reference 1).
3. Logic: PNP-NPN and diode combinations, resistor coupled. Also, core-transistor combinations.
4. Inputs: One core - diode per input line.
5. Outputs: One PNP-NPN latch, and one NPN gate per output line.
6. Approximate Component Count

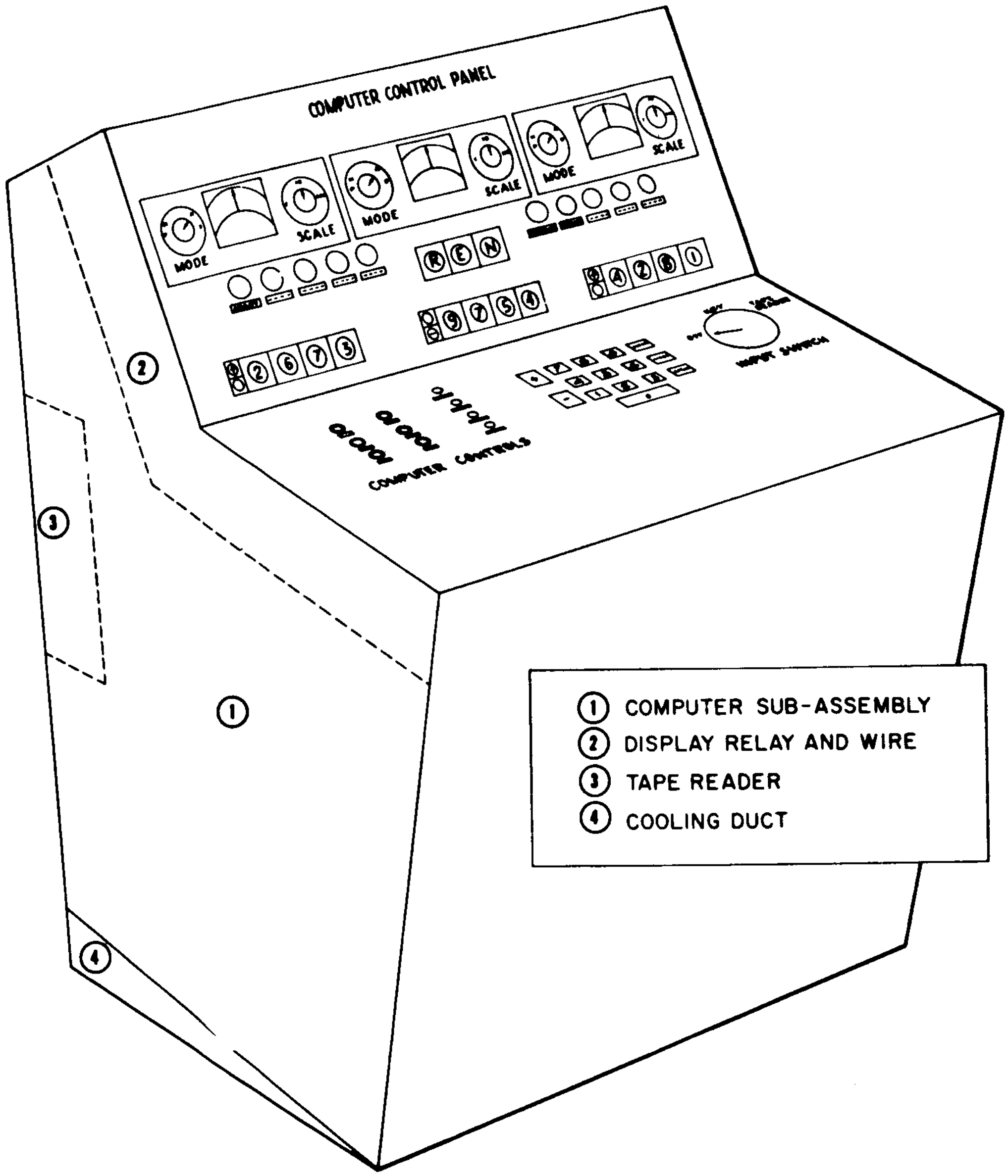
Cores:	Ferrite Matrix			16,000
	'Rope', two modules (tape wound)			
	512 cores per module			1024
	Special Registers and Logic (tape wound)			400
		Total	17400	
Transistors:	NPN			1200
	PNP			400
		Total	1600	
Diodes:				2000
Resistors:				4000
Capacitors (filters)				50
		Total	19000	

7. Power Consumption:

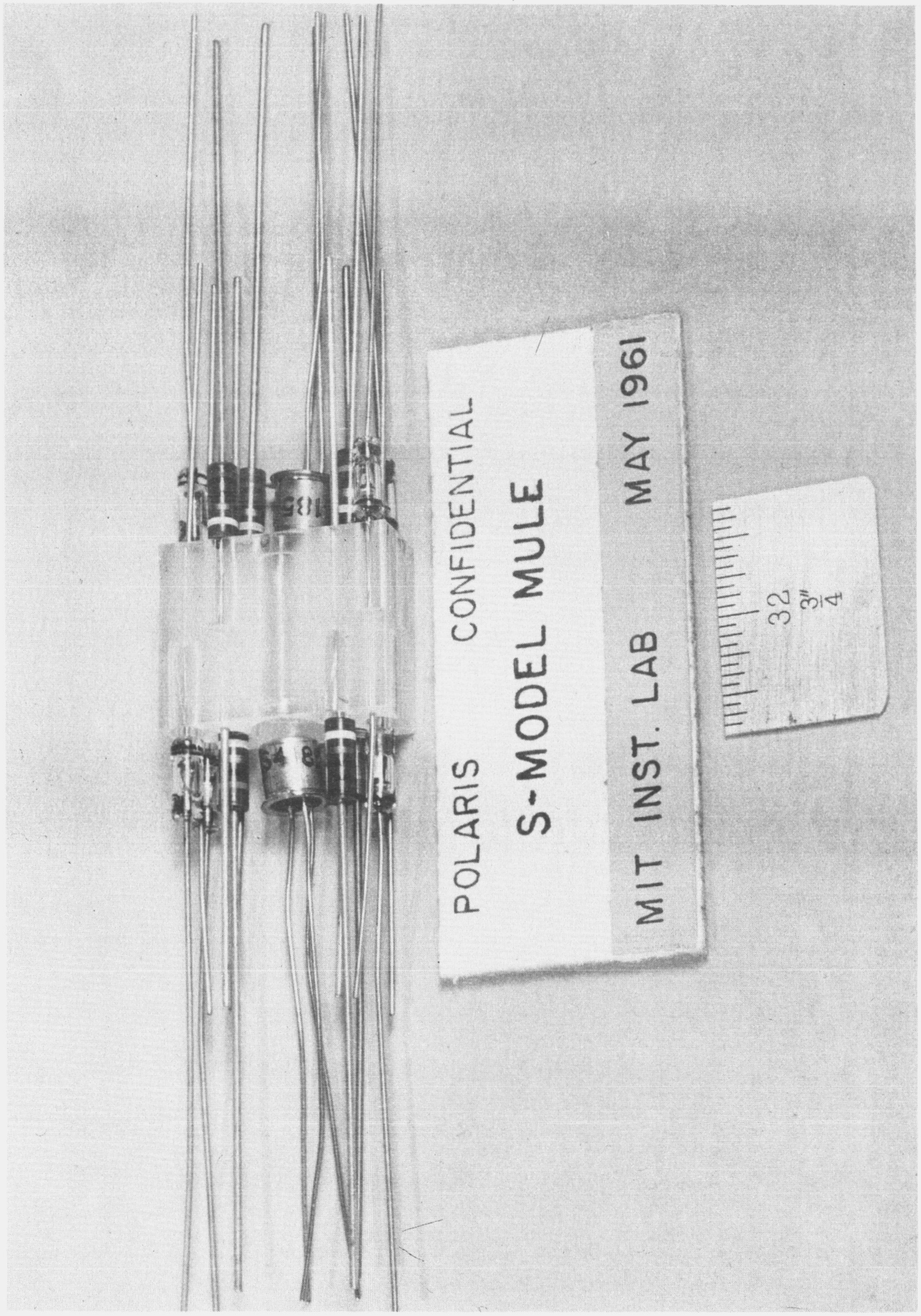
Maximum, at full speed, including output latches,	20 watts
Power approximately proportional to speed,	
Minimum power, at idling speeds (nominal)	2 watts

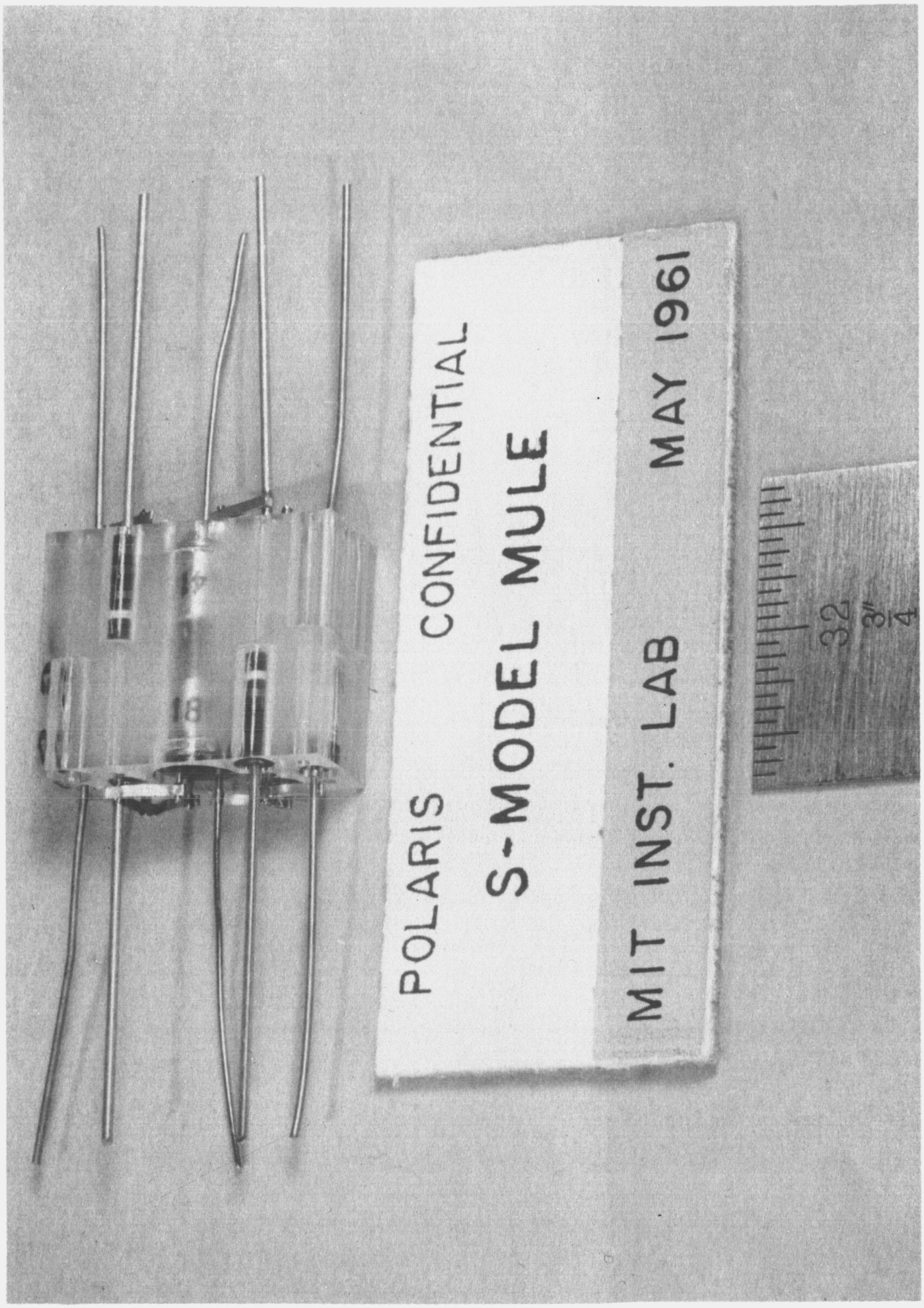


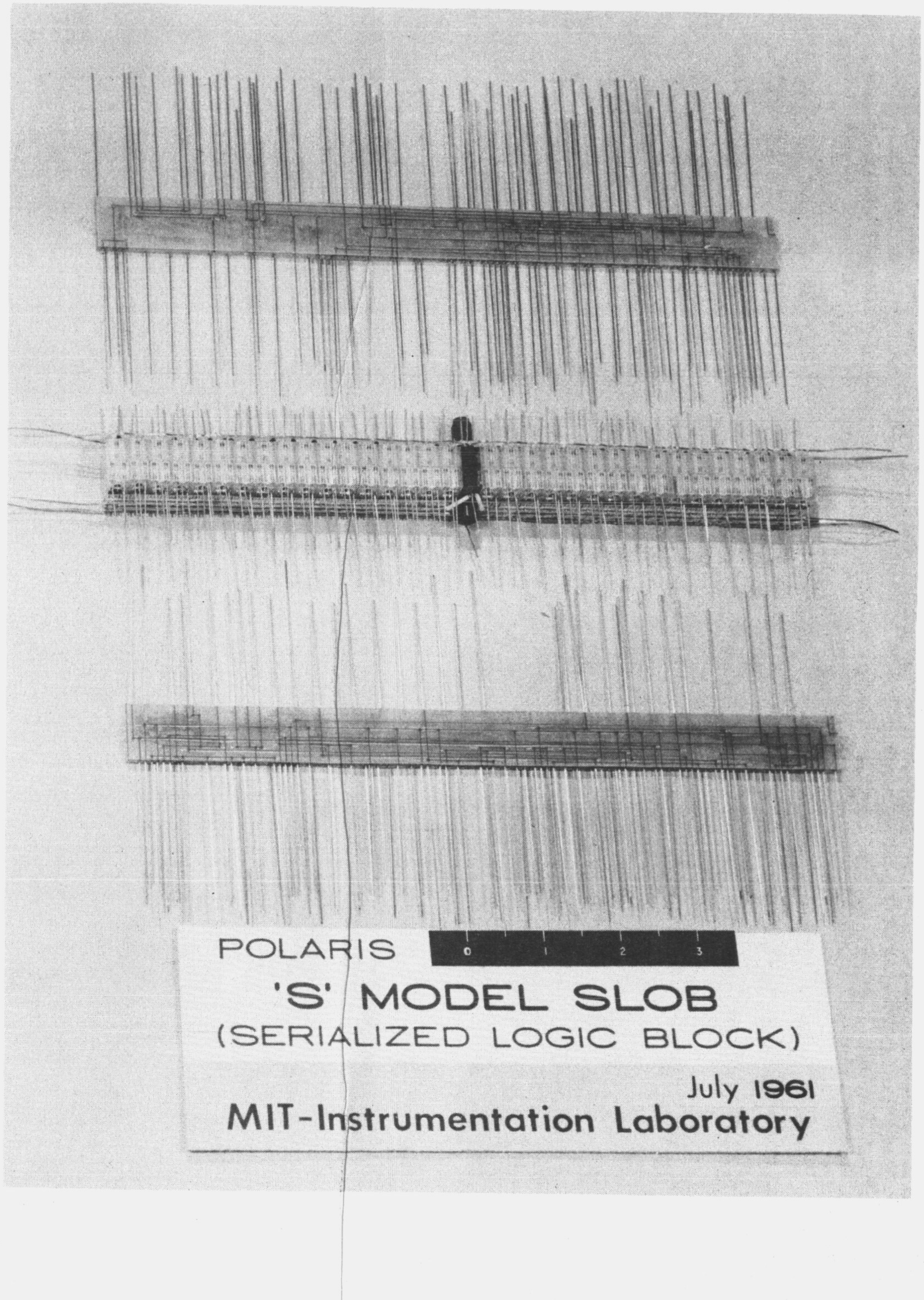
Computer control panel

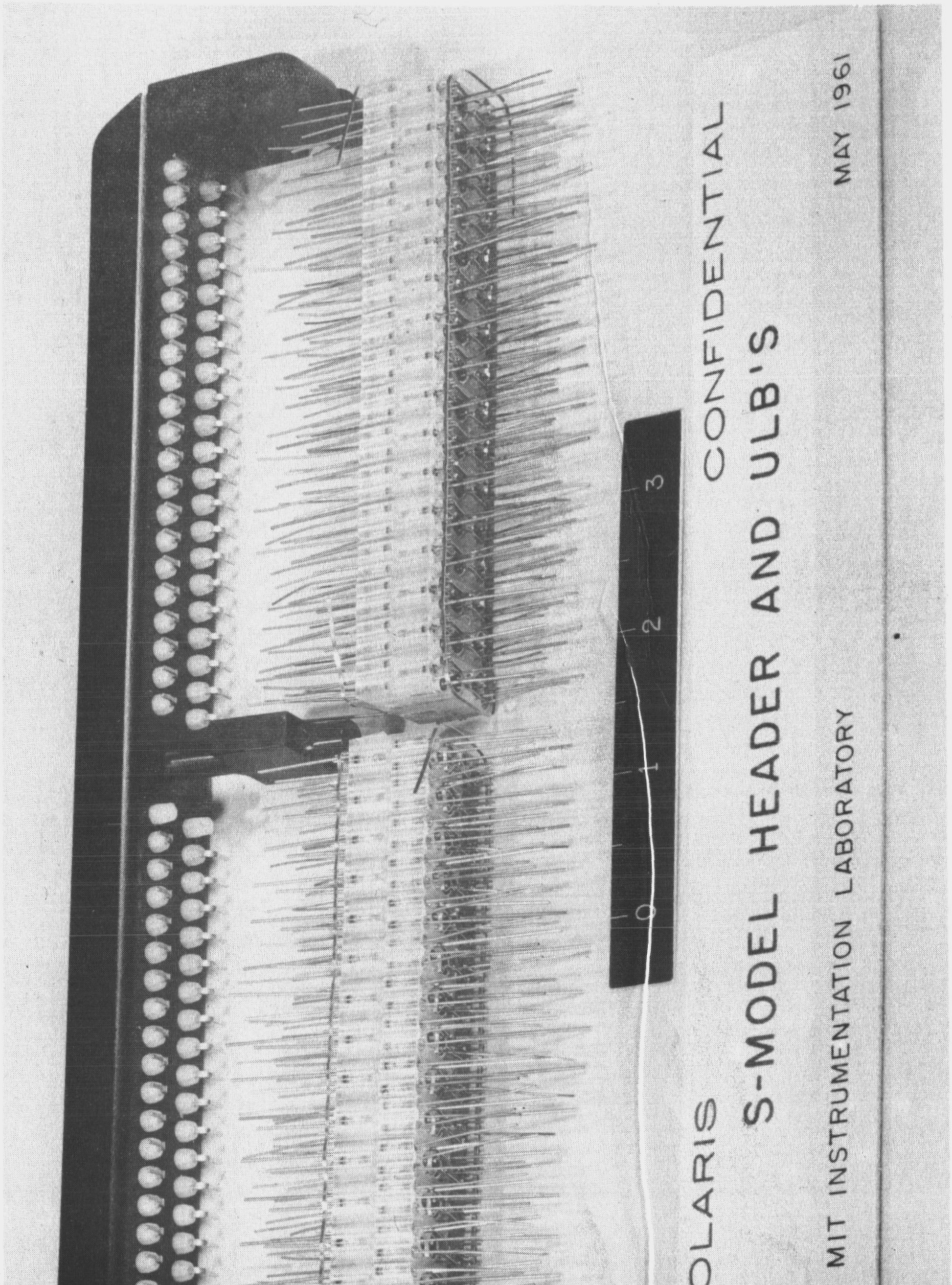


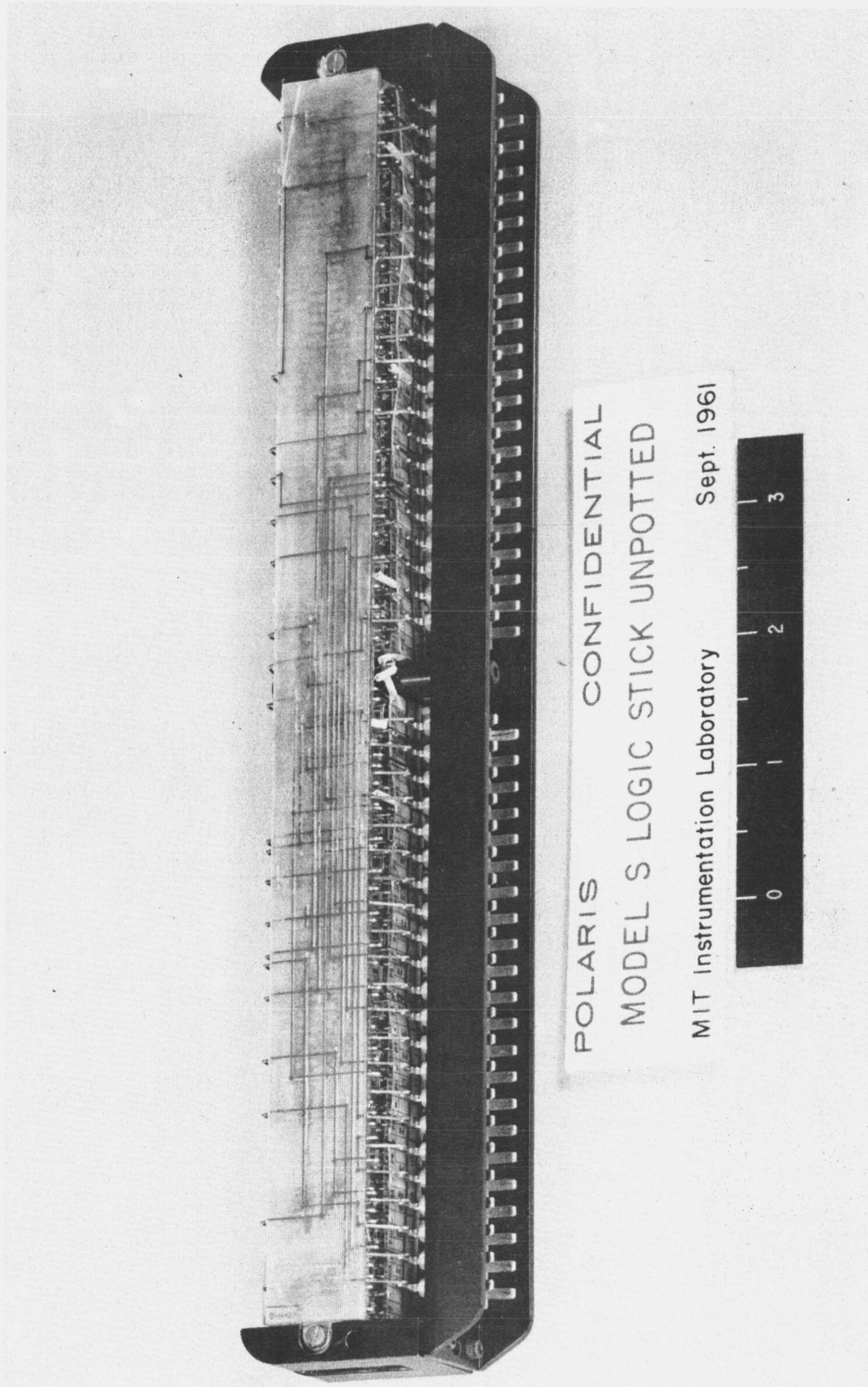
Artist's concept of computer display and control unit


POLARIS CONFIDENTIAL
S-MODEL MULE
MIT INST. LAB MAY 1961


POLARIS CONFIDENTIAL
S-MODEL MULE
MIT INST. LAB MAY 1961
32
3"
4


POLARIS
0 1 2 3
'S' MODEL SLOB
(SERIALIZED LOGIC BLOCK)
July 1961
MIT-Instrumentation Laboratory


POLARIS
CONFIDENTIAL
S-MODEL HEADER AND ULB'S
MIT INSTRUMENTATION LABORATORY
MAY 1961
0 1 2 3


POLARIS CONFIDENTIAL
MODEL S LOGIC STICK UNPOTTED
MIT Instrumentation Laboratory
Sept. 1961
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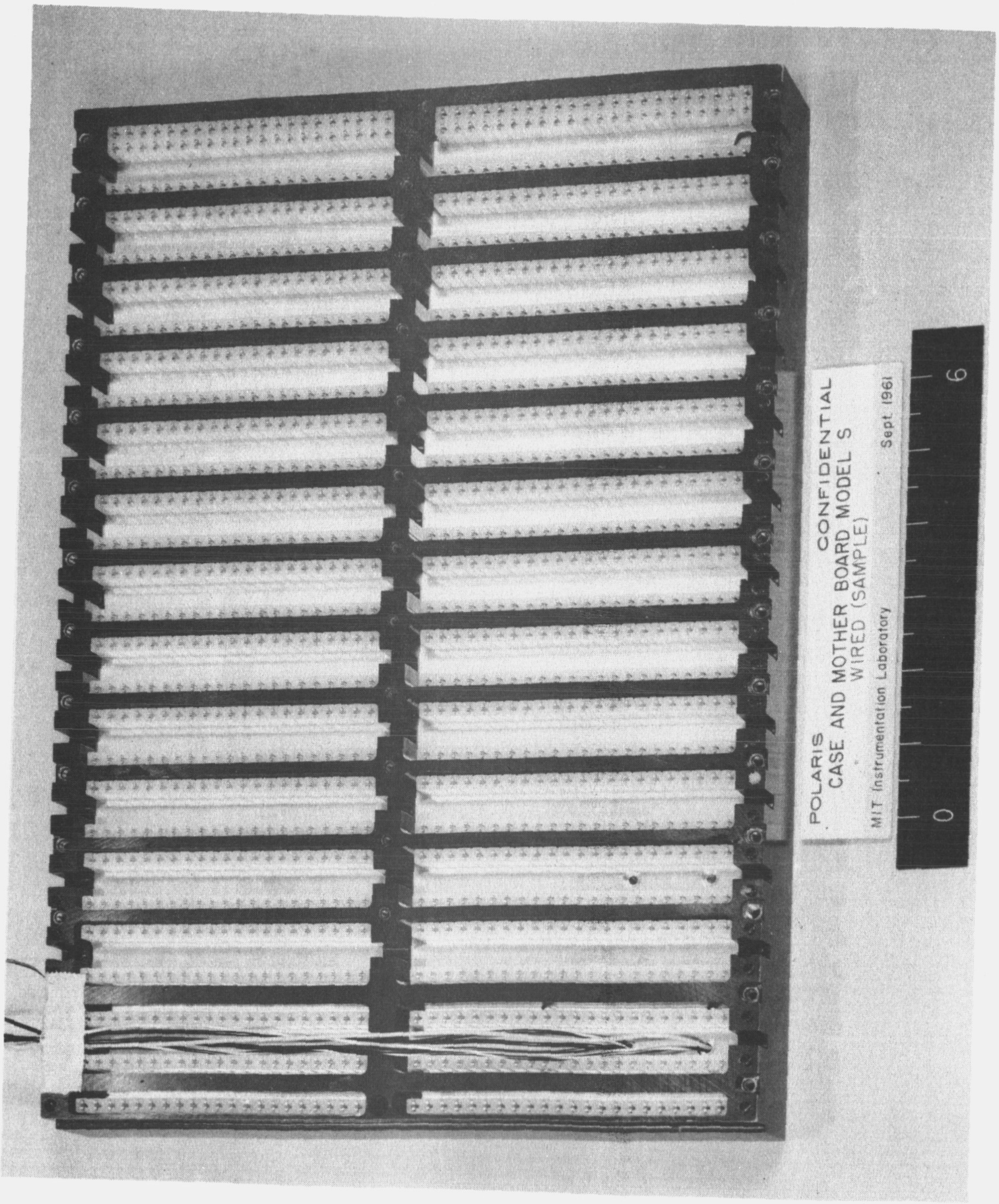
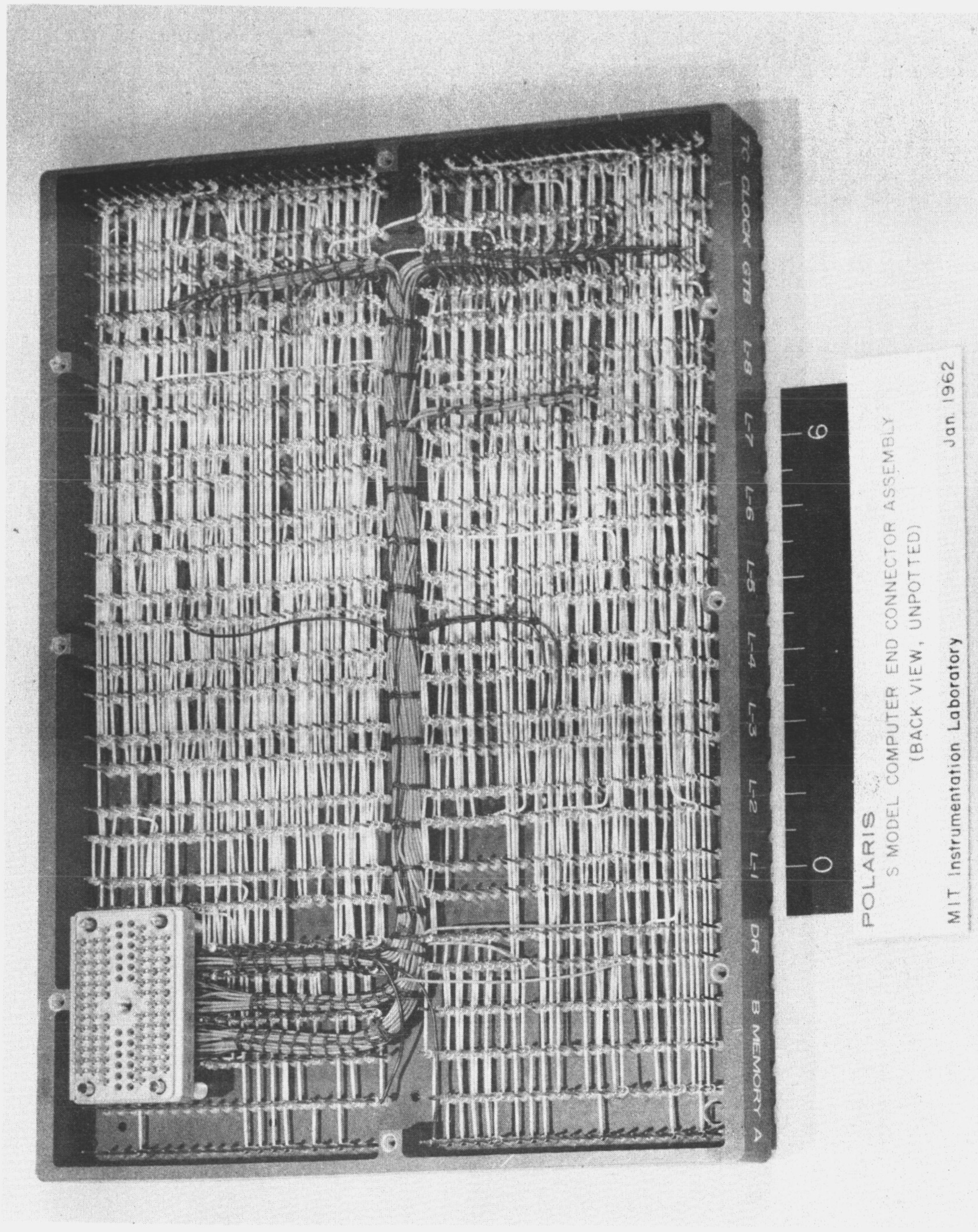
1
2
3


POLARIS CONFIDENTIAL
CASE AND MOTHER BOARD MODEL S
WIRED (SAMPLE)
MIT Instrumentation Laboratory Sept 1961
0
6


TC CLOCK GTB L-8 L-7 L-6 L-5 L-4 L-3 L-2 L-1 DR B MEMORY A
9
0
POLARIS
S MODEL COMPUTER END CONNECTOR ASSEMBLY
(BACK VIEW, UNPOTTED)
MIT Instrumentation Laboratory
Jan 1962

Addendum to E-1097

OPTICAL SUBSYSTEMS

ADDITIONS TO TECHNICAL APPENDICES

by John Hursh

A. SPACE SEXTANT

The design is moving toward what has been referred to as Configuration 3. The description of Configuration 3 given on page 3.4-17 of E-1097 should be modified in accordance with the following:

Sextant 3 is similar to Sextant 2 but incorporates only the two high magnification lines of sight. Only one side of each of the articulating mirrors is used. Studies in progress show that an advantage in terms of reduced maneuvering requirements with a minimum number of stars may be obtained by rearranging the optical paths such that 140° separation between the lines of sight is possible. This requires that the shaft drive axis (SDA) lie between the two lines of sight. The final disposition of the lines of sight has not been made pending the results of present studies. Displacement of the lines of sight from perpendicularity with TDA and PDA by a small angle, called the Dip Angle, probably will not be included in the design.

The Scanning Telescope, which performs the acquisition and low orbit landmark tracking functions in Configuration 3, is shown in Figures 1 and 2. It incorporates a variable magnification feature (1 to 4 power) with corresponding field of view (60^{o} to 15^{o}). Figure 1 schematically depicts the Scanning Telescope adjusted for a 30^{o} field of view. Figure 2 is a breadboard design layout of the instrument.

The Scanning Telescope drives will be similar to the sextant drives. In addition analog electromechanical instrumentation will link Sextant 3 to the Scanning Telescope in order that the latter may be used as a finder telescope for the sextant. In this acquisition mode, the sextant drives are operated as analog computing drives.

The electronics for the sextant and scanning telescope, as well as the link between the two instruments, will be packaged in the Power and Servo Assembly (PSA) or not depending on the form factor of space available in the spacecraft. In either case, for bidding purposes the electronics and link should be considered as part of the PSA.

B. MAP AND VISUAL DATA DISPLAY EQUIPMENT

Figure 3 shows schematically one possible arrangement for the Map and Visual Data Display Equipment featuring very low power consumption.

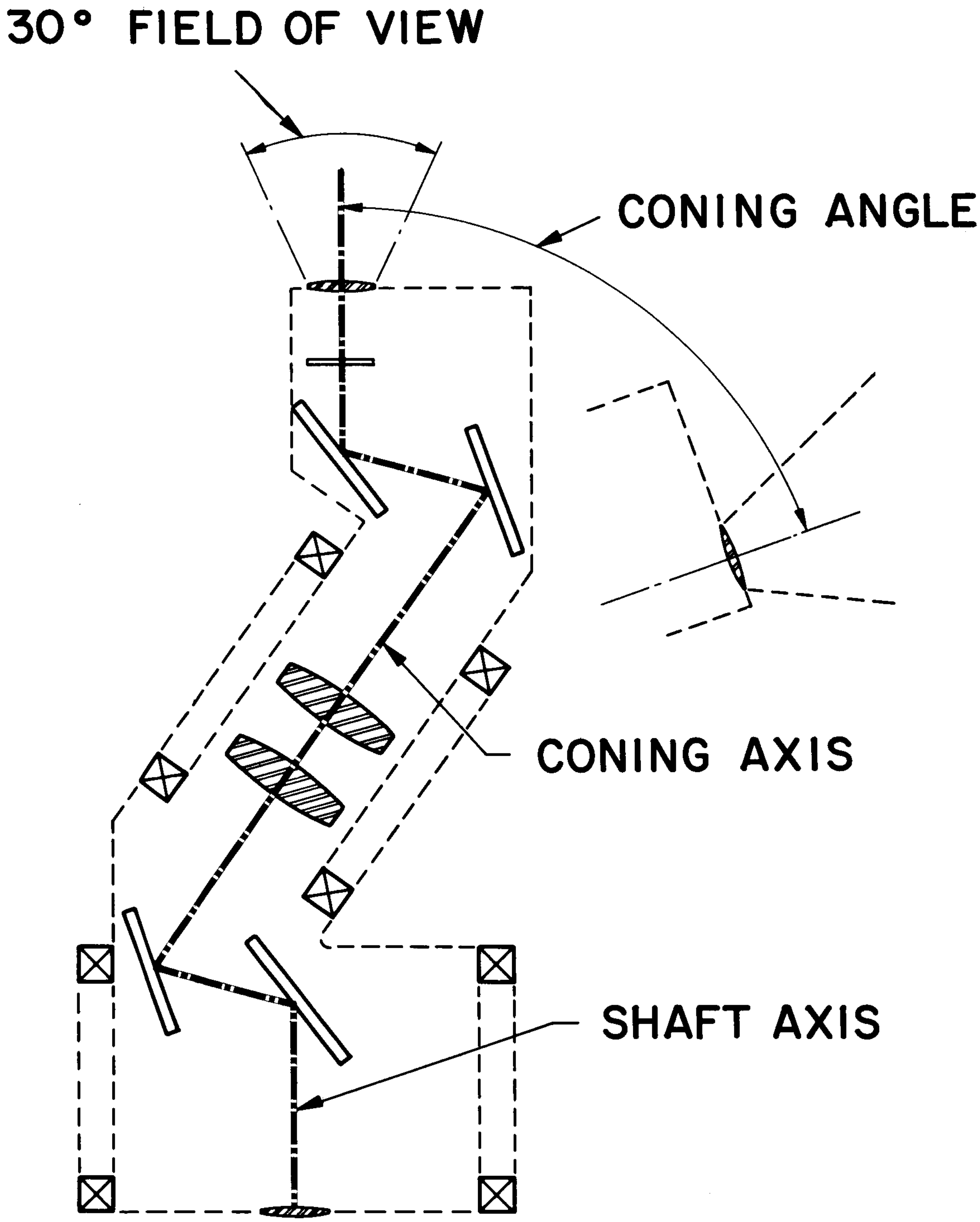


Fig. 1 Schematic Of Configuration No. 3 Scanning Telescope

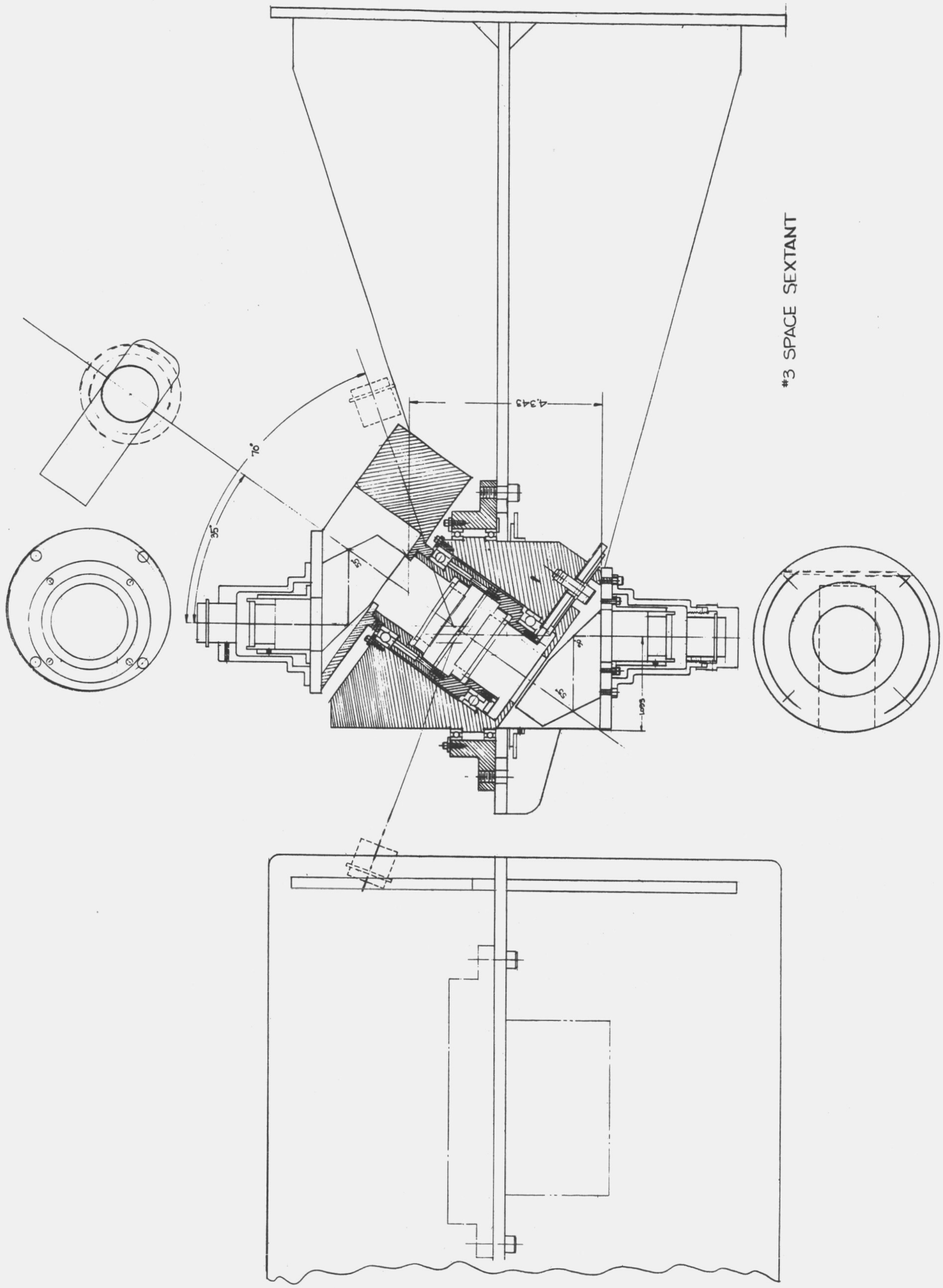


Fig. 2 Configuration No. 3 Scanning Telescope Breadboard Layout

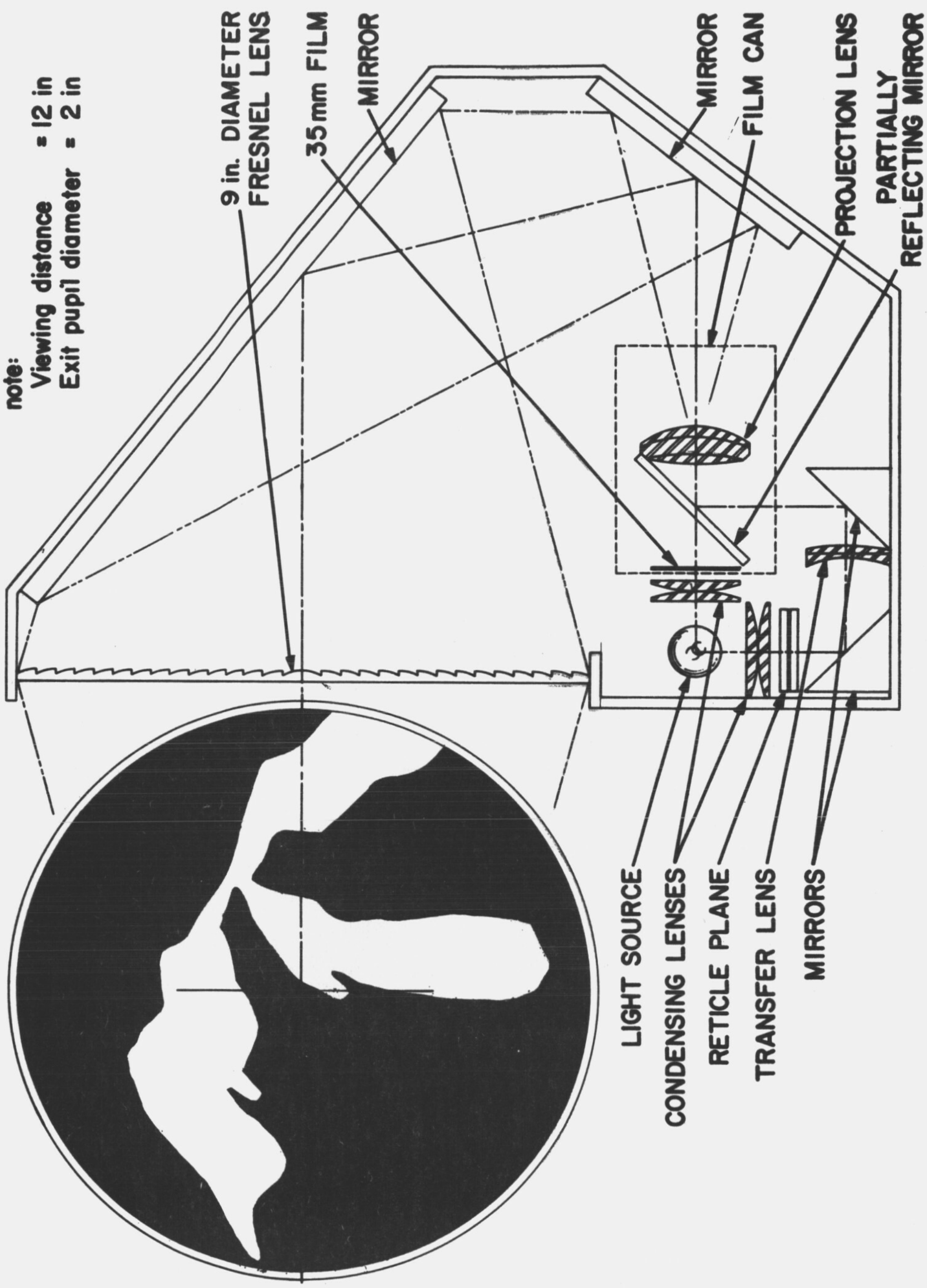

note:
Viewing distance = 12 in
Exit pupil diameter = 2 in
9 in. DIAMETER FRESNEL LENS
35 mm FILM
MIRROR
MIRROR
FILM CAN
PROJECTION LENS
PARTIALLY REFLECTING MIRROR
LIGHT SOURCE
CONDENSING LENSES
RETICLE PLANE
TRANSFER LENS
MIRRORS

Fig. 3 Viewer

Addendum to E-1097

IMU POWER AND SERVO ASSEMBLIES

WORK STATEMENT FOR INDUSTRIAL SUPPORT

by D. Hoag

Page

3.5-1 Under Indroduction A, number 5 delete "nine required". Add a number 8, "Drive Electronics for Sextant and Scanning Telescopes."

Under B Bracket the first 2 "yeses" rather than the first 3. Add this comment "is expected that some breadboards may be constructed at contractor's facility".

Under B Change the "no" opposite "Field Service" to "yes" and add the comment that "the offerer will be expected to provide field services for his equipment at any of the guidance and navigation operations".

3.5-2 Under G, FIELD SERVICE delete the comment and replace with "the offerer will be expected to provide field services for his equipment at any of the guidance and navigation operations."

3.5-8 Under 2.c. delete 100

Under 2.e. delete "Figure 3.5-6" and add the comment that "gimbal angle encoding has changed since writing of the original Work Statement". The new encoding scheme is described in Addendum to the Work Statement 3.1.6 and 3.1.8 . In addition to the digital encoding resolver anolog data buffering may be required in the Interface with the Autopilot.

Section 1

INTRODUCTION

This section provides a statement of the problem, brief statements of the types of support to be requested, and an index of references.

1.1 GENERAL REQUIREMENTS FOR INDUSTRIAL SUPPORT

This section describes in brief the requirements for industrial support to the Associate Contractor for the Project APOLLO Spacecraft Navigation and Guidance System. As described in the procurement plan for the navigation and guidance system, approved by NASA Headquarters, August 9, 1961, the Massachusetts Institute of Technology, Instrumentation Laboratory was chosen as the Associate Contractor. It was stipulated in the procurement plan that the efforts of the Instrumentation Laboratory would be augmented in the areas of manufacturing and engineering in order to obtain, on a timely basis, the necessary numbers of systems required to support the program. This additional effort or support is to be obtained by Industrial Support Contracts which will be technically administered by the MIT Instrumentation Laboratory. The procurement plan discusses the method of procurement and the selection of the contractors who will furnish the industrial support. Present estimates indicate a requirement for systems to be supplied by the industrial support contractors for the accomplishment of the APOLLO program through the earth orbital phases or Phase A. A detailed account of the Guidance and Navigation problem for this phase is given in Sections 1.3 and 1.4.

1.1.1 The System Contractor

This offeror will be responsible for assembling and testing complete sets of Guidance and Navigation equipment and providing the checked-out systems to NASA. The offeror will manufacture, assemble, and test the Inertial Measurement Unit, using inertial components furnished by another source. This offeror will manufacture, assemble, and test those displays and controls not assigned to other subsystems manufacturers and will assemble all displays and controls into the display and control console. The offeror will also manufacture the necessary system cabling and produce the system manuals requested of him.

1.1.2 Inertial Components Contractor

This offeror will manufacture the three single-degree-of-freedom gyros and three accelerometers per system which comprise the inertial components. Procurement of these components is not covered under this Work Statement.

1.1.3 Computer Contractor

This offeror will manufacture the onboard general purpose digital computer.

1.1.4 Power and Servo Assembly Contractor

This offeror will manufacture the guidance system electronics assembly.

1.1.5 Optical Subsystems Contractor

This offeror will manufacture the Space Sextant, the Map and Visual Data Display equipment and the Sunfinder Assembly.

1.1.6 Ground Support Equipment Contractor

This offeror will manufacture the guidance system pre-flight checkout equipment.

The detailed work statements for each technical area will include design engineering and operational support to varying degrees.

1.2 TYPES OF SUPPORT EFFORT TO BE REQUESTED

The Industrial Support contracts will provide manufacturing and engineering support in several technical areas. It is not expected that the desired demonstrated competence in every specific individual technical area can be found in any one company. In the Work Statement the specialty areas will be discussed as though each were directed to a separate offeror. In actual fact there are a number of possible technical area combinations for which a demonstrated competence can be found, and it is desirable to hold the number of contracts to as few as possible in order not to complicate the technical and contractual relationships. In order to perform in each of the equipment areas, the offeror may be required to supply some or all of the following services.

1.2.1 Analysis

Determination of design parameters from the mathematical models, the performance requirements, and the environments and disturbances. This may result in a report of the distribution of allowable tolerances among the parameters involved.

1.2.2 Design

Selection of engineering models (assemblies, parts, and components) that may, in combination, meet the requirements of the previous analysis. These normally include electronic, electrical, or mechanical schematics, with supporting engineering analyses of expected performance.

1.2.3 Breadboard

Construction of assemblies incorporating the most significant design features from the previous stage of effort. This usually stresses functional performance requirements, and is in the nature of a feasibility effort. Design requirements of life, interchangeability, and safety are not usually involved initially, but follow immediately thereafter. Coordination across electrical or electronic interfaces may be involved. This effort almost always includes the functional testing of the assembled breadboard and preparation of a report of results in terms of the functions and analysis work.

1.2.4 Manufacture

Construction of parts and components from approved drawings in accordance with documented procedures. Receiving inspection and in-process testing is a significant part of this phase of work, and described under the requirements of Reliability and Quality control.

1.2.5 Assembly

Assembly of subassemblies, assemblies, subsystems, or systems according to approved procedures. In-process testing, quality control procedures, and performance analysis are parts of this phase of work.

1.2.6 Test

This is different from the in-process testing (although related to it) by involving whole assemblies, subsystems, or systems. This effort usually involves more extensive testing facilities than normally found in manufacturing and assembling facilities.

1.2.7 Field Service

In this effort, the Industrial Support will furnish one or more qualified engineers to perform routine and unscheduled maintenance on equipments, assemblies, or components in field activities such as Houston, Launch Pad, and AMR. In some cases, this service may be in support of MIT field representative actions or of major system or subsystem field service requirements.

1.2.8 Documentation

Required, in varying amounts, to support MIT in all phases of work from design through use. The formal documentation required under this category does not include the informal reporting technical documents that normally result from the previously described efforts.

1.2.9 Level-of-Effort Assignment

This is a requirement for technical personnel services to be furnished to MIT in connection with the engineering design effort at MIT. It is similar to the field service type of support in that it is a general requirement and personnel are assigned to an area of program work. It is different from the field service effort in location.

1.2.10 Technical Proposal Requirements

Technical Proposals, in response to the Work Statements, should be limited to the number of standard pages indicated in Table 1.2-1 below for each technical work area. A standard page is equivalent, in reading and pictorial matter, to the following.

a. trim size : 8-1/2" x 11"

b. image size: 7" x 9"

c. PICA type (12-point, PSM or standard)

d. callouts and explanatory notes on illustrations shall be at least .07" high

e. foldouts are counted as multiple pages, equal to the integral number of 8-1/2" x 11" equivalents

f. copy may be reproduced on one side only, or on both sides of a sheet

Table 1.2-1. Number of Standard Pages Per Proposal

Technical Work Area	Proposal Pages
1. System	
a. System Support	40
b. IMU Subsystem Support	20
2. GSE	40
3. AGC	20
4. Optical Subsystems	
a. SXT	40 (a, b, c combined)
b. M and VD	
c. SFA	
5. PSA	20

1.3 GENERAL ACCOUNT OF GUIDANCE AND NAVIGATION PROBLEMS

1.3.1 Objective

The ultimate objective of Project APOLLO is the landing of men on the moon, limited observation and exploration of the moon by the crew in the landing area, and safe return to earth. Progress toward the ultimate objective will be taken in a number of steps and phases with corresponding missions. Three major phases are recognized:

Phase A will be limited to manned, low altitude earth orbital flights of up to two week duration and unmanned re-entry flights from super-orbital velocities. Objectives and missions will include:

Qualification of systems for the lunar landing mission
Qualification of rendezvous techniques
Qualification of re-entry equipment
Study of physiological and psychological reactions
Development of ground operational techniques
Conduct experimental investigations

Phase B will consist of circumlunar, lunar orbital, and parabolic re-entry test flights.

Phase C will consist of manned lunar landing and return missions. This Work Statement describes only the Industrial Support efforts through completion of Phase A. Industrial Support contractors can be expected to participate in the planning by the Laboratory for Phases B and C.

1.3.2 Requirements of Navigation and Guidance System

A. NAVIGATION AND GUIDANCE SYSTEM CHARACTERISTICS

The Navigation and Guidance System is located in the Command Module. It provides steering and thrust control signals for the Stabilization and Control System, Reaction Control Systems, and appropriate propulsion system and their respective gimbal systems. The functional requirements of the Navigation and Guidance System are presented below.

B. SPACE VEHICLE GUIDANCE

The Navigation and Guidance System shall be capable of controlling the injection of the spacecraft and of providing a monitoring capability of injection guidance to the crew. This shall be accomplished for both direct ascent and for injection from a parking orbit.

C. MIDCOURSE GUIDANCE

The Navigation and Guidance System shall provide navigation data and compute and control velocity corrections in cislunar space to achieve terminal conditions at the moon and earth which allow a safe lunar landing and earth re-entry, respectively. Enroute to the moon a mission abort capability shall be provided.

D. RE-ENTRY GUIDANCE

The Navigation and Guidance System shall be capable of guiding the Command Module during re-entry through the earth's atmosphere to a preselected landing site on the earth. This capability shall be provided for re-entry from lunar missions and earth orbits, from preinjection aborts, and from postinjection aborts.

E. LUNAR ORBIT AND LUNAR LANDING

The Navigation and Guidance System shall provide a capability for establishing lunar orbits and making lunar landings from orbit. An abort capability shall be provided from the lunar maneuver.

F. LUNAR TAKEOFF

The Navigation and Guidance System shall provide the capability of launch from the surface of the moon into an earth return trajectory by both direct ascent and by a parking orbit.

G. RENDEZVOUS

The Navigation and Guidance System shall be capable of accomplishing a rendezvous in earth orbit between the Spacecraft and the Space Laboratory or other cooperative Space Vehicles.

H. SYSTEM DESCRIPTION

The system shall achieve simplicity and reliability by effectively employing the crew whenever equipment design advantage and crew capability are compatible. The system shall achieve operational versatility but, when versatility results in disproportionate increase in equipment complexity, onboard versatility shall be sacrificed and reliance shall be placed upon ground assistance. The system shall be reliable but reliability shall be obtained by the use of system or subsystem redundancy only if it cannot be obtained by ground cooperation and/or onboard emergency systems.

1.3.3 Development Groundrules

The APOLLO guidance and navigation equipment, AGE, will be developed from the start with the ultimate APOLLO objective in mind to the extent that technological knowledge will allow. However, experience in the early phases will undoubtedly lead to required design changes in the later phases. Design changes of this nature will be accomplished by advancing to a new "block" design wherein major subsystems within a block will be identical -- or as near so as can be practically accomplished.

1.3.4 System and Subsystem Identification

Name	Symbol
Systems	
APOLLO Guidance and Navigation	AGE
Ground Support Equipment	GSE
Subsystems	
Inertial Measurement Unit	IMU
Sextant	SXT
Guidance Computer	AGC
Display and Control	D&C
Final Approach Equipment	FAE
Sun Finder Assembly	SFA
Power and Servo Assembly	PSA
Communications and Telemetry	CMM

1.3.5 General Method of Accomplishment

Primary navigation and guidance measurement by AGE will be based upon inertial and optical data. These data will be processed by the computer, AGC, to provide display and control functions.

Inertial measurements from the IMU will be primary during accelerated portions of the trajectory. Spacecraft attitude information will be available directly to the spacecraft autopilot as an attitude reference and also will be encoded for use by the AGC. IMU velocity increment measurements will provide the primary computer input for guidance control. No optics will be included as part of the IMU. Alignment of the stable member of the IMU will be accomplished prior to its use by the encoded gimbal angle signals in conjunction with the spacecraft attitude measured by the sextant.

During unaccelerated portions of the trajectory, the sextant, SXT, is the primary guidance and navigation measurement source. Position and velocity data are obtained from readings of angle between the stars and nearby landmarks or the edge of the moon or earth. Spacecraft attitude for IMU alignment purposes, as mentioned above, will be obtained from the sextant by tracking two stars, one after the other.

More detailed descriptions of these and other navigation and guidance equipment will be given under section 1.4 of this work statement.

One important area not covered in this work statement concerns the equipment for close-in measurements during rendezvous and final lunar letdown. The nature of this final approach equipment, FAE, will depend upon studies presently underway and characteristics of the spacecraft not yet defined. Visual and radar equipment will probably both be involved. Industrial support to MIT in this area will be separately negotiated after the basic characteristics of the FAE are determined.

1.3.6 Overall Schedule

The schedule for the AGE development and test is given in Chart 1.3-1. This chart covers only the first part of the Phase A program since sufficient detail is not firm enough for later flights at this time. The chart gives an overall schedule of major events which involve one or more of the major subsystems. Early flights, for instance, will not carry complete sextants since such flights are unmanned.

A more detailed description of flight objectives is given in Figures 1.3-1, 1.3-2, 1.3-3 and 1.3-4. Also, more detail on schedule of industrial support events appears under individual requirements later in this work statement.

1.3.7 Environment and Other Factors

The operating environment of AGE will be that of the interior of the spacecraft command module except for the sunfinder assembly and possibly the sextant which will experience the hard vacuum of outer space. During normal operation the

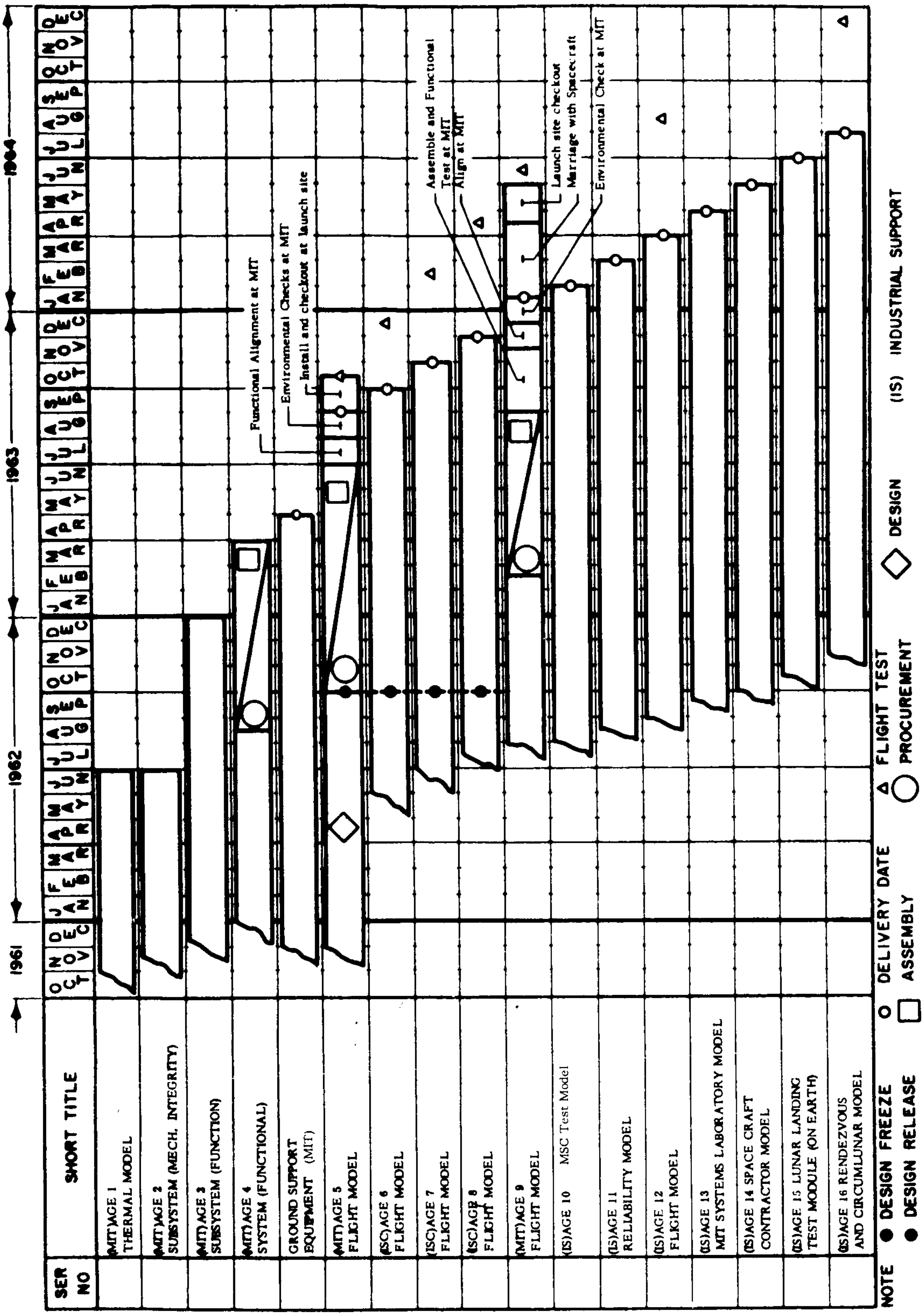


Chart 1.3-1. Milestone Chart for AGE.

APOLLO GUIDANCE AND NAVIGATION FLIGHT TEST OBJECTIVE, SA7

Flight SA7 Supercircular CM reentry - unmanned Primary Objectives Subsystem operability in spacecraft environment (no control function)

	Notes	SXT	IMU	AGC	D&C	FAE	GSE	SPA	CMM
Notes		1		4	2	X		EX	
Earth prelaunch & check		X	F	F	X	///	F	///	///
Monitor boost & injection		///	F	F	X	///	///	///	///
IMU in flight alignment	3	X	X	EX	X	///	///	///	///
Rendezvous	X	X	X	X	X	X	///	///	X
Free fall attitude control		X	///	EX	X	///	///	X	///
Autopilot attitude signals		///	EX	///	///	///	///	///	///
Midcourse navigation		X	///	EX	X	///	///	///	EX
Midcourse corrections		///	X	EX	X	///	///	///	///
Lunar letdown & landing	X	X	X	X	X	X	///	///	///
Lunar prelaunch	X	X	X	X	X	///	///	///	///
Lunar takeoff	X	///	X	X	X	///	///	///	///
Earth reentry	5	///	EX	EX	X	///	///	///	///
Abort. & emergency	ND	ND	ND	ND	X	///	///	///	ND

KEY: /// - no requirements for lunar landing mission
F - functions normally
X - no existent on flight or not performed
EX - experiment or exercise
ND - not defined sufficiently

NOTES:
1. Experimental SXT for environment tests
2. Only that part of D&C to turn on subsystems and preflight checks
3. IMU running throughout flight
4. AGC perform self sufficient accuracy checks exercising functions listed using link to CMM for all problems.
5. IMU & AGC velocity increment interface with open loop reentry exercise.

Figure 1.3-1. APOLLO Guidance and Navigation Flight Test Objective, SA7.

APOLLO GUIDANCE AND NAVIGATION FLIGHT TEST OBJECTIVE, SA8

Flight SA 8 Primary Objectives Controlled Reentry

	Notes	SXT	IMU	AGC	D&C	FAE	GSE	STA	CMM
Notes		1		4	2	X		EX	
Earth prelaunch & check		X	F	F	X	///	F	///	///
Monitor boost & injection		///	F	F	X	///	///	///	///
IMU in flight alignment	3	X	X	X	X	///	///	///	///
Rendezvous	X	X	X	X	X	X	///	///	X
Free fall attitude control		X	///	EX	X	///	///	X	///
Autopilot attitude signals	5	///	5	///	///	///	///	///	///
Midcourse navigation		X	///	EX	X	///	///	///	
Midcourse corrections		///	X	EX	X	///	///	///	///
Lunar letdown & landing	X	X	X	X	X	X	///	///	///
Lunar prelaunch	X	X	X	X	X	///	///	///	///
Lunar takeoff	X	///	X	X	X	///	///	///	///
Earth reentry	6	///	F	F	X	///	///	///	///
Abort. & emergency	ND	ND	ND	ND	X	///	///	///	ND

KEY: /// - no requirements for lunar landing mission
F - functions normally
X - no existent on flight or not performed
EX - experiment or exercise
ND - not defined sufficiently

NOTES:
1. Experimental SXT for environment tests
2. Only that part of D&C to turn on subsystems and preflight checks
3. IMU running throughout flight
4. AGC perform self sufficient accuracy checks exercising functions listed using link with CMM for all problems
5., 6. Reentry only. Full operational reentry control. IMU attitude interface with autopilot; velocity increment interface between IMU and AGC; steering command interface between AGC and autopilot

Figure 1.3-2. APOLLO Guidance and Navigation Flight Test Objective, SA8.

APOLLO GUIDANCE AND NAVIGATION FLIGHT TEST OBJECTIVE, SA9, SA10

Flight SA 9) SA 10) 7 Day Unmanned Orbital Primary Objectives Subsystem interface Operability in spacecraft environment

	Notes	SXT	IMU	AGC	D&C	FAE	GSE	STA	CMM
Notes		1			2	X		EX	
Earth prelaunch & check		EX	F	F	X	///	F	///	///
Monitor boost & injection		///	F	F	X	///	///	///	///
IMU in flight alignment	3	EX	EX	EX	X	///	///	///	///
Rendezvous	X	X	X	X	X	X	///	///	X
Free fall attitude control	4	EX	///	F	X	///	///	F	///
Autopilot attitude signals		///	EX	///	///	///	///	///	///
Midcourse navigation			///		X	///	///	///	EX
Midcourse corrections	X	///	EX	EX	X	///	///	///	///
Lunar letdown & landing	X	X	X	X	X	X	///	///	///
Lunar prelaunch	X	X	X	X	X	///	///	///	///
Lunar takeoff	X	///	X	X	X	///	///	///	///
Earth reentry	5	///	5	5	X	///	///	///	///
Abort. & emergency	ND	ND	ND	ND	X	///	///	///	ND

KEY: /// - no requirements for lunar landing mission
F - functions normally
X - no existent on flight or not performed
EX - experiment or exercise
ND - not defined sufficiently

NOTES:
1. SXT with all automatic interfaces with AGC operating
2. Only that part of D&C to turn on subsystems and preflight check
3. IMU turned off during most of flight. Aligned to spacecraft attitude prior to reentry. See Note 5.
4. Attitude control to sun if spacecraft flight objective requires or permits
5. Plan assumes Mercury horizon trackers puts command module vertical prior to reentry initiation of vertical retrothrust. This may permit controlled reentry using G&N by IMU alignment to spacecraft in two degrees of freedom and orbital plane determination for the third.

Figure 1.3-3. APOLLO Guidance and Navigation Flight Test Objective, SA9 and SA10.

APOLLO GUIDANCE AND NAVIGATION FLIGHT TEST OBJECTIVE, SA111

Flight SA 111 7 Day Manned Orbital Primary Objectives Major checkout of most functions and subsystems

	Notes	SXT	IMU	AGC	D&C	FAE	GSE	SPA	CMM
Notes		1			2	3			
Earth prelaunch & check	1	F	F	F	F	///	F	///	///
Monitor boost & injection		///	F	F	F	///	///	///	///
IMU in flight alignment		F	F	F	F	///	///	///	///
Rendezvous		EX	EX	EX	EX	EX	///	///	
Free fall attitude control		F	///	F	F	///	///	F	///
Autopilot attitude signals		///	F	///	///	///	///	///	///
Midcourse navigation	1	F	///	F	F	///	///	///	F
Midcourse corrections	5	///	F	F	F	///	///	///	///
Lunar letdown & landing		EX	EX	EX	EX	EX	///	///	///
Lunar prelaunch	X	X	X	X	X	///	///	///	///
Lunar takeoff	X	///	X	X	X	///	///	///	///
Earth reentry		///	F	F	F	///	///	///	///
Abort. & emergency	6	EX	EX	EX	EX	///	///	///	EX

KEY: /// - no requirements for lunar landing mission
F - functions normally
X - no existent on flight or not performed
EX - experiment or exercise
ND - not defined sufficiently

NOTES:
1. Complete SXT with sufficient accuracy for reentry setup. Major check of SXT optics for most functions.
2. Complete D&C for pilot use.
3. 4. } FAE aboard for integration, operability, and interface checks.
5. Midcourse corrections applied or rehearsed, depending upon motor status.
6. Complete Abort. & Emergency capability with inflight rehearsal of equipment.

Figure 1.3-4. APOLLO Guidance and Navigation Flight Test Objective, SA111.

command module will be pressurized to 3.5 psia minimum, and temperature will be consistent with human "shirtsleeve" comfort. Operation of all equipment for a limited period must be possible during emergency decompression of the command module. The duration of the limited operation must be consistent with the requirements of individual subsystem performance during emergency conditions, and may vary from subsystem to subsystem. A water-glycol mixture at 50° F is available for cooling power dissipating equipment as necessary.

Section 1.4 summarizes technical data as background information for this work statement.

1.3.8 Systems and Subsystems Correlation

Chart 1.3-2 correlates the assignments of AGE system numbers with subsystem designations.

It will be noted that the assignment of subsystems has been made by serial number to AGE systems through AGE 16. Although the MIT effort is expected to comprise an additional sequence from serial AGE 17 through AGE 29, the complete planning for that sequence is not yet available.

The offerors are requested to estimate the requirements for providing Industrial Support through the following initial milestones:

AGE #6
GSE #1 & #2 (delivered to MIT)
IMU #6
AGC #6
PSA #6
SXT #10
D & C #10

In addition, offerors will be requested to furnish estimates for the remainder of Industrial Support through AGE 16.

Chart 1.3-2. Systems and Subsystems Correlation Chart.

System AGE#	Ground Support GSE#	IMU #	AGC #	PSA #	SXT #	D&C #	Notes
1	-						) MIT developments;
2	-						) non-flight;
3	-						) abridged systems.
4	-						)
5	To Meet Scheduled Deliveries	5	5	5	6	-	MIT
6		6	6	6	7*	-	First Indus. Support
7		7	7	7	8*	-	IS
8		8	8	8	9*	-	IS
9		9	9	9	11	4	MIT
10		10	10	10^+	10	10	IS
11		11	11	11^+	15	7	IS
12		12	12	12	14	9	IS
13		13	13^+	13^+	13	6	IS
14		14	14^+	14	12	5	IS
15		15	15^+	15	17	11	IS
16		16	16	16	16	8	IS
17 through 29		17-29	17-29	17-29	18-30	12-24	IS (Note 1)
							TOTAL
2	0	2	2	2	2	1	MIT
23	10	23	26	26	(20, 3*)	20	Industrial Support

* Abridged versions of #10

\+ Spare unit, required in addition to serialized units shown in table.

Note 1: One or more will be MIT, introducing design improvements; remainder will be industrial support.

1.4 DETAILED ACCOUNT OF GUIDANCE AND NAVIGATION PROBLEMS

This section presents a technical description of the operational and flight plans and systems approach for the APOLLO Spacecraft. The description constitutes a technical framework within which the initial design and operational modes of the Spacecraft are to be further developed.

The APOLLO Spacecraft, operational, and flight plans described herein are defined by the requirements of the ultimate mission; lunar landing and return. The resulting basic systems are then considered to be off-loaded for intermediate missions and qualification flights.

Several techniques for effecting earth and/or lunar-launch can be considered depending on the capabilities of various launch vehicles and operational know-how. The Spacecraft System described is designed for direct earth-launch, lunar-landing, and lunar-launch; but is intended to be suitable for use with any of a variety of earth-launch systems and to be sufficiently flexible to adapt to special lunar-landing and lunar-launch techniques.

1.4.1 Spacecraft

The Spacecraft shall be composed of separable modules such that (1) "effective weight" principles can be realized through proper jettisoning of expendable units, and (2) module configurations peculiar to specific missions can be modified without substantial effect upon modules common to general missions. The general features of the Spacecraft are described in the following paragraphs.

A. COMMAND MODULE

The Spacecraft shall include a recoverable Command Module which shall remain essentially unchanged for all APOLLO missions.

1. Command Center

The Command Module shall be the space vehicle command center where there are exercised all crew-initiated control functions. As the command center, this module shall contain the communication, navigation, guidance, control, computing, display equipment, etc., requiring crew mode selection. In addition, other equipment required during nominal and/or emergency landing phases shall be included in the Command Module. As the command center, this mode shall include features which allow effective crew participation such as windows with a broad field of view for general observation, landing, rendezvous; equipment arrangements allowing access for maintenance and simple, manually-operated functions in lieu of complex automation.

2. Housing

The Command Module shall house the crew during all mission phases and shall contain those experimental measurements obtained during flight to satisfy mission objectives.

3. Re-entry and Landing

The Command Module shall be the re-entry and landing vehicle for both nominal and emergency mission phases. The use of equipment such as ejection seats or personal parachutes is not precluded for certain cases.

4. Ingress and Egress

Ingress and egress hatches to the Command Module shall not be obstructed at any stage of space vehicle countdown, flight, and recovery. Means of egress to free space without decompression of the entire Command Module shall be provided.

B. SERVICE MODULE

The Spacecraft shall include an unmanned Service Module for all missions except super-orbital-velocity re-entry tests. This unmanned module shall contain stores and systems which do not require crew maintenance or direct operation, and which are not required by the Command Module after separation from the Service Module. The Service Module shall house all propulsion systems except that required for lunar landing and attitude control during earth-entry. Consideration shall be given to inflight maintenance of equipment in the Service Module by crewmen in extra-spacecraft suits. The Service Module may be modified in accordance with particular mission requirements, but the principal structural load paths, geometric arrangement, and configuration shall remain unchanged for various missions and project phases. It is expected that the Service Module would normally be jettisoned prior to re-entry into the earth's atmosphere. The Service Module shall not be recoverable.

C. LUNAR LANDING MODULE

The Spacecraft shall include a Lunar Landing Module for the lunar landing missions.

D. SPACECRAFT ADAPTER

The Spacecraft Adapters shall structurally and functionally adapt the Service Module or Lunar Landing Module to the launch vehicle for the non-lunar landing and lunar landing configurations, respectively.

E. SPACE LABORATORY MODULE

The Spacecraft for certain earth-orbital flights may include a non-recoverable Space Laboratory Module in which various special tests may be performed. The Space Laboratory Module shall provide the structural and interface functions of an adapter.

1. Support Systems

The Space Laboratory Module shall have on board sufficient equipment to satisfy its own requirements, manned and unmanned, without demand upon other Spacecraft equipment.

2. Ingress and Egress

The Space Laboratory shall have a hatch suitable for ingress and egress to free space and for connection with the Spacecraft.

1.4.2 Operational Concept

A. MISSION PROFILES

The Spacecraft shall be designed with the capability of performing a variety of missions including earth orbital, circumlunar, lunar orbit, and lunar landing.

B. MANNING OF FLIGHTS

The Spacecraft shall be designed for manned operation with no system requirement for unmanned missions. Where unmanned development flights are required, specially equipped Spacecraft will be used.

C. ONBOARD COMMAND

The primary command and decision-making responsibility shall be on board the Spacecraft. The Spacecraft shall have the capability to perform the mission independent of ground-based information. This shall not preclude the use of ground-based information for crew use to increase reliability, accuracy, and performance.

D. FLIGHT CREW

The flight crew shall consist of three men.

1. Crew Participation

The flight crew shall control or direct the control of the Spacecraft throughout all flight modes. They shall participate in navigation, control, monitoring, computing, repair, maintenance, and scientific observation when advantageous. Status of systems shall be displayed for crew assessment and operational mode selection including Spacecraft and launch-vehicle-systems status, staging sequences, and touchdown control. The Spacecraft shall be designed so that any single crewman will be able to perform all tasks essential to return the Command Module.

2. Crew Mobility

The onboard command guideline requires a considerable degree of crew mobility. Toward this end, a "shirtsleeve" environment shall be provided during all noncritical flight phases and any special personal equipment shall not hamper or interfere with the crew's utility or exercise of Spacecraft control.

3. Automatic Systems

Automatic systems shall be employed to obtain precision, speed of response, or to relieve the crew of tedious tasks; but crew monitoring of these systems with provisions for crew override or mode selection is required.

4. Abort Initiation

Initiation of abort and subsequent control of abort modes shall be primarily the responsibility of the crew. There shall be no abort responsibility assigned to ground command or automatic systems except during prelaunch and launch periods if there is insufficient time for crew action. In such event, abort may be initiated without crew cognizance but subsequent flight control shall be the responsibility of the crew. Automatic and manual abort sequence modes shall be available for crew selection.

E. FLIGHT-TIME CAPABILITY

1. Flight Period

The Spacecraft systems shall be capable of performing at their nominal design performance level for a mission of 14 days without resupply. For lunar-landing missions, 7 of the 14 days may be on the lunar surface.

2. Postflight Period

The Command Module shall provide a habitable environment for the crew for a minimum three days after landing on water or land.

F. LANDING

The Spacecraft shall have the capability of initiating a re-entry and landing maneuver at any time during either lunar or orbital missions. Prior to each flight, a primary ground landing site and suitable backup landing site will be selected for normal mission landing. Additional criteria apply as follows:

1. Lunar Missions

Alternate landing sites shall be designated prior to flight, such that a landing is possible at these sites when inadvertent re-entry situations are encountered.

2. Earth-Orbital Mission

The Spacecraft shall be capable of landing at the primary landing site (or at the backup site) from at least three orbits per day. In addition, alternate sites which may involve either land or water landing will be designated such that at least one alternate site can be reached for a landing from each orbit.

G. GROUND MONITORING AND COMMUNICATION

1. Earth-Orbital Missions

a. Monitoring

(1) Powered flight. There shall be continuous monitoring of onboard system and crew status during powered flight.

(2) Orbital flight. Flight progress, onboard system operation, and crew status shall be monitored by the ground operational Support System, with a minimum of contact with the Spacecraft per hour.

b. Ground communications. The network shall operate on a centralized control basis.

2. Lunar Missions

Communications and ground tracking shall be provided throughout the lunar mission for the period between leaving the earth parking orbit and the initiation of earth re-entry except where limited by the Spacecraft being blanketed by the moon.

H. APOLLO CONTROL CENTER

All phases of APOLLO missions shall be directed from an APOLLO Control Center.

I. COMMUNICATIONS CENTER

All mission communications during APOLLO missions shall be controlled by the APOLLO Control Center.

J. TRACKING AND GROUND INSTRUMENTATION NETWORK

All existing networks and associated facilities shall be considered for support of an APOLLO mission where practical.

1.4.3 <u>Reliability and Crew Safety</u>

Mission reliability and crew safety goals, assuming a launch vehicle reliability of 0.90 and including the effect of ground complex reliability, but excluding consideration of radiation and meteoroid impact, shall be as follows:

A. MISSION RELIABILITY

The inherent design probability of accomplishing the mission objectives shall be 0.90.

1. Crew Safety

   a. Nominal. The inherent design probability that none of the crewmen shall have been subjected to conditions greater than the nominal limits specified in Design Criteria, shall be 0.90.

   b. Emergency. The inherent design probability that none of the crewmen shall have been subjected to conditions greater than the emergency limits specified in Design Criteria shall be 0.999.

1.4.4 Performance Criteria

Rational margins shall be apportioned to systems and components such that the greatest overall design efficiency is achieved within the Launch Vehicle capabilities and implementation criteria constraints. The following specific systems margins are derived from rational consideration of past and anticipated operational experience. They are to be used as design criteria until experience justifies modification.

A. REPRESSURIZATION

The repressurization system shall be designed for two complete cabin repressurizations, a minimum of 18 airlock operations, and a continuous leak rate as high as 0.2 lbs. per hour. Provisions shall be made for recharging portable life support systems (and "back packs").

B. VACUUM OPERATION OF CABIN EQUIPMENT

Equipment which is normally operated in the pressurized cabin environment shall be designed to function for a minimum of four days in vacuum without failure.

C. THERMAL RESISTANCE

The Spacecraft modules shall be designed such that additional or lesser requirements in thermal resistance may be accommodated or taken advantage of without major overall design changes.

D. METEOROID PROTECTION

The Spacecraft modules shall be designed such that additional or lesser requirements in meteoroid protection may be accommodated or taken advantage of without major overall design changes.

E. RADIATION SHIELDING

The Spacecraft modules shall be designed such that additional or lesser requirements in radiation protection may be accommodated or taken advantage of without major overall design changes.

F. ISOLATION OF MODIFICATIONS

The Spacecraft modules shall be designed such that general modifications to one module do not propagate through the other modules.

G. 20g RE-ENTRY

Primary structures are to be designed for a limit load of 20g during re-entry.

H. ACOUSTIC NOISE

The design shall accommodate sound pressure levels of 166 db in the frequency range 4 to 9600 cps emanating from the Launch Escape Propulsion System during both launch and abort modes.

1.4.5 Crew Requirements

Design and operational procedures shall be in accordance with the crew requirements data presented here. The data presented are for various limits as defined below.

A. NOMINAL LIMITS

Nominal limits are defined as the limits within which the crew's environment shall be maintained during normal operations.

1. Nonstressed Limits

Nonstressed limits are defined as the environmental limits to which the crew may be subjected for extended periods of time such as orbit, lunar transit, and periods subsequent to normal landings.

2. Emergency Limits

Emergency limits are defined as the environmental limits beyond which there is a high probability of permanent injury, death, or incapacity to such extent that the crew could not perform well enough to survive.

B. CREW ENVIRONMENT

1. Cabin Pressure

The cabin pressure nominal limits shall be 3.5 psia minimum and 15.0 psia maximum. The emergency limit shall be 3.5 psia minimum.

2. Cabin Temperature

The cabin temperature nonstressed limits shall be 70° F minimum and 80° F maximum. The stressed and emergency limits are presented in Figures 1.4-1 and 1.4-2 respectiveiy.

3. Cabin Relative Humidity

The cabin relative humidity nonstressed limits shall be 40 percent minimum and 70 percent maximum. The stressed and emergency limits are presented in Figures 1.4-1 and 1.4-2 respectively.

4. Radiation

The nominal limit shall be the average yearly exposure tabulated in Figure 1.4-3 and described in Figure 1.4-4. The emergency dose limits shall be the maximum permissible, single acute emergency dose as tabulated in Figure 1.4-3 and as referred to in Figure 1.4-4. In the absence of sufficient information to assign dose value due to secondary radiation, a value of 50 percent of the primary dose will be used.

5. Vibration

The vibration stressed, nonstressed, and emergency limits are presented in Figure 1.4-5.

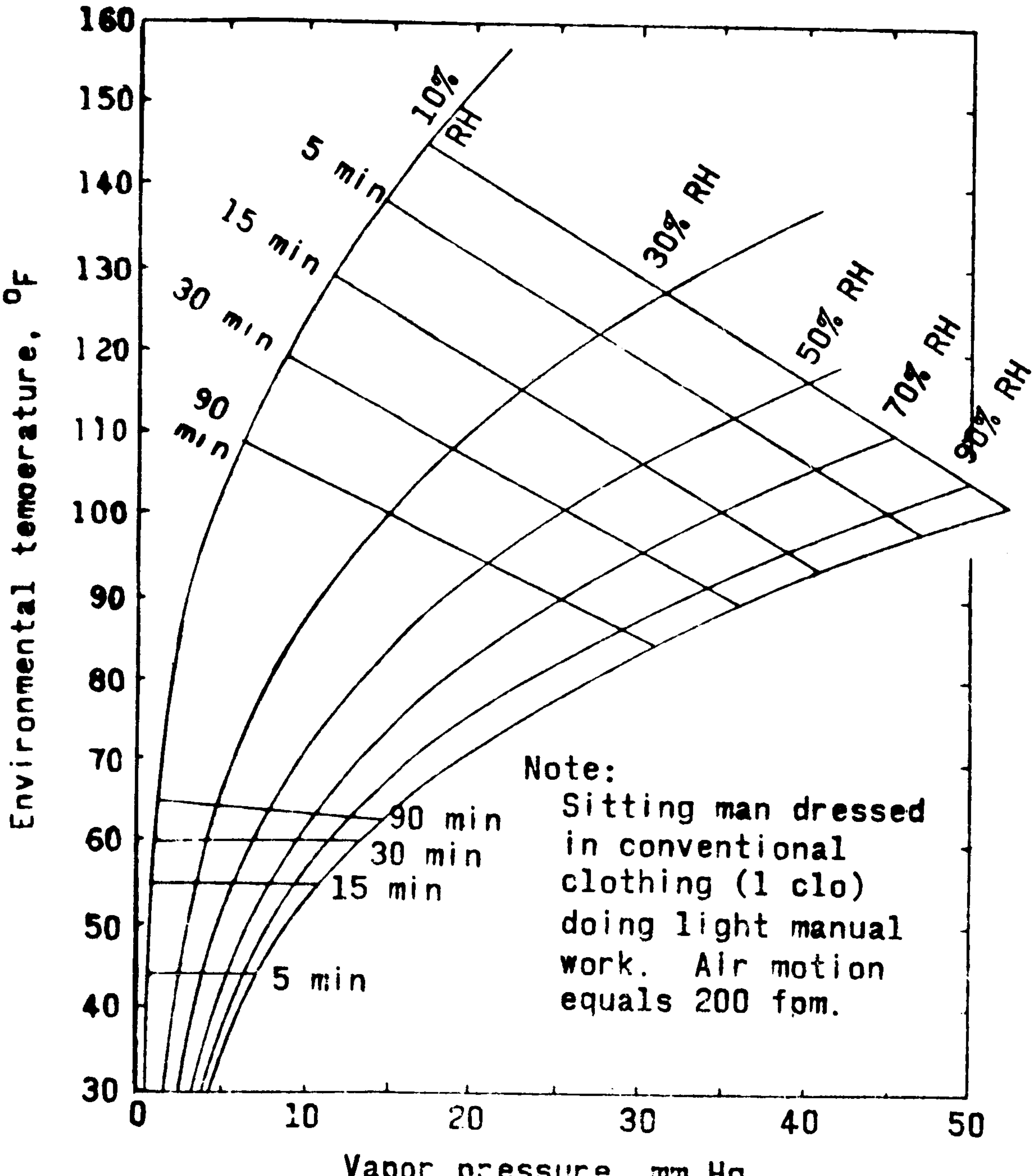


Figure 1.4-1. Temperature and Humidity Nominal Limit.

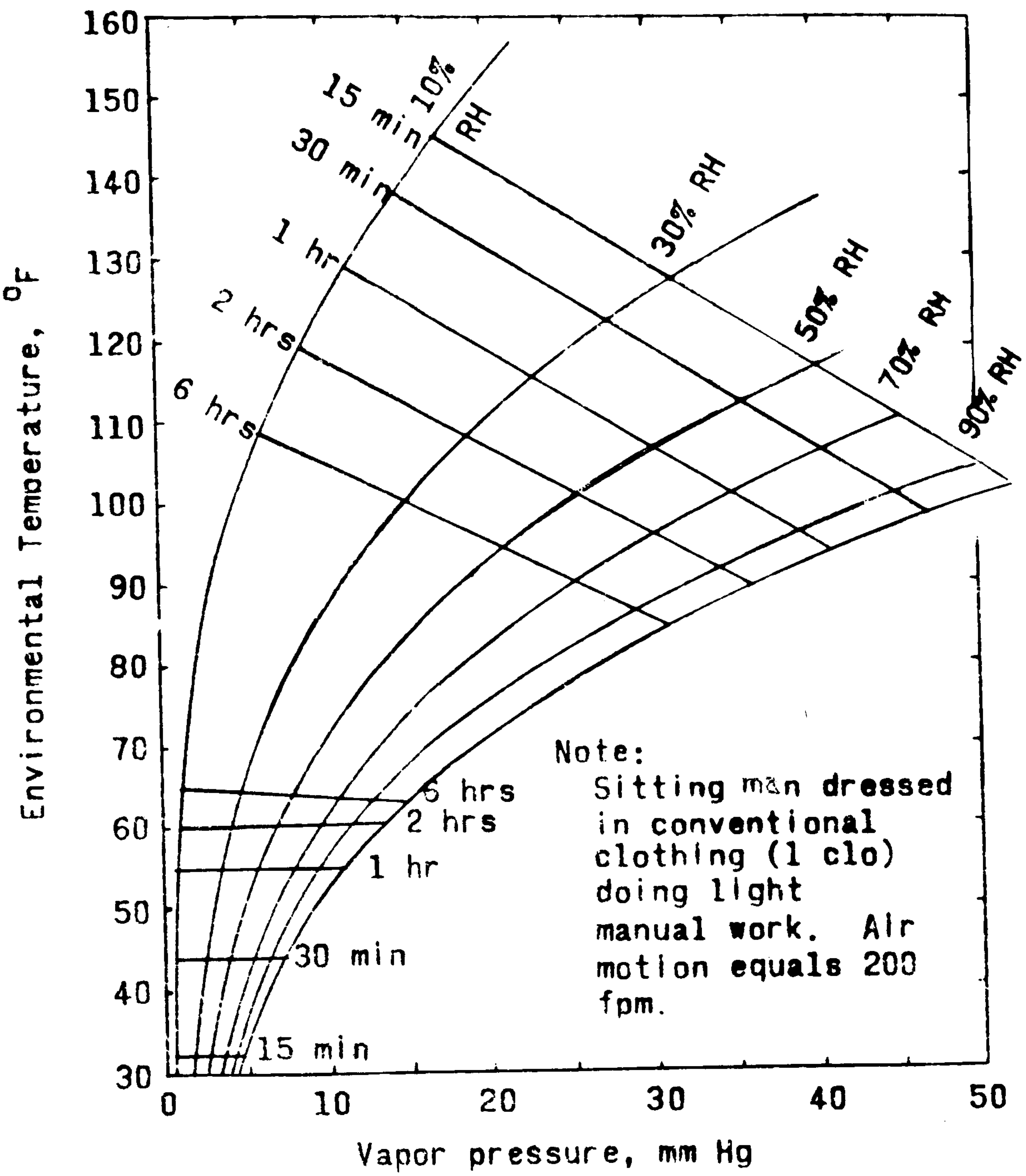


Figure 1.4-2. Temperature and Humidity Emergency Limit.

Critical organ	Maximum permissible integrated dose (rem)	RBE (rem/rad)	Average yearly dose (rad)	Maximum permissible single acute emergency exposure (rad)	Location of dose point*
Skin of whole body	1,630	1.4	233	500[1]	0.07-mm depth from surface of cylinder 2 at highest dose rate point along eyeline
Blood-forming organs	271	1.0	54	200	5-cm depth from surface of cylinder 2
Feet, angles, and hands	3,910	1.4	559	700[2]	0.07-mm depth from surface of cylinder 8 at highest dose point
Eyes	271	2[3]	27	100	3-mm depth from surface on cylinder 1 along eyeline

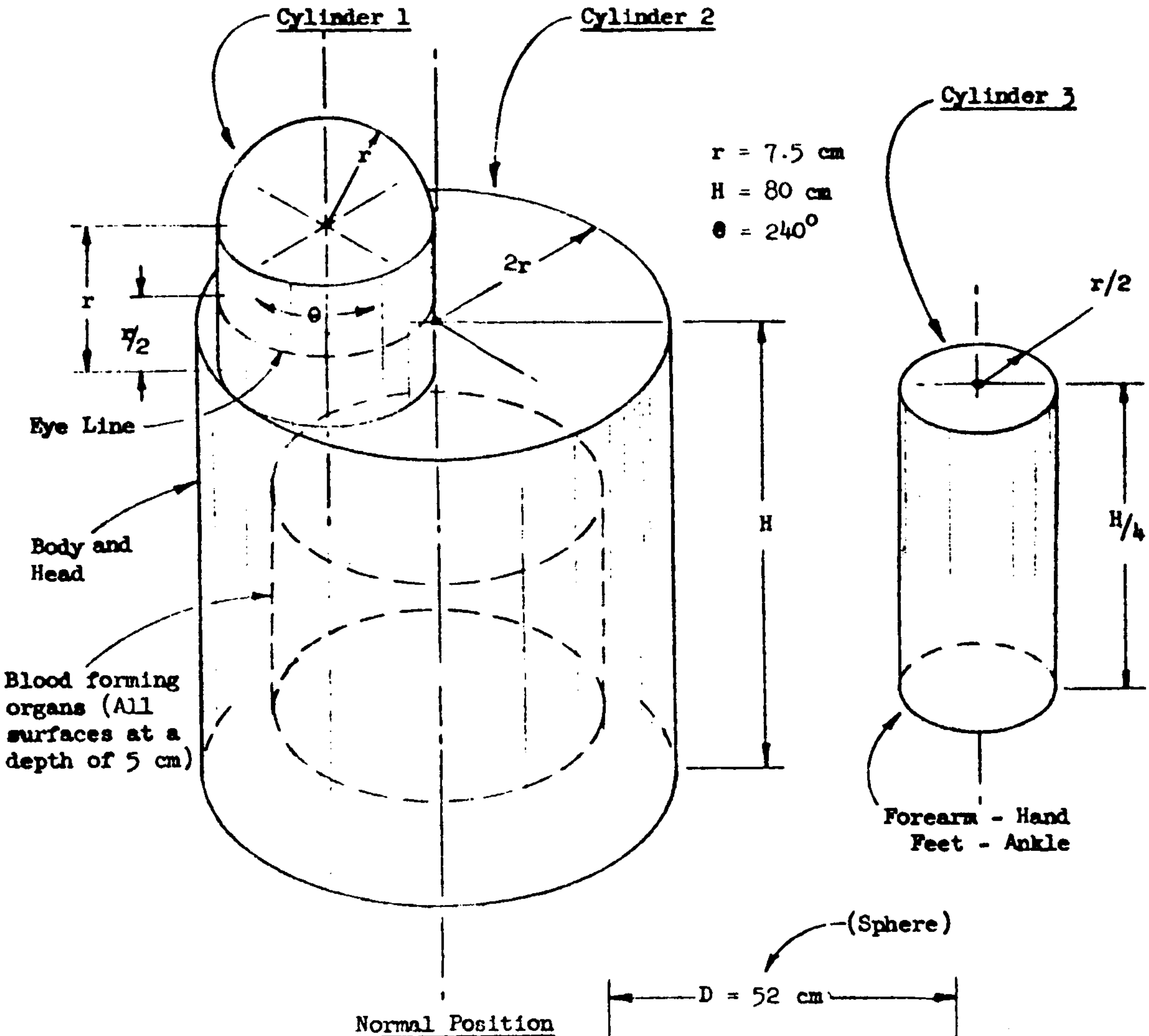
*See figure 1.4-4.

[1]Based on skin erythema level

[2]Based on skin erythema level but these appendages believed to be less radiosensitive

[3]Slightly higher RBE assumed since eyes are believed more radiosensitive

Figure 1.4-3. Radiation Exposure Dose Limits.



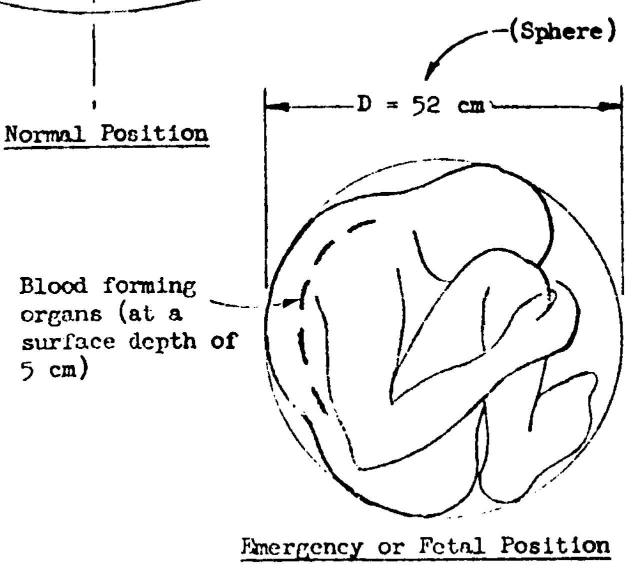


Figure 1.4-4. Models of the Radiation Standard Man.

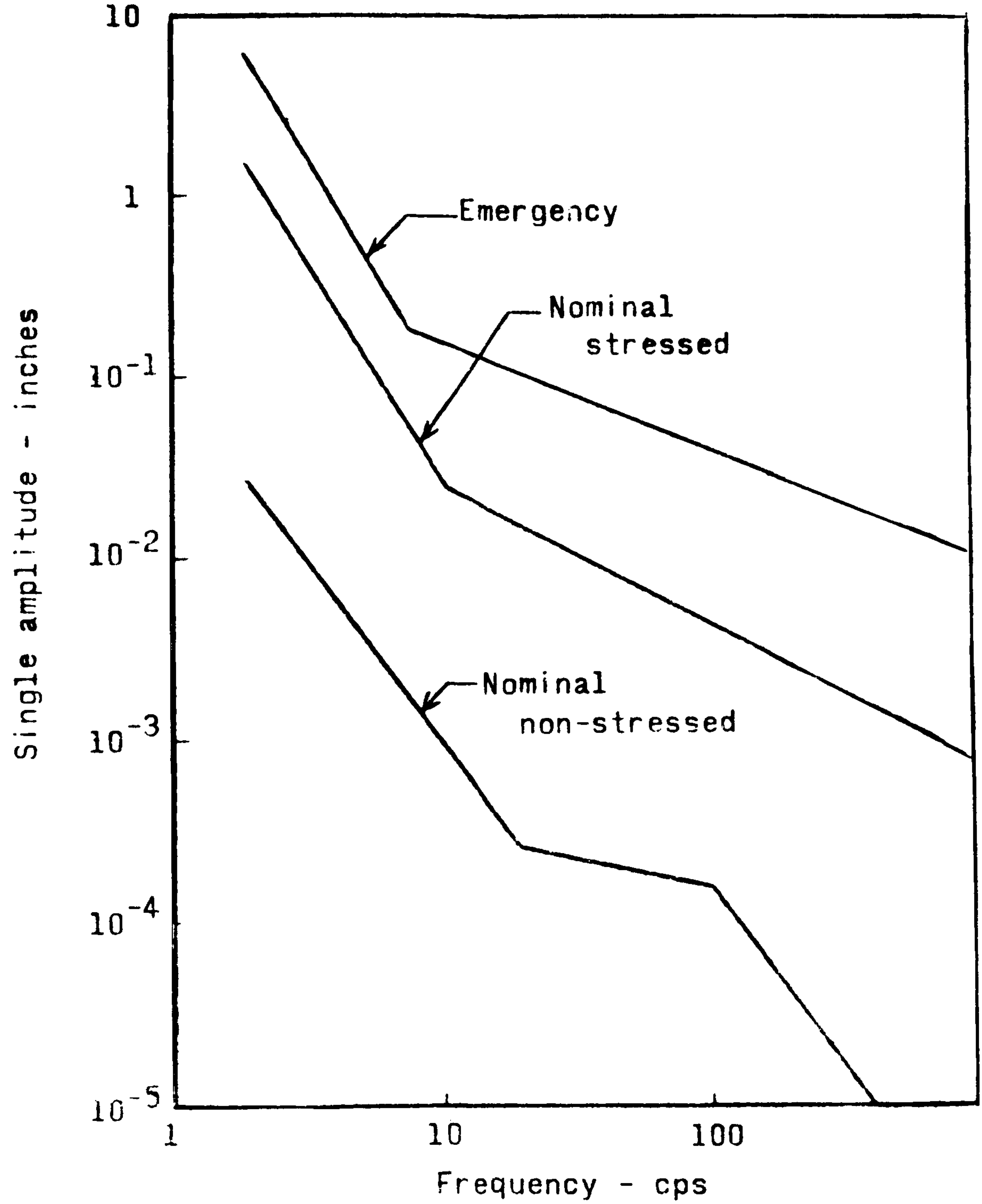


Figure 1.4-5. Vibration Limits.

6. Acceleration

Sustained Acceleration

	duration	0.1	0.3	1.0	3.0	Minutes
Eyeballs out	performance limit		10	8.5	7.0	g's
	emergency	20	15	9	7.5	g's
Eyeballs down	performance limit			6.5	5	g's
	emergency			7	5	g's
Eyeballs in	performance limit			10	7.5	g's
	emergency	25	18	15	8.0	g's

Impact Acceleration	Nominal	Emergency
forward or backward	20	40 g's
right or left	10	10
head or tailward at <250 g/sec	10	20 headward 10 tailward

1.4.6 Physical Configuration

A. GENERAL ARRANGEMENT

The Spacecraft arrangement for lunar landing missions is shown in Figure 1.4-6.

B. GEOMETRIC CHARACTERISTICS

The basic external geometry of the Command Module is shown in Figure 1.4-7. The Command Module shall be a symmetrical, blunt body developing a hypersonic L/D of approximately 0.50. The L/D vector shall be effectively modulated in hypersonic flight. The modulation is achieved through constant c.g. offset and roll control.

C. INBOARD PROFILE.

Basic arrangements of internal features fundamental to full utilization of the Command Module geometry are shown in Figure 1.4-8.

1.4.7 Guidance and Control System

The Guidance and Control System is comprised of a Guidance and Navigation System and a Stabilization and Control System. The Stabilization and Control System is located in the Command Module. It provides the attitude stabilization and maneuver control requirements for the Spacecraft and for combinations of

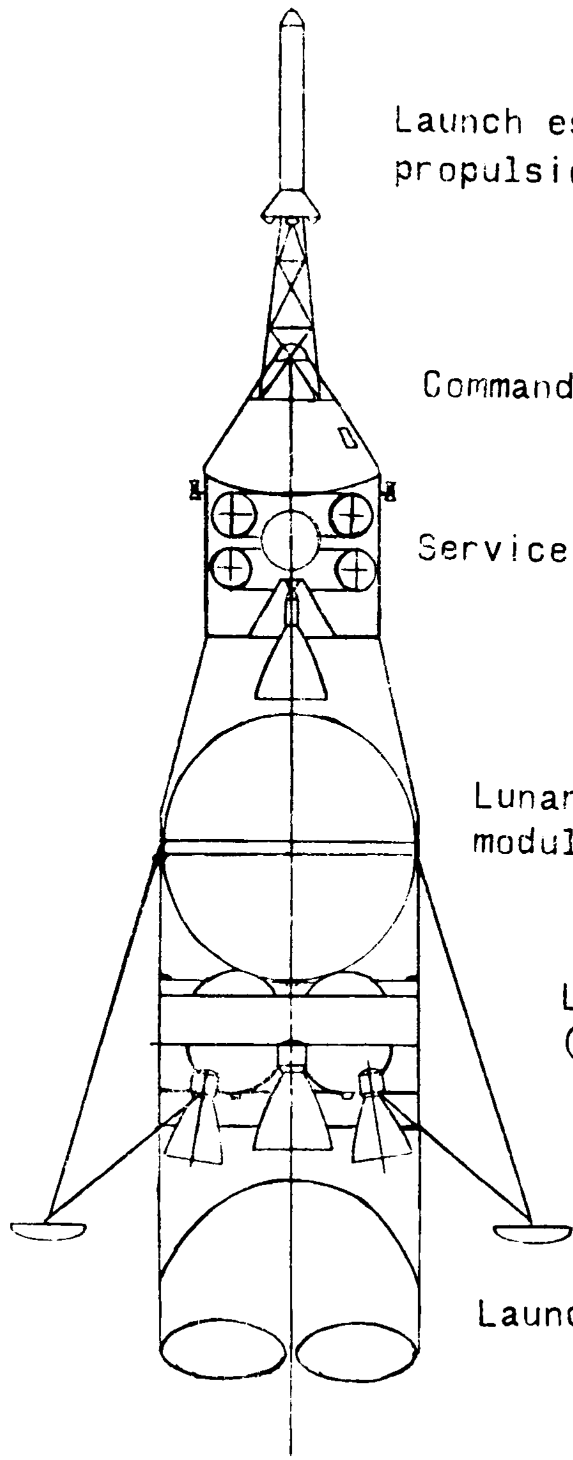


Figure 1.4-6. General Arrangement - Lunar Landing Configuration.

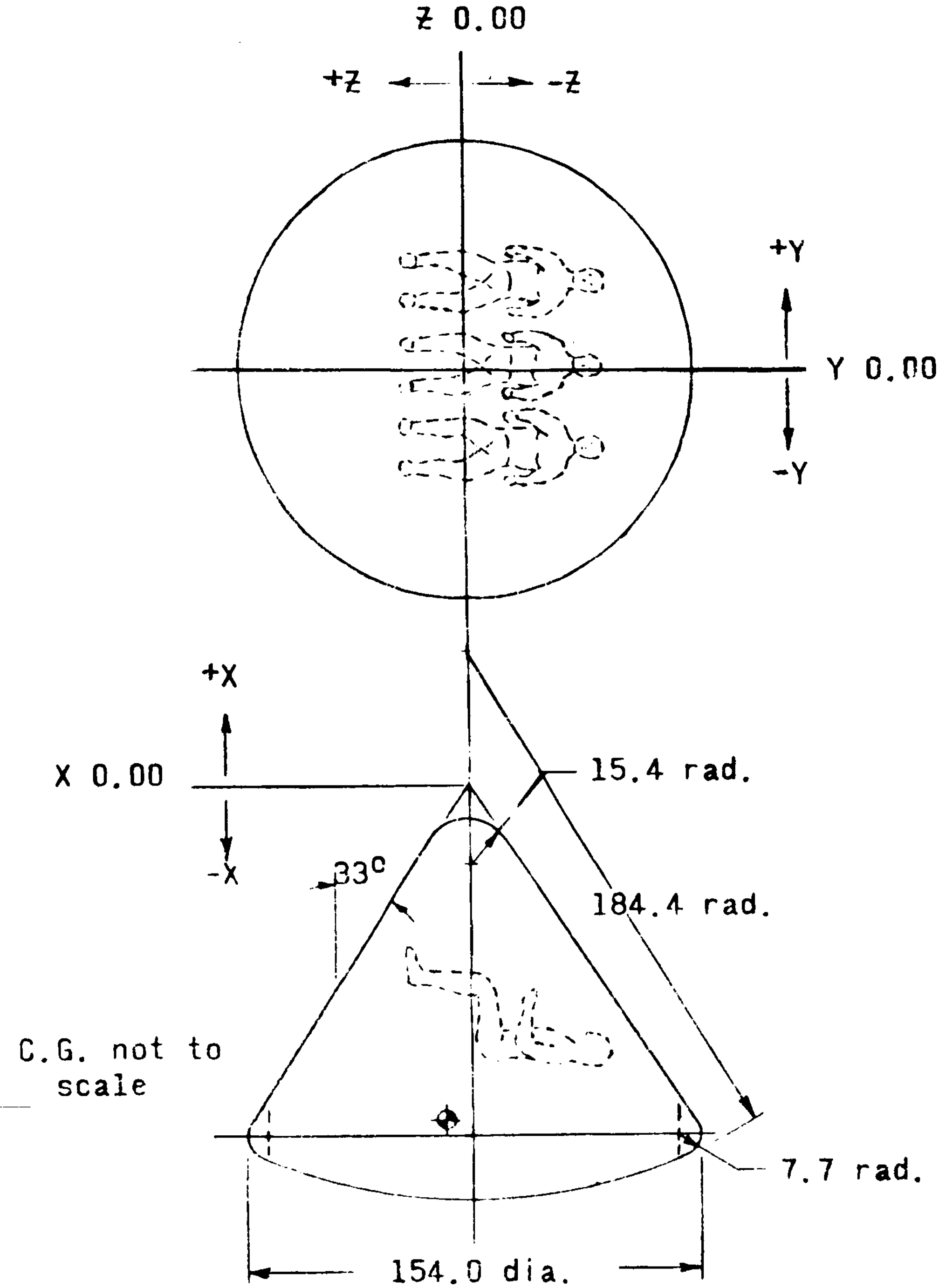


Figure 1.4-7. Command Module Nominal Geometry.

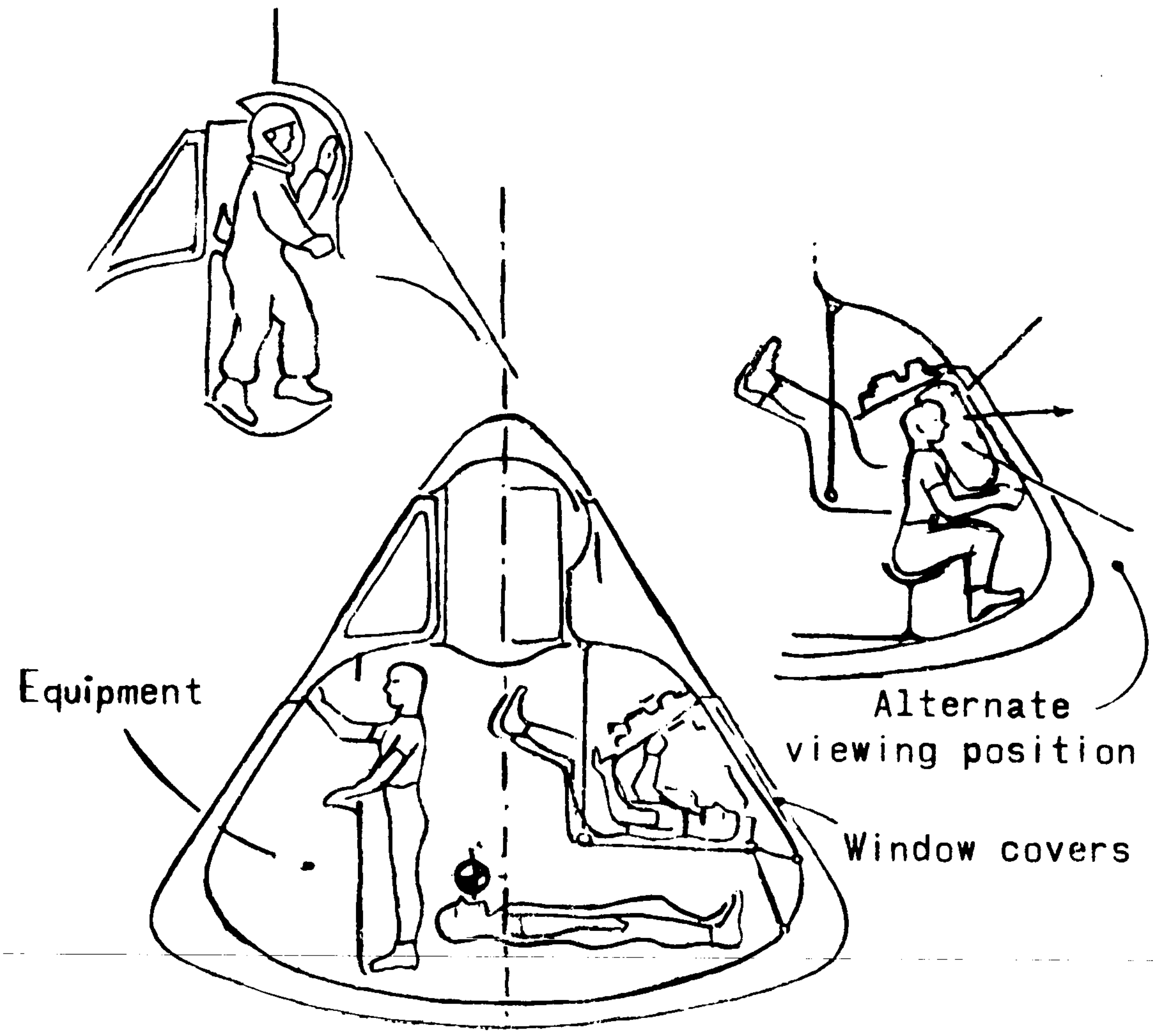


Figure 1.4-8. Command Module - Inboard Profile, Activity Areas.

Spacecraft and appropriate Propulsion Modules. The Guidance and Navigation System is also located in the Command Module. It provides steering and thrust control signals for the Stabilization and Control System, Reaction Control Systems, and appropriate propulsion system and their respective gimbal systems.

A. NAVIGATION AND GUIDANCE SYSTEM

These requirements are given in the main body of this work statement under paragraph 1. 3. 2.

B. STABILIZATION AND CONTROL SYSTEM

The functional requirements and a description of the Stabilization and Control System are presented below.

1. Requirements

The system shall satisfy the following requirements

a. Atmospheric abort. Roll control plus flight-path control during the thrusting period of atmospheric abort and stability augmentation after Launch Escape Propulsion System separation.

b. Extra-Atmospheric abort. Orientation, attitude control, and re-entry stabilization and control. The system shall accept commands from the guidance system for thrust vector control and re-entry control.

c. Parking orbit. Stabilization of the Spacecraft plus the lunar injection configuration while in a parking orbit.

d. Translunar and transearth. Stabilization and control during midcourse flight both outboard and inboard. The control technique shall provide fuel economy and shall satisfy all navigation requirements as well as solar orientation and antenna-pointing requirements. Attitude control and orientation for application of midcourse corrections shall be provided.

e. Orbital rendezvous and docking. Rendezvous and "docking" with the Space Laboratory or other cooperative space vehicles.

f. Lunar landing and take-off. Attitude control and hovering for accomplishing landings and take-offs from the moon and for entering and departing from lunar orbits. Attitude control commands shall be accepted from the Navigation and Guidance System and the crew. Hovering control will be by the crew.

g. Re-entry. Control requirements for re-entry guidance. Reaction jets will be employed for three-axis stabilization. Re-entry control will be provided by rolling the vehicle which is trimmed at an L/D.

h. Landing. Stabilizing and controlling the Command Module with respect to the flight direction in the landing configuration. Command control will be by the crew employing visual reference.

i. Special control features. Consideration shall be given to meeting a requirement for fine control of Spacecraft rolling response to tracking control commands from the Guidance and Navigation Systems. Consideration shall also be given to methods for optimizing overall system design for midcourse flight by integrating requirements for Spacecraft three-axis control and antenna-pointing requirements.

2. System Description

The Stabilization and Control System shall consist of the following basic components:

Attitude reference
Rate sensors
Control electronics assembly
Manual controls
Attitude and rate displays
Power supplies

a. Attitude reference. The attitude reference system provides angular displacement signals to the Stabilization and Control System and instrument panel displays. The primary reference system is provided within the Guidance and Navigation System. Requirements for additional special attitude sensors are not specified at this time. Division of responsibility between Principal Contractor and Guidance and Navigation Contractor will be determined by NASA after sufficient study and interface negotiations. Some examples of these requirements follow.

(1) Standby inertial reference. A standby reference which is capable of retaining an inertial reference throughout any combination of Spacecraft maneuver. This system may be erected by

the primary reference system but it must be capable of being erected to an inertial reference independent of the primary navigation system. It should also be capable of driving panel displays.

(2) Special sensors. Non-gyroscopic sensors are required for solar orientation during midcourse flight and for third-axis control in connection with antenna-pointing requirements. Consideration should be given to the use of the outputs of these sensors to control directly through the switching logic of the electronic assembly and to the use of derived rate from the sensor output.

b. Rate sensors. Three axes rate gyro packages shall provide stability augmentation during propulsion modes, maneuvers and re-entry. They also serve as a necessary sensor for the Rate Command System and require a dynamic range capable of dealing with all vehicle configurations and mission requirements. Redundancy shall be provided compatible with the overall system configuration.

c. Control electronics assembly. The Stabilization and Control System Control Electronics Assembly shall accept command inputs from the Navigation and Guidance System during periods of thrust vector control, periods of tracking for navigation purposes, and from the Stabilization and Control System attitude reference at all other times. The Control Electronics Assembly shall supply thrust command signals to the attitude control propulsion motors to establish correct orientation, stable limit cycle operation, and damping throughout all phases of the mission. The control electronics shall use pulse modulation or similar techniques by which the desired objectives of economical limit cycling, accurate control during periods of large disturbances, and satisfactory maneuver rates can all be achieved with the same switching logic. Flexibility to deal with all vehicle configurations and mission requirements shall be attained by the provision of adjustments for parameters such as attitude dead band, rate limits, and attitude to rate gain. To ease the control task of the pilot, the system must be capable of accepting discrete "dialed" orientation commands or provide an attitude followup for reengagement of attitude hold when the maneuver is completed. The control electronics shall be of modular construction and provide the necessary redundancy and inflight maintenance capability.

d. Manual control. The suggested method of maneuvering by the pilot is by opening the outer loop and imposing rate commands on the inner rate stabilization loop. The manual controls shall be capable of operating all reaction control motors by direct electrical connection, providing emergency operation in case of rate gyro or other automatic system failure. Design of the controls shall provide acceptable feel characteristics for all conditions of flight environment. Provision for the translational control by the crew for docking and hovering phases of the mission shall be compatible with the attitude control system concept.

e. Attitude and rate displays. Angular rates and vehicle attitudes with respect to the reference shall be displayed during manual maneuvering and critical phases of the mission. At all other times, displays shall be commensurate with crew requirements.

f. Power supplies. The Stabilization and Control System shall generate all levels of DC and AC voltage requirements internally from the basic vehicle electrical supply. Choice of operating frequencies and provision of redundancy in the power supplies shall be governed by the requirements for compatibility between Navigation and Guidance and Stabilization and Control Systems.

1.4.8 Environmental Control System

The Command and Service Modules shall include the Environmental Control System which provides a conditioned "shirtsleeve" atmosphere for the crew; provisions for pressure suits in event of cabin decompression; thermal control of all Command and Service Module equipment where needed; and provisions for charging self-contained extra-vehicular pressure suit support systems ("back packs"). See Figure 1.4-9.

1.4.9 Electrical Power System

A. SYSTEM DESCRIPTION

1. Purpose

The Electrical Power System shall supply, regulate, and distribute all electrical power required by the Spacecraft for the full duration of the mission, including the post-landing recovery period.

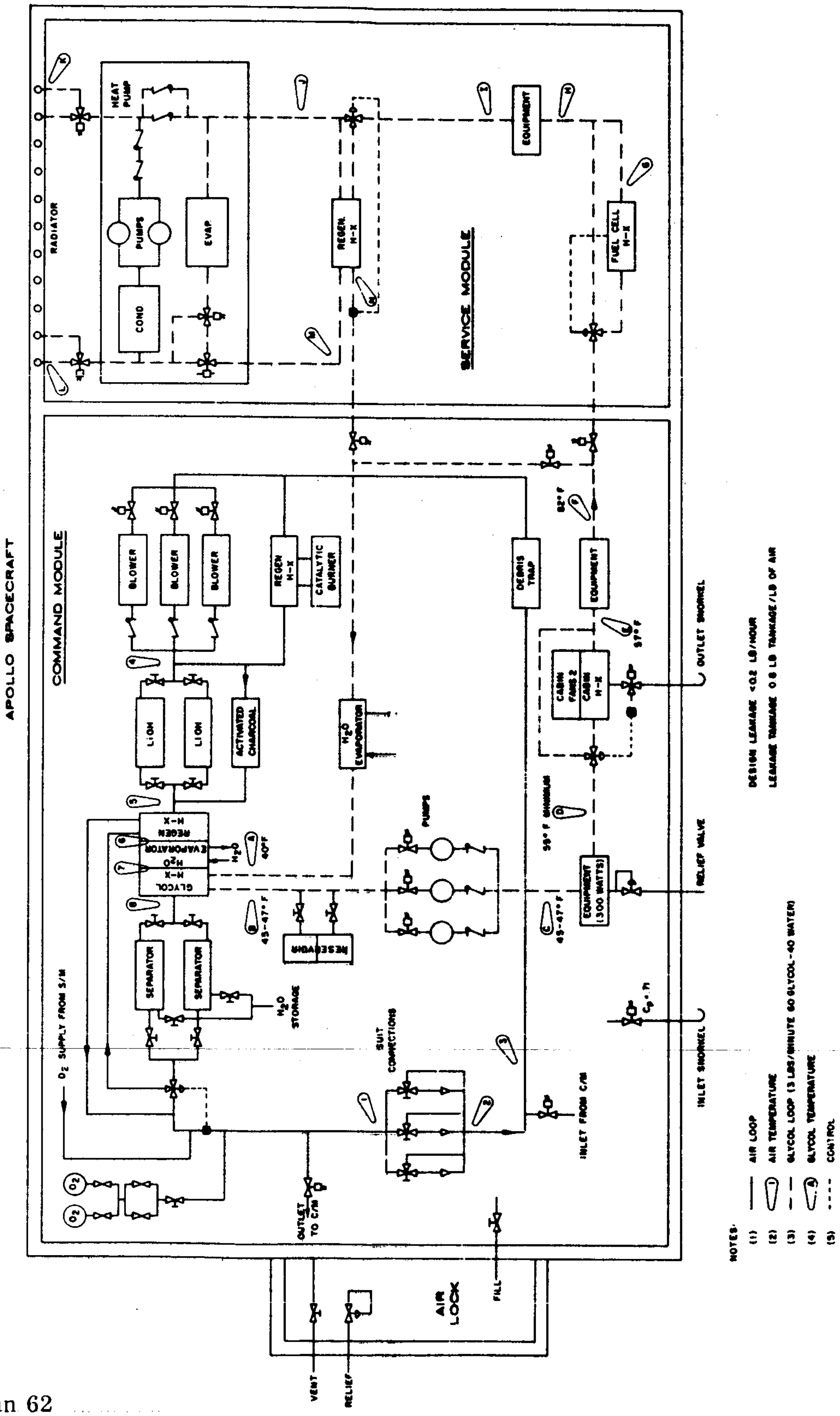


Figure 1.4-9. Environmental Control System.

2. Major Components

The Electrical Power System shall be comprised of the following major components.

a. Three (3) non-regenerative hydrogen-oxygen fuel-cell modules.

b. Mechanical accessories, including control components, reactant tankage, piping, radiators, condensors, hydrogen circulators and water extractors, isolation valves and such other devices as required.

c. Three (3) silver-zinc primary batteries, each having a nominal 28 volt output and a minimum capacity of 3000 watt-hours (per battery) when discharged at the 10 hour rate at 80^{o} F.

d. An Electrical Power System display and control panel, sufficient to monitor the operation and status of the system and for distribution of generated power to electrical loads, as required.

3. Location and Weight

The location of each of the above components within the spacecraft shall be as listed herein. Every effort shall be exercised to minimize equipment size and weight, commensurate with the established requirements and obtaining the highest practicable reliability.

Component	Location
Fuel-cell module and controls	Service Module
Tanks (empty), Radiators, Heat exchangers, Piping, Valves	Service Module
Total Reactants, plus reserves	Service Module
Silver-Zinc Batteries	Command Module
Electrical power distribution and controls	Command Module

4. Operating Modes

a. Normal operation. During all mission phases, from launch until re-entry, the entire electrical power requirements of the Spacecraft shall be supplied by the three fuel-cell modules operating in parallel. The primary storage batteries would be maintained fully charged under this condition of operation.

b. Emergency operation. In the event of failure to one of the fuel-cell modules the failed unit would be electrically and mechanically isolated from the system and the entire electrical load assumed by the two fuel-cell modules remaining in operation. The primary batteries would be maintained fully charged under this condition of operation.

In the event of failure of two of the fuel-cell modules, the failed units would be electrically and mechanically isolated from the system. Spacecraft electrical loads would be immediately reduced by the crew and manually programmed to hold within the generating capabilities of the remaining operable Fuel-Cell Module. The primary batteries would be recharged, if necessary, and maintained fully charged under this operating condition.

c. Re-entry and recovery. At re-entry, the Fuel-Cell Modules and accessories will be jettisoned. All subsequent electrical power requirements shall be provided by the primary storage batteries.

B. SYSTEM REQUIREMENTS

1. Fuel-Cell Module

Each Fuel-Cell Module shall have the following performance characteristics.

a. Type. Fuel-Cell Modules shall be of the low pressure intermediate temperature, Bacon-type, utilizing porous nickel, unactivated electrodes and aqueous potassium hydrogen as the electrolyte. Fuel cells shall be operated non-regeneratively, utilizing hydrogen and oxygen as the reactants.

b. Output power. Each Fuel-Cell Module shall have a nominal capacity of 1200 watts at an output voltage of 28 volts and a current density conservatively assigned such that 50% overloads can be continuously supplied.

c. Pressure and temperature. The nominal cell operating pressure and temperature shall be approximately 60 psia and 425^{o} F to 500^{o} F respectively.

d. Fuel consumption. Under normal conditions of operation, the specific fuel consumption shall not exceed 0.9 lb/Kw-Hr, total H_2 and O_2.

e. Water generation. The water generated by the Fuel-Cell Module shall be potable and shall be separated from the hydrogen and stored.

f. Start up. Self-sustaining reaction within the Fuel-Cell Module shall be initiated at a temperature of approximately 275^{o} F. Integral heaters shall be provided to facilitate ground starting as well as during the mission. These heaters shall not be capable of heating units to excessive temperatures with the fuel-cell and its cooling system inoperative.

g. Fuel-Cell Modules. A detection and control system shall be provided with each Fuel-Cell Module to prevent contamination of the collected water supply.

h. System redundancy. The degree of redundancy provided for mechanical and electrical accessory equipment such as radiator loops, control valves, piping circuits, voltage regulator, etc., shall, in general, be 100 percent.

2. Electrical Distribution

a. General. The distribution portion of the electrical power system shall contain all necessary busses, wiring protective devices, switching and regulating equipment.

Except as specified herein, the electrical distribution system shall conform to the requirements of standard MIL-STD-704.

Selection of parts and materials, workmanship, fabrication and manufacturing processes shall be guided by the requirements of MIL-E-5400, except as required to meet the performance or design requirement specified herein.

b. System voltage. Electrical power shall be generated and distributed at 28 volts DC (nominal).

c. Regulation. The voltage level shall be regulated to prevent variance of more than ±2 volts from the nominal voltage under all conditions of operation.

d. AC ripple. All DC busses in the system shall be maintained essentially free of AC ripple (as defined by paragraph 3.12 of MIL-STD-704) to within a limit of 250 millivolts peak to peak.

e. Protection. Busses and electrical loads shall be selectively protected such that individual load faults will not cause an interruption of power on the bus to which the load is connected. Likewise, a fault on the non-essential bus shall not cause an interruption of power to the essential bus.

f. Load Grouping. All electrical loads supplied by the distribution system shall be classified as Essential, Nonessential, Pyrotechnic, or Recovery. Essential loads are defined as those loads (except pyrotechnic circuits) which are mandatory for safe return of the spacecraft to earth from any point in the lunar mission. Such loads as are not mandatory for safe return of the spacecraft shall be grouped on the Nonessential bus and provision made for disconnecting these loads as a group under emergency conditions. All loads required during the post-landing recovery period shall be supplied by the Recovery bus and provision made for manually disconnecting this bus from the Essential bus following landing. Redundant busses shall be provided for pyrotechnic circuits, and used to supply only that type load.

g. Power conversion. Equipment which requires conversion of basic electrical power (28 volts DC) to power with other characteristics shall accept the basic power as defined herein for modification and use. Conversion or inversion devices required for this purpose shall be integral with the utilization system or utilization equipment.

h. External power. Provision shall be made to energize the distribution system from an external source (28 volts, 100 amps DC) through an umbilical connector and a blocking diode.

i. Electrical Distribution Panel. The Distribution Panel shall be dead front and adequately enclosed or otherwise protected to minimize hazards to the crew and provide maximum mechanical protection for the electrical system and components. Switching and control shall be accomplished by manually operated circuit breakers or contactors in preference to electrically operated contactors, except where use of a remotely controlled device is necessary to reduce the length of large electrical conductors.

j. System type. The distribution system shall be a two-wire grounded system, i.e., wire and busses shall be employed as the return path for electrical currents, in lieu of using the spacecraft structure for this purpose. The system negative shall be grounded at one point only and shall not be interrupted by any control or switching device.

The schematic arrangement Figure 1.4-10 is intended only to convey to the vendor the requirements covered above, rather than the complete system arrangement.

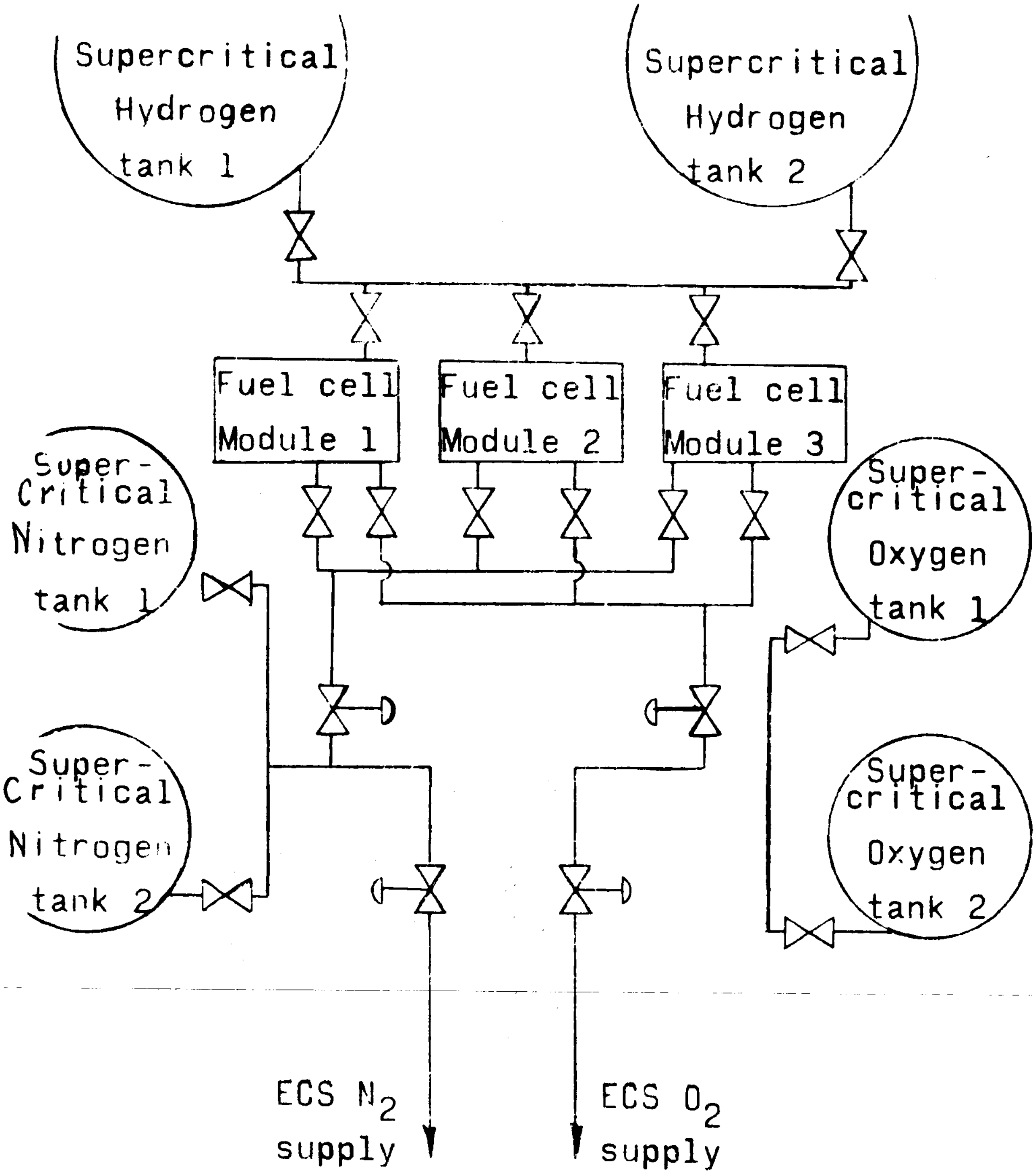


Figure 1.4-10. Electrical Power System - Schematic.

1.5 REFERENCES AND RELATED PUBLICATIONS

The following documents have been referenced in this work statement in various places. Those indicated by an asterisk (*) will be included as a part of this document or will be available separately at the bidders' conference. Others may be obtained from NASA or from the sources as indicated below:

Publication	Title	Source
* E-965A (Rev. 1)	A Sunfinder For An Interplanetary Vehicle; H. Seward	MIT/IL
* E-1074	Erasable Ferrite Memory - Mod 3C Computer; D. Shansky	MIT/IL
* E-1077	Preliminary Mod 3C Programmers Manual; Alonso, Laning, Blair-Smith	MIT/IL
* E-1105 (Conf.)	Computer Displays; Eldon Hall	MIT/IL
* R-276	Design Principles For A General Control Computer; Alonso, Laning	MIT/IL
* R-349	Guidance And Navigation System Reliability Program; G. Mayo	MIT/IL
	Missiles and Rockets Magazine (Sept. 1961 Reprint)	
APOLLO SIDL	System Identification Data List For APOLLO	MIT/IL
NASA-NCT 200-2	NASA Quality Publication (Not yet approved as of 5 Jan 62)	NASA
NASA 200.1, 200.2, and 200.3	NASA Quality Assurance Provision Requirements	NASA or GPO
USAF Spec. Bulletin No. 506	Reliability Monitoring Program for Use in the Design, Development, and Production of Air Weapon Systems and Support Systems	USAF

Publication	Title	Source
MIL-Q-9858	Quality Control System Requirements	GPO
MIL-H-5005A	Breakdown, Provisioning Parts and Illustrated Parts for Aeronautical Articles	GPO
MIL-STD-70327	Drawings, Eng. and Associated List	GPO
MIL-E-5400	Electronic Equipment, Airborne, General Spec. for	GPO
MIL-STD-2B	Engineering Drawings, Sizes, and Format	GPO
MIL-STD-704	Electric Power, Aircraft, Characteristics and Utilization of	GPO

Section 2

GENERAL REQUIREMENTS

This section contains a description of the general requirements, applicable portions of which will be cited in the individual technical work statements.

2.1 RELIABILITY

In general, the reliability effort for the design, development, production, and use phases of APOLLO Guidance and Navigation Systems is defined in MIT report R-349, Guidance and Navigation System Reliability Programs. *Elements of this program are binding upon each industrial support contractor to such a degree as may be consistent with the scope of his contract and are applicable to a subassembly contractor as well as a systems contractor. It is expected each contractor will effectively implement this program, comply with its intent, and achieve its objectives in all areas as they pertain to that element or elements of the system for which the contractor has obligation, subject to NASA approval.

Responsibility for the reliability program rests with MIT, and MIT will provide the technical direction, administration, and coordination of effort at individual industrial support contractors. Industrial support contractors may expect to play a large part in the conduct of this program as it affects their particular areas of concern. The contractor supporting MIT in overall systems assembly will be expected to furnish support to MIT in the coordination of the several reliability efforts. Specific tasks pertaining to reliability will be placed upon industrial support contractors by the means of engineering instructions. Each contractor must make provision in his bid for implementing the APOLLO Reliability Program commensurate with that portion of the APOLLO program he supports.

This type of effort may be expected on a reasonably broad scale in areas of training, production qualification testing, production controls, quality control of manufacturing facilities, material procurement, component part qualification testing, and failure reporting and data reduction.

Required quality control provisions are contained in NASA quality publication NCT 200-2, dated December 15, 1961. NASA will furnish a copy of this publication to each offeror at the briefing or by prior mailing.

*Not yet approved by NASA as of 5 Jan 62.

2.2 DOCUMENTATION

2.2.1 Introduction

Documentation requirements of each Industrial Support contractor will vary in scope and detail. At the least, the Industrial Support contractor may be required to prepare only those documents which adequately define the methods of assembling and testing the equipments for which total design and production features have been engineered at the Laboratory. At the most, the Industrial Support contractor may be required to prepare the complete documentation package from design drawings, through production, assembly and test, and handbooks of operational use and maintenance.

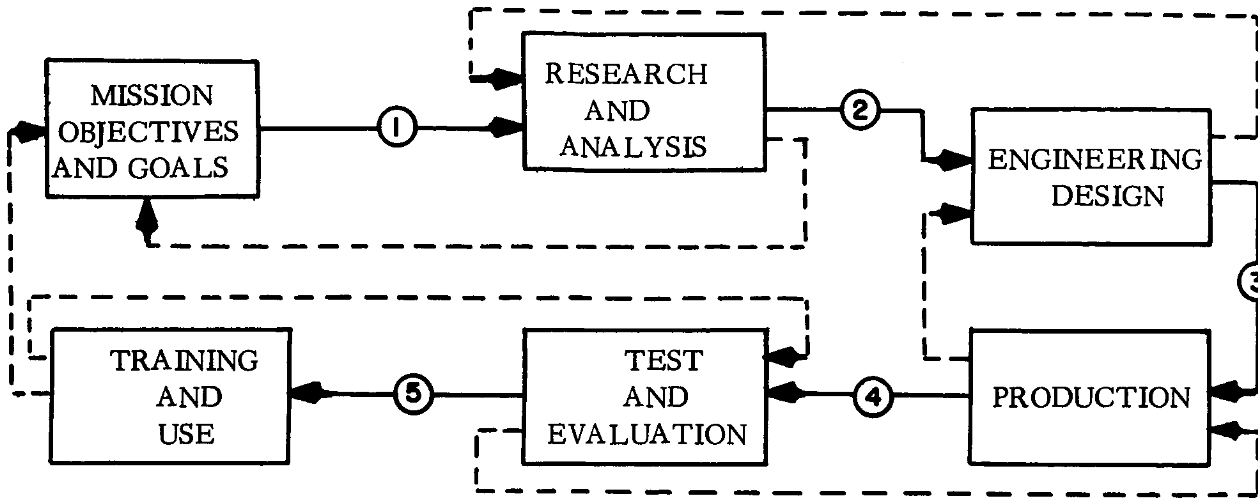
2.2.2 Objectives

The documents throughout this project serve as the links that close the loop in the communication channels among those who are responsible for:

Mission Objectives and Goals
Research and Analysis
Engineering Design
Production
Test and Evaluation
Training and Use

The documents provide an unambiguous set of ground rules for those concerned in the various phases of the project. They are the evidences of a disciplined application towards the orderly evolution of a reliable and producible design.

Figure 2.2-1 indicates the normal loop flow among these areas and indicates the types of documents normally expected from each effort. The illustration does not include all of the "loops within loops" that are in continuous circulation as feedbacks from activity to activity.



1. Work Statements, Development Plans, Programs, etc.
2. Performance and Interface Specifications, Technical Reports, Operating Procedures, etc.
3. Design Drawings, Process Requirements, Test Requirements, Logistics Requirements, etc.
4. Detail Drawings, Mfg. Specifications, Test Procedures, Maintenance Manuals, etc.
5. Qualification Test Plan, Checkout Manuals, Design Criteria, Design Changes, etc.

Figure 2.2-1. Documentation as Links that Close the Communication Loop.

2.2.3 Documents

The documents required to meet the objectives of paragraph 2 above include the following list. A brief description of each one is contained under paragraph 2.2.4 below.

A. Development Plan (Program, Fabrication, Test, and Facility)
B. Technical Progress Reports
C. Performance and Interface Specifications
D. Design Drawings
E. Equipment Status Reports
F. Qualification Status Report
G. Weight and C. G. Report
H. Familiarization Manual
I. Purchase Specifications
J. Materials, Parts, and Process Specifications
K. Factory Test Plan(s)
L. Detail Test Procedures
M. Detail Production Drawings
N. Qualification Test Reports
O. Checkout Manuals
P. Launch Operation Manuals
Q. Flight Operation Manuals
R. Maintenance and Repair Manuals
S. Illustrated Parts Breakdowns
T. Reliability and QC Documents

Each of these documents, when required, will be specified in format, content, coverage, etc., when assigned. Maximum use will be made of standard MIL specifications and industrial practices as reference specifications for these documents.

2.2.4 Administration

Assignment of documentation requirements will be made by Engineering Instruction. Although the complete documentation coverage cannot be specified at this time, procurement from the appropriate industrial support offeror of the following documents is anticipated in the equipment areas shown. Those documents not indicated in Table 2.2-1 will be prepared by MIT.

Table 2.2-1. Documentation Requirements.

Document Type	Documentation Requirements: System Offeror		GSE	AGC	Optical Subsystems Offeror			PSA
	AGE	IMU			SXT	M & VD	SFA	
A. Development Plan	X	%	X	%	X	X	%	%
B. Tech.Prog.Report	X	X	X	X	X	X	X	X
C. Perf.& Interface Spec	%	%	X	%	%	%	%	+
D. Design Drawings	▒	%	X	▒	%	+	▒	%
E. Equip.Status Report	X	X	X	X	X	X	X	X
F. Qual.Status Report	▒	X	X	X	X	X	X	X
G. Wt.&C.G. Report	X	X	▒	X	X	X	X	X
H. Familiarization	%	X	X	+	X	X	X	X
I. Purchase Spec	%	X	X	+	X	X	X	X
J. Mat.,Parts & Pro.Spec	%	+	X	X	X	X	X	+
K. Factory Test Plan	X	X	X	X	X	X	X	X
L. Detail Test Proced.	X	+	X	X	+	X	X	X
M. Detail Prod.Dwgs.	%	▒	X	▒	X	X	X	%
N. Qual.Test Reports	%	X	X	X	X	X	X	X
O. Checkout Manuals	X	X	X	+	X	X	X	X
P. Launch Oper.Man.	+	▒	X	+	+	+	▒	▒
Q. Flight Oper.Man.	+	▒	X	X	+	+	▒	▒
R. Maint.&Repair Man.	+	X	X	X	X	X	X	X
S. Ill.Parts Breakdowns	%	▒	▒	X	X	X	X	X
T. Reliab.& QC Doc.	X	X	X	X	X	X	X	X

CODE: X Required to full extent of specification for that document, under MIT direction.
% A moderate effort, required only to the extent of supporting existing or planned MIT effort.
\+ A major effort, supplemented in part by existing or planned MIT effort.
▒ Not applicable, or to be prepared completely by MIT efforts.

A. DEVELOPMENT PLAN

This plan shall delineate the responsibilities of the support contractors with regard to the accomplishment of the support listed herein. This shall include the following.

1. Manufacturing Plan

The Contractor shall provide a plan covering such items as manufacturing plans, schedules, methods, and controls.

2. Support Plan

The Contractor shall provide a support plan which describes all required functions of guidance and navigation system equipment overhaul material (spares) support, training, and transportation. Material support considerations shall include the methods of selection, distribution and control of spare parts, and the disposition of obsolete spare parts. Training considerations shall include training of ground operations and maintenance personnel, as well as training facilities, equipment, aids and materials. Transportation considerations shall include the transportation requirements including guidance and navigation transportation, peculiar spare parts and GSE requiring transportation, and other pertinent transportation data. Packaging requirements shall be specified in the plan.

3. Facilities

This plan shall cover the complete requirements for facilities development of the APOLLO guidance and navigation system and shall identify those which are to be government furnished.

B. PROGRESS REPORTS

1. Program Progress Reports

This report shall be provided in accordance with the provisions of the "Program Progress Reports" clause of the Additional General Provisions of the contract and shall also include master phasing charts and milestone charts for the overall program and general management, technical, manufacturing, facilities, test, and support schedules. Anticipated critical schedule problems shall be identified and the intended method for their solution indicated. Subsidiary schedules for the development of major components shall be included. Major actions and events required of all agencies affecting the development of the APOLLO guidance and navigation system shall be shown, including the government as well as major contractors and subcontractors.

2. Technical Data, Reports, and Analyses

The Contractor shall provide technical reports which describe the studies, analyses, and results of the contractual effort. The reports shall be prepared at times when complete blocks of work have been accomplished and, if appropriate, as logical subdivisions thereof. Major technical areas shall not be combined in a single document, but shall be published individually. The individual reports shall cover such technical specialties as stress analyses, reliability analyses, failure-mode analyses, etc.

3. Materials Reports

Material usage report shall be submitted in accordance with MIT requests.

4. Flight Reports

A report showing the results of each guidance and navigation system flight test shall be submitted. Each such report shall consist of a detailed evaluation of the particular flight test and shall include the following types of information.

a. Performance of the guidance and navigation system together with an analysis of any malfunctions and the probable cause of the subject-malfunction.

b. Unexpected significant guidance and navigation system difficulties, or results which were encountered during the flight test or preparations therefore, their bearing on future tests, and any corrective measures or product improvement proposed.

5. Failure Data

The Contractor shall prepare failure reports on all failures which occur on Contractor-furnished equipment during all phases of testing, operation, etc.

6. Emergency Action Reports

These reports shall be used by the Contractor for reporting any urgent matters which, unless solved immediately, could cause serious program delay. Such reports shall be forwarded by the most expeditious means available. Such urgent matters shall include:

Strikes
Shortages of material and equipment in critical areas
Transportation tie-ups
Safety of flight problems
Critical development problems
Factors outside the Contractor's responsibility.

7. Still Photographs

The Contractor shall provide "still photographs" showing major and critical system equipments and any significant events occurring during the period of the contract. All photographs so furnished shall be 8" x 10" black-and-white, continuous-tone positive prints. The Contractor may provide color photographs in those instances where the Contractor believes that the importance of the subject matter requires such coverage.

8. Motion Picture Photography

The Contractor shall provide 16-mm motion picture coverage with sound of all significant highlights of the program, within the area of his activity and responsibility, as the events occur. Edited positive film, which is capable of being used as a master, shall be furnished. All motion picture photography shall be in color except where technical reasons prevent the use of color film. The Contractor shall also supply unedited film upon request.

9. Weekly Launch Site Activities Reports

This report shall cover the status of the launch site activities relative to the preparation of the guidance and navigation system.

10. Monthly Technical Progress Reports

For those months for which quarterly technical progress reports are not required, a monthly technical progress report shall be furnished. This report shall consist primarily of statements describing the status of the overall program for the preceding month. Any significant events or problems shall be identified as will the need for any necessary action or assistance by the NASA.

11. Quarterly Technical Progress Reports

This report shall cover progress and status of the development of the APOLLO guidance and navigation system including management and major technical aspects, facilities, and other similar items for the preceding quarter. Major problems encountered and the solutions undertaken, or planned, shall be included. Any situation requiring NASA action or assistance shall be highlighted. Progress and status in relation to the master phasing and milestone schedules and any actual or anticipated changes thereto shall be shown, either in chart or by data sufficient to show this information on the charts previously submitted.

12. Final Report

The Contractor shall submit a final report which documents and summarizes the results of the entire contract work, including recommendations and conclusions based on the experience and results obtained. The final report shall include tables, drafts, diagrams, curves, sketches, photographs and drawings in sufficient detail to comprehensively explain the results achieved under the contract.

C. PERFORMANCE AND INTERFACE SPECIFICATIONS

1. Guidance and Navigation Performance and Interface Specifications

These specifications shall specify the function, performance, and interface requirements of the guidance and navigation system and include qualification, reliability, and acceptance requirements.

2. Ground Support Equipment Performance and Interface Specifications

These specifications shall specify the function, performance, and interface requirements of the guidance and navigation system GSE and include qualification, reliability, and acceptance requirements.

D. DESIGN DRAWINGS

Submittal sketches, using the Contractor's internal drawing system, shall be submitted for approval. Finalized drawings shall be in accordance with NASA drawing standards. A complete set of up-to-date drawings shall be maintained sufficient to describe all components of the guidance and navigation system and GSE.

E. EQUIPMENT STATUS REPORT

This report shall present a list of all guidance and navigation system equipment indicating pertinent characteristics, qualification status, required qualification status, usage, reuseability, importance to Spacecraft mission, and flight performance of each part.

F. QUALIFICATION STATUS REPORT

The Contractor shall provide and maintain a status list showing the planned and completed qualification of each part, component, and subsystem for which he is responsible. The basis for qualification of those parts and components for which APOLLO qualification tests are not required shall be shown. Where qualification is based on qualification tests conducted under the APOLLO program, the date of such tests and reference to the detailed test reports shall be shown.

G. WEIGHT AND CENTER OF GRAVITY REPORTS

The Contractor shall provide monthly weight and center of gravity reports which provide continuing weight and center of gravity information for all guidance and navigation system equipment furnished by the Contractor.

H. FAMILIARIZATION MANUAL

The guidance and navigation system familiarization manual shall provide a description of the complete guidance and navigation system. The guidance and navigation system shall be described in general terms but with sufficient detail to convey a clear understanding of the system as a whole. This manual shall cover the general operational procedures and include a reference index of all operating and maintenance manuals. This manual shall serve as an orientation-indoctrination type document and as a reference document containing information relative to the guidance and navigation system and all components thereof.

I. PURCHASE SPECIFICATIONS

In-house procurement specs in present format may be used, provided adequate change control is exercised. They shall be technically reviewed by MIT, then approved by MIT Change Control Board, and identified in the APOLLO SIDL (System Identification Data List), produced and maintained by MIT. Changes to an approved purchase spec will require similar treatment.

J. MATERIALS, PARTS, AND PROCESS SPECIFICATIONS

The Contractor shall provide all material, parts, and process specifications which are used during the project. In cases where adequate materials and parts specifications do not exist, or are not suitable for the intended use, procurement specifications will be prepared by the Contractor. Where standards and process specifications covering items such as cleaning, forming, heat treatment, etc., are not available or are not adequate, process specifications will be prepared by the Contractor.

K. FACTORY TEST PLAN

1. Factory Test Plan

The Contractor shall provide a plan for conducting the acceptance tests required on guidance and navigation system equipment covering such items as a technical description of the system, subassemblies and assemblies; parameters to be tested at each level of assembly; the nominal and tolerance values of the functional parameters; and sequence of tests.

2. Test Plan

The Contractor shall provide a test plan for the portion of the program within the area of his activity and responsibility. The plan shall cover all types of tests required under the contract including such items as engineering development tests, design verification tests, tests to determine operating environments or conditions, qualification tests, system compatibility tests, reliability demonstration tests, prelaunch tests, and flight tests. It shall outline the types and quantities of tests to be run, equipment and configurations to be tested, concepts and objectives of the tests, test locations, support requirements, and major time phasing.

L. DETAILED TEST PROCEDURES

1. Detailed Inspection and Test Plans and Procedures

The Contractor shall provide detailed inspection and test plans and procedures for all tests.

2. Acceptance Test Data Sheets

Copies of data sheets showing the results of acceptance tests on major end items of ground support equipment and on major components of the guidance and navigation system shall be prepared and furnished for approval. Acceptance test data on all other items shall be maintained by the Contractor and shall be made available for review upon request.

3. Data and Reports on Other Tests

Data showing the results of all required tests not otherwise provided for herein, which are the responsibility of the Contractor, shall be recorded and maintained on file. Reports shall be submitted on each of these tests or test series.

4. Final Test Methods

The Contractor shall provide final test methods which include a detailed explanation of the methods for determining acceptability of the product.

5. Special Sampling Plans

Sampling plans other than standard military plans shall be submitted for approval.

6. Standards, Test, and Inspection Equipment Maintenance Procedures

The Contractor shall provide procedures for the maintenance of (1) standards and (2) inspection and test equipment which includes a description of the check method and action to be taken in case of unsatisfactory results.

M. DETAIL PRODUCTION DRAWINGS

Drawing preparation shall be in accordance with NASA drawing standards, which essentially interprets the optional provisions of MIL STD 70327, and MIL STD 2B.

N. QUALIFICATION TEST REPORTS

Data showing the results of all qualification tests shall be maintained and indexed in a master file by the Contractor. Reports shall be forwarded to MIT showing the results of all qualification tests.

O. CHECKOUT MANUALS

1. Checkout Manuals

The checkout manuals shall provide the procedures and information required to perform checkout and tests of the appropriate equipment. They shall permit complete checkout in the maintenance area or launch site.

2. Ground Support Equipment Manuals

A manual shall be provided for each major item of guidance and navigation system ground support equipment. The manuals shall contain all the procedural instructions directly associated with, and required for, operation and checkout of the ground support equipment.

P. LAUNCH OPERATION MANUALS

Guidance and navigation system launch operation manuals shall define the detailed procedures required to perform the tasks directly associated with the guidance and navigation system prior to, including, and subsequent to launch. The manuals shall present, in sequential order, the instructions for tasks performed by members of the launch team who participate in the Spacecraft launch operations.

Q. FLIGHT OPERATION MANUAL

This operation manual shall provide the instructions and procedures to be followed by the Spacecraft crew in relation to the guidance and navigation system during all phases of the mission. The tasks to be performed by the Spacecraft crew shall be presented in a logical sequence in individual sections pertinent to each phase of the mission.

R. MAINTENANCE AND REPAIR MANUALS

1. Maintenance and Repair Manuals

These manuals shall provide complete instructions and procedures for the maintenance and repair of the guidance and navigation system and its GSE. A manual shall be provided for each major item of equipment or component. The Programed Integrated System Maintenance, "PRISM," approach shall be employed in the preparation of maintenance manuals. (See Missiles and Rockets Magazine, Sept. 1961 Reprint.) MIT will provide guidance in this area.

2. Handbooks, Manuals, and Field Instructions

The Contractor shall provide manuals to define, in detail, operating and launch instructions as well as maintenance, checkout, and test procedures as indicated in the following paragraphs. The instructions and procedures contained in the manuals shall be arranged to permit operation, maintenance, checkout or test of the equipment covered by the appropriate manual in the minimum feasible amount of time. The material shall be designed to be readily understood by the personnel who will operate and/or maintain the equipment.

3. Maintenance Plan

The Contractor shall provide a maintenance plan which describes the detailed requirements and procedures necessary to provide for the maintenance of all guidance and navigation system equipment throughout all phases of the program, in accordance with NASA established maintenance concepts. The plan shall include maintenance during factory testing, storage, assembly, and prelaunch testing.

S. ILLUSTRATED PARTS BREAKDOWN

Only for those assemblies anticipated to be replacement-type spares, in accordance with MIL-H-5005A.

T. RELIABILITY AND QUALITY CONTROL

1. Reliability Plan

The Contractor shall provide a reliability plan incorporating all elements compatible with MIT R349 Reliability Program.

2. Quality Control Operating Procedures

The Contractor shall provide quality control procedures which encompass the total range of actions that describe the operations of the Contractor s quality control program.

3. Monthly Quality Report

The Contractor shall provide a monthly quality report which includes all required trouble, failure, and quality data.

4. Quarterly Reliability Status Report

The Contractor shall provide reliability status reports which provide a comprehensive view of the reliability program including the current demonstrated reliability level for each major element and component, as defined in the reliability program plan; a discussion of reliability problems; failure analyses; and results of corrective action taken and corrective actions proposed.

5. Quarterly Summaries of Quality Control Performance Audits

The Contractor shall provide quarterly summaries of quality control audits which include corrective actions taken and the results of reviews of deficient areas.

2.2.5 Schedule

The schedule for each document to be obtained from the Contractor will be established jointly by the Industrial Support Contractor, MIT, and NASA within thirty (30) days after start of the support effort. The schedule will be prepared on a form similar to that of Figure 2.2-2. Both initial release and subsequent revision of schedules will require prior approval by both MIT and the Industrial Support Contractor before distribution.

Documentation must be <u>timely</u>. The documents will be scheduled to fit the equipment development schedule. However, as a basic groundrule, the document defining design, assembly, or test must be developed in the early hardware development program and released through Change Control Board action <u>prior</u> to its use in the "final" design.

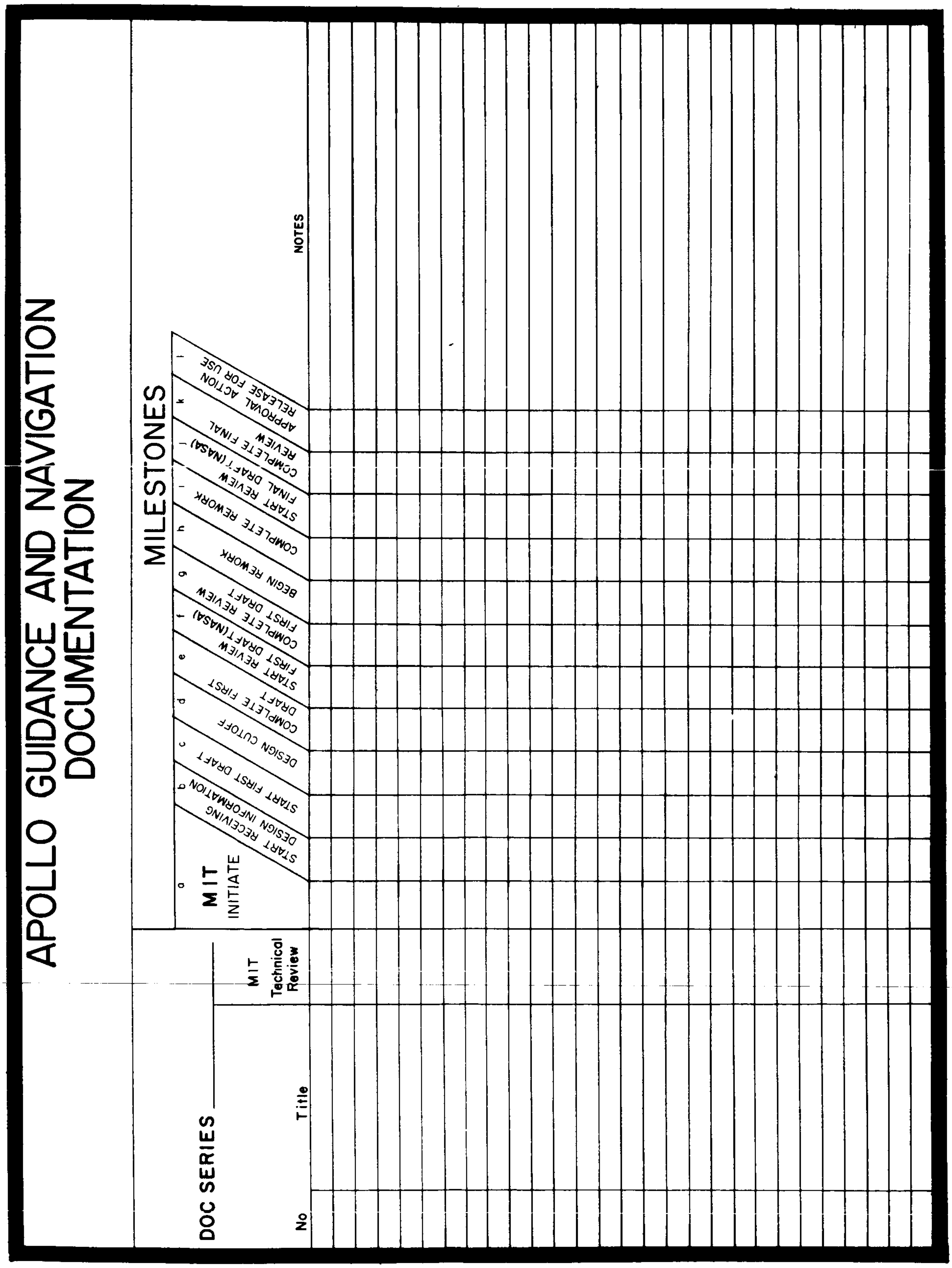


Figure 2.2-2. Sample Documentation Milestone Chart.

2.3 FIELD SERVICE

2.3.1 General Requirements

Requirements for field service personnel will be fulfilled in two ways. First from MIT, on a rotational basis, design engineers will be used. Second, some or all of the industrial support contractors will be required to furnish design personnel and field service personnel at the various field activities.

It must be stressed that these field personnel must be of the highest quality. The most direct measure of performance of a system team is obtained from field operations. The work performed at the field activities does not properly fall into the classical field service category; rather, each of the field operations is an integral part of design engineering. Every attempt must be made to obtain a flow of personnel from concept, to design, to manufacture, and to field test. This diverges from the usual procedure of obtaining a flow of paper.

An MIT engineer will be assigned as lead engineer responsible for guidance and navigation and checkout at each field activity. Industrial support personnel at these activities will receive direction from the MIT lead engineer.

2.3.2 Contractor's Personnel

The offeror should indicate how he will implement the flow of personnel through the various program phases. Where possible he should indicate who the personnel are.

2.3.3 Contractor's Manpower

The offeror should estimate how many personnel he will need at the launch site and spacecraft test site to support the testing, alignment, and checkout.

2.3.4 Test Site Operation

Any support activity at the test site that is an MIT responsibility, such as stock room, GSE installation, documentation, data reduction, routine AGE maintenance, and maintenance of facilities, will be performed by an industrial support contractor. MIT will direct these functions.

Section 3

DETAILED TECHNICAL AREA REQUIREMENTS

This section contains detailed descriptions of the technical aspects of the industrial support program. This section is divided into individual descriptions of the major technical areas.

3.1 SYSTEM ASSEMBLY AND TEST, WORK STATEMENT FOR INDUSTRIAL SUPPORT

The system offeror will be requested to perform in two major areas: System Assembly and Test, and Inertial Measurement Unit Manufacture. The requirements for System support are described in 3.1.1 and 3.1.2. Requirements for IMU support are described in 3.1.3 and 3.1.4.

3.1.1 Introduction (System)

A. This offeror will be responsible for assembling and testing complete sets of Guidance and Navigation equipment, AGE, and providing the checked-out systems to NASA. The offeror will receive completely tested subsystems (AGC, SXT, etc.) that have passed their Acceptance Tests. He will be required to assemble these units with those he built and operate them so as to perform System Acceptance Tests. This offeror will manufacture, assemble, and test those displays and controls not assigned to other subsystems manufacturers and will assemble all displays and controls into the display and control console. The offeror will also manufacture the necessary system cabling and produce the system manuals requested of him.

B. Checklist of Type of Effort to be Furnished

Analysis (exclusive of Major System)	yes
Design	yes
Breadboard	yes
Manufacture	yes
Assembly	yes
Test	yes
Field Service	yes
Documentation	yes
Level-of-Effort Assignment	yes
Major System Analysis	yes

3.1.2 Detail Requirements (System)

A. ANALYSIS (Exclusive of Major System)

Determine tolerance levels of parameters being tested in System Test.

Correlate with maintenance philosophy and Subsystem contractors.

B. DESIGN

1. Devise test equipment to simulate the spacecraft wiring, power, and mechanical interfaces to the extent required for production testing. Where

possible the test equipment should be the same modular construction as GSE. The offeror may be requested to participate with MIT in design of equipment for system development testing.

C. BREADBOARD

1. The offeror may be required to construct breadboard models of test set-ups to demonstrate feasibility.

D. MANUFACTURE

1. Interface cabling, and some displays and controls not otherwise manufactured as parts of other subsystems.

E. ASSEMBLY

1. Receive environmentally tested subsystems (AGC, SXT, etc.) that have passed their Acceptance Tests and assemble these units for the performance of System Acceptance Tests. The schedule for accomplishment is shown in Chart 1.3-1 (Milestone Chart for AGE).

2. Have the capability to assemble field repair kits (in cooperation with the subsystem contractors) and to install these kits (not to overlap Field Site Operations).

3. Maintain a repair facility (not to duplicate main subsystem repair facilities).

F. TEST

1. Devise and perform an Acceptance Test Procedure.

2. Devise and perform an Operational Checkout Procedure.

3. Devise and perform Environmental Tests as required.

G. FIELD SERVICE

1. The offeror will furnish a minimum of one engineer per system to be responsible for each system being shipped. That engineer will become familiar with each subsystem at an early stage of the design phase, witness, and participate where possible, in the test phases of subsystem

manufacture. He will supervise system test at the offeror's plant, and participate in System Acceptance Tests at the field site under MIT direction. The offeror will furnish additional field service personnel as needed to support the field site operations. This latter requirement will depend upon support furnished by other subsystem contractors.

H. DOCUMENTATION

1. Conform to general requirements listed in Section 2.2 of this report.

2. Maintain system log books which will include pertinent data as follows:

   a. subsystem manufacturing history

   b. repair and failure history and reporting (TFR)

   c. system alignment and calibrations

   d. telemetry calibrations, if any

   e. the entire applicable drawing list

3. Issue flight test reports to the extent that they complement, but do not duplicate the efforts of NASA, MIT, and other associate contractors.

I. LEVEL-OF-EFFORT ASSIGNMENT

1. Coordinate scheduling between NASA, the subsystem contractor and the spacecraft contractor to insure timely delivery.

J. MAJOR SYSTEM ANALYSIS

1. The contractor may be required to participate in the analytic and computer study phases of the program, but the extent to which this participation will occur depends upon the capabilities of the contractor.

2. Efforts in each of the following areas are currently underway at MIT. Various of these could be supplemented by the contractor.

   a. Saturn Booster Monitoring - the derivation of a guidance technique and the AGC programming requirements to achieve specified orbits about the earth or direct injection into a specified translunar orbit.

Consideration will be given to the guidance for performing an abort during the ascent-booster phase.

b. Earth Orbit Guidance and Navigation - a study of the accuracy requirements for navigation using feasible measurements and the derivation of techniques for on-board improvements of data.

The study shall encompass both short term orbits, such as the parking orbit used prior to injection into lunar orbit and long term orbits of many days. Particular goals of this study will be the development of techniques and AGC programming requirements for generating accurate initial data prior to injection into translunar orbit or initiating re-entry from an earth orbit.

c. Translunar and Transearth Insertion Guidance - the techniques for inserting the APOLLO spacecraft into a translunar (transearth) trajectory from parking orbits around the earth (moon) and by direct ascent from the earth (moon).

The techniques and insertion data shall account for variations in launch conditions and meet the capabilities of both circumlunar flight and of achieving an orbit around the moon and return to earth.

d. Midcourse Navigation - techniques and AGC programming requirements for guiding translunar and transearth flight beginning at the injection into these trajectories and ending with either de-boost for insertion into lunar orbit or initiation of atmospheric re-entry guidance.

In the course of this study, considerations will be given to:

(1) Methods of generating data and navigation matrices with the AGC.

(2) The effects of uncertainties in launch time.

(3) Optimum navigation measurements using the space sextant currently under design at MIT/IL.

(4) Optimum use of corrective propulsion.

(5) Practical on-board iteration techniques applicable to explicit guidance as an alternate to the method of linearized, precalculated reference trajectory navigation.

e. Lunar Orbiting, Landing and Take-Off - the guidance and control required to effect these phases efficiently and successfully.

In the course of the study, consideration shall be given to:

(1) The improvement of estimates of orbital position and velocity prior to descent through techniques employing such devices as the MIT/IL optical system, radar ranging, and doppler velocity measurements.

(2) The optimization of the descent trajectory with respect to orbital altitude, propellant consumption, and guidance accuracy.

(3) The effects of the variations in the time of transearth flight as related to time spent in lunar orbit or on the moon.

f. Re-entry Guidance - techniques to optimize the success of re-entry as well as to control the vehicle to a landing site.

The study shall include an exploration of optimum trajectory characteristics for a variety of re-entry conditions and range requirements. Consideration shall be given to the effects of errors in measurement of position and velocity prior to re-entry and the inaccuracies in the inertial measurement unit. All re-entry schemes shall include predictions of down-range, lateral range, and remaining time of flight.

g. Rendezvous Guidance - techniques of achieving orbital injection and performing rendezvous maneuvers which minimize the required propellant expenditure.

Consideration shall be given to the following important rendezvous problems:

(1) During launch and ascent, uncertainties in timing are critical to success. The use of an intermediate orbit and a final orbital transfer maneuver to reduce this criticality shall be studied.

(2) Abort or emergency guidance procedures if target lockon or successful docking cannot be accomplished.

(3) Highly accurate guidance and attitude control during terminal docking must be achieved in order to stay with impact limits of the coupling devices. Techniques shall be considered to achieve the required accuracies.

3. Several types of personnel can be considered. The range can be from those who do only analysis to programming to engineering plus personnel who combine these talents into one. The offeror should show how personnel who contribute in the analytical phases can be used to insure that engineering, manufacturing, and field operations properly follow through. A continual shifting of personnel into and out of the program will lead to having other contractors perform these tasks.

4. Initially all analysis work should be performed at MIT to effect efficient and quick solution to the many problems.

5. Perform flight test data reduction analysis of flight test data, and issue flight test reports to the extent that they complement but do not duplicate the efforts of NASA, MIT, and other associate contractors.

3.1.3 Introduction (Inertial Measurement Unit)

A. The industrial support contractor will manufacture, assemble, align, and checkout Inertial Measurement Units (IMU) according to MIT's design and procedures. These IMU's will be required according to the schedule shown in Chart 1.3-1. The inertial components, IRIG's and PIP's, will be supplied as GFE. These must be acceptance tested and calibrated for use in the IMU. The acceptance test equipment will be GFE from NASA through the Ground Support Equipment (GSE) industrial support. For checkout and alignment, portions of the GSE will also be used.

The IMU is a three-gimbal stabilized platform using three 25 Size Inertial Reference Integrating Gyroscopes (IRIG's) and three 16 Size Pulsed Integrating Pendulums (PIP's). The axis orientation of the IMU is such that with all gimbal angles zero (gimbal axes orthogonal) the inner axis will be aligned with the spacecraft pitch plane, the middle axis along the spacecraft yaw plane, and the outer gimbal axis along the spacecraft roll plane. All axes will have unlimited angular freedom. To avoid gimbal lock, provision will be made for accurately re-orienting the stable member about the middle axis. The IMU will be space aligned by means of Space Sextant information.

B. Checklist of Type of Effort to be Furnished

Analysis (exclusive of Major System)	no
Design	no
Breadboard	no
Manufacture	yes
Assembly	yes
Test	yes
Field Service	yes
Documentation	yes
Level-of-Effort Assignment	yes

3.1.4 Detail Requirements (Inertial Measurement Unit)

A. ANALYSIS (Exclusive of Major System)

Not applicable.

B. DESIGN

Not applicable.

C. BREADBOARD

Not applicable.

D. MANUFACTURE

On October 1, 1962, a "design freeze" will be effected; this means that the information on the drawings at that time will essentially depict the parts to be procured for IMU-4 through -16, and at that time a design release will be transmitted to the Industrial Support Contractor. During the period prior to this date, preliminary design information will have been forwarded to the contractor for his planning.

Revisions to the drawings will continue beyond October 1, 1962 for reasons of producibility, format, etc. Any design change will be passed upon by the Change Control Board before incorporation in the formal IMU's design. The intention is to produce all IMU's through -16 to the same design, backfitting if necessary in the case of major changes.

The Industrial Support Contractor should have a Liaison Engineer who will be the contact between the MIT Mechanical Design Group and the Contractor. This man should be a senior engineer, and his duties should include the following:

1. A visit to the Instrumentation Laboratory periodically, (probably weekly) to receive and discuss design information. These visits should coincide with the Change Control Board meetings when they start.
2. He should become as familiar as possible with the design so that he can answer questions and instruct personnel at the Contractor's facility.

3. He should oversee a Producibility Review where various groups at the Contractor's facility will review the drawings for ease of fabrication, cost, inspection methods, etc., as they are affected by the production quantity anticipated.

4. He should oversee the writing of component specifications at the Contractor's facility.

E. ASSEMBLY

1. General

The Inertial Measurement Unit (IMU), see Figure 3.1-1, will be a three-axis gimbal assembly designed to space stabilize a member denoted as the Stable Member (SM). The SM is supported by the Middle Gimbal (MG) and is free to rotate with respect to the MG about the inner axis, in like manner, the MG is supported by the Outer Gimbal (OG) and rotates about the middle axis, and the OG is supported by the Gimbal Case (GC) and rotates about the outer axis.

The SM supports six inertial components (IC) suitably oriented with respect to each other, these are three Size 25 Inertial Reference Integrating Gyros (25 IRIG) and three Size 16 Pulsed Integrating Pendulums (16 PIP). Also mounted on the SM are the necessary Gimbal-Mounted Electronics (GME) modules associated with these IC's.

The SM, MG, and OG are each supported respectively in the MG, OG, and GC by means of a pair of assemblies called Inter-Gimbal Assemblies (IGA). The IGA's consist of a stubshaft, bearings, bearing support and such items as torquers, electromagnetic components, and slip ring assemblies as are required for the axis in question.

Temperature control of the IC's and heat dissipation for all power consuming items, such as the inertial components, torquers, and electromagnetic components, will be designed into the IMU. A more detailed description of the temperature control scheme is given in the "Thermal Control" section of this report.

The IMU, together with the SXT, will be supported in a rigid structure to maintain the alignment required between the two units. This structure in turn is attached to the Command Module.

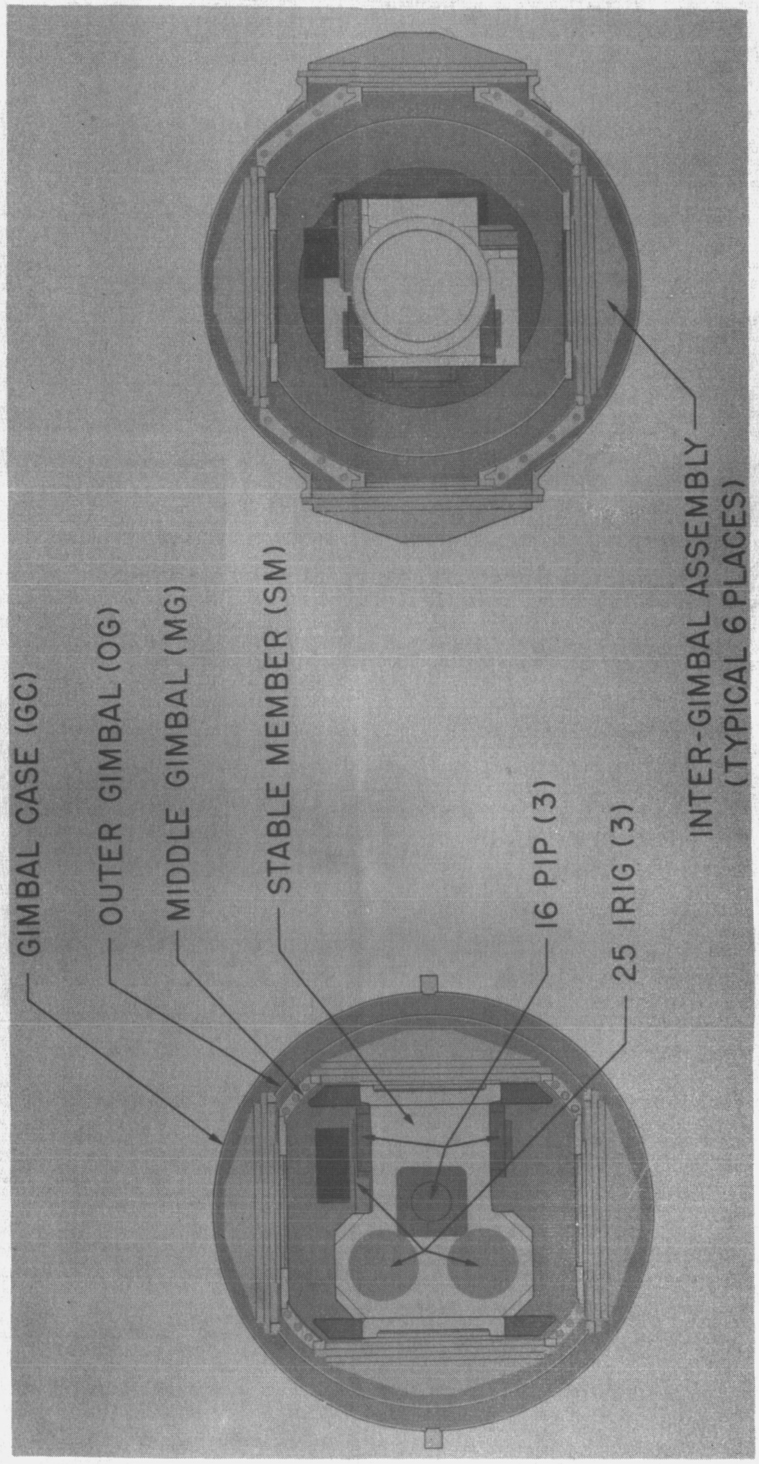


Figure 3.1-1. Inertial Measurement Unit.

At this time, it appears necessary that the IMU be enclosed in an hermetically-sealed case to guarantee its operation at 0 psia, as specified for emergency operation.

The weight and volume allotted to the IMU is 60 pounds and 1 cubic foot; it appears at this time that the weight allowance is adequate, but the volume allowance will be exceeded if the hermetic case is required.

2. Detail

The Inertial Components will be assembled with mounting hardware and all necessary electronics to allow interchangeability, the mounting hardware will include provisions for prealignment of the IRIG or PIP. Figure 3.1-2 shows a mockup of a typical 25 IRIG prealigned and wired assembly. These assemblies will be wired to connectors so that they may be plugged into the wiring harness on the SM.

The Stable Member will probably be a solid beryllium block, toleranced to guarantee the specified alignment accuracy from IC to IC to the inner gimbal axis.

The MG, OG, and GC will be hydroformed roll-bonded hemispheres dip brazed to precision cast mounting flanges. The roll-bonded sheets will be "blown-up" to give stiffening ribs in a particular pattern on the hemispheres prior to brazing, see Figure 3.1-3. The gimbal case or hermetic case will have integral cooling passages, possibly the roll-bonded pattern, through which the water glycol coolant will flow. The gimbals and case will be spheres split into hemispheres through the axes; this will permit access to the SM by simply removing one hemisphere from the case and each gimbal.

The case, gimbals, and SM will be attached to each other with Inter-Gimbal Assemblies (IGA). A typical IGA (see Figure 3.1-4) will include:

Stub Shaft - beryllium
Bearing Mount - beryllium
Bearings - duplex pair, with low preload
(fixed to or floated on the stub shaft)
Slip Ring Assembly - approximately 35 rings

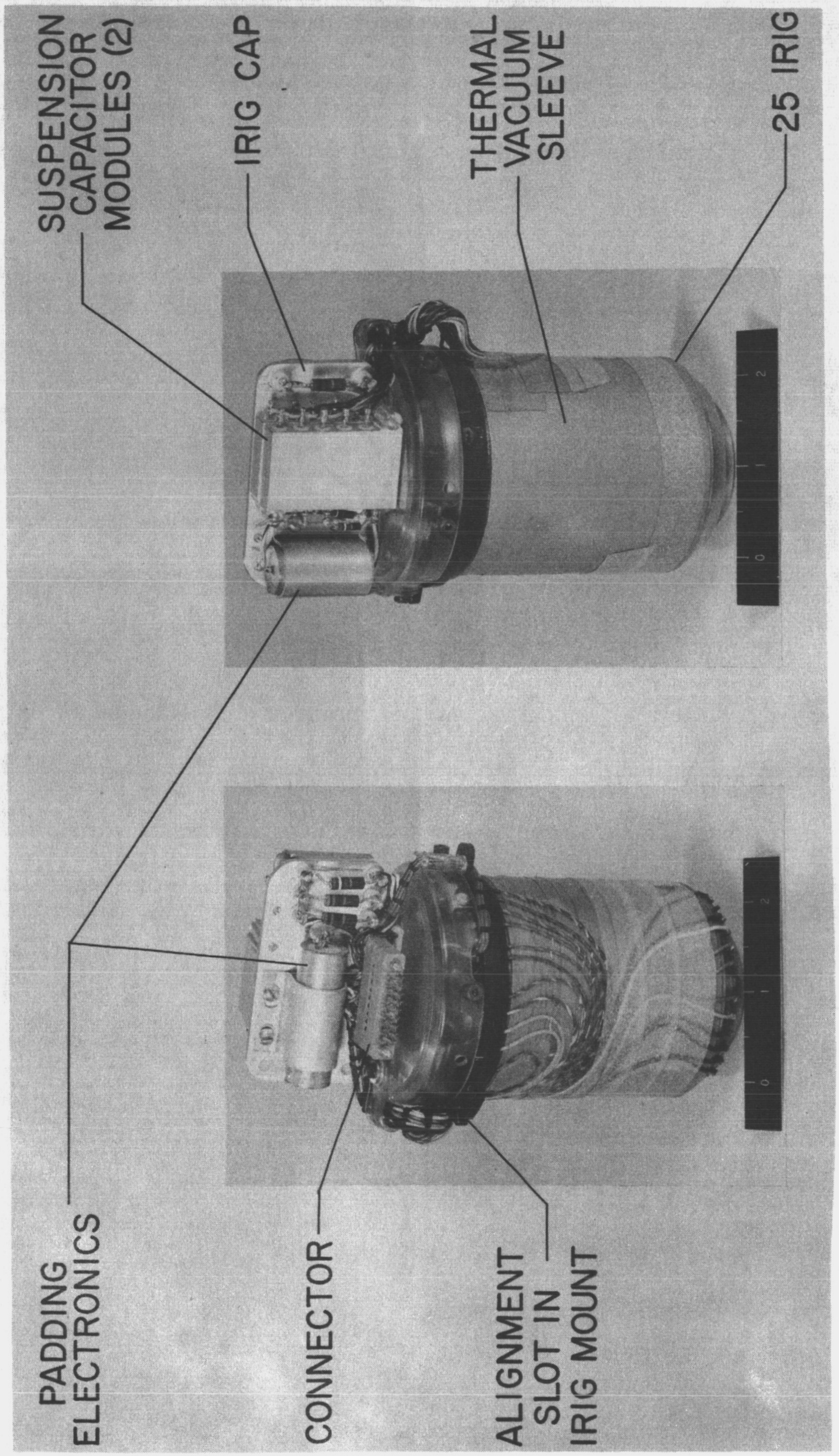


Figure 3.1-2. 25 IRIG Prealigned and Wired Assembly for IMU.

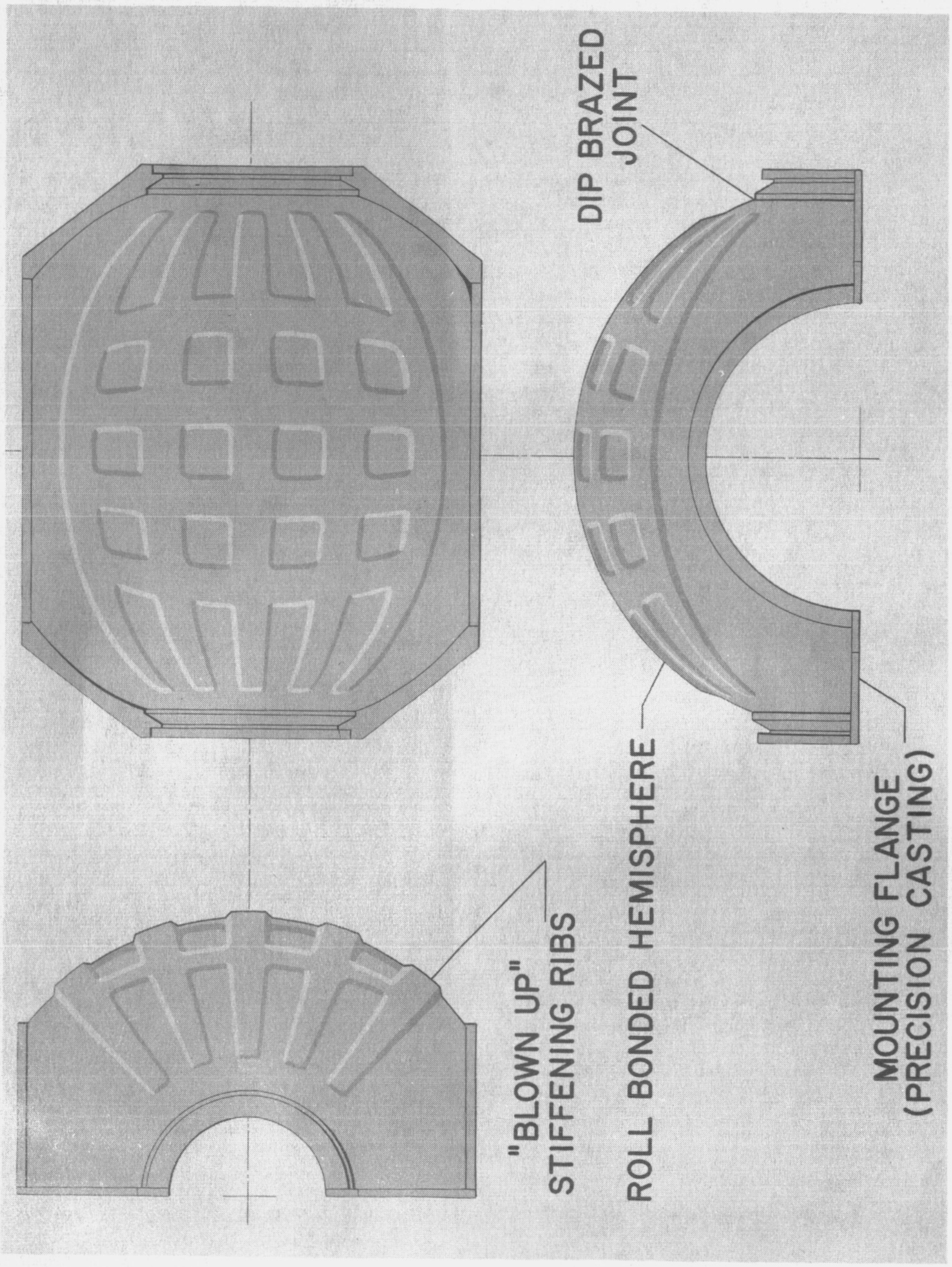


Figure 3.1-3. Typical Gimbal Hemisphere for IMU.

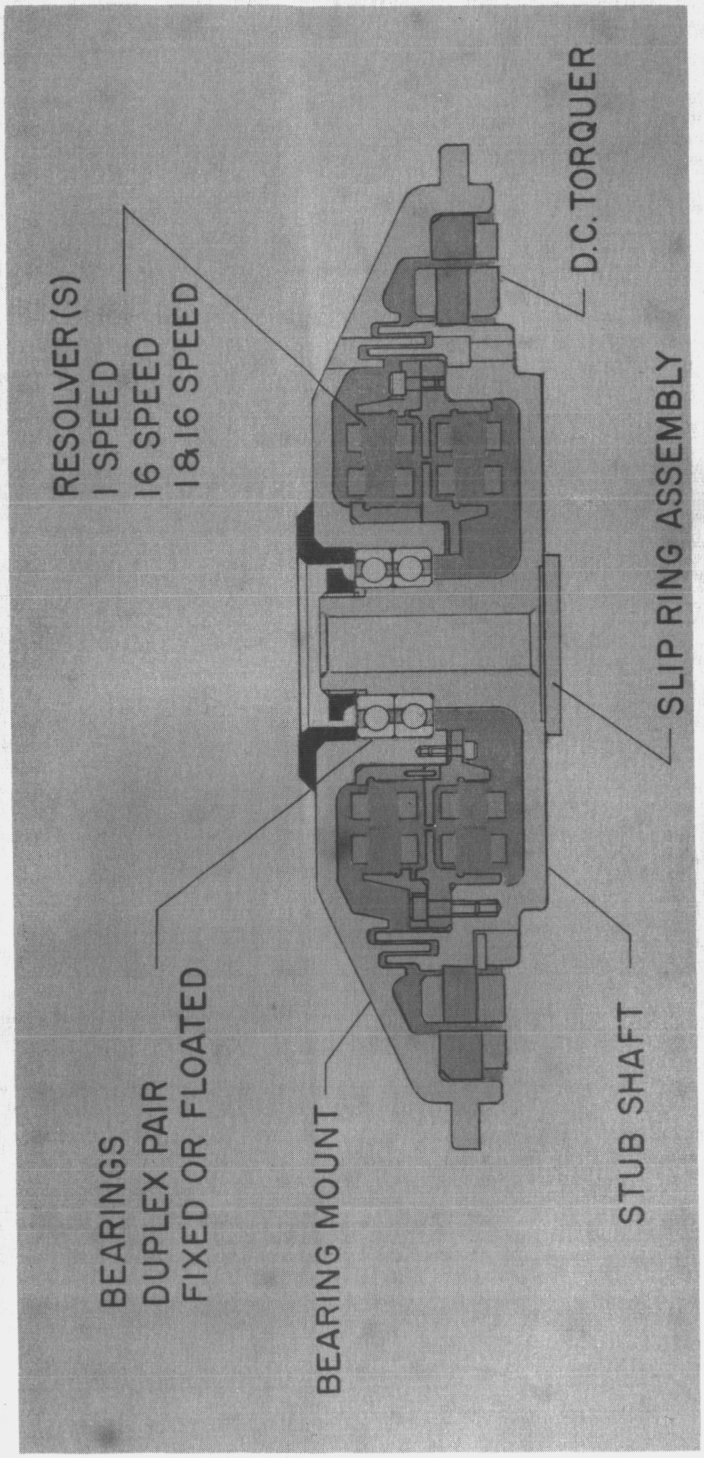


Figure 3.1-4. Typical Inter-Gimbal Assembly for IMU.

Resolvers - 1 single speed
1 16 speed
or
1 single speed
Torquer - approximately 5.5" air gap dia. direct current
Wiring and Connectors

The gimbal case will be mounted in an hermetically sealed case, which will be a sphere approximately 16-1/2" in diameter. One-half of this hermetic case will be attached to the IMU-SXT mount.

F. TEST

1. To support manufacture as necessary.

G. FIELD SERVICE

1. To conform to general requirements of paragraph 2.3 of this report. Also, see I. below.

H. DOCUMENTATION

1. Conform to general requirements listed in Section 2.2 of this report.

I. LEVEL-OF-EFFORT ASSIGNMENT

1. IRIG Testing and Calibration

One man will be required to learn to test and calibrate the IRIG as it will be used in the IMU. It is estimated that at least one month will be the in-residence period, depending upon a number of factors.

2. Accelerometer Testing and Calibration

One man will be required to learn to test and calibrate the PIPA as it will be used in the IMU. It is estimated that one month in-residence will be required.

3. System Alignment

Two men are required, both for an extended period of time. Both of these men will work on the system alignment and environmental testing. At the time AGE 1/6 is ready for alignment, one of these men will return to the industrial support contractor. The other man will remain at MIT until after the SA-7 flight of AGE 1/5. IMU lead-time schedule is given in Chart 3.1-1.

4. IMU Temperature Control System

During initial development, one liaison engineer is required in full-time residency at MIT. During the later phases, he will only be required to visit MIT for a period of two to three days per month.

During the initial phases of development, he will be expected to become familiar with all phases of the design so that he can answer questions and instruct personnel at the contractor's facility.

In the later phases of design, he will be expected to keep up to date with all modifications and see that these modifications are properly attended to at the contractor's facility.

He will also be relied upon to oversee the writing of component and system specifications at the contractor's facility.

5. Other Personnel

Other personnel will be required at various times and for various periods to insure close coordination between MIT and the industrial support source.

It may become necessary in the future to request assistance from the industrial support contractor on various studies, for example:

a. Slip Ring Evaluation - life, environment, reliability, noise, etc.
b. Torquer Evaluation - brushes, commutator
c. Bearing Evaluation - friction, lubrication
d. Wiring

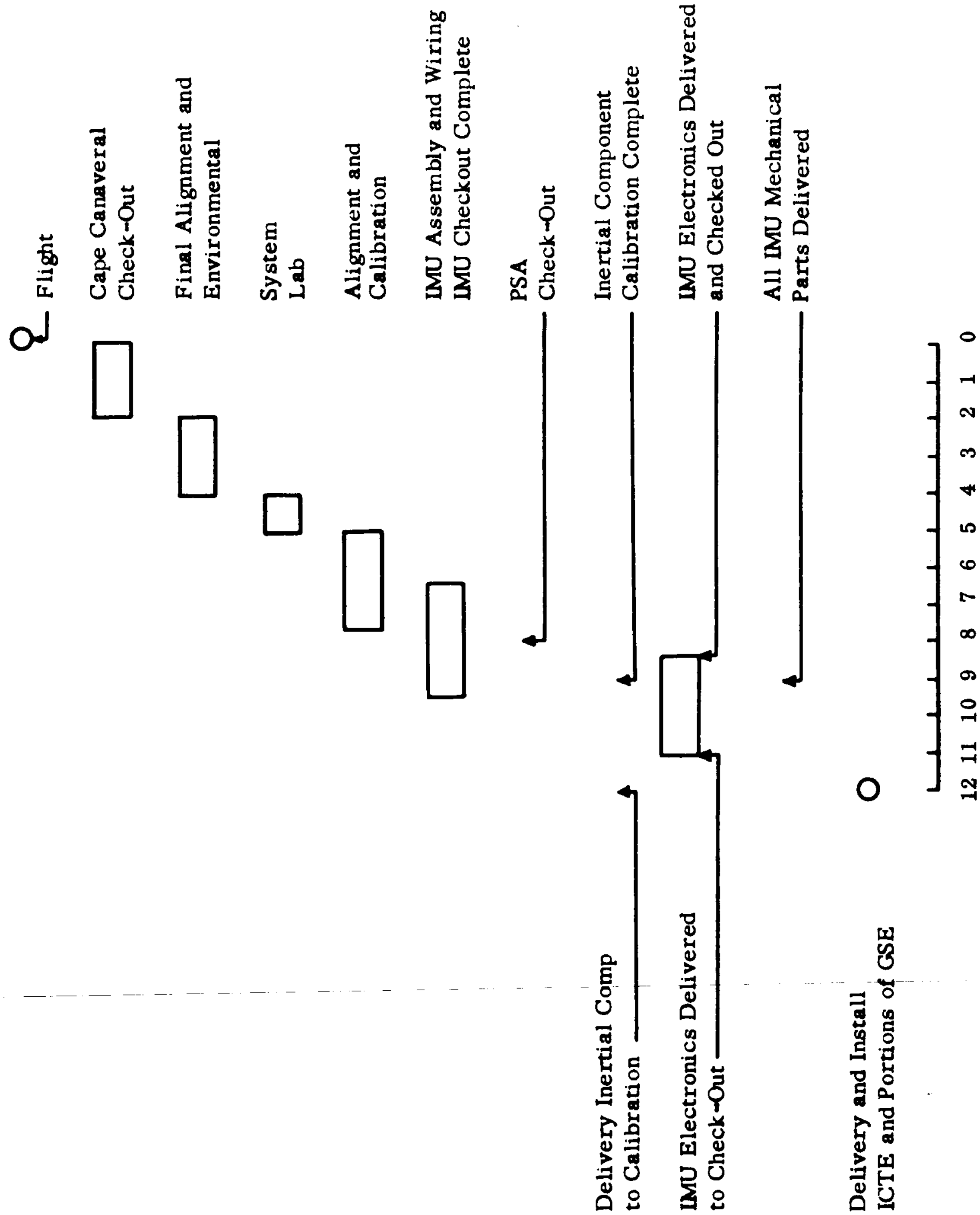


Chart 3.1-1. IMU Lead-Time Schedule.

3.1.5 Technical Appendices

A. GENERAL DESCRIPTION OF THE INERTIAL MEASUREMENT UNIT

The Inertial Measurement Unit (IMU) is a three gimbal stabilized platform using three 25 Size Inertial Reference Integrating Gyroscopes (IRIG). The stable member of the IMU has three 16 Size Pulsed Integrating Pendulums (PIP). The axis orientation of the IMU is such that with all gimbal angles Zero (gimbal axis orthogonal) the inner axis will be aligned with the spacecraft pitch axis, the middle axis along the spacecraft yaw axis, and the outer gimbal axis along the spacecraft roll axis. All axes will have unlimited angular freedom. To avoid gimbal lock, provision will be made for accurately re-orienting the stable member about the middle axis. The IMU will be space aligned by means of Space Sextant information and because of this the IMU and Space Sextant will be mounted in close proximity with as much rigidity as necessary.

The IRIG gyroscopes have an angular momentum of 450, 000 gm cm^2 sec. These are floated integrating gyroscopes and geometrically stabilized with respect to the case by the fluid and the magnetic suspension system (ducosyn). Signal information is transmitted by a microsyn signal generator. There is a microsyn torque generator which will be utilized for re-aligning the IMU in flight and for pre-flight erection and alignment. The gyroscope will be pulse torqued for these alignments.

The accelerometers are pulse torqued pendulums utilizing the 16 PIP as designed for the APOLLO mission. The accelerometers provide velocity increments of the integrated acceleration. The pendulums are geometrically stabilized with respect to the case by the flotation fluid and the magnetic suspension (ducosyn). The pendulum also contains a microsyn signal generator and torque generator.

It will be the function of the IMU to provide a space stabilized coordinate system and measure the specific force. It may be used in the initial earth launch guidance system. It will be used for rendesvous guidance, orientation and guidance for injection into the earth-lunar orbit, mid-course velocity correction measurements, guidance for lunar landing and lunar takeoff and guidance for the earth re-entry.

B. DESCRIPTION OF IMU TEMPERATURE CONTROL SYSTEM

1. Operational Temperature Control System

a. System Philosophy. The requirement of a low power system and the indication that a duty cycle type of operation will exist together with recent developments in the formulation of high capacity heat storage materials dictates that a unique temperature control system should be developed. It is MIT's intent to pursue the tremendous overall system efficiencies that can be achieved utilizing the aforementioned heat storage techniques. It is believed that it will be possible to achieve, sometime in the future, a temperature control system requiring zero power consumption. This can be achieved only if a definite duty cycle is established, and the inertial component temperature sensitivity is sufficiently small. In any case, a minimum power temperature control system will be the result.

b. Detailed description of system

(1) Heat transfer. The design objectives to be met by the heat transfer portion of the overall temperature control system is to effect the removal of heat generated by the inertial component and other heat dissipating components from the stable member to the command module heat sink. This heat transfer must be accomplished along paths in the case of the inertial components which result in the least disturbance to inertial component performance. It is also desirable to transfer the heat generated at the stable member through the gimbals to the IMU heat sink at an optimum rate compatible with the duty cycle. This rate ideally should be constant under all conditions of temperature, pressure, and gravity. It is planned to accomplish these objectives in the following manner:

(a) Heat dissipated by the inertial components will be transferred through its mounts by metallic conduction to the thermal storage material.

(b) The heat storage material contained in an appropriate heat exchanger will be located on the stable member.

(c) Heat transferred from the stable member to the CM heat sink will be achieved under normal operating conditions by metallic and gas conduction and radiation.

(d) The heat transfer rate from the stable member to the CM heat sink will be controlled by the mechanical and thermal design of the IMU. This rate will be such that under normal duty cycle operation the thermal storage material will never be completely filled.

It is realized that a prediction, at this time, of the exact duty cycle is impossible. We, therefore, plan to have an outer gimbal mounted blower which will be used only in a case where the thermal storage material has been saturated due to extended periods of operation. The purpose of this blower is to obtain a substantial increase in heat transfer from the stable member to the CM heat sink.

(2) Control. As stated previously, it is our objective to achieve inertial component temperature control without electrical power. This is, of course, a long range objective. Due to the time schedule and the unknown factors involved, it is planned in the interim to obtain fine temperature control by utilizing inertial component end mount heaters controlled by a magnetic or transistor amplifier temperature controller utilizing the inertial component temperature probe as a control sensor. It is planned that a minimum of two amplifiers will be used, one controlling the average IRIG temperature, the other controlling the average accelerometer temperature. The exact location of the amplifiers has not yet been determined, but it would be desirable to locate them on the stable member.

(3) Monitoring. It is presently planned to have two temperature monitoring circuits, one for the IRIGs, the other for the accelerometers. These circuits will consist of a dc bridge, an amplifier and an appropriate readout device located in the display console. The temperature indicating sensors will be IRIG thermistors and accelerometer probes.

2. Non-Operating Temperature Control

   a. At the present time, it is desirable to maintain an inertial platform utilizing floated inertial components at or near their operating temperature throughout all phases of its life. This means that it will be necessary to develop specialized equipment for maintaining IMU temperature control during non-operating conditions. These non-operating conditions consist of short-term storage either in laboratories, checkout areas, or launching facilities. It will be necessary to develop special temperature controlled shipping and handling containers for transporting the IMU from one location to another unless some suitable shipping and handling container design already exists.

	GYRO UNITS	ACCEL. UNITS	MATERIALS	MISC.
STABLE MEMBER	3-25 IRIG (APOLLO)	3-16 PIP	BERYLLIUM	GIMBAL MOUNTED ELECTRONICS
MIDDLE GIMBAL	NONE	NONE	HYDRO-FORMED ROLL-BONDED ALUMINUM HEMISPHERES	NONE
OUTER GIMBAL	NONE	NONE	HYDRO-FORMED ROLL-BONDED ALUMINUM HEMISPHERES	NONE
GIMBAL CASE	NONE	NONE	HYDRO-FORMED ROLL-BONDED ALUMINUM HEMISPHERES	NONE
HERMETIC CASE	NONE	NONE	HYDRO-FORMED ROLL-BONDED ALUMINUM HEMISPHERES	COOLING TUBES ELECTRICAL & COOLANT CONNECTORS

	SLIP RINGS	BEARINGS	RESOLVERS	TORQUERS	ANGULAR MOTIONS
INNER GIMBAL AXIS	2 ASSEMBLIES APPROX. 35 RINGS EACH	DUPLEX PAIRS 1-FIXED 1-FLOATING	2-SINGLE SPEED 1-16 SPEED	2-5.5" AIR GAP D.C.	UNLIMIT'D.
MIDDLE GIMBAL AXIS	2 ASSEMBLIES APPROX. 35 RINGS EACH	DUPLEX PAIRS 1-FIXED 1-FLOATING	1-SINGLE SPEED 1-16 SPEED	2-5.5" AIR GAP D.C.	±80°
OUTER GIMBAL AXIS	2 ASSEMBLIES APPROX. 35 RINGS EACH	DUPLEX PAIRS 1-FIXED 1-FLOATING	2-SINGLE SPEED 1-16 SPEED	2-5.5" AIR GAP D.C.	UNLIMIT'D.

Figure 3.1-5. Mechanical Design Specification Summary for IMU.

3.2 GROUND SUPPORT EQUIPMENT, WORK STATEMENT FOR INDUSTRIAL SUPPORT

3.2.1 Introduction

A. This effort involves the design and manufacture of Ground Support Equipment to operate complete APOLLO Guidance and Navigation Equipments.

Using the reference data provided and his own initiative, the offeror should propose concepts for the GSE, design guide lines, mechanical and electrical feature, design details, manufacturing techniques, delivery schedules, quantities, and usage.

The offeror should show what his organization will be and how it will function. The possibility exists of having lead analytical and design personnel resident at MIT during the conceptual and design phase. Show what the responsibilities of these personnel would be during the manufacturing phase.

B. Checklist of Type of Effort to be Furnished

Analysis (exclusive of Major System)	yes
Design	yes
Breadboard	yes
Manufacture	yes
Assembly	yes
Test	yes
Field Service	yes
Documentation	yes
Level-of-Effort Assignment	yes

3.2.2 Detail Requirements

A. ANALYSIS (Exclusive of Major System)

A major analytical effort leading to design of GSE is expected of the offeror. MIT expects to furnish general guidelines and design review. The offeror will estimate the effort required to fulfill the objectives described in other paragraphs of this work statement.

B. DESIGN

1. General

The technical concepts for the Ground Support Equipment (GSE) have not been fully established, but some development guide lines may be stated:

a. There will be a requirement to operate complete APOLLO Guidance Equipments (AGE) in the development laboratory, the test laboratory, the manufacturer's plant(s), the training site, the spacecraft check-out and test sites, launch site, and others not yet defined. Furthermore, partial AGE equipments such as computer (AGC), sextant (SXT), etc., must be capable of independent test, checkout, alignment, and calibration at many different places. It would be most desirable to have one basic set of Ground Support Equipment to serve in all of these roles.

   It may, for example, be possible to design a module of equipment called the Inertial Measurement Unit Ground Support Equipment (IMUGSE). This module could operate the IMU during the development, manufacturing, and test phases of the IMU. This same ground support equipment module could be combined with the computer GSE module, the sextant GSE module, etc., to form an integrated GSE for operation of a complete set of APOLLO Guidance Equipment.

b. The design must have growth potential. It must be expected that modification of the GSE will be extensive as the program progresses. When these modifications are made, cost must be held to a minimum. This may mean that circuits should be reconnected rather than replaced.

c. The number of different types of spare parts should be kept to a minimum; at the same time, the unit cost of each spare part should be kept small.

d. Design must be compatible with the launch vehicle and spacecraft support equipment.

e. Life:

operating time	________________	) The offeror will
		) suggest appropri-
shelf life	________________	) ate limits for
		) these specifications.

f. Reliability: Offeror is invited to suggest specifications.

g. Environment: Offeror is invited to suggest specifications.

2. Inertial Component Test Equipment (ICTE)

There is a requirement for ICTE for both the accelerometer and gyroscopes. This equipment will be as identical as possible to that of the GSE when considered in modular form. Presently, the design for the accelerometer ICTE is very advanced and detailed. Effort at MIT will finalize the design of this equipment in the near future. It is estimated that five (5) sets of this equipment will be provided. The offeror is not expected to bid on any assist effort at this time.

a. Pendulum development MIT
b. Accelerometer development MIT
c. IMU alignment and calibration MIT
d. Pendulum manufacture
e. Industrial support for IMU

The gyroscope ICTE has not been designed in as great a detail as the accelerometer ICTE. The requirement exists for several functions of the IMU, which necessitates alteration and addition to present procedures for gyroscope acceptance testing. To insure in-flight performance, acceptance testing procedures and test equipment will be modified or redesigned to accomplish their end. Four sets of equipment are required, and the offeror may be required to manufacture the items resulting from these design modifications.

a. Gyroscope development MIT
b. IMU calibration and alignment MIT
c. Gyroscope manufacture
d. IMU industrial support

In-residence liaison of the GSE contractor personnel will be required at MIT for the ICTE design, development, and evaluation. The first of both sets of ICTE must be installed by October 1962. This is only a moderately tight time schedule. The first inertial components will arrive well ahead of this date. There is a need for installation and delivery of the equipment to be completed earlier, if possible. This identity of modular equipment between ICTE and GSE and the fact that it will be the test equipment utilized on the APOLLO IMU will help insure uniformity of test data. Modification of the ICTE will be under the control of MIT to insure uniformity.

3. Other Test Equipment

As the program progresses requirements for additional test equipment will be identified. An attempt will be made to use GSE building blocks providing such building blocks are at such state of maturity and availability that this can be done.

4. Design Phase

a. The GSE contractor will participate in the design phase. He will be encouraged to propose design concepts. These concepts will be established jointly with the GSE subsystem designers, NASA, other associate contractors as required, and a GSE group at MIT.

An example of how interdependent the design phase will be can be obtained from looking at some concepts that are emerging now in the APOLLO Guidance Computer (AGC) and the associated GSE.

The computer will be designed with a capability of self checking. Thus a power supply and an oscilloscope might suffice for the AGC GSE. For the Lunar launch operation it must be necessary to have a pre-launch checkout. Presumably, this checkout would be an operation self-contained within the command module, although one can conceive of jettisonable Lunar GSE. Presumably, the AGC will perform many checking functions, not only for itself, but for other AGE subsystems. It might be used for checking other spacecraft major subsystems. With all this subsystem and system self-checking capability, what is there left for the terrestrial GSE? That is a question that must be answered during the design phase.

If it is assumed that there will be a requirement for more extensive checkout for terrestrial launch vs. Lunar launch, then it follows that the AGC GSE must contain that equipment which adapts the AGC for this extensive checkout. Add to this a requirement that the AGC GSE also adapt the AGC to training exercises, development tests, system acceptance tests, factory testing, etc., with all associated subsystems; then one sees that there is probably more than a power supply and oscilloscope required.

b. When the concepts are approved by NASA, the contractor will participate in the detail design. It is expected that most of the design will be executed at the GSE contractor's plant. However, MIT, with NASA approval, may execute some of the design at MIT and/or an MIT subcontractor.

c. The possibility of using the AGC to provide automatic checkout has been mentioned. However, this should not indicate that automatic system checking will be desirable when, for example, an Inertial Measurement Unit is subjected to development and factory testing. The production quantity is small, and the differences from system to system may be great. Any tendency to provide automation in all GSE areas must be justified fully.

C. BREADBOARD

1. To support the design effort as necessary.

D. MANUFACTURE

When MIT and NASA have approved a design and a production schedule, the GSE contractor will manufacture the GSE. Some parts, assemblies, or groups of assemblies may be furnished to the contractor, but it is not possible to define these at this time.

E. ASSEMBLY

1. To support manufacture as necessary.

F. TEST

1. To support manufacture as necessary.

G. FIELD SERVICE

1. To conform to general requirements listed in paragraph 2.3 of this report.

H. DOCUMENTATION

1. Conform to general requirements listed in paragraph 2.2 of this report.

I. LEVEL-OF-EFFORT ASSIGNMENT

1. Chart 3.2-1 (Milestone Chart for GSE) is a proposed delivery schedule and usage chart for the GSE. It is certain that the quantities indicated are

inadequate. The delivery schedule is tight, and it is recognized that GSE might well become the limiting item in the Guidance and Navigation program.

WORK STATEMENT FOR INDUSTRIAL SUPPORT

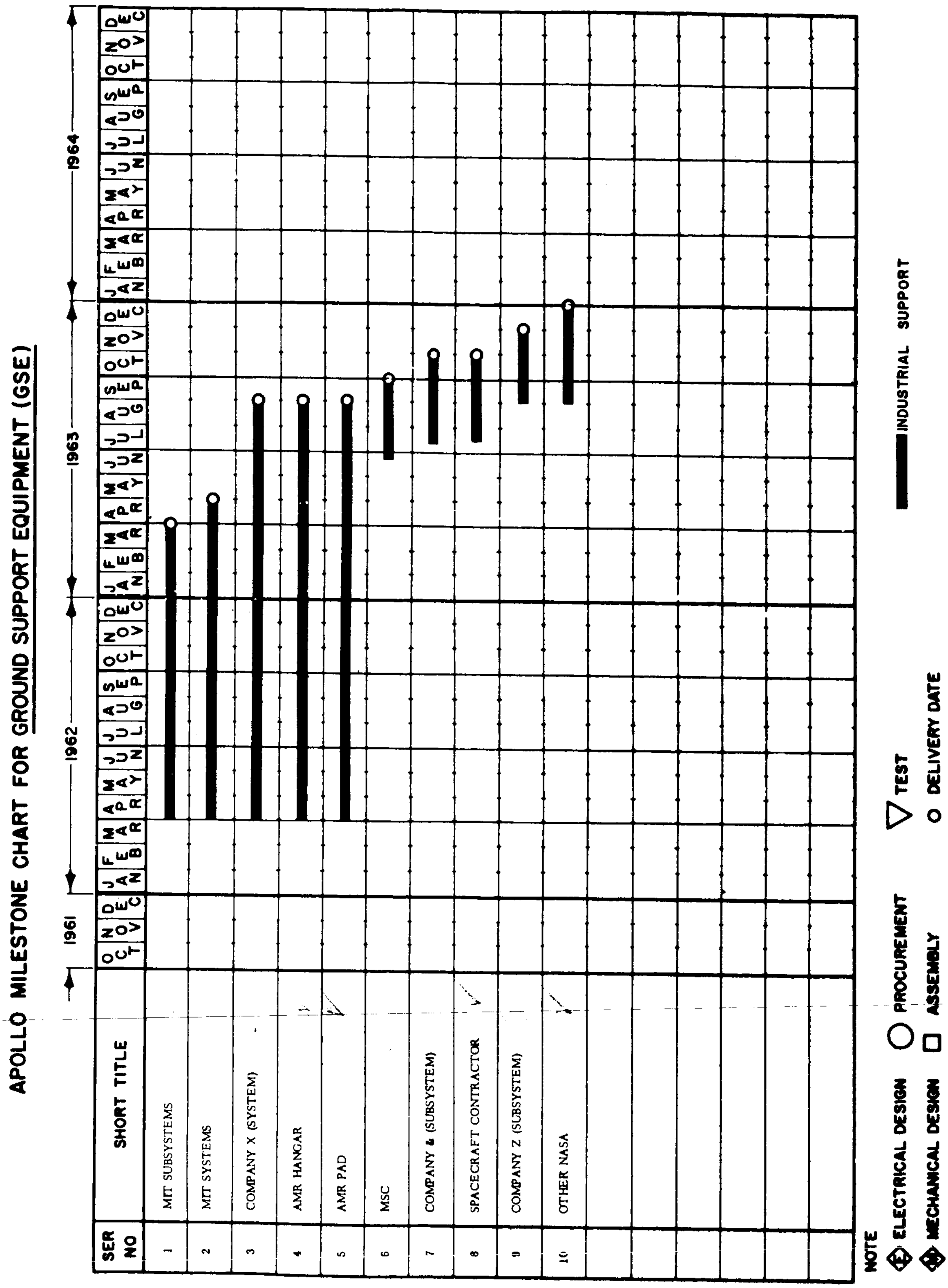


Chart 3.2-1. Milestone Chart for GSE.

Date 5 Jan 62*

WORK STATEMENT FOR INDUSTRIAL SUPPORT E-1097

3.2.3 Technical Appendices (Drawings, reports, test data, etc.)

None

3.3 APOLLO GUIDANCE COMPUTER, WORK STATEMENT FOR INDUSTRIAL SUPPORT

3.3.1 Introduction

A. The Guidance Computer industrial support offeror must manufacture, assemble, test, and deliver the computers in accordance with the schedule of Chart 3.3-1. In addition, the offeror is expected to assist in the design, specification, and packaging of the equipment.

The industrial support offeror will design and build field service test equipment necessary to supplement GSE.

B. Checklist of Type of Effort to be Furnished

Analysis (exclusive of Major Systems)	yes
Design	yes
Breadboard	yes
Manufacture	yes
Assembly	yes
Test	yes
Field Service	yes
Documentation	yes
Level-of-Effort Assignment	yes

3.3.2 Detail Requirements

A. ANALYSIS (Exclusive of Major Systems)

1. Some analytical assistance may be requested by MIT.

B. DESIGN

1. Assist in the design, specification, and packaging of the computer. See also Level-of-Effort in I. below.

2. Specify and design the factory test equipments.

3. Design and build field service test equipment that may be necessary to supplement the guidance GSE.

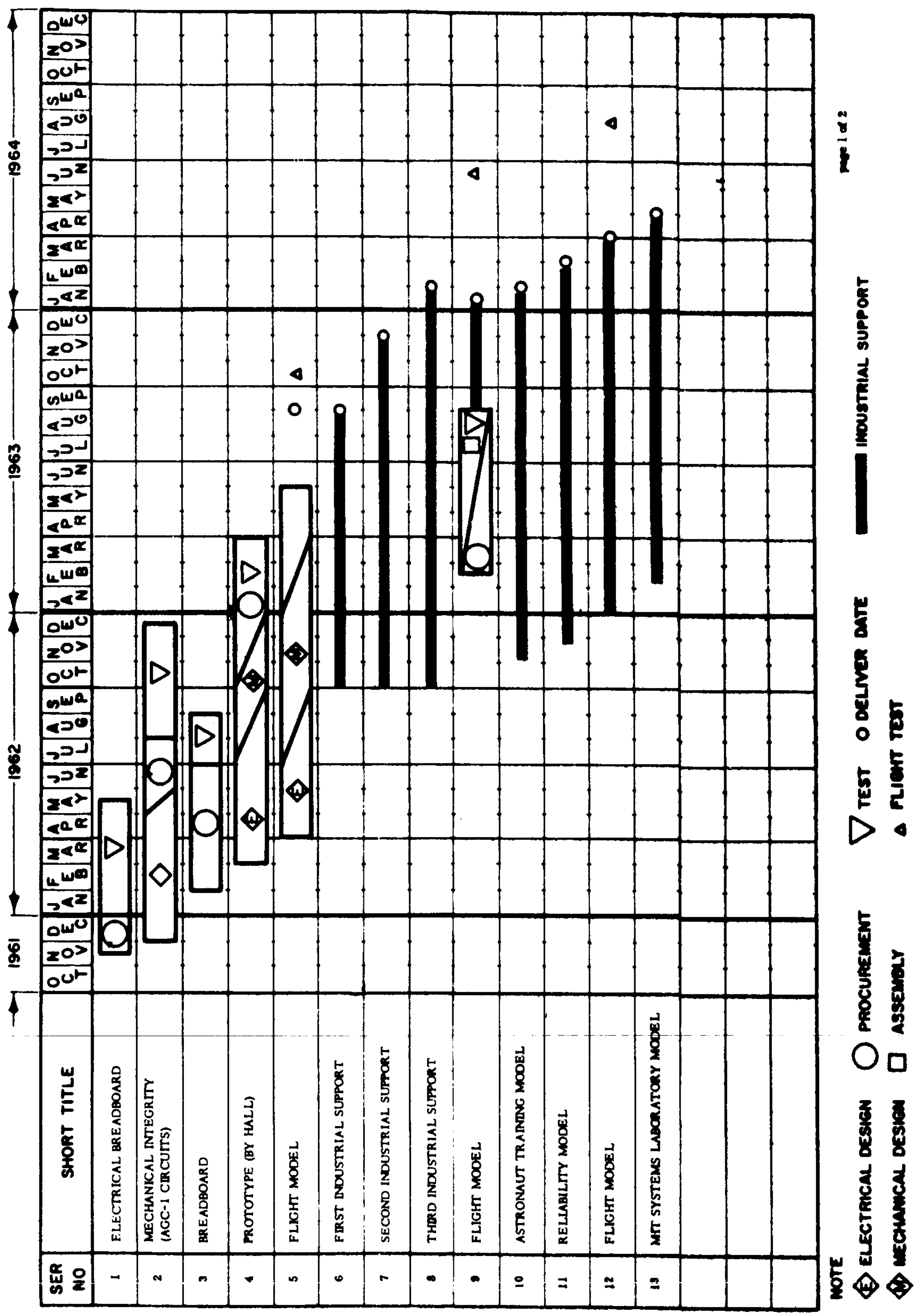


Chart 3.3-1. Milestone Chart for the AGC (Sheet 1 of 2).

WORK STATEMENT FOR INDUSTRIAL SUPPORT E-1097

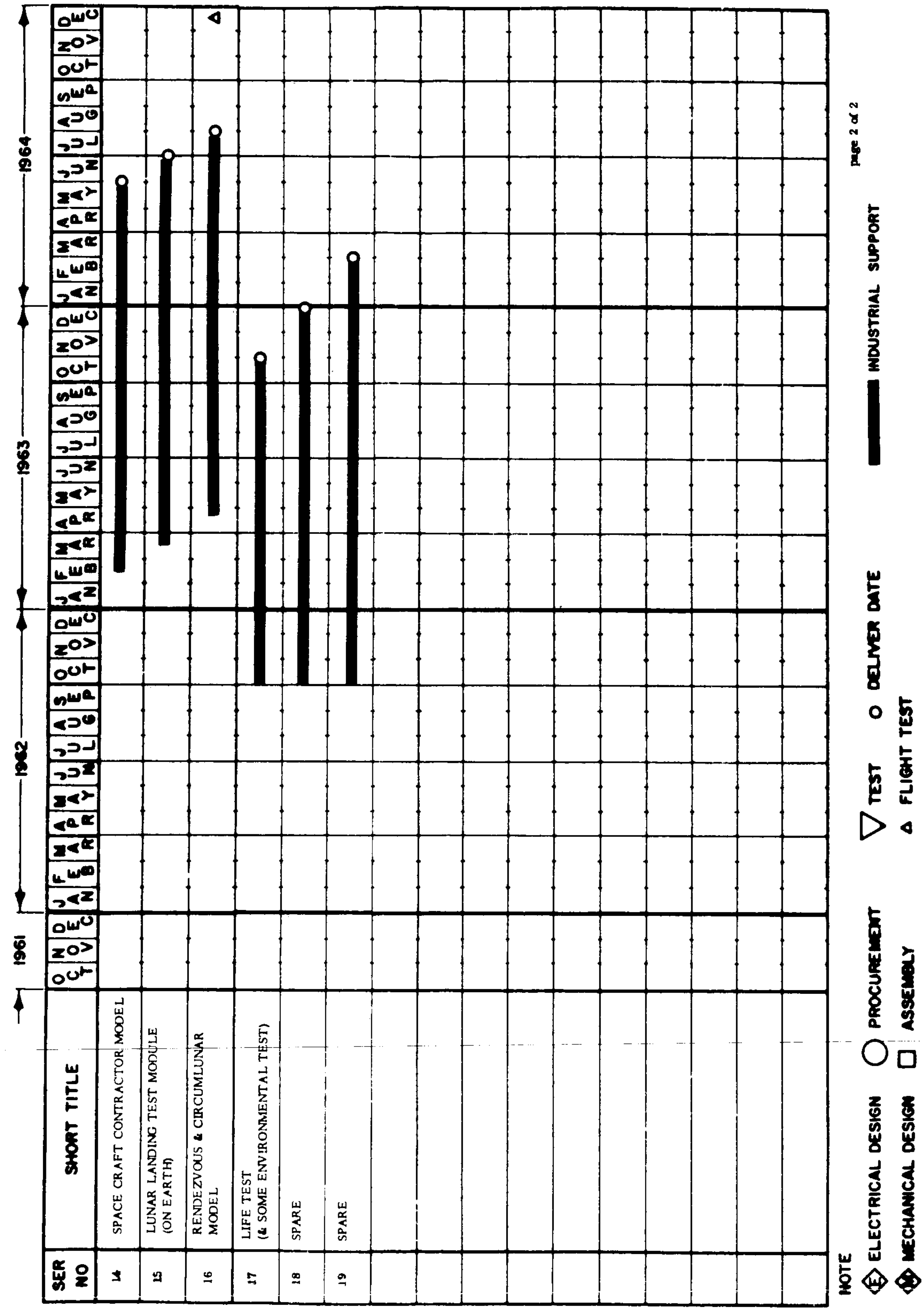


Chart 3.3-1. Milestone Chart for the AGC (Sheet 2 of 2).

Date 5 Jan 62*

C. BREADBOARD

1. Prototypes needed by the offeror will be in addition to the scheduled number of computers.

D. MANUFACTURE

1. Manufacture and deliver computers per the schedule given in Chart 3.3-1.
2. Manufacture field service test equipment to supplement guidance GSE. Schedule delivery to conform with field service requirements.

E. ASSEMBLY

1. As required for complete computer manufacture.

F. TEST

1. Perform qualification tests on components and assemblies.
2. Perform environmental tests on prototype equipment to qualify factory processes.

G. FIELD SERVICE

1. Provide field service personnel and the training of these personnel.

H. DOCUMENTATION

1. Conform to general requirements listed in Section 2.2 of this report.
2. Prepare production line test specifications and procedures.
3. Prepare field service and training manuals.
4. Prepare and maintain computer log books.

I. LEVEL-OF-EFFORT ASSIGNMENT

1. Supply one or two resident engineers to assist in design, specifications, and packaging of the computer. These engineers must also coordinate the liaison activity required to transfer the design and test specifications to the industrial support contractor.
2. Provide field service personnel and the training of these personnel. This will require one or more qualified people at the various locations that check out, use, or prepare the guidance computer for operational flights.

3.3.3 Technical Appendices

A. GENERAL COMPUTER CHARACTERISTICS

Following is a preliminary description of the computer that is being planned for the guidance system. Since the computer requirements have not been completely defined, the computer is being designed to provide flexibility in memory size and interface characteristics. As the computer requirements are better defined the memory size and interface will be changed to optimize the final computer. In general, the interfaces that the computer must have include IMU angle pickoffs as whole numbers, accelerometer readouts as increments of velocity, sextant angle readouts, sextant drive, information for pilot display, clock signals for guidance system, GSE and signals between computer and spacecraft such as radar altimeter, autopilot, communications, and telemetry.

As an integral part of the computer subassembly there will be the necessary control equipment to operate and check out the computer. The control equipment will be made up of command buttons, mode selection switches, keyboard, and paper tape reader as input devices, and as output devices there will be meters, decimal number lights, and discrete lights. The computer subassembly will contain service access doors, provision for temperature control, and cabling between computer modules.

The computer will be constructed using Weld Pack techniques for the computer modules. The module sizes and form factor will be chosen with consideration for the packaging problems, production testing of the modules, reliability, repairability, and the possible requirement for in-flight replacement of modules.

The following is a description of the logical and electrical characteristics of the computer:

1. Logical

a. Word length and format 16 bits

Data: Sign, 14 bits, parity. One's complement.
Instructions: Operation code (3 bits)
Data address (12 bits), parity.

b.	Parallel transfer of words.	
c.	Bit rate	200 kc
d.	Normal Instruction Time	40 µsec
e.	Add Instruction Time	40 µsec
f.	Multiply Instruction Time	640 µsec
g.	Double Precision Add Time (subroutine)	400 µsec
h.	Double Precision Multiply Time (subroutine)	2.000 msec
i.	Variable Instruction rate. Two nominal speeds: Full and Idle.	
j.	Counter Incrementing Time, per counter incremented (see item 3).	20 µsec
k.	Interrupt Reaction Time (see item 4).	1 instruction time
l.	Storage, in additive modules, per module	4096 words
	Erasable (volatile) storage, including addressable IN-OUT	512 words
	Fixed (wired-in) storage. All words are 16 bits long.	3584 words
m.	Input Registers. Each has 15 input bits for 15 input lines	6 registers
	Used to sample the D. C. state of each line.	(90 lines)
n.	Input lines for pulse trains into addressable counters.	20 lines
o.	Counter Registers (part of Erasable Storage)	20 registers
p.	Automatic Interruption Options (one input line per option).	8 options

q.	Output registers, 15 bits each. Each output bit can be either a D.C. level, or a pulse.	4 registers (60 lines)
r.	Outputs from counters - overflow, underflow pulses	20 lines

2. Electrical

a. Erasable Storage: Coincident Current Ferrite Matrix. The Ferrite Material is of a temperature insensitive kind.

b. Fixed Storage: 'Rope' type, one core per four words of 16 bits. (See reference 1.)

c. Logic: PNP-NPN and diode combinations, resistor coupled. Also, core-transistor combinations.

d. Inputs: One core - diode per input line.

e. Outputs: One PNP-NPN latch, and one NPN gate per output line.

f. Approximate Component Count

Cores:	Ferrite Matrix, per module			8000
	'Rope,' per Module (tape wound)			1024
	Special Registers and Logic (tape wound)			400
		Total:	9400	
Transistors:	NPN			1000
	PNP			350
		Total:	1350	
Diodes:				2000
Resistors:				4000
Capacitors (filters)				50
		Total:	6050	

g. Power Consumption:

Maximum, at full speed, including output latches,	20 watts
Power approximately proportional to speed,	
Minimum power, at idling speeds (nominal)	5 watts

3. Counter Incrementing Feature

Certain erasable registers, addressable by program, can act as counters. Upon receipt of an input pulse, the contents of the counter register are read into the arithmetic units' adder, incremented by +1 (or -1), and placed back into the counter register. These registers are otherwise normal erasable ones, and may be written into; in this way, a counter may be set to overflow after any number of pulses.

The overflow or underflow of a counter may be used as an output, as the input to another counter, and as the input to the Program Interrupt circuit. No time is spent on the incrementing operation unless there is a non-zero increment. Each incrementing operation requires 20 μsec. Hence, if the total input rate into all counters is 12 x 10^3 pulses per second, the normal computer activates proceed at 75% of full speed; if the aggregate input rate is 3 x 10^3 pps, the execution of instructions is done at 94% of full speed.

4. Program Interrupting Feature

Once during each instruction time the Interrupt circuit is scanned, and, if an input has been received, the computer puts away the contents of relevant central register in the Arithmetic Unit and proceeds to execute some other program. There are 8 possible interrupt inputs, and each results in a different program being executed. Upon completion of the interrupt program, the original contents of the central registers are restored and the original task resumed exactly where it was interrupted.

An interrupt program may not itself be interrupted. Inputs to the Interrupt circuit are not lost; however, should they occur during an interrupt program, they are stored and processed according to some predetermined priority.

The interrupt reaction time is one instruction time; i.e., the interruption occurs at the end of the instruction presently executed. This time can be from 10 μsec to 640 μsec (the multiply instruction time).

Reference 1: For General Background.

Design of a General Control Computer, Alonso, Laning. Fairchild Publications Fund Paper #29, May 1959. (Also R-276, MIT/IL Publication.)

Reference 2:

E-1077, Preliminary Mod 3C Programmer's Manual. Alonso, Laning & Blair-Smith, December 1961. (MIT/IL Publication.)

Reference 3:

E-1074, Eraseable Ferrite Memory, Mod 3C Computer. D. Shansky, October 1961.

Reference 4:

E-1105, Computer Displays, Eldon Hall, January 1962.

3.4 OPTICAL SUBSYSTEMS, WORK STATEMENT FOR INDUSTRIAL SUPPORT

3.4.1 Introduction

A. The Optical Subsystems consist of the space sextant, map and visual data display equipment, and the sunfinder assembly. These units are described in the technical appendices to this section of the report.

B. Checklist of Type of Effort to be Furnished

Analysis (exclusive of Major System)	no
Design	yes
Breadboard	no
Manufacture	yes
Assembly	yes
Test	yes
Field Service	yes
Documentation	yes
Level-of-Effort Assignment	no

3.4.2 Detail Requirements

A. ANALYSIS (Exclusive of Major System)

1. None.

B. DESIGN

Provide design help in the form of three senior engineers, four layout draftsmen, three detailers and three checkers at MIT with necessary support at the offeror's facility. With this assistance MIT intends to produce major optical subsystems design in-house as follows:

1. Sextant -- Design of the space sextant and special calibration and test equipment needed for its operation and ground support.

2. Map and Visual Data Display Equipment -- Design of the optical portion of the Display and Control Equipment. This will include a device for storing quantities of visual data on film capable of quickly calling up and displaying any desired portion in a viewer or projector. Some type of electrically operated curve plotting device may be needed, possibly combined with the viewer or projector.

C. BREADBOARD

None

D. MANUFACTURE

1. Sextant -- Manufacture and assemble instruments according to schedule given in Chart 3.4-1. The first four instruments (for use in unmanned flight) need have only limited capability and may not be the complete, final instrument.

2. Map and Visual Data Display Equipment -- Manufacture, assemble, and test sets of Map and Visual Data Display Equipment for delivery according to Chart 3.4-2.

3. Sunfinder Assembly -- Manufacture, assemble, and test Sunfinder assemblies in accordance with Chart 3.4-3.

E. ASSEMBLY

1. Sextant -- Same as D.1 above.

2. Map and Visual Data Display Equipment -- Same as D.2 above.

3. Sunfinder Assembly -- Same as D.3 above.

F. TEST

1. Sextant -- Test instruments at offeror's plant to assure delivery schedule of Chart 3.4-1.

2. Map and Visual Data Display Equipment -- Test instruments at offeror's plant to assure delivery schedule of Chart 3.4-2.

3. Sunfinder Assembly -- Test instruments at offeror's plant to assure delivery schedule of Chart 3.4-3.

G. FIELD SERVICE

1. Provide field service at points of use of instruments. These may be NASA, Manned Spacecraft Center, MIT, spacecraft contractor's plant, and launch site. This requirement applies to all subsystems.

H. DOCUMENTATION

1. Conform to general requirements listed in Section 2. 2 of this report.

2. Provide information on progress of all work being performed by contractor, in particular, provide detailed history of each instrument for use in failure analysis.

I. LEVEL-OF-EFFORT ASSIGNMENT

Not applicable.

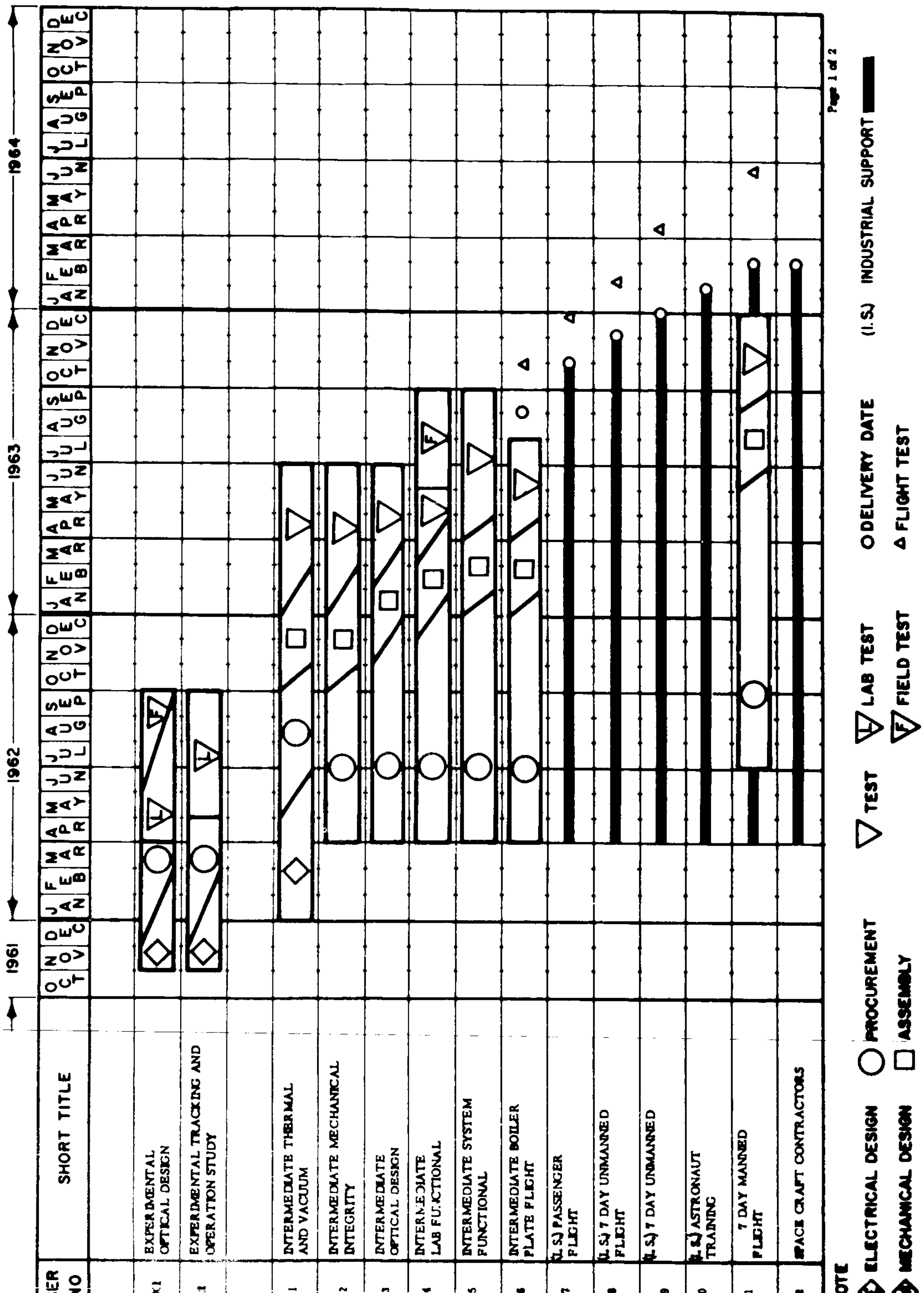


Chart 3.4-1. Milestone Chart for Sextant (Sheet 1 of 2).

WORK STATEMENT FOR INDUSTRIAL SUPPORT

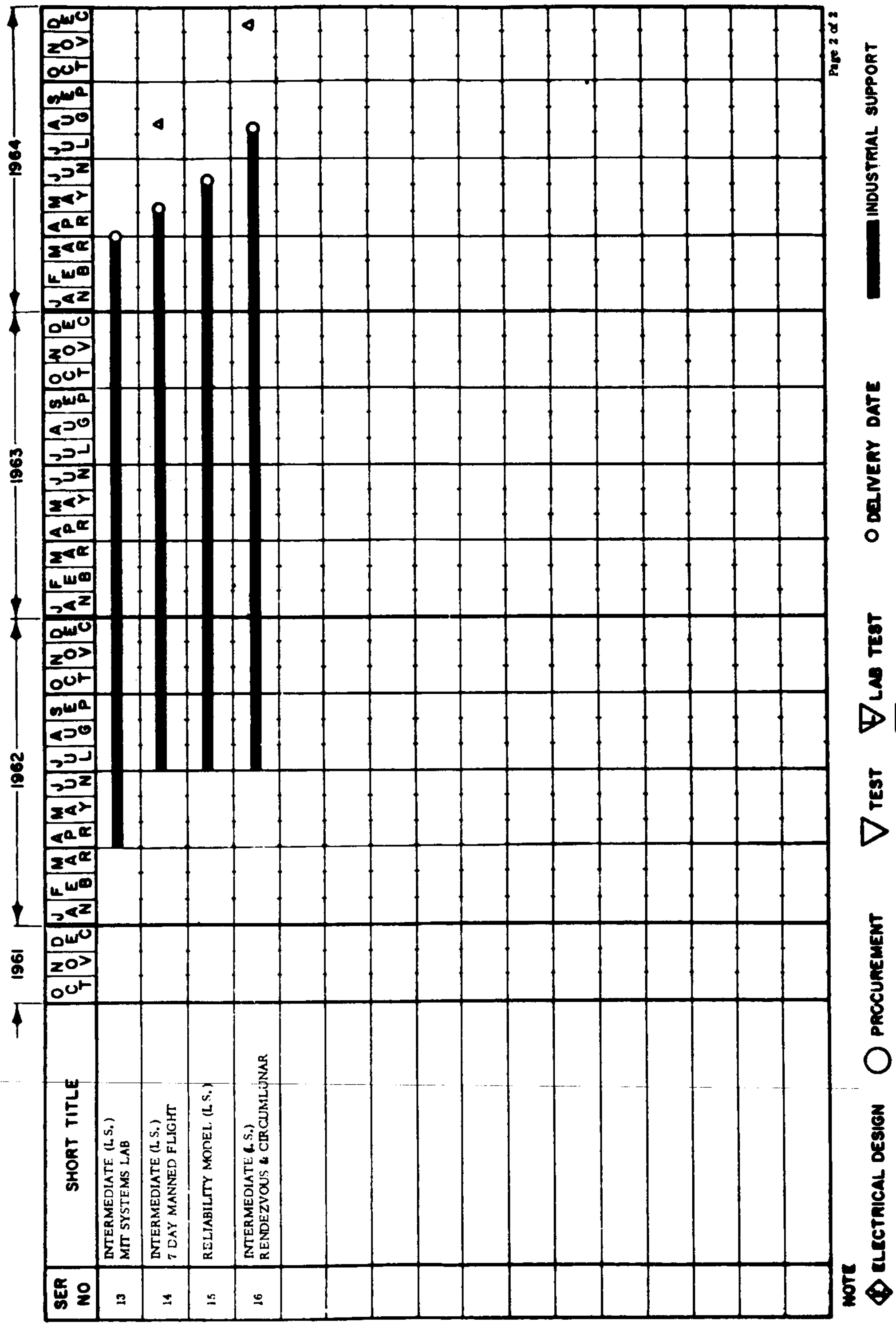


Chart 3.4-1. Milestone Chart for Sextant (Sheet 2 of 2).

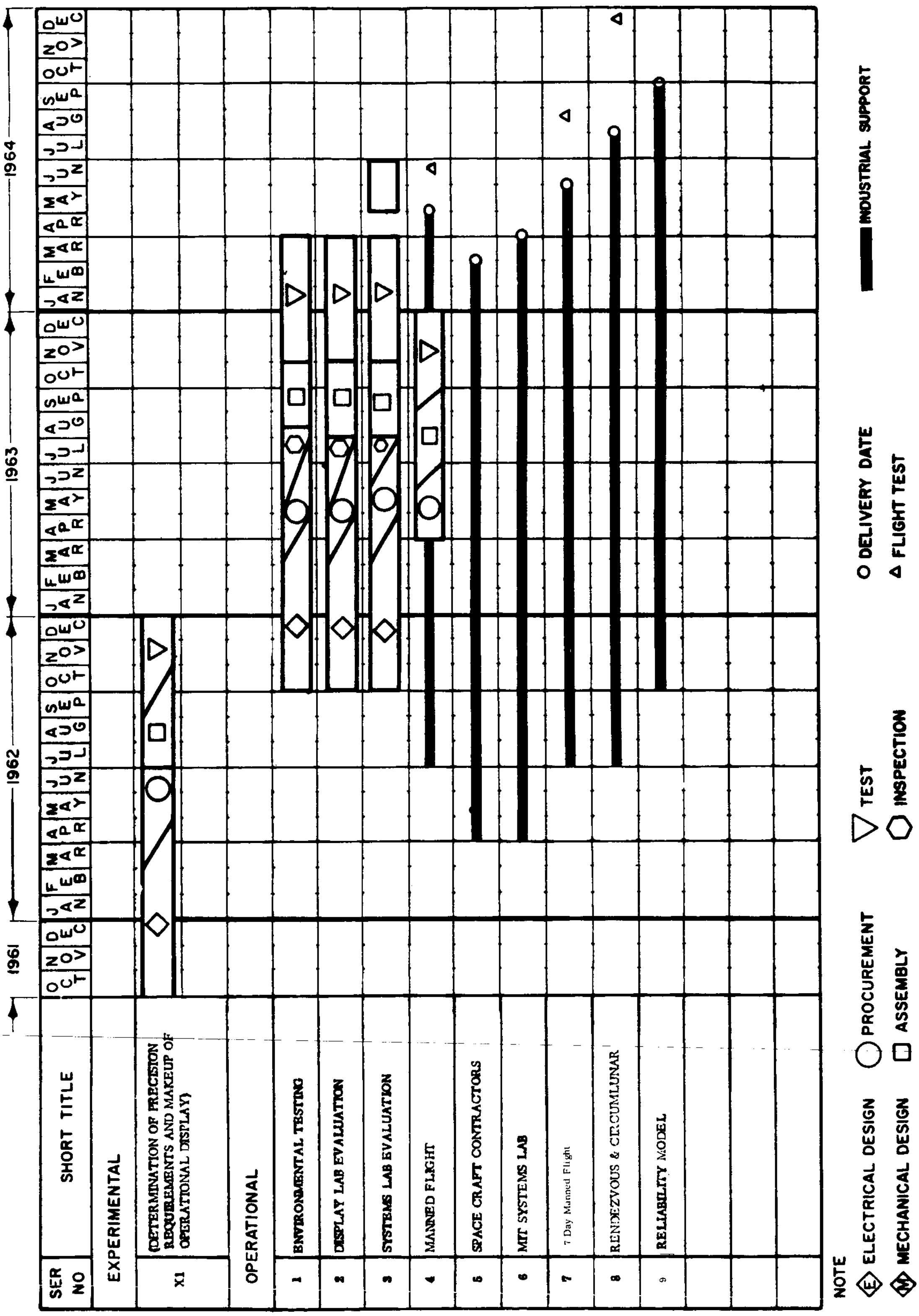


Chart 3.4-2. Milestone Chart for Map and Visual Data Display Equipment.

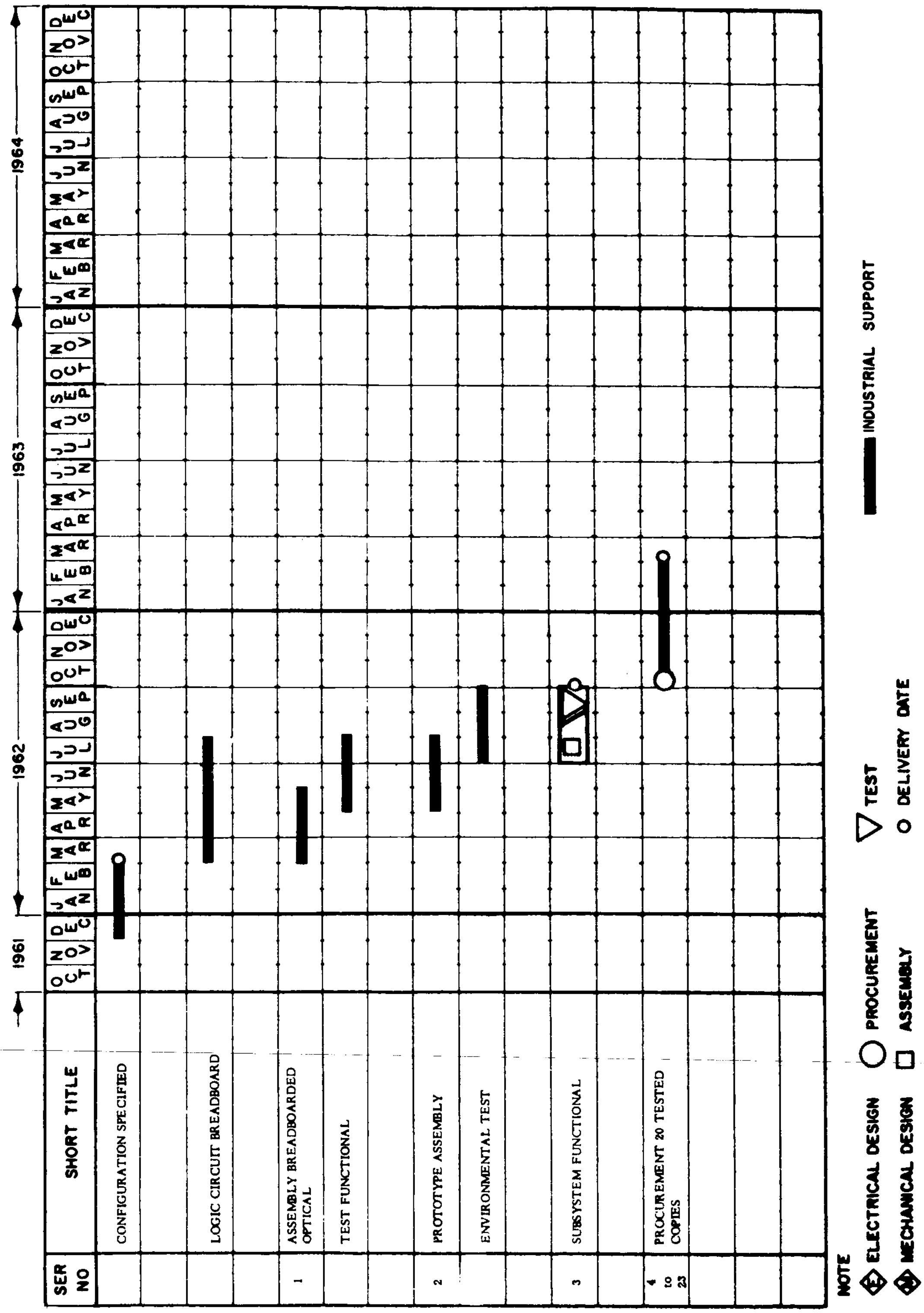


Chart 3.4-3. Milestone Chart for Sunfinder Assembly.

3.4.3 Technical Appendices

A. SPACE SEXTANT

1. Introduction

The value of an instrument capable of precise measurement of angles between celestial bodies became apparent early in the studies of space navigation. Detailed studies of the guidance and navigation requirements for the manned lunar mission indicated the desirability of a visual instrument to be used in measuring angles between reference stars and features on the earth or moon such as landmarks or limb. Analytical and experimental work will continue to determine the method of use of the visual instrument as well as the physical character of the observed phenomena.

Design concepts have evolved based on the results of work to date. A detailed description of the space sextant is not possible at the present time, since the design and development work is still going on and also the requirements and method of use are not as yet completely defined. Broad requirements and methods of use will be given. The description is as complete as can be presented at this time, reflecting current thinking.

2. General Requirements of Sextant

The basic requirement is measurement of the angle between lines of sight to celestial bodies with high precision (better than 20" of arc, perhaps a few seconds of arc). Simplicity, reliability, and low power consumption are major design objectives for the space sextant. These are to be accomplished in an instrument of minimum size and weight. In keeping with these design objectives, an examination of the physical quantities available for measurement has resulted in the selection of radiation in the visible range as first choice. The instrument will be primarily visual, to be used by the astronaut.

The sextant is used to:

Measure angle between line of sight to a star and line of sight to landmark on the earth or lunar surface.

Measure elevation of line of sight to a star above horizon of earth or moon.

Detect occultation of a star by earth or moon.

Provide erection signals for the inertial measurement unit.

The instrument as presently conceived will consist of an optical assembly and a controller assembly. The optical assembly will have two lines of sight incorporating high magnification optics and an alternate line of sight, incorporating low magnification optics with somewhat wider field. Means for precise reading of the angle between two selected lines of sight will be provided. Articulation of the lines of sight will be accomplished by rotating the sextant head about an axis (shaft axis) perpendicular to the spacecraft surface and a second axis (trunnion axis) perpendicular to the lines of sight and the shaft axis. Depending on the results of research in high vacuum environment the instrument will be mounted in the space environment or behind an optically flat window. The former configuration is preferred.

Some degree of attitude maneuvering will be required of the spacecraft in making sextant readings. The sextant controller will be used by the astronaut to provide resolved drive signals for the sextant and spacecraft attitude stabilization system during readings. The controller will also read the sextant angles into the APOLLO guidance computer.

3. Measurement Requirements of Sextant

The sextant provides the primary celestial angle data used for determination of the spacecraft orbit and orientation of the inertial platform. The primary angle data may be classified into three types for convenience in describing the measurement requirements.

a. Midcourse or high orbit primary angle data. This angle is measured between two telescope sight lines, one of which is pointed at a star and the other of which is pointed at either a recognizable landmark on the earth or moon, or the point on the illuminated edge of the earth or moon which appears to be directly beneath the star. Each of these angles "fixes" the spacecraft on a particular curved surface in space. It is anticipated that the allowable measurement error will be approximately 10 seconds of arc; however, the studies which will define this error exactly have not been completed.

The midcourse or high orbit angle measurement problem is characterized by four conditions which are of utmost importance in the design of the equipment.

(1) The sight line angular rates are slow, less than one milliradian per second with respect to inertial space on the spacecraft.

(2) There is an abundance of time available for conducting each measurement, approximately 10-15 minutes.

(3) The great distance from the observed earth or lunar features and the high accuracy requirement dictates the use of high magnification, fine resolution tracking telescopes.

(4) Possibility of cloud cover in the viewing of earth landmarks.

b. Low orbit primary angle data. In low satellite orbit the observer tracks a landmark with a single telescope. When he is on target he presses a button which marks the time and causes the telescope angles to be read into the computer. The components of the sight line in inertial space are computed from the angle readouts which measure the landmark tracking telescope and inertial platform orientations with respect to the spacecraft structural frame. The direction of a landmark so obtained "fixes" the spacecraft on a line of position. The allowable measurement error here is expected to be approximately 3 minutes of arc, which is consistent with timing and mapping errors.

The conditions which characterize the low orbit landmark tracking problem are:

(1) The sight line angular rates are high, being several degrees per second with respect to inertial space and the spacecraft, the exact magnitude depending upon the orbital altitude and range to the landmark.

(2) Very little time is available for tracking the landmark, probably about one minute depending upon the altitude and range.

(3) In order for the operator to identify and acquire the landmark in the presence of spacecraft position errors, the low orbit landmark tracker should have a large field of view, estimated to

be 20°. This tracker should also have a resolving power of about one minute of arc.

(4) Possibility of cloud cover in the viewing of earth landmarks.

c. Inertial platform primary orientation data. When a star is tracked with a single telescope, the components of the star line in inertial platform coordinates can be found. Just as in the case of landmark sight lines, these components are computed from the angle readouts which measure the star tracking telescope and inertial platform orientations with respect to the spacecraft structural frame. The direction of two stars so obtained defines the orientation of the platform with respect to inertial space. The allowable measurement error in this case is one half minute of arc, and is dictated by a requirement that platform orientation uncertainties not exceed one minute of arc.

The platform orientation procedure will be conducted in low orbit, during approach to the earth and moon and on the surface prior to lift-off. In each of these cases ample time is available to carry out the procedure, and the tracking rates are slow, being always less than one milliradian per second with respect to the spacecraft.

It should be noted that the platform orientation procedure defines sight line with respect to spacecraft angle readout accuracy, and angular stability of the platform-star tracker base structural tie.

4. Description of Sextant

Two configurations are presently under study. They represent our present best solution to the requirements stated in the preceding section. One, referred to as Configuration 2, consists of a single instrument called Space Sextant 2. The other, referred to as Configuration 3, consists of a sextant and a wide field telescope which are called Space Sextant 3 and the Scanning Telescope respectively. These instruments are visual in the sense that tracking errors are usually detected by the human operator and semiautomatic in the sense that external computation and servo drives are used to convert the operator's commands into angular motions of the sight lines. Sextant 2 will be described in this section. Sextant 3 is very similar and therefore will not be described except to point out its unique features. The Scanning Telescope will also be described only briefly because it is still in the preliminary design stage.

a. General description of Sextant 2. Sextant 2 is shown schematically in Figure 3.4-1. The articulating mirrors rotate the sight lines about the trunnion drive and precision drive axes. The trunnion itself is rotated about the shaft drive axis, which will be approximately normal to the mounting surface of the spacecraft. One mirror collects light from a star. The adjacent mirror collects light from an illuminated portion of the earth or lunar surface.

In the sextant mode of operation the two beams enter from the front side of the instrument, are colineated and are directed to a focus before the eyepiece by the set of prisms and lenses shown. In this mode the optical paths constitute a star tracking telescope and a landmark tracking telescope, both of which have 1.6 inch aperture, 1.9 degree fields, 3 seconds of arc resolution and 28 power magnification.

One of the articulating mirrors is two sided. The back side of this mirror can collect a beam from the back side of the instrument which is then brought to a focus before a second eyepiece. This path constitutes a tracking telescope having a 0.75 inch aperture, 20 degree field, 30 seconds of arc resolution and 3 power magnification. It is used primarily for tracking landmarks in low orbit and as an aid in acquisition and identification of objects.

A shaft axis drive motor turns the trunnion about the shaft drive axis (SDA). A trunnion drive motor rotates both mirrors together about the trunnion drive axis (TDA). A precision drive motor rotates the star tracker mirror with respect to the landmark tracking mirror about the precision drive axis (PDA). PDA and TDA are colinear. The shaft and trunnion angles (SA and TA) are read out with 20 seconds of arc accuracy. The precision angle (PA) is read out with 10 seconds of arc accuracy.

During midcourse and high orbit operation when the sextant measures the angle between selected star-landmark pairs, a fourth degree of freedom of the sight lines is required. This is provided by spacecraft roll mobility. When objects are tracked individually, only the shaft and trunnion drives are required. Figures 3.4-2 and 3.4-3 illustrate the axes, sight lines and angular freedoms involved in celestial tracking. It is seen that large roll and small pitch spacecraft attitude changes are generally required to permit acquisition of

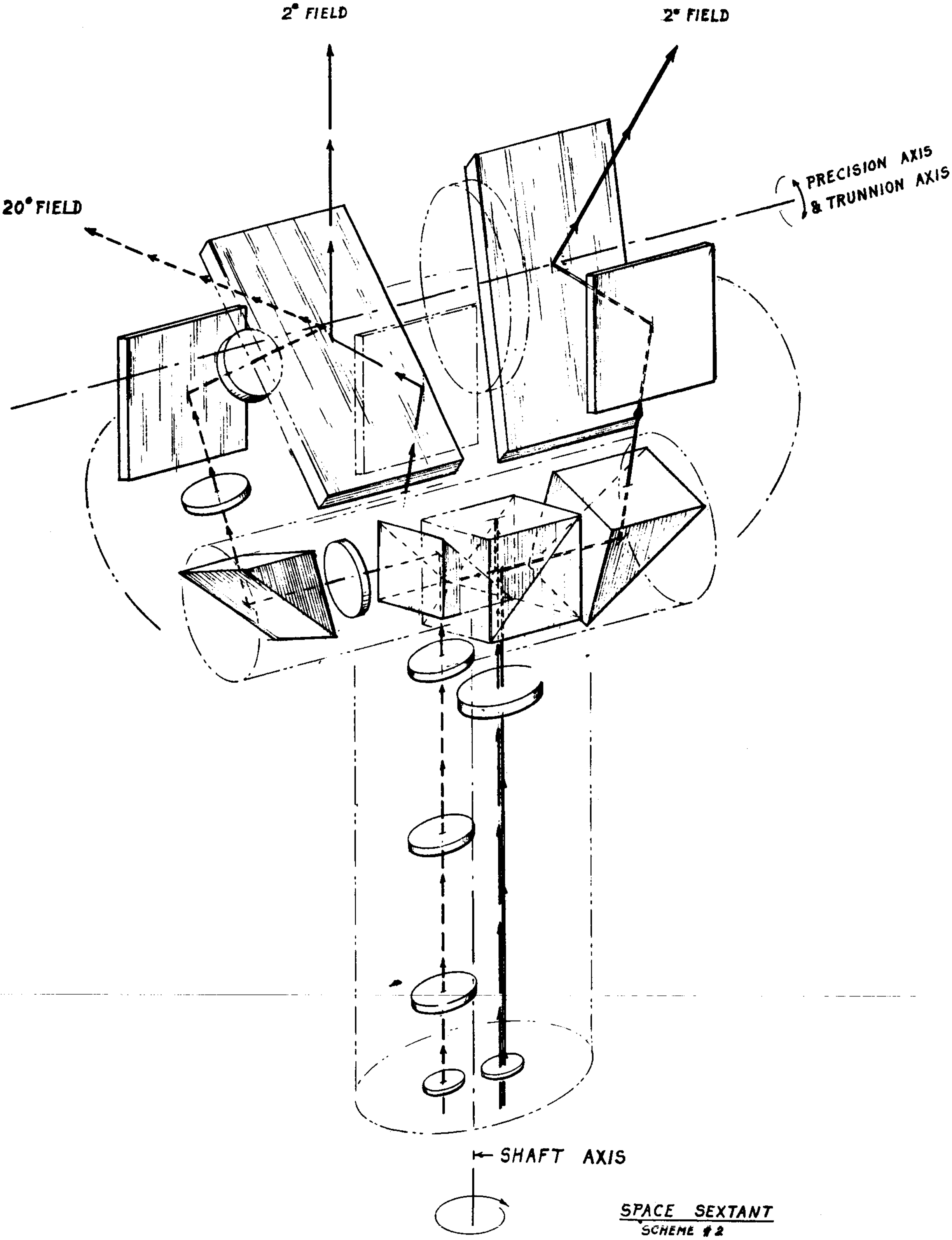
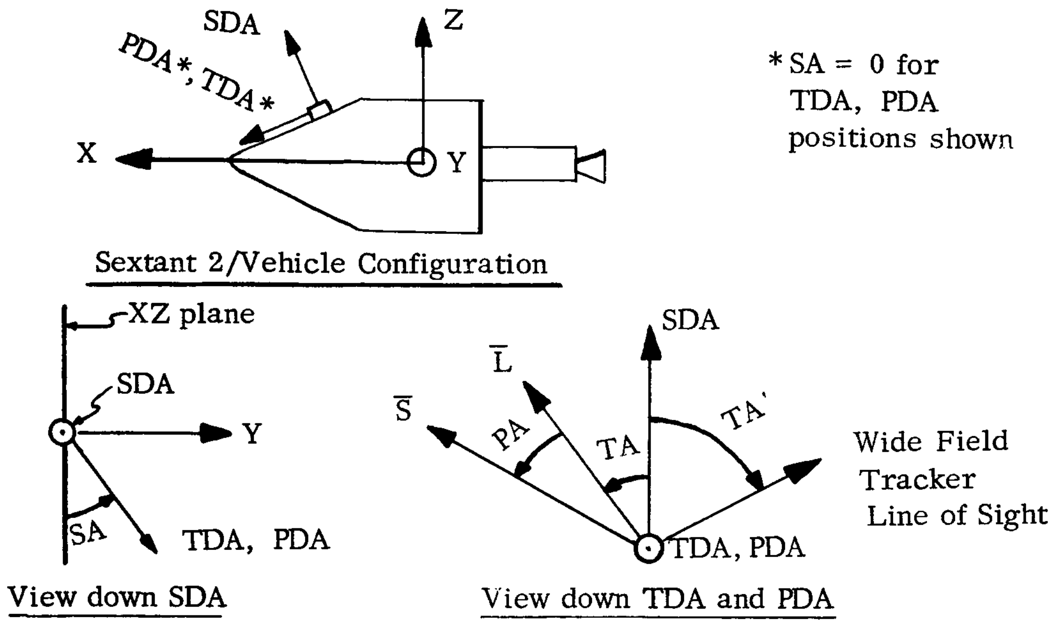


Figure 3.4-1. Schematic of Sextant 2.



Notes:

1. Positive SA, TA and PA advance right-handed screws along SDA, TDA, and PDA respectively.
2. $\bar{L}$ and $\bar{S}$ are unit vectors along high power lines of sight to a landmark (or horizon) and a star respectively.
3. LIMITS: $-180^{o} < SA < 180^{o}$, TA min $<$ TA $<$ TA max, TA min $<$ TA' $<$ TA max, TA min $<$ TA + PA $<$ TA max. For the present assume: TA min = 0, TA max = 20^{o} if sextant inside spacecraft, and TA max = 70^{o} if sextant outside spacecraft.
4. SA ≡ Shaft Angle; SDA ≡ Shaft Drive Axis
   TA ≡ Trunnion Angle; TDA ≡ Trunnion Drive Axis
   PA ≡ Precision Angle; PDA ≡ Precision Drive Axis
   TA' ≡ Trunnion Angle to wide field tracker line of sight

Figure 3.4-2. Celestial Tracking Sight Lines, Axes, and Angular Freedoms.

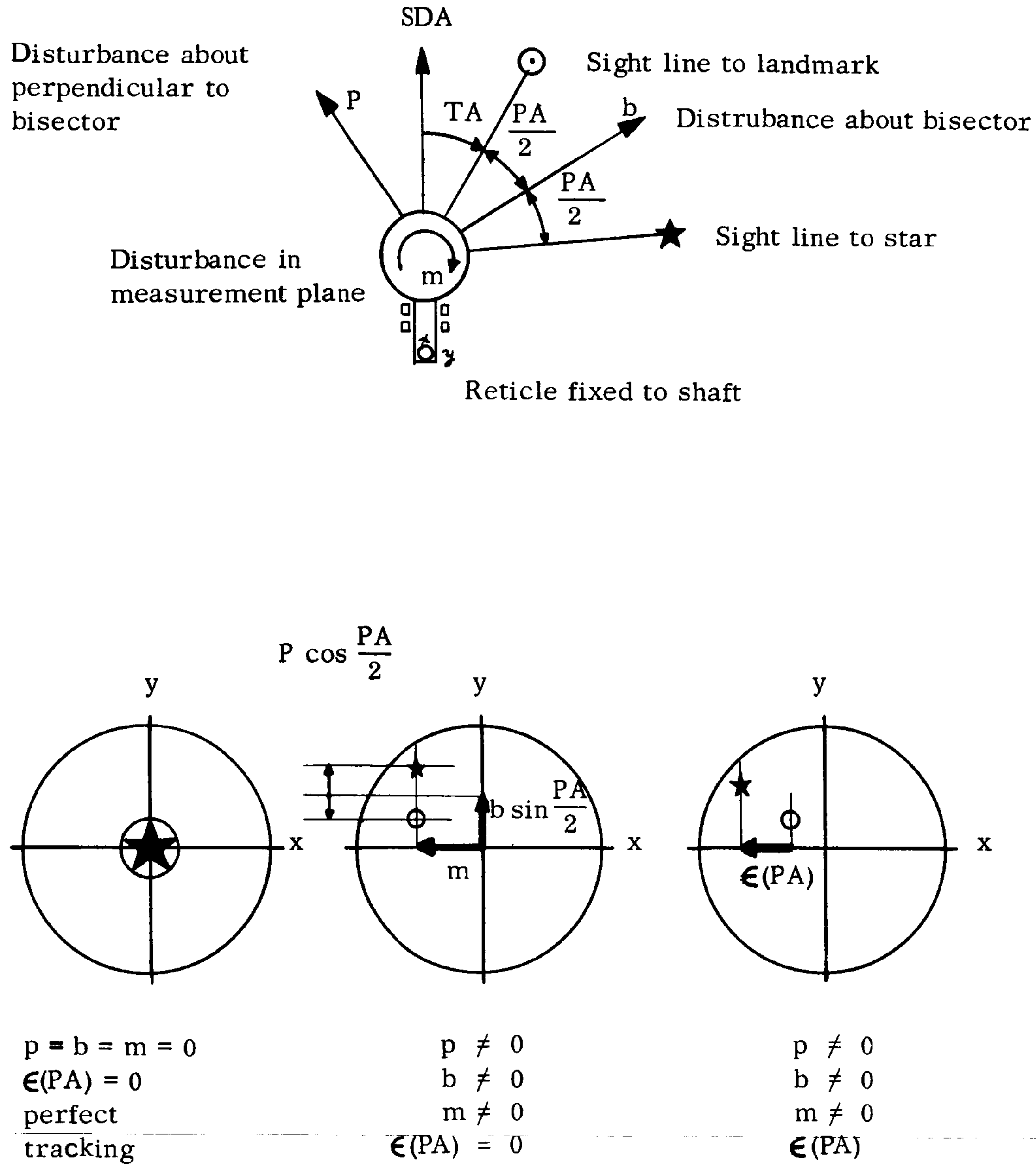


Figure 3.4-3. Observer's View of Star and Landmark.

desired celestial objects. As already indicated, very small roll oscillations are called for when tracking two objects simultaneously for midcourse and high orbit primary angle data.

Direct command of the sextant drives will be given to the operator for slewing and single telescope tracking. It is anticipated that digital servos will be used. Special command programs generated in the guidance computer may be switched into the loops at the operator's discretion to enhance the acquisition and low orbit landmark tracking functions.

The most interesting control problem, which was a principal factor in defining the mechanical-optical configuration, arises in the precise midcourse and high orbit primary angle measurement mode. Here we attempt to measure the angle between two objects with 10 seconds of arc accuracy. Physically this requires that we measure the angle between two sight lines which are approximated by the articulating mirrors. To align these lines within a few arc seconds of the light beams would require precise stabilization and control of them and therefore the utilization of the inertial platform and precision drives on all axes.

To avoid this complication, the optical design principle found in marine and aircraft bubble sextants has been employed. In these instruments the observer can discriminate between image displacements due to base motion and image displacements which indicate that the precision angle set between the two sight lines is in error. Figure 3.4-3 illustrates the application of this design principle to the space sextant. Angular disturbances of the optical head, which is the space defined by the two sight lines, with respect to the space defined by the two light beams are represented by vectors $\bar{p}$, $\bar{b}$, $\bar{m}$. It is seen that an error in the precision angle set between the two articulating mirrors appears to the observer as an x displacement. Disturbances only destroy superposition by shifting the images with respect to each other in the y direction.

Through a simple resolution matrix the observer's commands for image motion will be converted to sextant drive motor and vehicle roll commands. The observer will first acquire the objects and observe their motion in his field. He will then displace the images such that they will drift toward each other smoothly and slowly across his field. When they have zero relative x displacement the operator pushes a timing button and causes the precision angle to be read into the computer.

No treatment will be given here of the acquisition or backup modes of operation since they are in a state of development and should not influence the basic sextant design features.

b. Description of Configuration 3. Sextant 3 is similar to Sextant 2 except for the following distinctions:

(1) The 20° tracker is replaced by two more narrow field tracking telescopes. Both articulating mirrors are now two-sided and the sextant is symmetrical front to back.

(2) The sight lines are displaced a small angle from perpendicularity with the TDA and PDA. This angle, called the Dip Angle, will be about 20°.

The effect of these changes is to reduce the amount of spacecraft attitude changing required for midcourse and high orbit primary angle measurements. Maximum sight line angular velocities are also reduced.

The Scanning Telescope performs the acquisition and low orbit landmark tracking functions assigned to the 20° field tracker in Sextant 2. It is a variable field (15° - 60°) telescope having two degrees of freedom with respect to the spacecraft which are provided by two shaft drive axes offset from each other by about 30 degrees.

This telescope would logically replace a viewing window in the command module and should, therefore, not be the cause of a weight penalty of much significance. It has the decided advantage of providing a back-up for the space sextant. Both servo and manual control seem feasible.

c. Description of Non-Visual Features. The non-visual features will not be described at this time because the selection of a particular horizon detecting scheme has not yet been made. It can be said, however, that both Sextant 2 and Sextant 3 will contain provisions for automatic star and horizon tracking.

5. Mechanical Design

The mechanical design of the space sextant attempts to meet the design objectives of accuracy, simplicity, reliability, size and weight control, and low power consumption. Another important design objective is to make a configuration which is compatible with either external or internal spacecraft mounting. With these objectives in mind the optical geometry shown in Figure 3.4-1 appears to offer the best potential. This geometry provides two articulating 2° field lines of sight free from image rotation in an objectionable sense, which are as close together as feasible within the constraints of the angular freedom and size of objective lens. A separate 20° field of view line of sight is incorporated in the sextant body to provide recognition and landmark tracking requirements. This line of sight is articulated by using the back side of one of the 2° field mirrors, since the requirements are nonconflicting. Articulation and basic angle measurements are to be accomplished by a precision worm drive with appropriate ratios for encoding. Visual interpolation of the celestial angle may be possible using optical bridge techniques. This then encompasses the basic mechanical design objectives and attacks. The mechanical design layout for Sextant 2 is shown in Figure 3.4-4.

Design problems affecting accuracy and reliability which are faced in this effort are many and varied and deserve some amplification.

a. Basic behavior of materials in a space environment (i. e.) vacuum and radiation.

b. Thermal effects and dissipation of heat flux in space environment.

c. Accuracy and repeatability of angle transducers, (i. e.) gearing, etc.

d. Dynamic and static high vacuum seals.

6. Controller and Readout Design

a. Basic function. The controller is essentially a digital servo receiving information from the APOLLO Guidance Computer, the sextant readouts, and the hand controller. It provides information to the APOLLO Guidance Computer, the sextant drives and the attitude stabilization system.

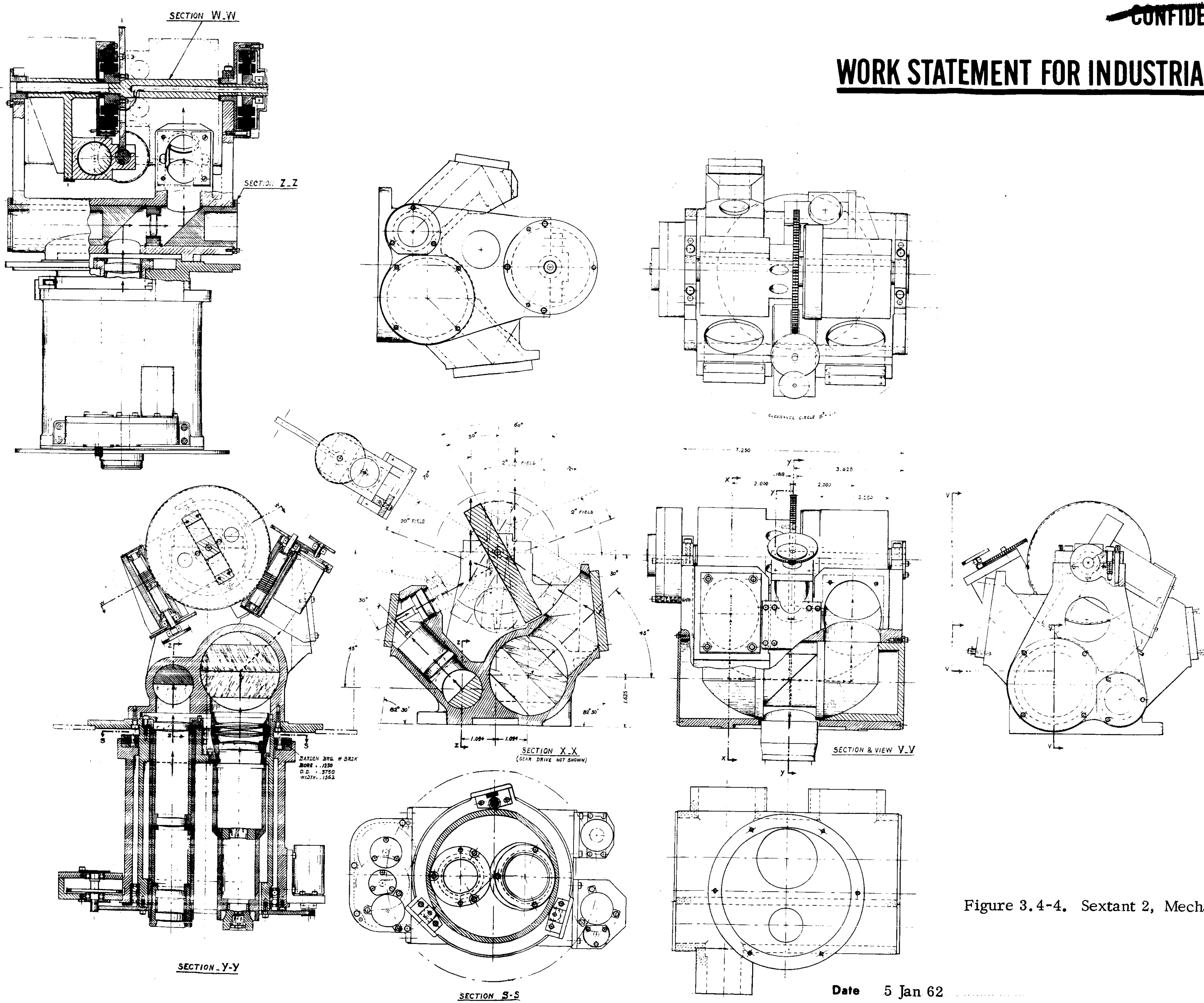


Figure 3.4-4. Sextant 2, Mechanical Design Layout.

b. Inputs. From the APOLLO Guidance Computer it may receive up to seven sequentially presented words. In conjunction with Sextant 2 configuration, there will be six words representing the required shaft, trunnion and precision angles as well as the corresponding angular rates. Alternately in conjunction with Sextant 3 configuration there will be seven words representing the three desired shaft, trunnion and precision angles; the two desired angles of the two-degree of freedom wide angle tracker and the two desired angular rates of the wide angle tracker.

From the sextant there will be pulses representing incremental readout of shaft, trunnion and precision axis rotation as well as indexing markers from the three axes.

From the hand controller there will be commanded image motions and miscellaneous control signals.

c. Outputs. The APOLLO Guidance Computer in the midcourse mode requires one word corresponding to the precision angle and a time marker. In the erection mode the Computer requires two words, one corresponding to shaft angle and the other corresponding to trunnion angle, as well as a time marker.

The attitude stabilization system requires roll rate commands.

The sextant requires appropriate voltages to drive motors.

d. Instrumentation design. The central problem is the choice of a sextant (tracker) axis drive motor and associated drive circuitry. Present plans call for a motor generator with 400-cycle excitation. The driving would be accomplished in a trinary fashion as illustrated in Figure 3.4-5. The tachometer feedback will be used to maintain a non-oscillatory condition during standstill, and constant velocity while driving. As is shown, each of the flip-flops controls one direction of motion. Switch II in addition to receiving two phase 400cps excitation receives the flip-flop signals which choose between the two phases for proper axis rotation. Switch I allows for an inching mode by providing 2 different amplitudes of 400 cps two phase excitation.

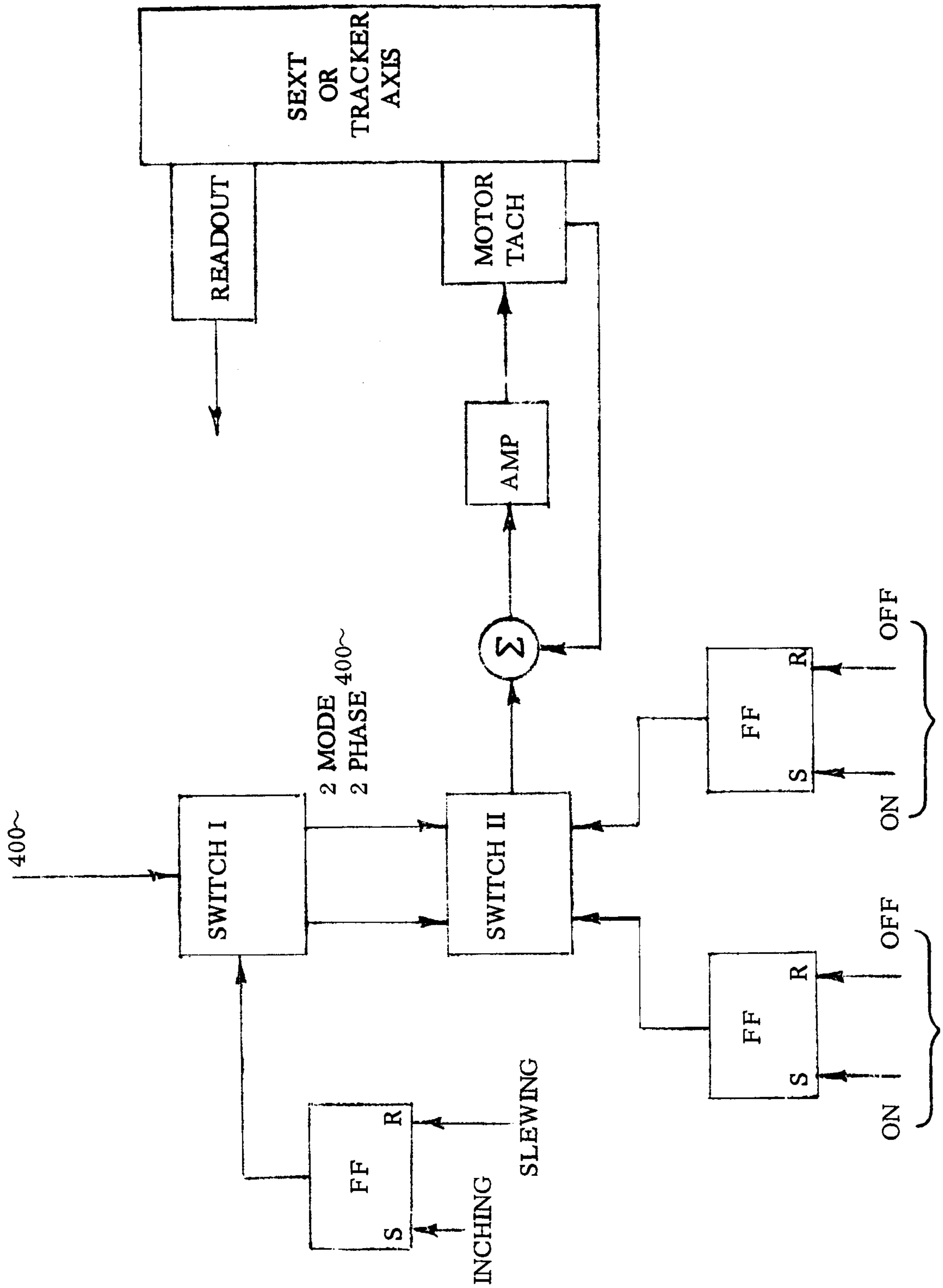


Figure 3.4-5. Sextant or Tracker Axis Drive Configuration.

The control pulses necessary for operating the shaft axis systems as described in Figure 3.4-5 will be generated by the controller as a result of digital operations performed on incoming data from the APOLLO Guidance Computer, the hand controller and the shaft single readouts.

When a controlled rate is desired at a particular axis, it will be obtained by switching the appropriate motor excitation on and off with the proper duty cycle, and when a particular position is desired the shaft angle readout will be compared to the desired position and the motor switched appropriately. These operations can be performed in either of the two modes.

e. Readout. The primary readout on all sextant axes is an incremental gear tooth counter. The precision axis may also be repeated in a gear box having an optical readout mounted on it, or it may be read directly with an optical scale.

B. MAP AND VISUAL DATA DISPLAY EQUIPMENT

1. Introduction

Large quantities of information in the form of maps, photographs, check lists, and instructions, numerical data and other information vital to the success of the lunar mission must be stored in the Command Module available as needed by the crew. The use of photographic film affords an efficient means of meeting this storage requirement in a viewer or projector incorporating a transport mechanism for selecting the desired section of the film. Bright images of the markers under the control of the computer superimposed on the image of the film can be used to relate the prevailing flight conditions or situation to the stored information on a real time basis.

2. Description of Map and Visual Data Display Equipment

The design of the map and visual data display equipment has not as yet proceeded to the point where a description is possible. Broad requirements and methods of this will be given.

In the optical design, a viewer configuration is favored over a projector in the matter of power consumption. The use of 35mm. film is planned in the film transport mechanism. The latter should be capable of calling up any desired frame in a few seconds, possibly under control of the computer but with provision for manual operation as well. In addition, means should be provided for viewing selected portions of a particular frame as well as variable magnification in the optics to change the size of the selected portion.

Approximately 6 symbols as determined by work presently in progress will be required to appear as bright images superimposed on the film image for identifying landmarks or landing sites, vehicle position, etc. These images are to be positioned by the computer. The considerations of reliability and low power consumption are foremost in accomplishing this design.

C. SUNFINDER ASSEMBLY

1. Introduction

During the midcourse portion of lunar flight, the sunfinder assembly will be used as an attitude reference. Each sun sensing element has a null plane. A pair of elements mounted with null planes orthogonal determines the sun direction. Several such pairs with null directions at zero and increasing angles with respect to the Spacecraft roll axis will make up the attitude reference for use while performing the maneuvers required to make midcourse celestial observations.

2. Description of Sunfinder Assembly

For a general physical and operational description of the sunfinder elements which make up the sunfinder assembly, reference is made to the attached report, E-965-A by H. H. Seward, A Sunfinder for an Interplanetary Vehicle.

The sunfinder assembly is made up of several orthogonally mounted pairs of elements, with null axes fixed one at zero and the others at increasing angles with respect to the roll axis of the Spacecraft. One or two such assemblies will be used to establish a set of attitude reference nulls with respect to the sun. Since the sunfinder assemblies will be required to operate in the hard vacuum outside the vehicle, space environmentalization is a primary design problem of the subsystem.

As shown in Chart 3.4-3 the choice between one or two sunfinder assemblies and the number of pairs of elements in each assembly will be determined at the end of February 1962.

If the total number of sunfinder sensors on the Spacecraft is sufficiently large, a logic circuit will be used to minimize the number of wires required to bring their information to the guidance system in the Command Module.

3.5 IMU POWER AND SERVO ASSEMBLIES, WORK STATEMENT FOR INDUSTRIAL SUPPORT

3.5.1 Introduction

A. Contractors are expected to assemble and manufacture the required IMU Power and Servo Assemblies. The assemblies involved for each PSA are:

1. Platform Servo Amplifiers, three required
2. Accelerometer Electronics, three required
3. Gimbal Mounted Preamplifiers, six required
4. Power Supplies
    a. 100, 800, 3200 cps sine wave
    b. DC-DC Converters
    c. Power Distribution Interlocks
5. Gimbal Angle Data Buffer, nine required
6. IRIG Torque Generator Amplifiers, three required
7. Buffers for Analog Displays

B. Checklist of Type of Effort to be Furnished

Analysis (exclusive of Major System)	yes	only in support of MIT through resident personnel
Design	yes	(same)
Breadboard	yes	(same)
Manufacture	yes	
Assembly	yes	
Test	yes	
Field Service	no	
Documentation	yes	
Level-of-Effort Assignment	yes	

3.5.2 Detail Requirements

A. ANALYSIS (Exclusive of Major System)

Perform analyses of operational block diagrams to establish appropriate tolerance levels on performance parameters.

B. DESIGN

1. Optimize circuit configurations and techniques proven successful in the POLARIS program.
2. Adapt digital and switching techniques in configurations that can replace the more classical analog configurations.
3. Anticipate and assist in the design of related GSE.
4. Refer to paragraph 3.5.3, Technical Appendices, for additional design guidelines.

C. BREADBOARD

Sufficient breadboards to cover at least one design for a complete PSA will be made at MIT, however, the contractor will be asked to reproduce these in the effort to optimize circuit parameters.

D. MANUFACTURE

Manufacture and deliver to schedule shown in Chart 3.5-1.

E. ASSEMBLY

To meet D. above.

F. TEST

To meet D. above.

G. FIELD SERVICE

None expected of this offeror.

H. DOCUMENTATION

1. Conform to general requirements listed in Section 2.2 of this report.

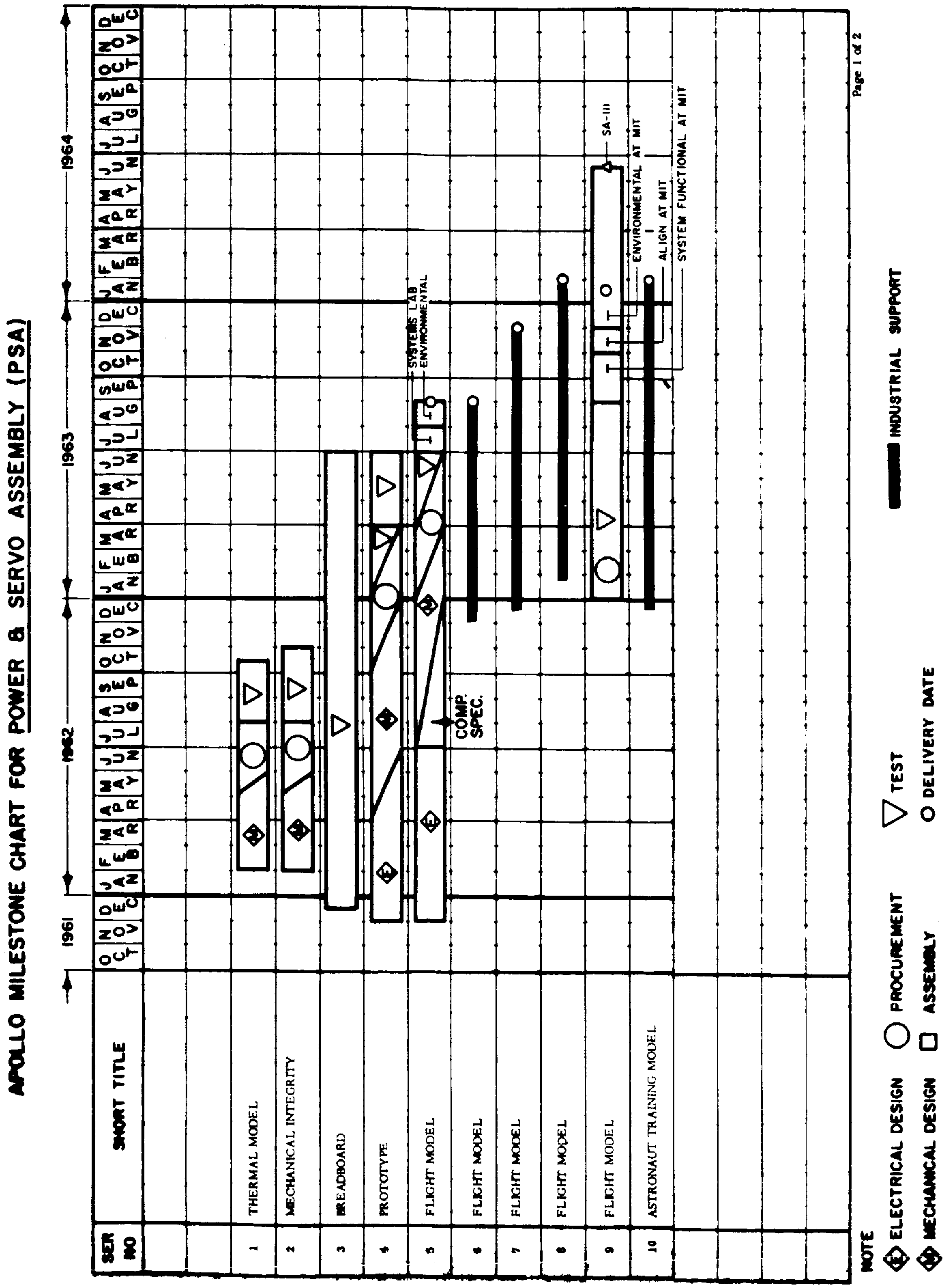


Chart 3.5-1. Milestone Chart for PSA (Sheet 1 of 2).

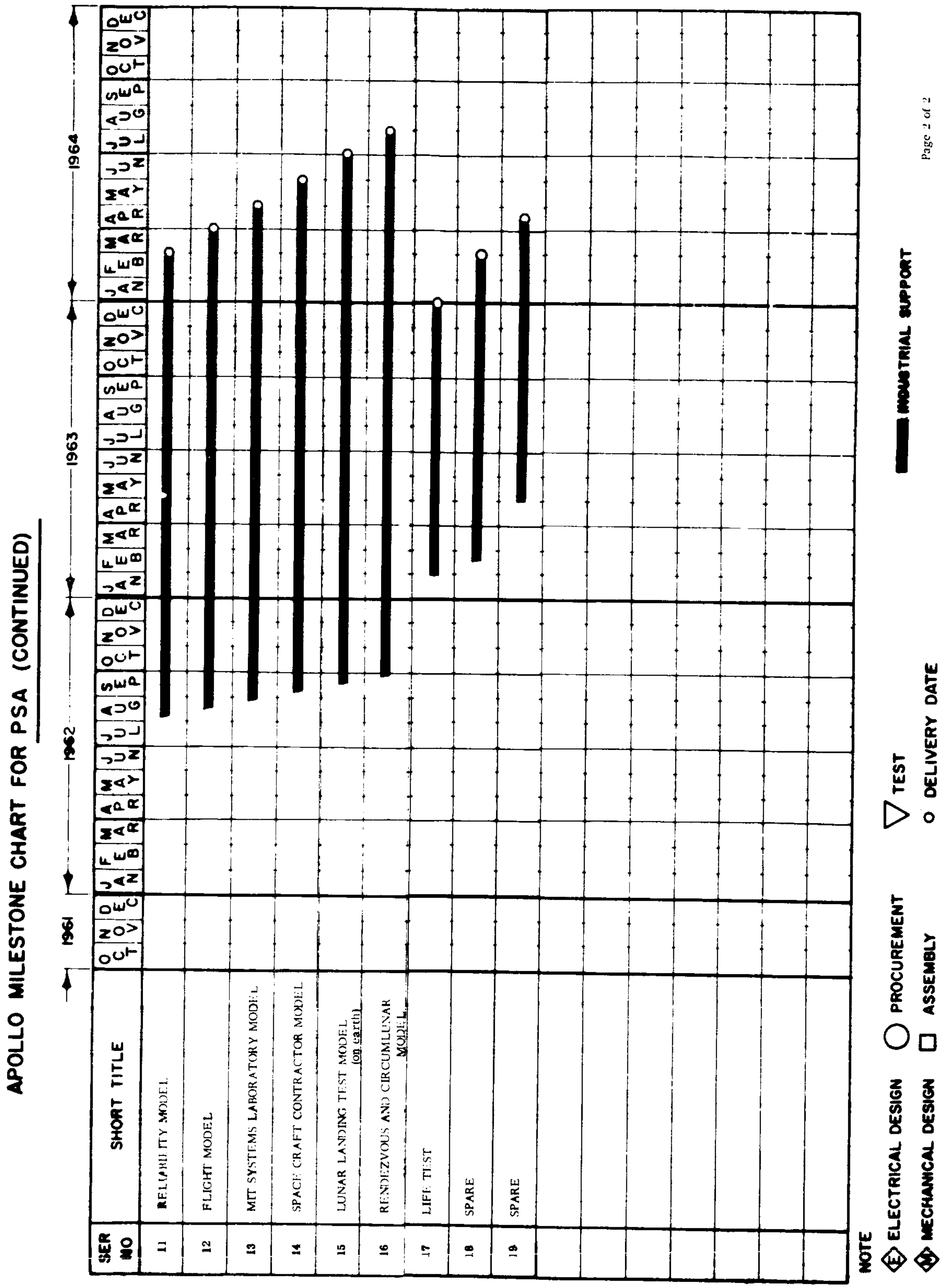


Chart 3.5-1. Milestone Chart for PSA (Sheet 2 of 2).

I. LEVEL-OF-EFFORT ASSIGNMENT

1. An estimate for the minimum industrial support staff is indicated in Chart 3.5-2. It will be left to the discretion of the contractor to furnish adequate support for this staff in the form of draftsmen, technical aides, engineers, etc.

The following comments are included to add completeness to the title of Senior Electrical Engineer:

> The tight time schedule does not allow time for MIT to train support engineers. Industrial support staff in residence at MIT will be expected to comprehend and contribute to the design effort after a very brief indoctrination. They will also be expected to carry the major portion of responsibility of translating all circuit design intents into the manufacturing process. It is, therefore, required that they be senior enough to be given authority to dictate controls to the staff of the contractor's manufacturing facility.

2. The PSA delivery schedule, Chart 3.5-1, is an estimate of delivery and usage for the PSA. The offeror should propose any changes that he feels would be desirable.

3. As the design becomes firmer, it may be possible to identify the need for a larger support effort than is shown in this work statement. The offeror is invited to show any of these additional needs that can be identified at this time.

3.5.3 Technical Appendices

A. GUIDELINES FOR IMU ELECTRONICS DEVELOPMENT

1. General

Currently there is available the necessary know-how to design circuits that can adequately instrument the IMU. However, it is recognized that design emphasis for APOLLO will put new and more stringent demands on the present state-of-the-art circuits, especially in the area of reliability

WORK STATEMENT FOR INDUSTRIAL SUPPORT E-1097

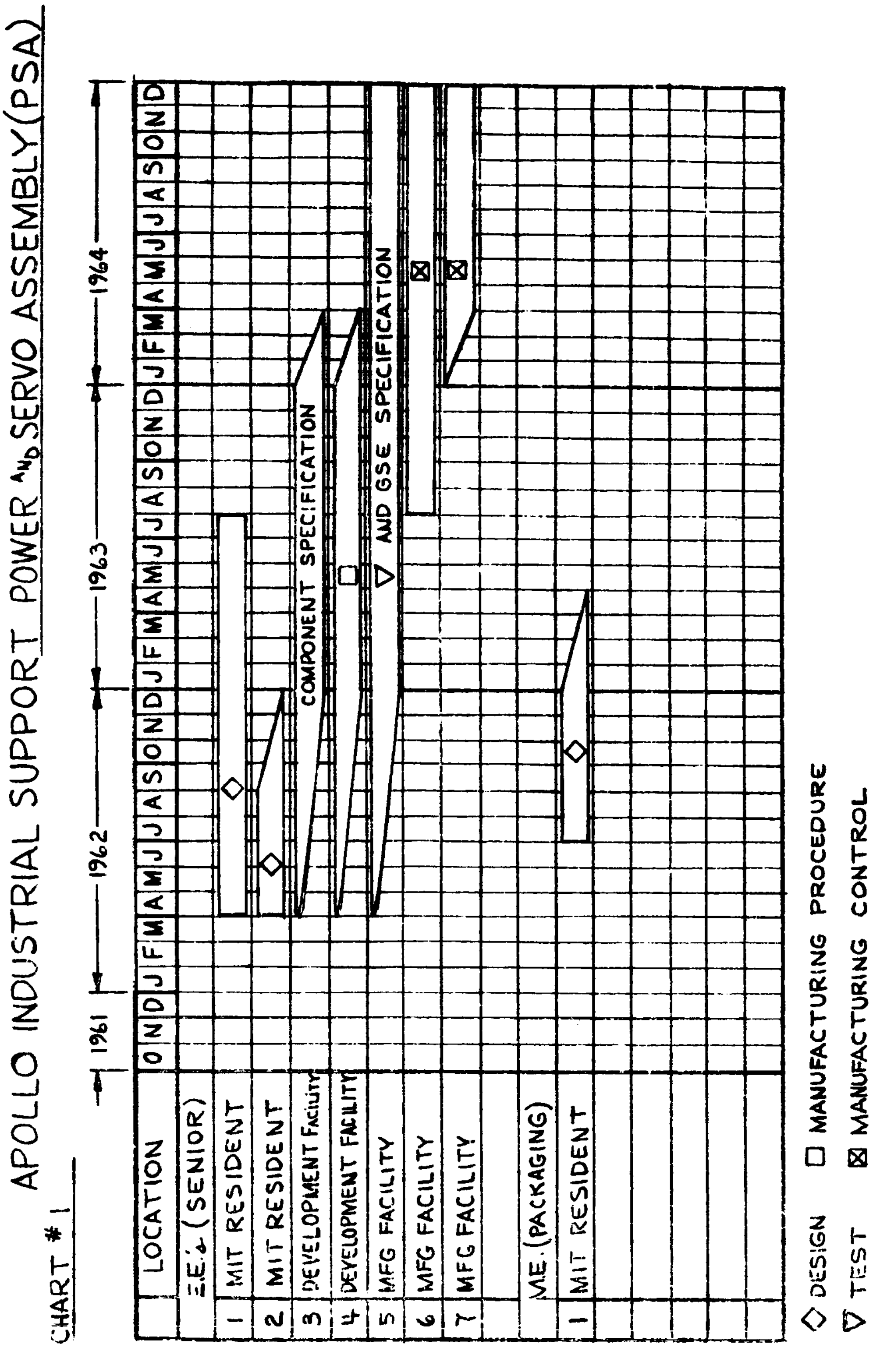


Chart 3.5-2. PSA Industrial Support Schedule

and power conversion efficiency. The design effort will require all MIT/IL's and industry's latest break-throughs to do justice to the APOLLO system.

Below is a list of ELECTRONICS DESIGN CRITERIA in order of their priority that reflects the new emphasis for the APOLLO mission:

a. Performance

b. Reliability

c. Power Consumption

d. Size and Weight

e. Standardization

f. Complexity

Optimum compromise of these criteria comprise the substance of the analog design effort.

To this end two approaches will be pursued simultaneously by MIT, with the assistance of the Industrial Support Contractor. The first will be to optimize circuit configurations and techniques that have had proven success in the POLARIS program. The second will be an effort to adapt digital and switching techniques in configurations that can replace the more classical analog configurations. Work of this nature is currently being carried on at MIT.

Electronic circuit configurations will be limited by the following ground rules:

a. Semiconductors will be silicon.

b. Circuits will be thermally stable, at 100 degrees F. heat sink temperature for worst case design.

c. Circuits will be electrically stable by gain margin factor of two (2) for worst case design.

d. Component selection will take precedence over degenerating an increased number of components.

e. All configurations will account for overall consequences of built-in ground loops.

MIT/IL experience indicates that these design limits are necessary for a dependable system and not unduly restrictive. These ground rules are not inviolable, but any deviation will require a critical examination.

2. Block Diagrams of PSA Circuits for IMU

The following block diagrams are provided.

a. Platform Servo Amps - Figures 3.5-1 and 3.5-2

b. Gimbal Mounted Preamps - Figure 3.5-3

c. 100, 800, 3200 cps sine wave power supplies - Figure 3.5-4

d. DC-DC Converters - Figure 3.5-5

e. Gimbal Angle Data Buffer - Figure 3.5-6

3. Ground Support Equipment

Design of special ground support and test equipment will be anticipated and specified by MIT with the help of the Industrial Support Contractor. In all cases special test equipment will be approved by the MIT group. (See section on GSE.) Categories of these equipments are:

a. Simulated Terminations

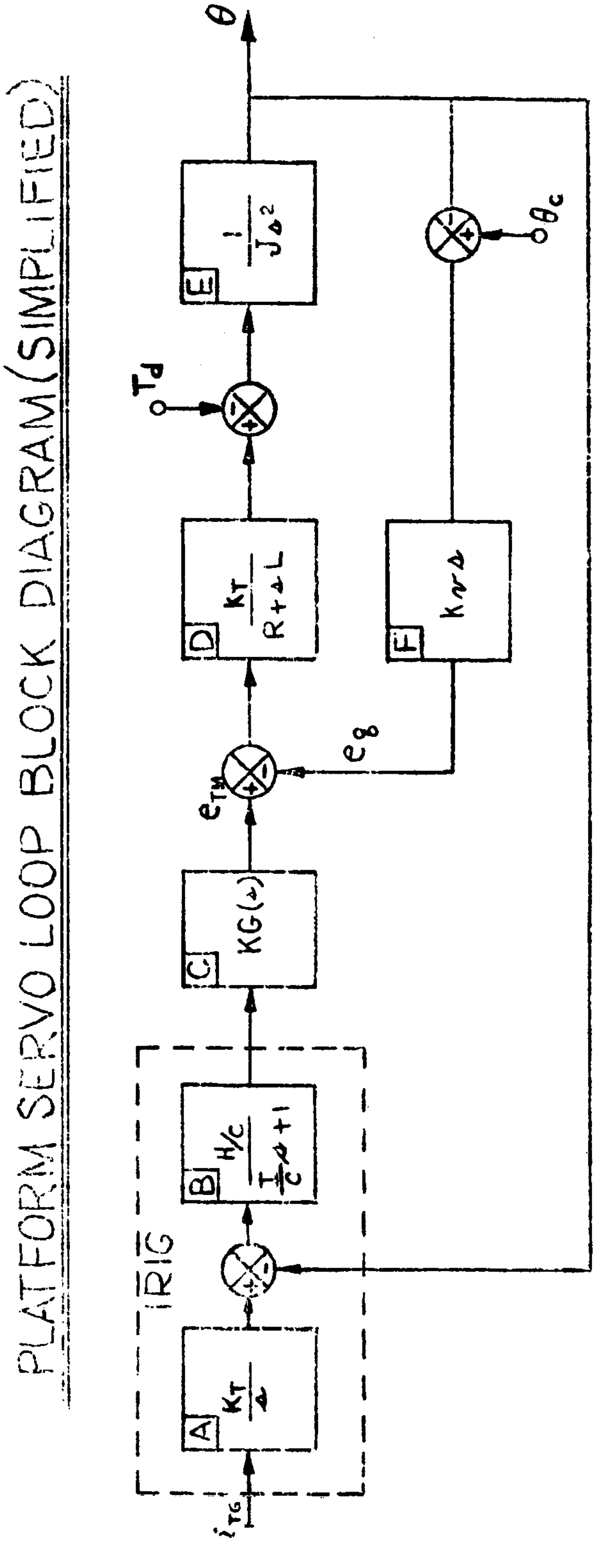
b. Performance Comparators

c. Data Conversion and Presentation Circuits

4. Circuit Design Release Schedule

(See Chart 3.5-1)

June 1962	Preliminary Release for Packaging
July 1962	Preliminary Release for Prototype
January 1963	Final Release for Flight Model



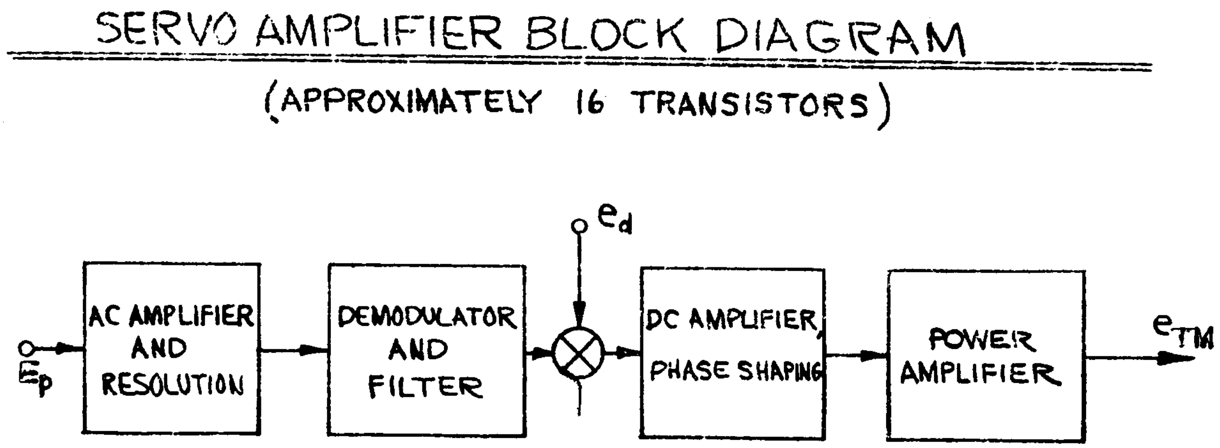
VARIABLE FUNCTIONS

1. i TG ~ IRIG Torque Generator Current
2. T_d ~ Disturbance Torque
3. θ_c ~ Capsule Orientation

TRANSFER FUNCTIONS

A. IRIG Torque Generator
B. IRIG
C. Servo Amplifier
D. Torque Motor
E. Platform
F. Back EMF

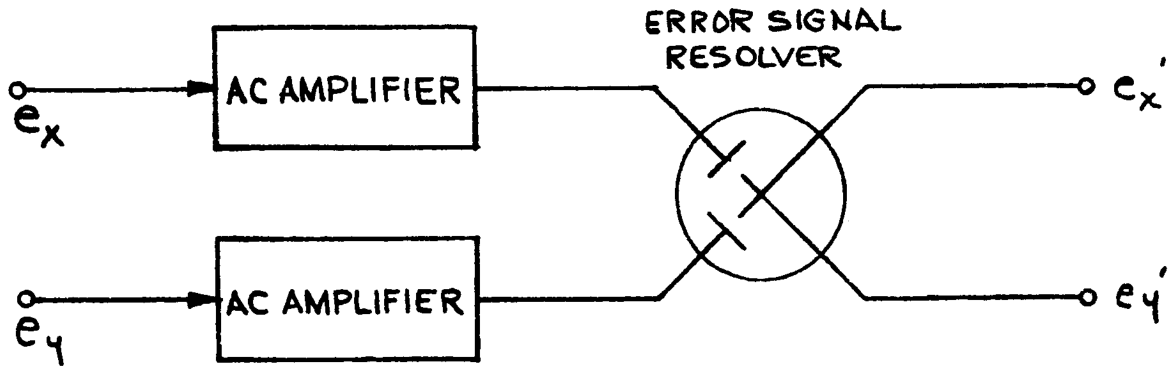
Figure 3.5-1. Platform Servo Loop Block Diagram.



1. E_p ~ Suppressed carrier modulated platform error.
2. e_d ~ DC Amplifier and Demodulator drift.
3. e_{TM} ~ Voltage applied to Torque Motor.

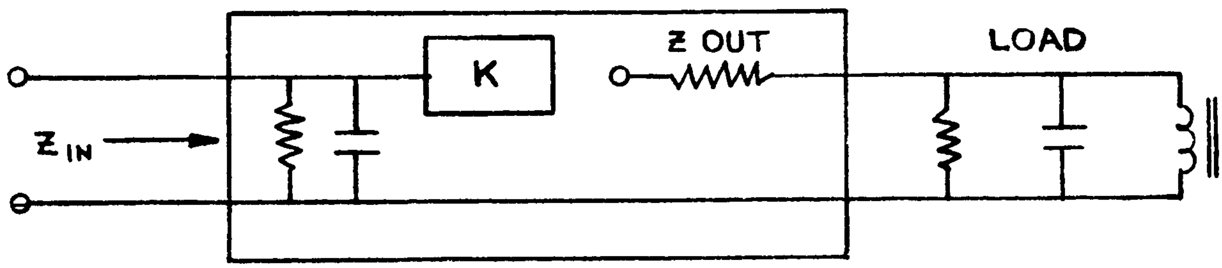
Figure 3.5-2. Servo Amplifier Block Diagram.

GIMBAL MOUNTED BANDPASS AMPLIFIER



FUNCTIONAL DIAGRAM

(4 TRANSISTORS)



TERMINATION DIAGRAM

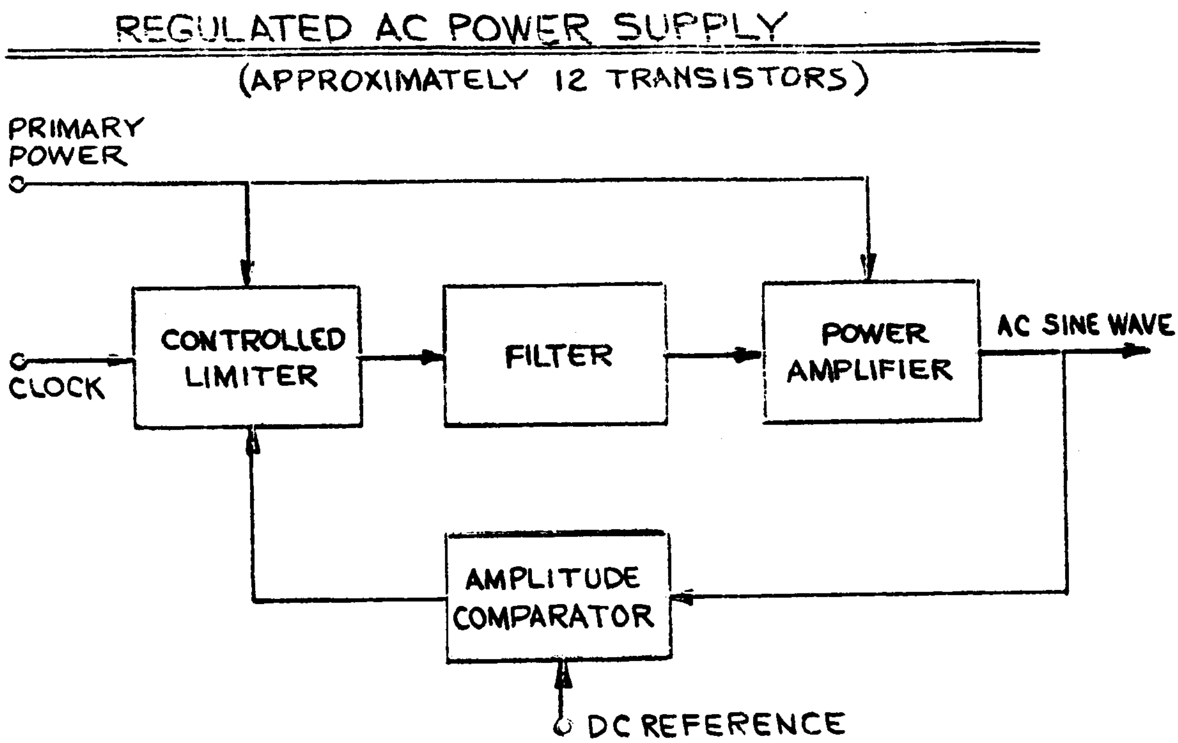
GENERAL PERFORMANCE PARAMETERS

1. **Frequence Response**
2. **Gain Stability**
3. **Dynamic Range**
4. **Ground Loop Isolation**

GOALS

1. **High Reliability**
2. **Decrease Sensitivity to Mismatched Components**
3. **Decrease Size**

Figure 3.5-3. Gimbal Mounted Bandpass Filter.

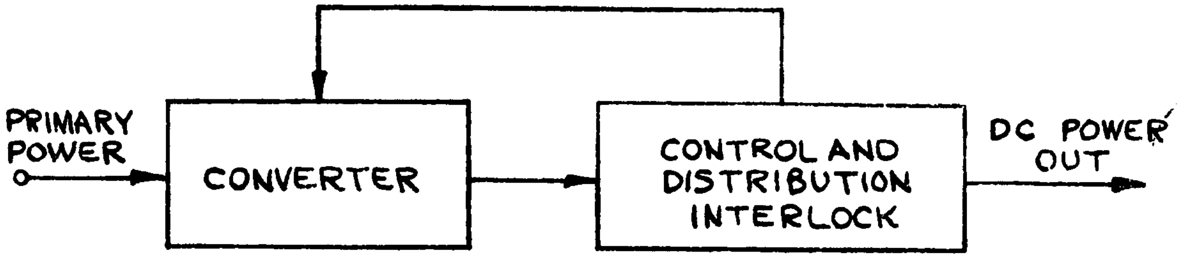


GENERAL PERFORMANCE PARAMETERS	GOALS
1. Output Stability Versus	1. High Power Efficiency
(a) Load Variation	2. High Reliability
(b) Primary Power Variation	3. Decrease Weight & Size
(c) Temperature & Time	
2. Output Harmonic Content	
3. Phase of Output with respect to Input	
4. Ground Loop Isolation	

Figure 3.5-4. Regulated AC Power Supply.

DC - DC CONVERTERS

APPROXIMATELY 10 TRANSISTORS



GENERAL PERFORMANCE PARAMETERS

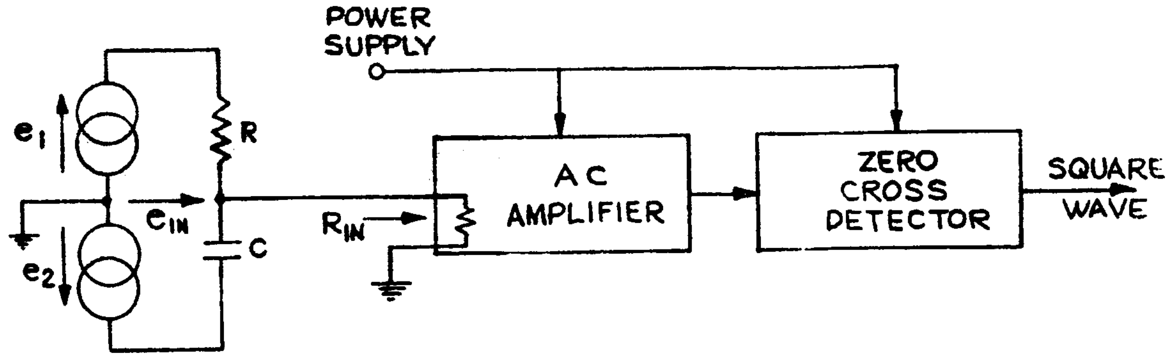
1. **Regulation Versus**
   - **(a) Load Variation**
   - **(b) Supply Variation**
   - **(c) Temperature & Time**
2. **Characteristic of Load on Primary Power Source**

GOALS

1. **High Power Efficiency**
2. **High Reliability**
3. **Decrease of Weight & Size**

Figure 3.5-5. DC-DC Converters.

RESOLVER DATA BUFFER (SIMPLIFIED)



(APPROXIMATELY 6 TRANSISTORS)

GENERAL PERFORMANCE PARAMETERS

1. **Stability of Zero Cross Detection to 1:2000 Versus**
   - **(a) Primary Power Variation**
   - **(b) Amplitude of e_{in}**
   - **(c) Temperature & Time**
2. **R_{in} > 1 Megohm**
3. **Ground Loop Isolation**

GOALS

1. **High Reliability**
2. **Size & Weight**

Figure 3.5-6. Resolver Data Buffer.