

CONFIDENTIAL

APOLLO GUIDANCE COMPUTER
Information Series
ISSUE 1D
APOLLO MISSION AND GUIDANCE
FR-2-101D
18 December 1964

CONFIDENTIAL

CONFIDENTIAL

FR-2-101D

This document contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18, U. S. C., Sections 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.

GROUP 4

Downgraded at 3-year intervals;
declassified after 12 years.

CONFIDENTIAL

CONTENTS

Paragraph		Page
1-1	INTRODUCTION	1-1
1-6	APOLLO MISSIONS	1-3
1-7	Apollo Vehicles.	1-3
1-11	Mission Phases.	1-5
1-20	APOLLO GUIDANCE AND NAVIGATION SYSTEMS	1-9
1-21	The CM and LEM G&N Systems	1-9
1-25	The IMU and Optics	1-10
1-32	AGC Subsystems	1-32

ILLUSTRATIONS

Number		Page
1-1	CSM-LEM-Saturn C-5 Vehicle	1-4
1-2	Major Mission Phases	1-5
1-3	The G&N System within the Command Module	1-11
1-4	Block I Guidance and Navigation System (2 sheets)	1-13
1-5	Block IF Guidance and Navigation System	1-17
1-6	Block II Guidance and Navigation System	1-19
1-7	IMU Gimbal Arrangement	1-21

TABLES

Number		Page
1-1	AGC Subsystems	1-25

1-1. INTRODUCTION

1-2. This is the first issue of the Apollo Guidance Computer Information Series (AGCIS), which is published to inform the technical staff at MIT/IL and Raytheon about the Apollo guidance computer subsystems. This issue contains a very general description of an Apollo lunar mission and a general description of the Apollo guidance and navigation Systems (G&N).

1-3. The objectives of an Apollo lunar mission are the navigation of a manned spacecraft to the moon, the landing of a man on the moon, and the safe return of the crew to the earth's surface. The vehicle used for such a lunar mission is described in paragraphs 1-7 through 1-10; the mission phases are described in paragraphs 1-11 through 1-19. Prior to the lunar mission mentioned, various flights will be undertaken to test the Apollo system and to provide experience. For this purpose some vehicles, which differ from those used in a lunar mission, will be launched. The Saturn C-1B booster, for instance, will launch unmanned and manned Apollo spacecrafts into earth orbit; the Saturn C-5 will be used in later test flights and in lunar missions.

1-4 An Apollo G&N system which is built into the command module (CM) enables the astronauts in it to navigate the Apollo spacecraft (command and service module, CSM). Systems on the ground are able to support the astronauts in navigating the CSM. A G&N system which is built into the lunar excursion module (LEM) enables the astronauts in it to navigate the LEM. The astronaut in the CM is able to assist the astronauts in the LEM. The G&N systems of the CM's and the LEM's are similar. So far four different types of Apollo G&N systems can be distinguished:

- a. Block I G&N systems (system numbers 5 through 20)
- b. Block IF G&N systems (systems numbers 108 through 128)
- c. Block II G&N systems for CM's (system numbers 201 through 226)
- d. Block II G&N systems for LEM's (system numbers 601 through 625)

CONFIDENTIAL

FR-2-101D

The Block I G&N systems are used in ground tests. The Block IF G&N systems will be used for orbiting the earth. The Block II G&N systems will be used for later flights. The various G&N systems are described in paragraphs 1-20 through 1-31.

1-5. In a similar way, four different types of Apollo guidance computer (AGC) subsystems can be distinguished:

- a. Block I AGC's (subsystem numbers 5 through 20)
- b. Block IF AGC's (subsystem numbers 108 through 128)
- c. Block II AGC's for CM's (subsystem numbers 201 through 226)
- d. Block II AGC's for GEM's (subsystem numbers 601 through 625)

Block I AGC subsystems 8, 10, 11, 12, and 17 will be retrofitted to become Block IF AGC subsystems 108, 110A, 120, 112 and 117 respectively.

1-5A. The AGC subsystems, which are used with the Command Module G&N's, consist of one AGC, one Display and Keyboard (DSKY) built into the navigation panel, and one DSKY built into the main panel. The AGC subsystems, which are used with the LEM G&N's consist of one AGC and only one DSKY. The Block I and the Block IF AGC's are very similar in their electronic design but vary considerably in their physical arrangements. Both are built from integrated NOR gates contained in transistor cans. The Block II AGC's of both the CM and the LEM will be built from integrated NOR gates contained in flat packages. The Block II AGC's will have more circuits, a larger memory, more machine instructions, and will control more equipment than the Block I and Block IF AGC's. All DSKY s mentioned are similar in their electrical configuration but vary in their physical design to suit space and viewing requirements. The various AGC subsystems are described from paragraph 1-32 on.

1-6. APOLLO MISSIONS**1-7. APOLLO VEHICLES**

1-8. An Apollo spacecraft (CSM of figure 1-1) consists of a command module (CM) and a service module (SM). The CM houses three astronauts and forms the head of the spacecraft. The SM, which consists mainly of a propulsion thrust engine, attitude control jets, and tanks, constitutes the rocket plant of the spacecraft. The CM encloses the stabilization and control system (SCS) and a guidance and navigation (G&N) system for the spacecraft. It also carries telemetry and telecommunication equipment, an environmental system, equipment for landing the CM on earth, etc. The CM weighs 8.5 to 10 thousand pounds, and the SM weighs about 46 thousand pounds when fully fueled. The CM and the SM remain together during a mission until about one hour prior to re-entry into the earth's atmosphere.

1-9. A lunar excursion module (LEM) is carried by an Apollo spacecraft into a lunar parking orbit, where two astronauts transfer from the CM into the LEM. Thereafter, the LEM descends to the lunar surface while the CSM remains in the lunar orbit until the return of the LEM. The crew operating the LEM is able to perform all tasks by means of equipment built into the LEM and is capable also of accepting support from the CSM. The LEM consists of two major parts: the LEM Launch Stage and the LEM Landing Stage. The LEM landing stage houses the engines used during landing and forms a launching pad for the LEM launch stage when it returns to the lunar parking orbit. The LEM launch stage houses the two astronauts, SCS for the LEM, G&N system communication equipment, landing instruments, an environmental system, etc. After rendezvous of the CSM and LEM in the lunar parking orbit, the LEM crew returns to the CSM and the LEM is jettisoned.

1-10. An Apollo spacecraft (CSM) with a LEM is mounted on top of a C-5 Saturn booster such that the LEM housing connects the CSM to the Saturn (figure 1-1). The Saturn consists of three stages (S-1C, S-II, and S-IVB). When standing on the launch pad, the entire CSM-LEM-Saturn vehicle, including an escape tower on top of the CSM, is about 360 feet high and weighs about 6 million pounds when fully fueled. The Saturn has its own guidance and control system, which is

located in the instrumentation ring mounted on top of the third stage. The Saturn guidance and control system guides the third stage which carries the CSM and the LEM into earth orbit, leaving behind the first and second stage. (Whenever the Saturn guidance and control system is in control of the vehicle, the G&N system in the CM makes its own inertial measurements and records them for later use). Once the proper earth orbit has been established, the third stage is re-ignited at the proper time to inject the remaining CSM-LEM-S-IVB vehicle into a translunar trajectory. After burn-out of the S-IVB stage, it is jettisoned. Then the LEM is freed from its housing and secured to the nose of the CM, and the LEM housing, which connected the CSM to the Saturn, is jettisoned. The SM can then be fired to undertake midcourse corrections and perform other CSM maneuvers.

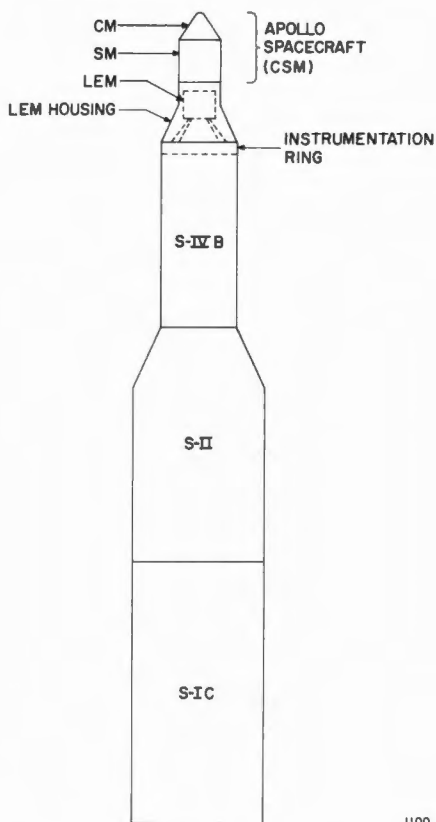


Figure 1-1. CSM-LEM-Saturn C-5 Vehicle

1-11 MISSION PHASES

1-12. The major mission phases are illustrated in figure 1-2 (derived from MIT Report R-373 and from "Project Apollo Lunar Landing Mission Design Plan" of 15 March 1963 published by the Manned Spacecraft Center). During phase 1 (prelaunch) final preparation and check-out of all equipment is performed. During phase 2 (about 11.8 min) the S-IVB stage, together with the CSM and LEM, is injected into a 100-nmi circular earth orbit. One to four earth orbits (each about 88 min) are allowed during phase 3 for checking out all systems, for establishing ephemeris data, for comparing measurements made in the spacecraft and by ground-operated support system (GOSS) stations, and for computing the time of translunar orbit injection.

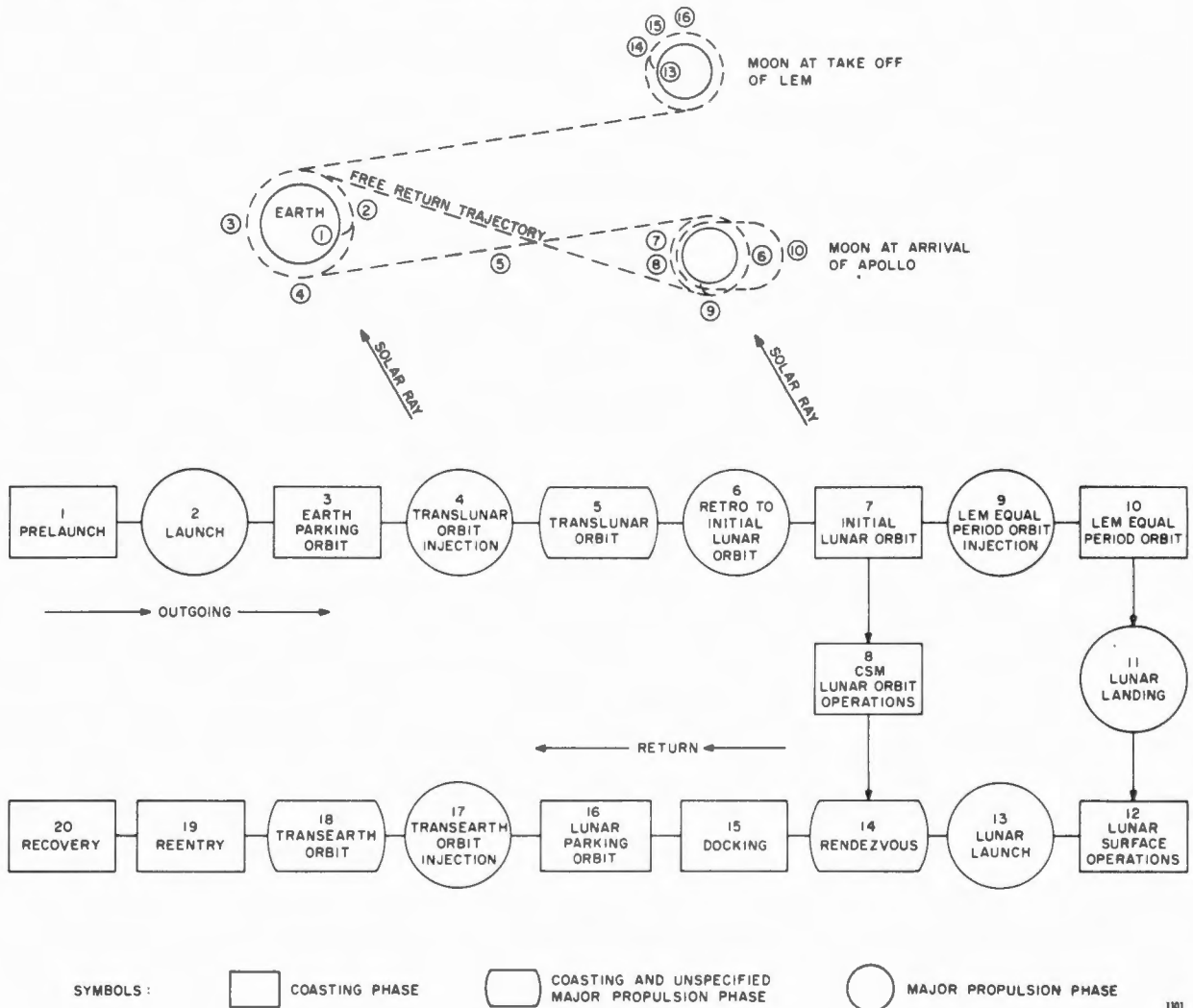


Figure 1-2. Major Mission Phases

CONFIDENTIAL

FR-2-101D

1-13. During phase 4 (about 5.2 min) the S-IVB engine is re-ignited to inject the spacecraft into a translunar orbit. This trajectory has the characteristics that if no further maneuvers are attempted after injection, the CSM and LEM will coast around the moon and return to earth. This is called a "free return" trajectory. During phase 5 (about 62 hours) the S-IVB is jettisoned and the LEM is freed from its housing and mounted onto the nose of the CM. Midcourse measurements are made several times; midcourse corrections can be performed about three times. A crew member enters the LEM to check it out and returns to the CM.

1-14. During phase 6 (about 5 min) a retrograde impulse is generated to establish an 80-nmi circular lunar orbit. This is done near the pericyynthion of the translunar orbit (behind the moon with respect to the earth). During phase 7 (2 to 7 hours) two astronauts enter the LEM, all systems are checked, lunar orbit ephemeris is established, and the proposed landing site is surveyed. Thereafter, the LEM is separated from the mother ship and checked once more while coasting in the lunar parking orbit together with the mother spacecraft, both being about 320 ft apart. The CSM (one astronaut on board) orbits the moon about once every 123 minutes during phase 8 and assists the LEM, when necessary and possible, during phases 9 through 14.

1-15. During phase 9 (about 80 sec) the LEM is injected into an elliptical orbit of equal period with that of the CSM. The orbit has its pericyynthion at approximately 50,000 ft above the lunar landing site and its apocynthion at about 152-nmi behind the moon with respect to earth. During phase 10 (0.5 to 2.5 hours) the LEM coasts in this orbit, its systems are checked, orbital ephemeris is established, and the landing site is surveyed from a lower attitude.

1-16. Phase 11 can be divided into two subphases. About 5.5 minutes are provided for the LEM to descend from 50,000 ft to 1,000 ft where it will hover to view the landing site and perform necessary translation maneuvers. About 1.1 minutes are required to descend from 1,000 ft and to land.

1-17. During phase 12 (two days or less) lunar surface operations take place. First, all necessary preparations are made for launching. Then one crew member descends from the LEM, carries out specified tasks on the lunar surface, and returns to the LEM. Thereafter, the second astronaut carries out similar tasks. Communication is maintained with the CSM to report progress and to confirm launching and rendezvous plans.

1-18. During phase 13 (about 5.8 min) the LEM is launched to a position about 50,000 ft above the lunar surface. During phases 14 and 15 (about 58 min) a Hohmann transfer orbit is flown to intercept the CSM and to dock. During phase 16 (1 hour to 7 days) the LEM crew enters the CM, the LEM is jettisoned, and all necessary preparations for return to earth are made.

1-19. During phase 17 (about 2.4 min) the CSM is injected into trans-earth orbit. This takes place behind the moon with respect to the earth. Phase 18 is similar to phase 5. Late in phase 18 and prior to re-entry into the earth's atmosphere the SM is jettisoned. Phase 19 begins at an altitude of about 400,000 ft above the earth and takes about 23.5 minutes. Re-entry takes place in the direction of earth rotation. Phase 20 (recovery) is under ground control.

1-20. APOLLO GUIDANCE AND NAVIGATION SYSTEMS**1-21. CM AND LEM G&N SYSTEMS**

1-22. The Apollo G&N System, which is built into the CM enables an astronaut to:

- a. Determine (fix) the earth orbit in which the CSM-LEM-S-IVB spacecraft is traveling and hold it in this orbit.
- b. Inject the spacecraft into a translunar orbit.
- c. Jettison the S-IVB stage.
- d. Perform the necessary maneuvers when freeing the LEM and mounting it onto the nose of the CM.
- e. Perform navigational measurements and course correction in the translunar orbit.
- f. Inject the CM-LEM spacecraft into a circular lunar parking orbit.
- g. Determine the circular lunar parking orbit and hold the spacecraft in that parking orbit.
- h. Perform the necessary maneuvers when separating the LEM from the CM.
- j. Assist the LEM during its descent, lunar landing, launching, rendezvous, and docking.
- k. Jettison the LEM.
- l. Inject the CSM craft into a transearth orbit.
- m. Perform navigational measurements and course corrections in the transearth orbit.
- n. Jettison the SM.
- p. Re-enter the CM into the earth's atmosphere and land it within a defined area.
- q. Abort a mission in case of emergency and safely return the CM to the earth's surface.

CONFIDENTIAL

FR-2-101D

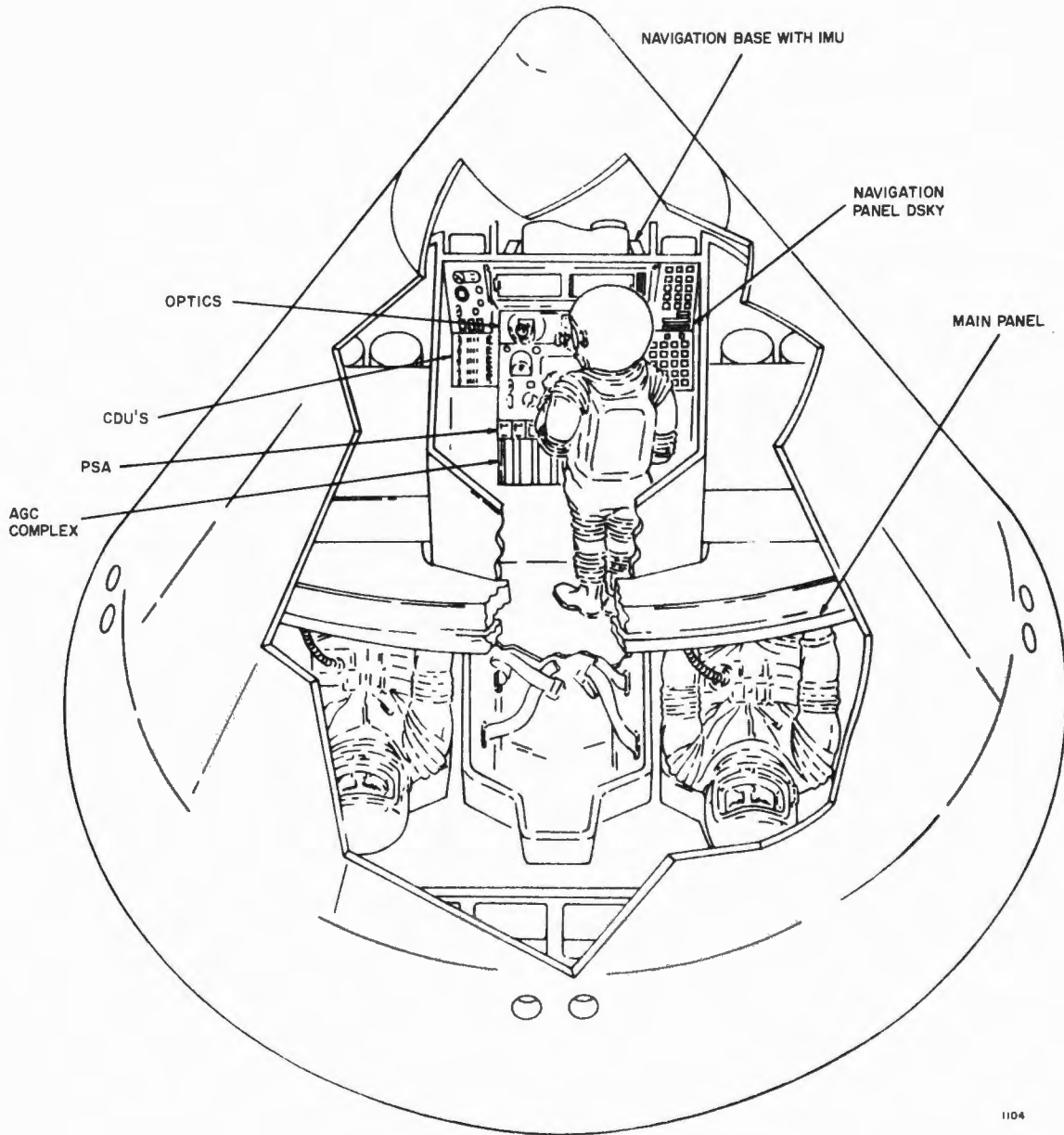
1-23. The G&N system which is built into the LEM enables an astronaut to:

- a. Separate the LEM from the CSM and hold it in the circular lunar parking orbit.
- b. Inject the LEM into an elliptical lunar orbit of equal period with that of the CSM.
- c. Determine this orbit and hold the LEM in it.
- d. Decide on a landing site and land.
- e. Launch the LEM launch stage.
- f. Inject the LEM into a Hohmann transfer orbit which brings the LEM into the parking orbit of the CM.
- g. Rendezvous and dock the LEM with the CM.
- h. Abort a LEM mission in case of emergency and safely return to the lunar parking orbit for rendezvous and docking with the CM.

1-24. The G&N systems consist of various sensors, a computer subsystem, and auxiliary units. The sensors of the G&N systems are the inertial measurement unit (IMU), a scanning telescope (SCT), a sextant (SXT), and a star tracker, referred to as the optics; a tracking radar; and a transponder. The radar, together with the transponder, is provided for rendezvous maneuvers. The G&N system of the LEM, in addition, also consists of a radar subsystem used during the lunar landing maneuvers. The computer (AGC) subsystems are able to control the sensors, to accept data from the sensors, and to control the stabilization and control system (SCS) of the CM or LEM. Both the CM and the LEM G&N systems also include coupling "display" units (CDU's) and a power and servo assembly (PSA) which link the IMU and the Optics with the AGC. The CDU's also link the AGC with the SCS. The arrangement of the G&N system within the CM is shown in figure 1-3. Figures 1-4 and 1-5, originated by MIT/IL, represent the Block I and Block IF G&N systems.

1-25. THE IMU AND OPTICS

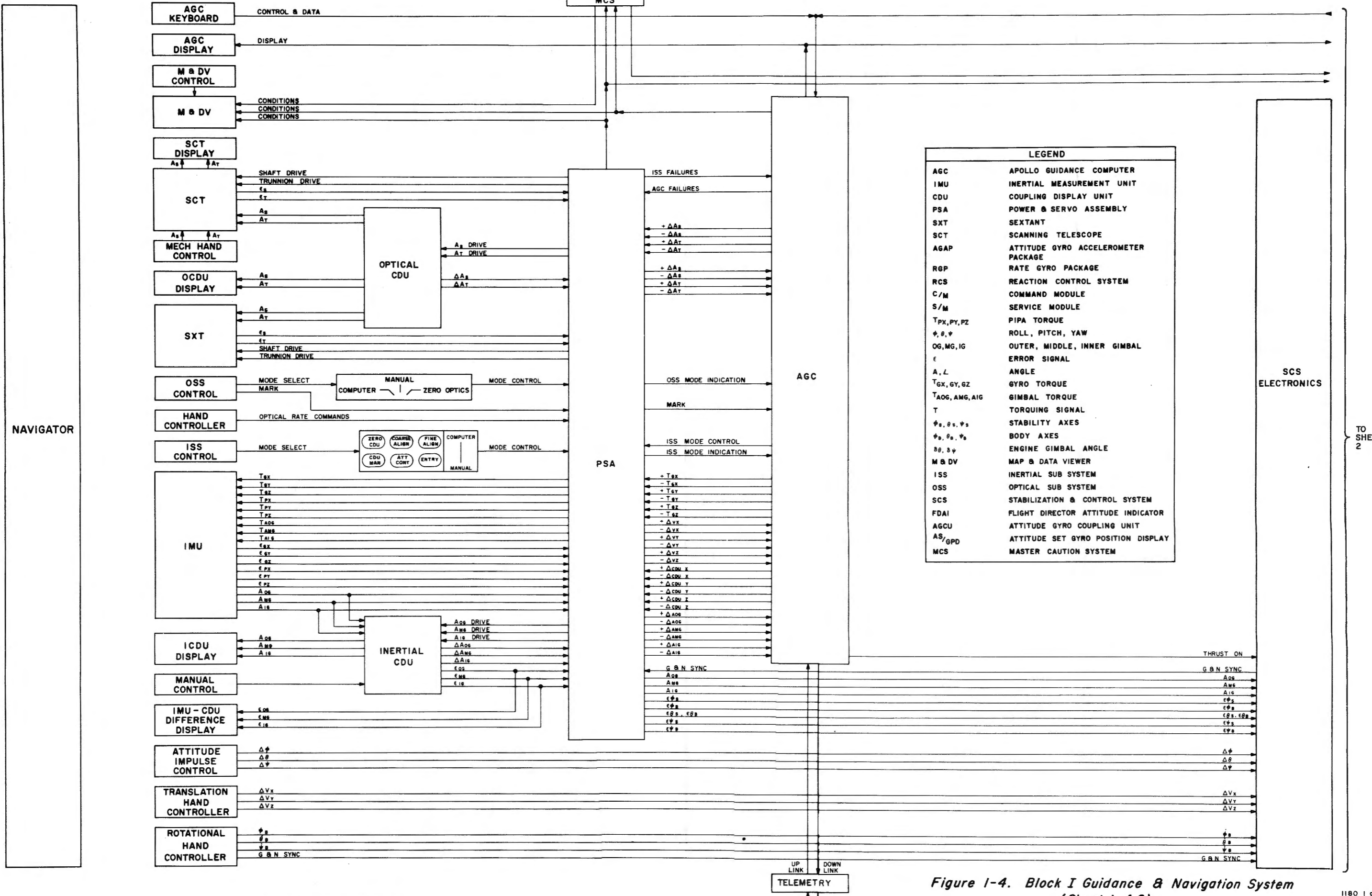
1-26. The inertial measurement unit (IMU) consists of a stable platform mounted on three gimbals which carry three pulse integrating pendulous accelerometers (PIPA's) and three single-degree-of-freedom inertial reference integrating gyros (IRIG's). Each gimbal has a torque motor (tm) and an angle sensor (as, figure 1-7). The



1104

Figure 1-3. The G & N System within the Command Module

CONFIDENTIAL



LEGEND

AGC	APOLLO GUIDANCE COMPUTER
IMU	INERTIAL MEASUREMENT UNIT
CDU	COUPLING DISPLAY UNIT
PSA	POWER & SERVO ASSEMBLY
SXT	SEXTANT
SCT	SCANNING TELESCOPE
AGAP	ATTITUDE GYRO ACCELEROMETER PACKAGE
RGP	RATE GYRO PACKAGE
RCS	REACTION CONTROL SYSTEM
C/M	COMMAND MODULE
S/M	SERVICE MODULE
$T_{PX, PY, PZ}$	PIPA TORQUE
ϕ, θ, ψ	ROLL, PITCH, YAW
OG, MG, IG	OUTER, MIDDLE, INNER GIMBAL
ϵ	ERROR SIGNAL
A, L	ANGLE
$T_{GX, GY, GZ}$	GYRO TORQUE
$T_{AOG, AMG, AIG}$	GIMBAL TORQUE
T	TORQUING SIGNAL
ϕ_s, θ_s, ψ_s	STABILITY AXES
ϕ_b, θ_b, ψ_b	BODY AXES
θ_g, θ_ψ	ENGINE GIMBAL ANGLE
M & DV	MAP & DATA VIEWER
ISS	INERTIAL SUB SYSTEM
OSS	OPTICAL SUB SYSTEM
SCS	STABILIZATION & CONTROL SYSTEM
FDAI	FLIGHT DIRECTOR ATTITUDE INDICATOR
AGCU	ATTITUDE GYRO COUPLING UNIT
AS/GPD	ATTITUDE SET GYRO POSITION DISPLAY
MCS	MASTER CAUTION SYSTEM

Figure 1-4. Block I Guidance & Navigation System (Sheet 1 of 2)

CONFIDENTIAL

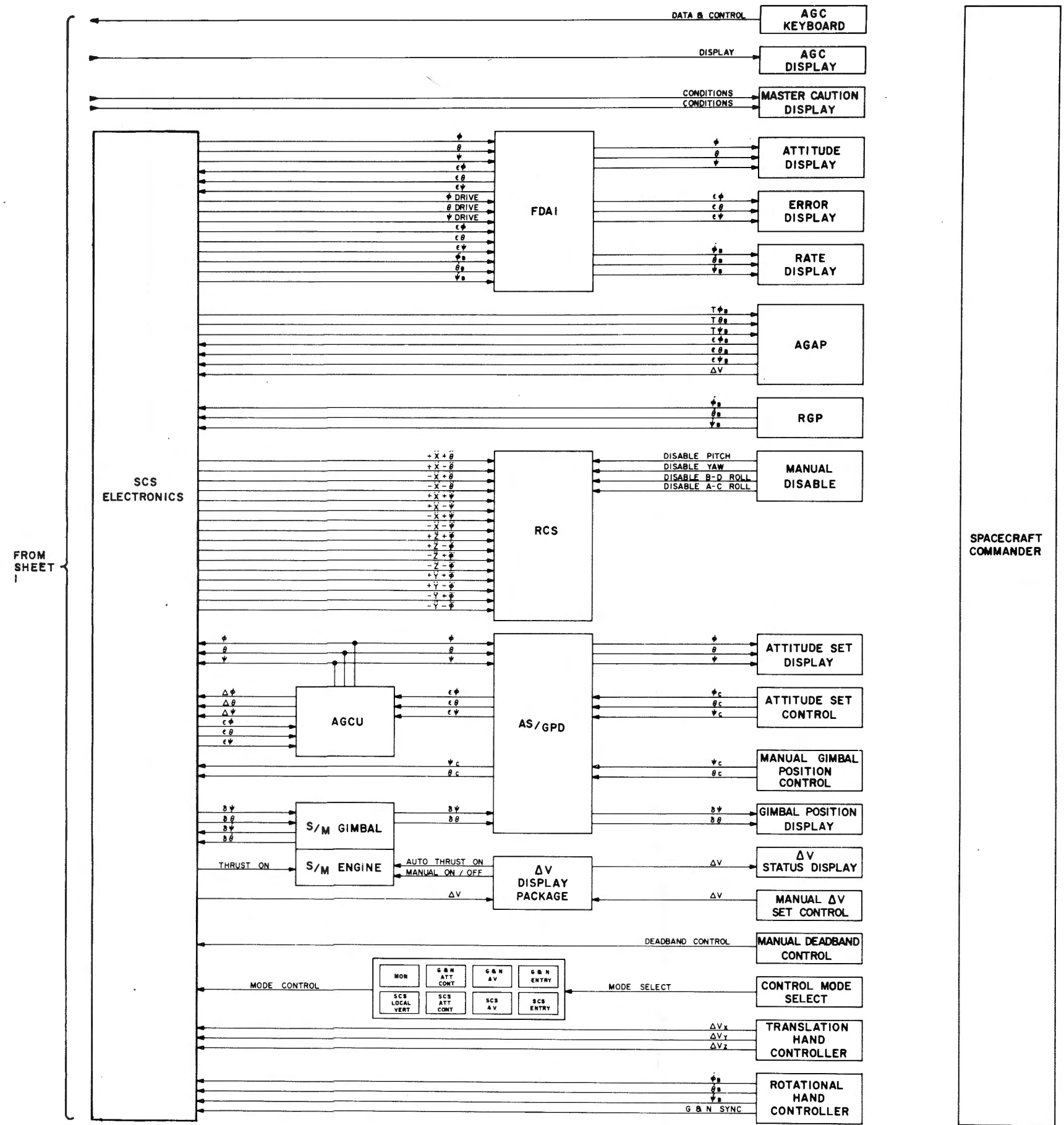


Figure 1-4. Block I Guidance & Navigation System (Sheet 2 of 2)

(To be supplied)

Figure 1-5. Block IF Guidance and Navigation System

(To be supplied)

Figure 1-6. Block II Guidance and Navigation System

The preamplifiers for the PIPA's and the IRIG's are mounted near the sensors. A heater, its controls, and some IMU system switching are contained within the IMU, but most of the other circuits which drive and control the IMU are located in the PSA.

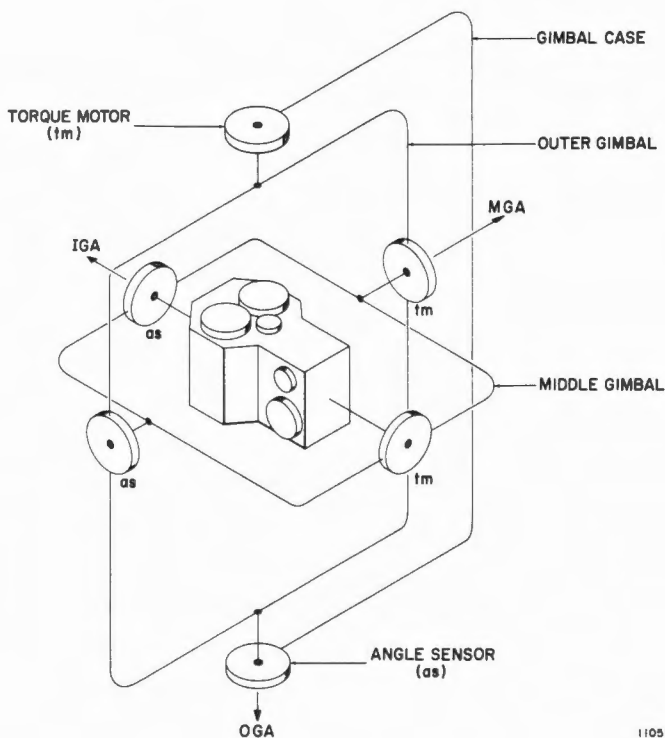


Figure 1-7. IMU Gimbal Arrangement

1-27. The three IRIG's in conjunction with the servo loops driving the three torque motors, hold the platform at a certain attitude with respect to a space co-ordinate system. The three gimbal angle sensors provide signals which indicate the attitude of the Apollo spacecraft or LEM with respect to the stable platform. These signals are fed into the three IMU CDU's where they are transformed into other angular data to be sent to the AGC and the SCS.

1-28. The three PIPA's detect acceleration and provide the AGC (via the PSA) with pulses representing velocity increments in reference to space coordinates as defined by the attitude of the stable plat-

CONFIDENTIAL

FR-2-101D

form. The PSA supplies the IMU with a variety of control signals, some of them originating in the AGC or at a manual control. The IMU may be called the internal navigation reference. Data generated by the IMU is integrated and recorded by the AGC. At times when no change of motion occurs, such as during midcourse coasting, the IMU may be switched off to save power but must be turned on and aligned before any maneuver.

1-29. The three IMU CDU's compare the angular information received from the IMU with the angular values set in the CDU and provide signals for the SCS which, in turn, maintains the spacecraft at a chosen attitude. The values for a chosen attitude can be set manually in the CDU's or by the AGC and are displayed on the CDU's. Therefore, lines are provided between the IMU CDU's and the AGC to transmit control signals from the AGC to the CDU's and data from the CDU's to the AGC. The CDU's do not control the SCS when the Saturn booster lifts the spacecraft into earth orbit, but it is in active control whenever a maneuver is initiated by the spacecraft. A maneuver can be controlled by the AGC, by manually setting the CDU's (in case of AGC failure), or by using the hand control (control stick). When the control stick is used, the CDU's cannot control the attitude of the spacecraft, instead the CDU's follow the IMU. At the moment control is returned to the CDU's, the CDU's keep the spacecraft at the last-chosen attitude until a new command is received from the AGC or until the CDU is set by hand.

1-30. The Block I (and Block IF) Optics consists of the SCT and the SXT. The Block IF will be provided with a star tracker, however, this star tracker will operate independently of the Optics. The Block II Optics will include a star tracker. Various lines exist between the optics, the two optics CDU's, the PSA, and the AGC for the transmission of control signals and data. The SCT and the SXT can be controlled manually or by the AGC. The SCT and the SXT are used during midcourse navigation and during IMU alignment to define position and attitude in space. During orbital navigation and lunar landing only the SCT is needed.

1-31. A tracking radar will be provided in the CM and the LEM for rendezvous maneuvers. The tracking radar of the Block II will be coupled with the Optics. The tracking radar of Block IF, if provided, will operate independently. The LEM will also be equipped with a landing radar.

1-32. AGC SUBSYSTEMS

1-33. There are 10 Block I AGC subsystems being built, however, five of these will be retrofitted to the Block IF configuration. In addition, 11 Block IF AGC subsystems will be built. Table 1-1 lists the various Block I and Block IF AGC subsystems, their associated part and serial numbers, and retrofit kit numbers where applicable. The table is divided into five major sections. The first section contains information pertaining to the AGC subsystems. The next three sections contain information pertaining to the subsystem components (the AGC, Navigation Panel DSKY, and Main Panel DSKY). The last section contains information in regard to modified AGC subsystems. The Block I AGC subsystem is described in Issue 15, the Block IF AGC subsystem in Issue 20, and the Block II AGC subsystem in Issue 21.

TABLE 1-1. AGC SUBSYSTEMS

Subsystem Number	Raytheon Serial Number	Subsystem Part Number	AGC			NAV DSKY			MAIN DSKY			New Subsystem Number	New Raytheon Serial No.	New Part Number
			Part Number	Retrofit Kit No. or its Part Number	New Part Number	Part Number	Retrofit Kit Number	New Part Number	Part Number	Retrofit Kit Number	New Part Number			
5	1	1003400-1	1003186			1003458			1003459	8104003	1003459MD1			
6	2	1003400-1	1003186	8104013	1003186MD1	1003458			1003459	8104003	1003459MD1			
7	3	1003400-1	1003186	8104013	1003186MD1	1003458			1003459	8104003	1003459MD1			
8 [⚠]	4	1003400-2	1003469	8104013	1006469MD1	1003524			1003540	8104003	1003540MD1			
			1003469MD1	RFK5									108	
20	5	1003400-2	1003469	8104013	1003469MD1	1003524			1003540	8104003	1003540MD1			
10 [⚠]	6	1003400-3	1003477	RFK4	1003700-011	1003706			1003707			110A	140	1003770-011
11 [⚠]	7	1003400-3	1003477	RFK1	1003700-011	1003551			1003484			120	110	1003770-011
17 [⚠]	8	1003400-3	1003477	RFK2	1003700-011	1003551			1003484			117	120	1003770-011
12 [⚠]	9	1003400-3	1003477	RFK3	1003700-011	1003551			1003484			112	130	1003770-011
9	10	1003400-3	1003477			1003524			1003540	8104003	1003540MD1			
109, 111, 119, 121 through 128 [⚠]	170 through 270	1003770-021	1003700-011			1003706			1003707					

[⚠] Block I subsystems retrofitted to Block IF

[⚠] Block IF subsystem