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MISSION OPERATION REPORT
SUPPLEMENT

APOLLO 8 (AS.503) MISSION

19 DECEMBER 1968

NASA

OFFICE OF MANNED SPACE FLIGHT
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FOREWORD

MISSION OPERATION REPORTS are published expressly for the use of NASA Senior Management, as required by the Administrator in NASA Instruction 6-2-10, dated August 15, 1963. The purpose of these reports is to provide NASA Senior Management with timely, complete, and definitive information on flight mission plans, and to establish official mission objectives which provide the basis for assessment of mission accomplishment.

Initial reports are prepared and issued for each flight project just prior to launch. Following launch, updating reports for each mission are issued to keep General Management currently informed of definitive mission results as provided in NASA Instruction 6-2-10.

Because of their sometimes highly technical orientation, distribution of these reports is limited to personnel having program-project management responsibilities. The Office of Public Affairs publishes a comprehensive series of pre-launch and post-launch reports on NASA flight missions, which are available for general distribution.

THE MISSION OPERATION REPORT SUPPLEMENT is intended to discuss facilities and equipments common to all Apollo-Saturn V missions. This supplement allows an adequate description of facilities and equipments without detracting from the unique mission information contained in each basic Mission Operation Report.

Specific technical data has been referenced to the SA-504 launch vehicle and the Block II spacecraft as a baseline.

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SPACE VEHICLE

The primary flight hardware of the Apollo program consists of a Launch Vehicle (LV), designated the Saturn V, and an Apollo Spacecraft. Collectively, they are designated the Space Vehicle (SV) (Figure 1).

The Saturn Launch Vehicle consists of three propulsive stages (S-IC, S-II, S-IVB), two interstages, and an Instrument Unit (IU).

The Apollo Spacecraft (SC) includes the Spacecraft/Lunar Module Adapter (SLA), the Lunar Module (LM), the Service Module (SM), the Command Module (CM), and the Launch Escape System (LES). The Command Module and the Service Module, considered as a unit, is termed the Command/Service Module (CSM).

S-IC STAGE

GENERAL

The S-IC stage (Figure 2) is a large cylindrical booster, 138 feet long and 33 feet in diameter, powered by five liquid propellant F-1 rocket engines. These engines develop a nominal sea level thrust of 1,526,500 pounds each (approximately 7,632,500 pounds total) and have a burn time of 150.5 seconds. The stage dry weight is approximately 295,300 pounds and the total loaded stage weight is approximately 5,030,300 pounds.

The stage interfaces structurally and electrically with the S-II stage. It also interfaces structurally, electrically, and pneumatically with Ground Support Equipment (GSE) including two umbilical service arms, three tail service masts, and certain electronic systems by antennas.

The stage consists of structures, propulsion, environmental control, fluid power, pneumatic control, propellants, electrical, instrumentation, and ordnance systems.

STRUCTURE

The S-IC structural design reflects the requirements of F-1 engines, propellants, control, instrumentation, and interfacing systems. Aluminum alloy is the primary structural material. The major components, shown in Figure 3 are the forward skirt, oxidizer tank, intertank section, fuel tank, and thrust structure.

The 345,000-gallon oxidizer tank is the structural link between the forward skirt and the intertank structure which provides structural continuity between the oxidizer and fuel tanks.

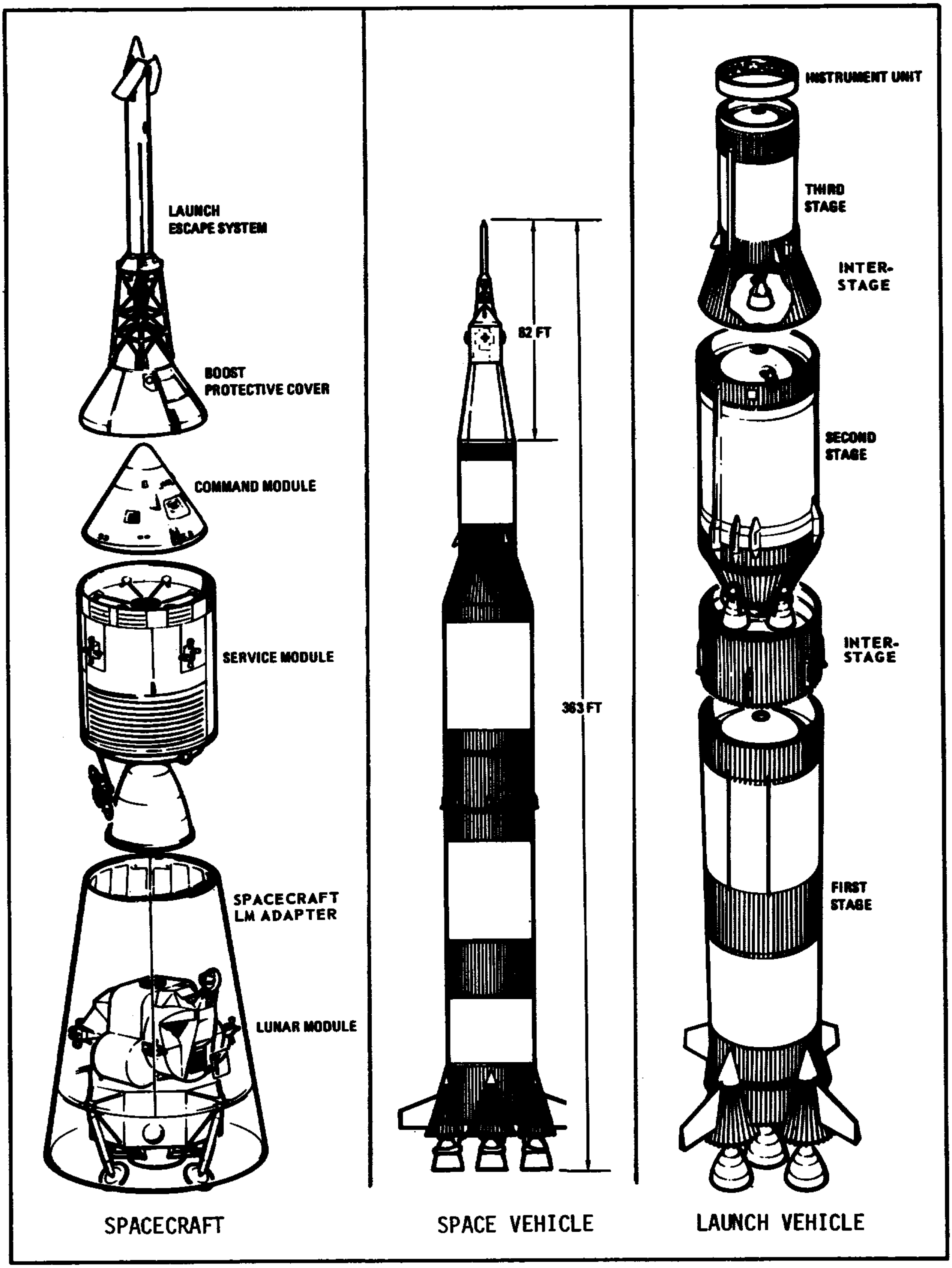
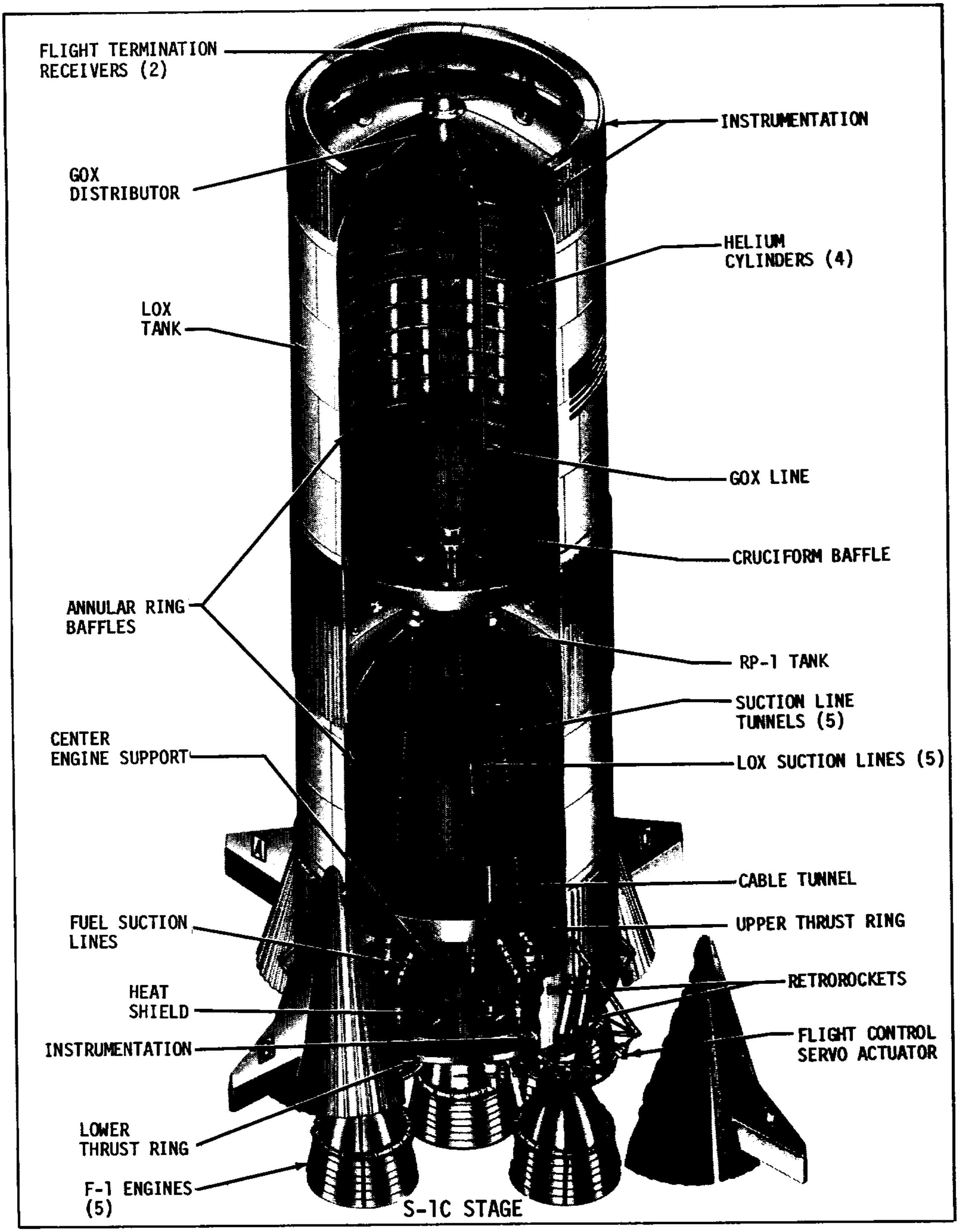

LAUNCH
ESCAPE SYSTEM
BOOST
PROTECTIVE COVER
COMMAND MODULE
SERVICE MODULE
SPACECRAFT
LM ADAPTER
LUNAR MODULE
82 FT
363 FT
INSTRUMENT UNIT
THIRD
STAGE
INTER-
STAGE
SECOND
STAGE
INTER-
STAGE
FIRST
STAGE
SPACECRAFT
SPACE VEHICLE
LAUNCH VEHICLE

Fig. 1


FLIGHT TERMINATION RECEIVERS (2)
INSTRUMENTATION
GOX DISTRIBUTOR
HELIUM CYLINDERS (4)
LOX TANK
GOX LINE
CRUCIFORM BAFFLE
ANNULAR RING BAFFLES
RP-1 TANK
SUCTION LINE TUNNELS (5)
CENTER ENGINE SUPPORT
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CABLE TUNNEL
FUEL SUCTION LINES
UPPER THRUST RING
RETROROCKETS
HEAT SHIELD
FLIGHT CONTROL SERVO ACTUATOR
INSTRUMENTATION
LOWER THRUST RING
F-1 ENGINES (5)
S-1C STAGE

Fig. 2

The 216,000-gallon fuel tank (Figure 3) provides the load carrying structural link between the thrust and intertank structures. It is cylindrical with ellipsoidal upper and lower bulkheads. Five oxidizer ducts run from the ozidizer tank, through the fuel tank, to the F-1 engines.

The thrust structure assembly (Figure 3) redistributes the applied loads of the five F-1 engines into nearly uniform loading about the periphery of the fuel tank. Also, it provides support for the five F-1 engines, engine accessories, base heat shield, engine fairings and fins, propellant lines, retrorockets, and environmental control ducts. The lower thrust ring has four holddown points which support the fully loaded Saturn V/ Apollo (approximately 6,000,000 pounds) and also, as necessary, restrain the vehicle during controlled release.

PROPULSION

The F-1 engine is a single-start, 1,526,500-pound fixed-thrust, calibrated, bi-propellant engine which uses liquid oxygen (LOX) as the oxidizer and Rocket Propellant-1 (RP-1) as the fuel. The thrust chamber is cooled regeneratively by fuel, and the nozzle extension is cooled by gas generator exhaust gases. LOX and RP-1 are supplied to the thrust chamber by a single turbopump powered by a gas generator which uses the same propellant combination. RP-1 is also used as the turbopump lubricant and as the working fluid for the engine hydraulic control system. The four outboard engines are capable of gimbaling and have provisions for supply and return of RP-1 as the working fluid for a thrust vector control system. The engine contains a heat exchanger system to condition engine supplied LOX and externally supplied helium for stage propellant tank pressurization. An instrumentation system monitors engine performance and operation. External thermal insulation provides an allowable engine environment during flight operation.

The normal inflight engine cutoff sequence is center engine first, followed by the four outboard engines. Engine optical-type LOX depletion sensors initiate the engine cutoff sequence. A fuel level engine cutoff sensor in the bottom of the fuel tank initiates engine shutdown when RP-1 is depleted if the LOX sensors have failed to cut the engines off first.

In an emergency, the engine can be cut off by any of the following methods: Ground Support Equipment (GSE) Command Cutoff, Emergency Detection System, Outboard Cutoff System.

PROPELLANT SYSTEMS

The systems include hardware for fill and drain, propellant conditioning, and tank pressurization prior to and during flight, and for delivery to the engines.

Fuel tank pressurization is required during engine starting and flight to establish and maintain a net positive suction head (NPSH) at the fuel inlet to the engine turbopumps. During flight, the source of fuel tank pressurization is helium from storage bottles mounted inside the oxidizer tank.

Fuel feed is accomplished through two 12-inch ducts which connect the fuel tank to each F-1 engine. The ducts are equipped with flex and sliding joints to compensate for motions from engine gimbaling and stage stresses.

Gaseous oxygen (GOX) is used for oxidizer tank pressurization during flight. A portion of the LOX supplied to each engine is diverted into the engine heat exchangers where it is transformed into GOX and routed back to the tanks.

LOX is delivered to the engines through five suction lines which are equipped with flex and sliding joints.

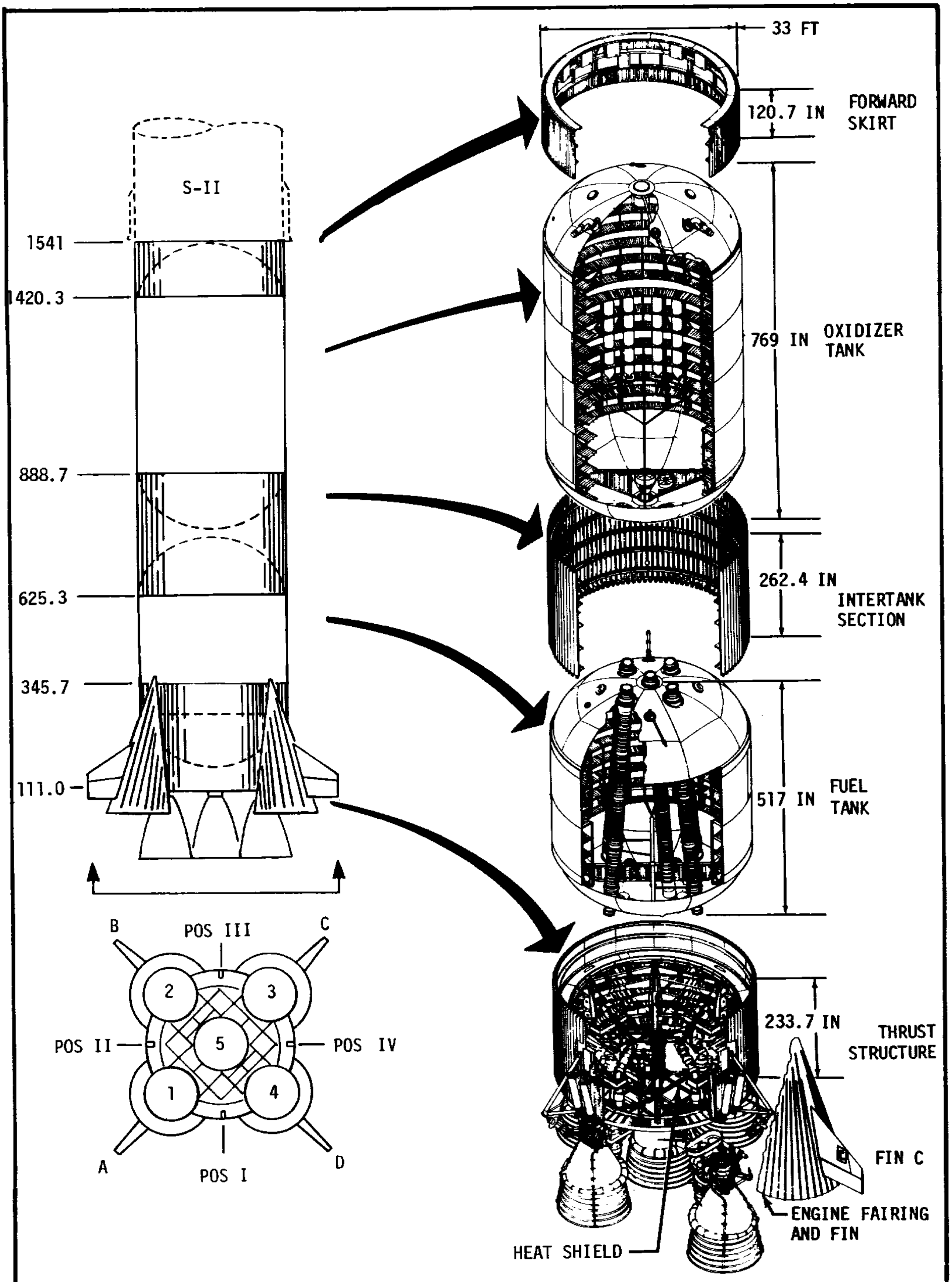
FLIGHT CONTROL SYSTEM

The S-IC thrust vector control consists of four outboard F-1 engines, gimbal blocks to attach these engines to the thrust ring, engine hydraulic servoactuators (two per engine), and an engine hydraulic power supply.

Engine thrust is transmitted to the thrust structure through the engine gimbal block. There are two servoactuator attach points per engine, located 90 degrees from each other, through which the gimbaling force is applied. The gimbaling of the four outboard engines changes the direction of thrust and as a result corrects the attitude of the vehicle to achieve the desired trajectory.

ELECTRICAL

The electrical power system of the S-IC stage is made up of two basic subsystems: the operational power subsystem and the measurements power subsystem. Onboard power is supplied by two 28-volt batteries. Battery number 1 is identified as the operational power system battery. It supplies power to operational loads such as valve controls, purge and venting systems, pressurization systems, and sequencing and flight control. Battery number 2 is identified as the measurement power system. Batteries supply power to their loads through a common main power distributor, but each system is completely isolated from the other. The S-IC stage switch selector is the interface between the Launch Vehicle Digital Computer (LVDC) in the IU and the S-IC stage electrical



S-IC STRUCTURAL ASSEMBLIES

Fig. 3

circuits. Its function is to sequence and control various flight activities such as telemetry calibration, retrofire initiation, and pressurization.

ORDNANCE

The S-IC ordnance systems include the propellant dispersion (flight termination) system and the retrorocket system.

The S-IC propellant dispersion system (PDS) provides the means of terminating the flight of the Saturn V if it varies beyond the prescribed limits of its flight path or if it becomes a safety hazard during the S-IC boost phase.

The eight retrorockets that provide separation thrust after S-IC burnout are attached externally to the thrust structure inside the four outboard engine fairings.

The S-IC retrorockets are mounted, in pairs, in the fairings of the F-1 engines. The firing command originates in the IU and activates redundant firing systems. At retro-rocket ignition the forward end of the fairing is burned and blown through by the exhausting gases. The thrust level developed by seven retrorockets (one retrorocket out) is adequate to separate the S-IC stage a minimum of six feet from the vehicle in less than one second.

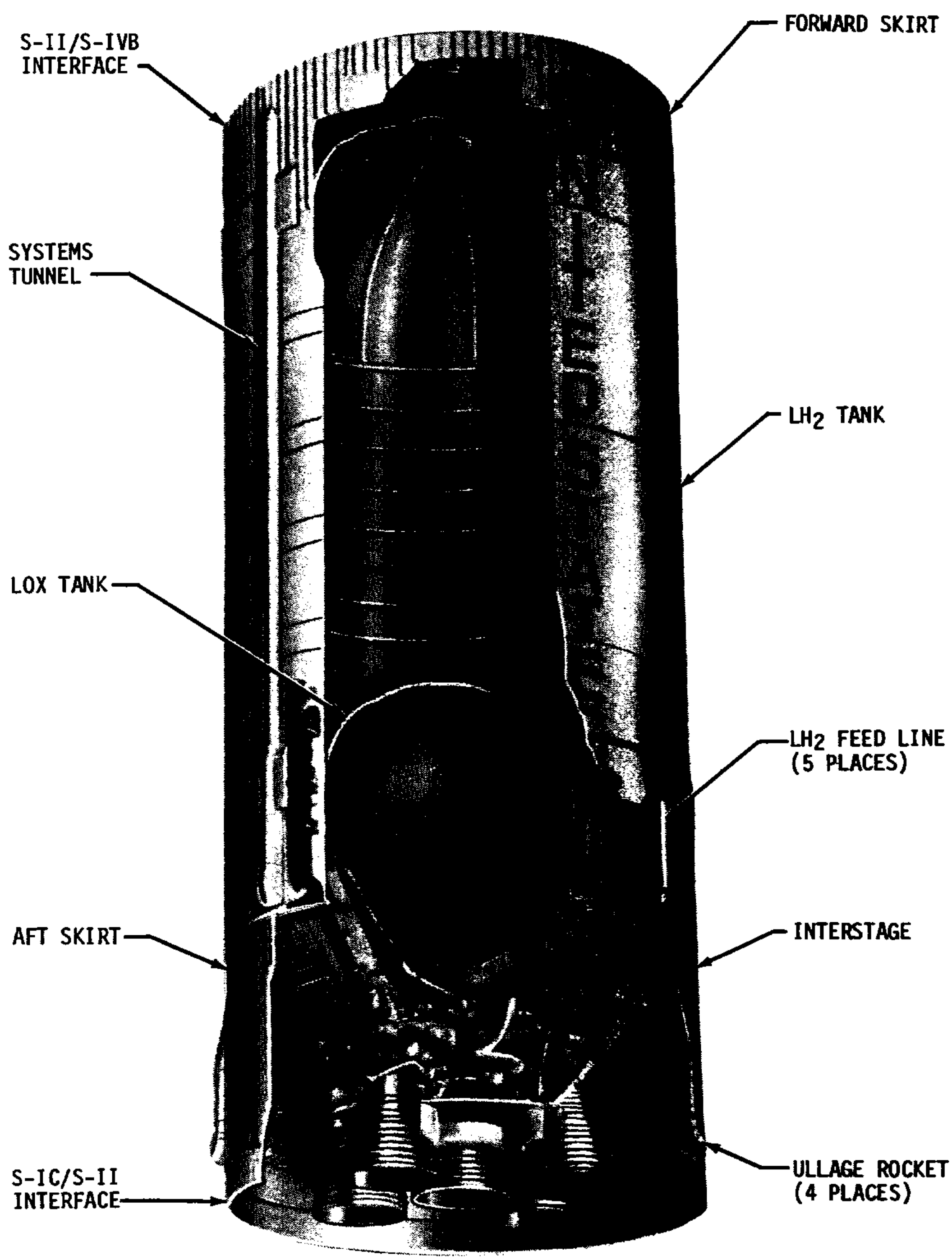
S-II STAGE

GENERAL

The S-II stage (Figure 4) is a large cylindrical booster, 81.5 feet long and 33 feet in diameter, powered by five liquid propellant J-2 rocket engines which develop a nominal vacuum thrust of 230,000 pounds each for a total of 1,150,000 pounds.

Dry weight of the S-II stage is approximately 85,522 pounds (95,779 pounds including the S-IC/S-II interstage). The stage approximate loaded gross weight is 1,080,500 pounds. The four outer J-2 engines are equally spaced on a 17.5-foot diameter circle and are capable of being gimbaled through a plus or minus 7.0 degree square pattern for thrust vector control. The fifth engine is mounted on the stage centerline and is fixed.

The stage (Figure 5) consists of the following major systems: structural, environmental control, propulsion, flight control, pneumatic, propellant, electrical, instrumentation and ordnance. The stage has structural and electrical interfaces with the S-IC and S-IVB stages; and electric, pneumatic, and fluid interfaces with GSE through its umbilicals and antennas.



S-11 STAGE

Fig. 4

STRUCTURE

The S-II airframe (Figure 5) consists of a body shell structure (forward and aft skirts and interstage), a propellant tank structure (fuel and oxidizer tanks), and a thrust structure. The body shell structure transmits boost loads and stage body bending and longitudinal forces between the adjacent stages, the propellant tank structure, and the thrust structure. The propellant tank structure holds the propellants, liquid hydrogen (LH_2) and liquid oxygen (LOX), and provides structural support between the aft and forward skirts. The thrust structure transmits the thrust of the five J-2 engines to the body shell structure; compression loads from engine thrust; tension loads from idle engine weight; and cantilever loads from engine weight during S-II boost.

PROPULSION

The S-II stage engine system consists of five single-start, high performance, high altitude J-2 rocket engines. The four outer J-2 engines are suspended by gimbal bearings to allow thrust vector control. The fifth engine is fixed and is mounted on the centerline of the stage.

The engine valves are controlled by a pneumatic system powered by gaseous helium which is stored in a sphere inside the start tank. An electrical control system, which uses solid state logic elements, is used to sequence the start and shutdown operations of the engine. Electrical power is stage supplied.

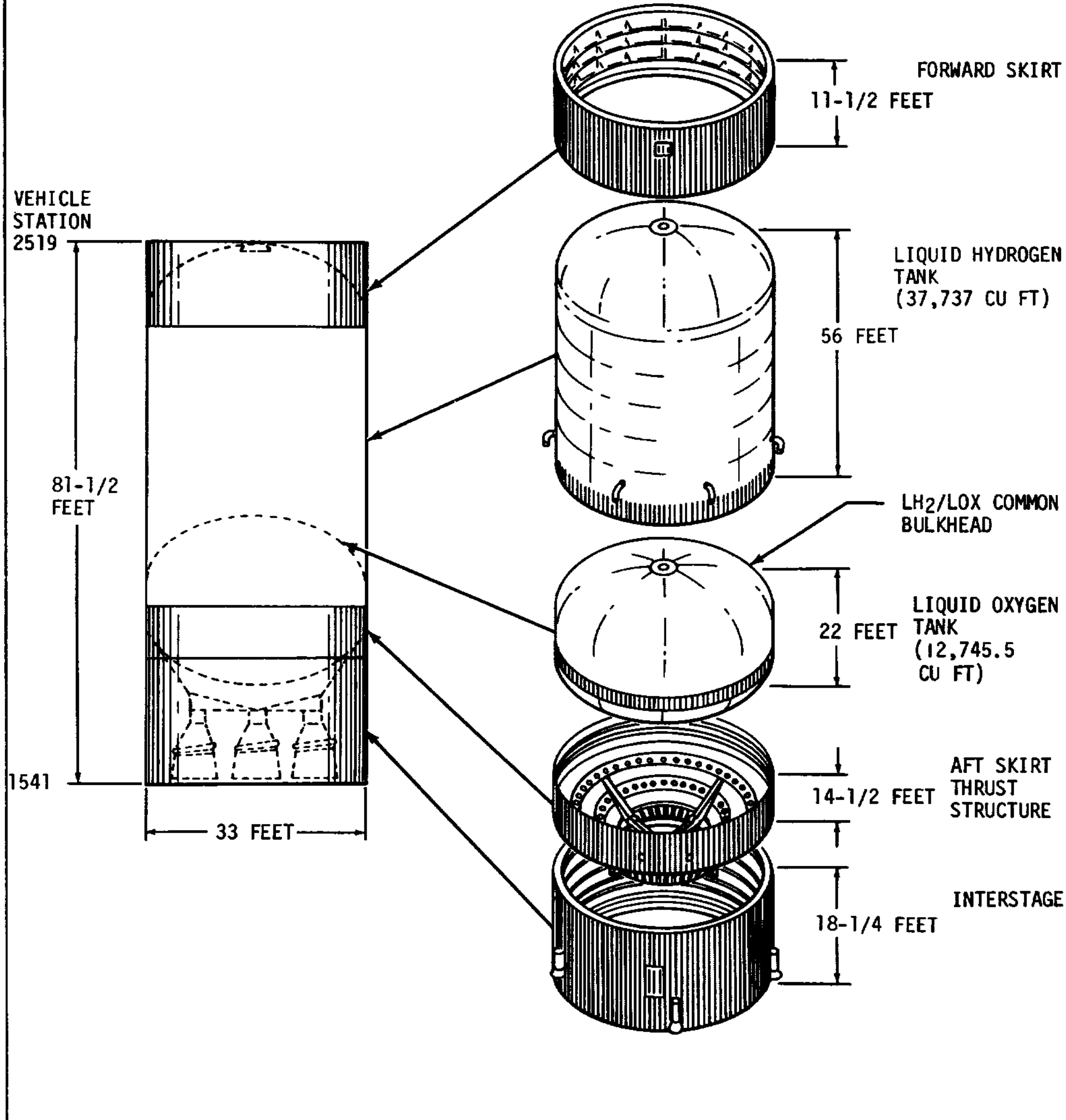
The J-2 engine may receive cutoff signals from several different sources. These sources include engine interlock deviations, EDS automatic manual abort cutoffs and propellant depletion cutoff. Each of these sources signal the LVDC in the IU. The LVDC sends the engine cutoff signal to the S-II switch selector, which in turn signals the electrical control package, which signals for the cutoff sequence.

Five discrete liquid level sensors per propellant tank provide initiation of engine cutoff upon detection of propellant depletion. The cutoff sensors will initiate a signal to shut down the engines when two out of five engine cutoff signals from the same tank are received.

PROPELLANT SYSTEMS

The propellant systems supply fuel and oxidizer to the five engines. This is accomplished by the propellant management components and the servicing, conditioning, and engine delivery subsystems.

The LH_2 feed system includes five 8-inch vacuum-jacketed feed ducts and five prevalves.



S-II STAGE STRUCTURAL ASSEMBLIES

Fig. 5

During powered flight, prior to S-II ignition, gaseous hydrogen (GH_2) for LH_2 tank pressurization is bled from the thrust chamber hydrogen injector manifold of each of the four outboard engines. After S-II engine ignition, LH_2 is preheated in the regenerative cooling tubes of the engine and tapped off from the thrust chamber injector manifold in the form of GH_2 to serve as a pressurizing medium.

The LOX feed system includes four 8-inch vacuum jacketed feed ducts, one uninsulated feed duct and five prevalves.

LOX tank pressurization is accomplished with GOX obtained by heating LOX bled from the LOX turbopump outlet.

The propellant management system monitors propellant mass for control of propellant loading, utilization, and depletion. Components of the system include continuous capacitance probes, propellant utilization valves, liquid level sensors, and electronic equipment.

During flight, the signals from the tank continuous capacitance probes are monitored and compared to provide an error signal to the propellant utilization valve on each LOX pump. Based on this error signal, the propellant utilization valves are positioned to minimize residual propellants and assure a fuel-rich cutoff by varying the amount of LOX delivered to the engines.

FLIGHT CONTROL SYSTEM

Each outboard engine is equipped with a separate, independent, closed-loop, hydraulic control system that includes two servoactuators mounted in perpendicular planes to provide control over the vehicle pitch, roll and yaw axes. The servoactuators are capable of deflecting the engine $\pm$ 7 degrees in the pitch and yaw planes, $\pm$ 10 degrees diagonally, at the rate of 8 degrees per second.

ELECTRICAL

The electrical system is comprised of the electrical power and electrical control subsystems. The electrical power system provides the S-II stage with the electrical power source and distribution. The electrical control system interfaces with the IU to accomplish the mission requirements of the stage. The LVDC in the IU controls inflight sequencing of stage functions through the stage switch selector. The stage switch selector outputs are routed through the stage electrical sequence controller or the separation controller to accomplish the directed operation. These units are basically a network of low-power, transistorized switches that can be controlled individually and, upon command from the switch selector, provide properly sequenced electrical signals to control the stage functions.

ORDNANCE

The S-II ordnance systems include the separation, ullage rocket, retrorocket, and propellant dispersion (flight termination) systems.

For S-IC/S-II separation, a dual plane separation technique is used wherein the structure between the two stages is severed at two different planes. The S-II/S-IVB separation occurs at a single plane. All separations are controlled by the LVDC located in the IU.

To ensure stable flow of propellants into the J-2 engines, a small forward acceleration is required to settle the propellants in their tanks. This acceleration is provided by four ullage rockets.

To separate and retard the S-II stage, a deceleration is provided by the four retrorockets located in the S-II/S-IVB interstage.

The S-II PDS provides for termination of vehicle flight during the S-II boost phase if the vehicle flight path varies beyond its prescribed limits or if continuation of vehicle flight creates a safety hazard. The S-II PDS may be safed after the launch escape tower is jettisoned.

The LH_2 tank linear shaped charge, when detonated, cuts a 30-foot vertical opening in the tank.

The LOX tank destruct charges simultaneously cut 13-foot lateral openings in the LOX tank and the S-II aft skirt.

S-IVB STAGE

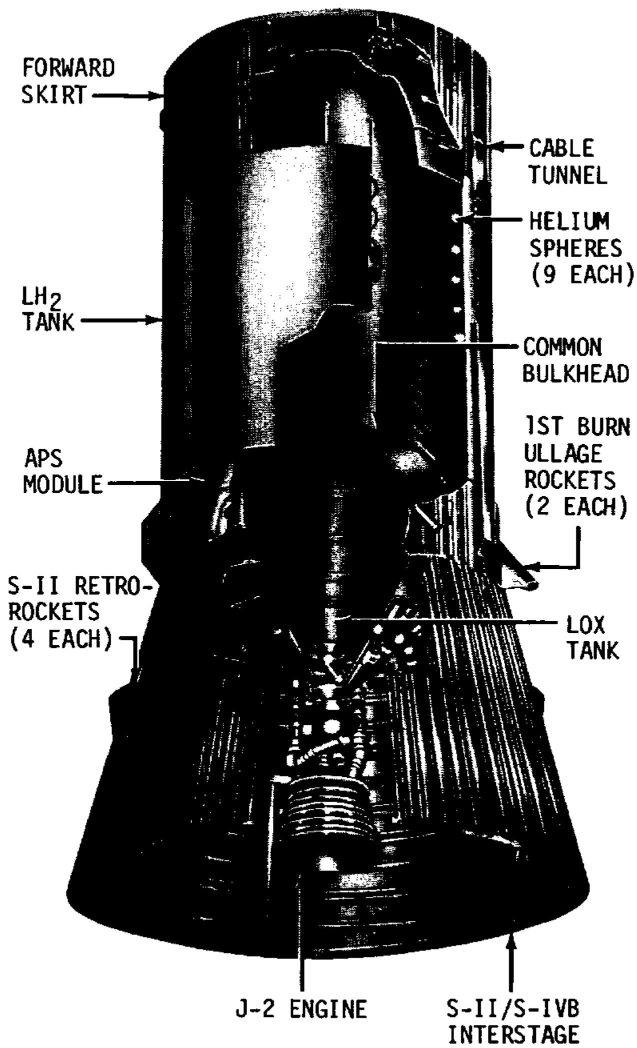
GENERAL

The S-IVB (Figure 6) is the third launch vehicle stage. Its single J-2 engine is designed to boost the payload into a circular earth orbit on the first burn then inject the payload into the trajectory for lunar intercept with a second burn. The subsystems to accomplish this mission are described in the following section.

STRUCTURE

The S-IVB stage is a bi-propellant tank structure, designed to withstand the normal loads and stresses incurred on the ground and during launch, pre-ignition boost, ignition, and all other flight phases.

ENGINE:	J-2	
PROPELLANT:	LOX/LH_2	
THRUST:	1st BURN	232,000 LBS
	2nd BURN	211,000 LBS
WEIGHT:	DRY	26,421 LBS
	AT IGNITION	263,204 LBS



S-IVB STAGE

Fig. 6

The basic S-IVB stage airframe, illustrated in Figure 7, consists of the following structural assemblies: the forward skirt, propellant tanks, aft skirt, thrust structure, and aft interstage. These assemblies, with the exception of the propellant tanks, are all of a skin/stringer-type aluminum alloy airframe construction. In addition, there are two longitudinal tunnels which house wiring, pressurization lines, and propellant dispersion systems.

The cylindrical forward skirt extends forward from the intersection of the fuel tank sidewall and the forward dome, serving as a load-supporting member between the fuel tank and the IU.

The propellant tank assembly consists of a cylindrical tank with a hemispherical shaped dome at each end, and a common bulkhead to separate the fuel (LH_2) from the oxidizer (LOX). This bulkhead is of sandwich-type construction, consisting of two parallel hemispherical shaped aluminum alloy domes bonded to and separated by a fiberglass-phenolic honeycomb core.

Attached to the inside of the fuel tank are a 34-foot propellant utilization (PU) probe, nine cold helium spheres, brackets with temperature and level sensors, a chilldown pump, a slosh baffle, a slosh deflector, and fill, pressurization, and vent pipes. Attached to the inside of the oxidizer tank are slosh baffles, a chilldown pump, a 13.5-foot PU probe, temperature and level sensors, and fill, pressurization and vent pipes.

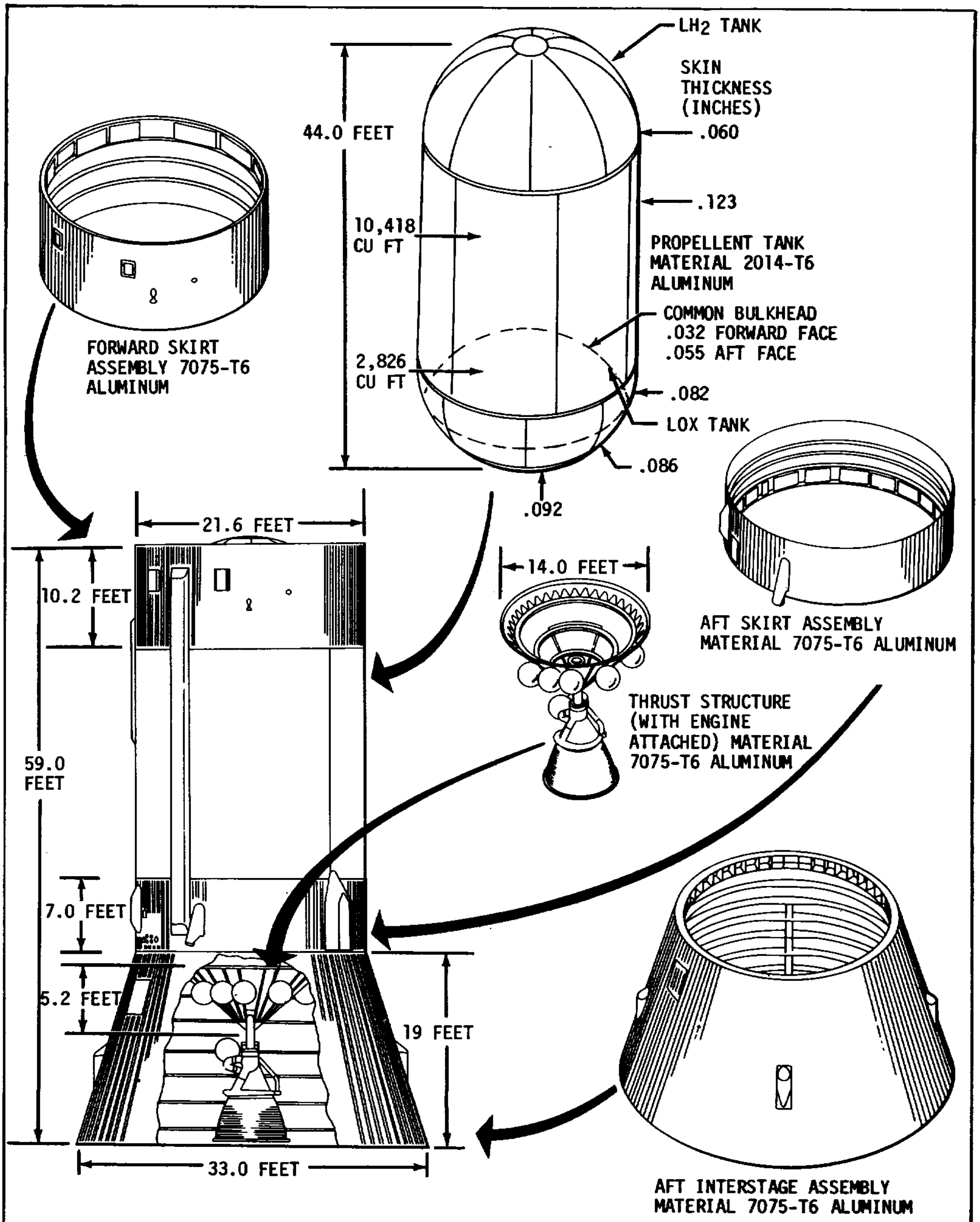
The thrust structure assembly is an inverted, truncated cone attached at its large end to the aft dome of the oxidizer tank and attached at its small end to the engine mount. It provides the attach point for the J-2 engine.

The aft skirt assembly is the load-bearing structure between the fuel tank and aft interstage. It is bolted to the tank assembly at its forward edge and connected to the aft interstage with a frangible tension tie which separates the S-IVB from the aft interstage.

The aft interstage is a truncated cone that provides the load supporting structure between the S-IVB stage and the S-II stage. The interstage also provides the focal point for the required electrical and mechanical interface between the S-II and S-IVB stages. The S-II retrorocket motors are attached to this interstage and at separation the interstage remains attached to the S-II.

MAIN PROPULSION

The high performance J-2 engine as installed in the S-IVB stage has a multiple restart capability. The engine valves are controlled by a pneumatic system powered by gaseous helium which is stored in a sphere inside a start bottle. An electrical control system, which uses solid state logic elements, is used to sequence the start and shutdown operations of the engine. Electrical power is supplied from aft battery No. 1.



S-IVB STRUCTURAL ASSEMBLIES

Fig. 7

During the burn periods, the oxidizer tank is pressurized by flowing cold helium through the heat exchanger in the oxidizer turbine exhaust duct. The heat exchanger heats the cold helium, causing it to expand. The fuel tank is pressurized during burn periods by GH_2 from the thrust chamber fuel manifold.

Thrust vector control, in the pitch and yaw planes, during burn periods is achieved by gimbaling the entire engine.

The J-2 engine may receive cutoff signals from the following sources; EDS, range safety systems, "Thrust OK" pressure switches, propellant depletion sensors, and an IU programmed command (velocity or timed) via the switch selector.

The restart of the J-2 engine is identical to the initial start except for the fill procedure of the start tank. The start tank is filled with LH_2 and GH_2 during the first burn period by bleeding GH_2 from the thrust chamber fuel injection manifold and LH_2 from the Augmented Spark Igniter (ASI) fuel line to refill the start tank for engine restart. (Approximately 50 seconds of mainstage engine operation is required to recharge the start tank.)

To insure that sufficient energy will be available for spinning the LH_2 and LOX pump turbines, a waiting period of between approximately 90 minutes to 6 hours is required. The minimum time is required to build sufficient pressure by warming the start tank through natural means and to allow the hot gas turbine exhaust system to cool. Prolonged heating will cause a loss of energy in the start tank. This loss occurs when the LH_2 and GH_2 warms and raises the gas pressure to the relief valve setting. If this venting continues over a prolonged period the total stored energy will be depleted. This limits the waiting period prior to a restart attempt to six hours.

PROPELLANT SYSTEMS

LOX is stored in the aft tank of the propellant tank structure at a temperature of -297°F.

A six-inch, low-pressure supply duct supplies LOX from the tank to the engine. During engine burn, LOX is supplied at a nominal flow rate of 392 pounds per second, and at a transfer pressure above 25 psia. The supply duct is equipped with bellows to provide compensating flexibility for engine gimbaling, manufacturing tolerances, and thermal movement of structural connection.

The tank is prepressurized to between 38 and 41 psia and is maintained at that pressure during boost and engine operation. Gaseous helium is used as the pressurizing agent.

The LH_2 is stored in an insulated tank at less than -423° F. LH_2 from the tank is supplied to the J-2 engine turbopump by a vacuum-jacketed, low-pressure, 10-inch duct. This duct is capable of flowing 80-pounds per second at -423° F. and at a transfer pressure of 28 psia. The duct is located in the aft tank side wall above the common bulkhead joint. Bellows in this duct compensate for engine gimbaling, manufacturing tolerances, and thermal motion.

The fuel tank is prepressurized to 28 psia minimum and 31 psia maximum.

The PU subsystem provides a means of controlling the propellant mass ratio. It consists of oxidizer and fuel tank mass probes, a PU valve, and an electronic assembly. These components monitor the propellant and maintain command control.

Propellant utilization is provided by bypassing oxidizer from the oxidizer turbopump outlet back to the inlet. The PU valve is controlled by signals from the PU system. The engine oxidizer/fuel mixture mass ratio varies from 4.5:1 to 5.5:1.

FLIGHT CONTROL

The flight control system incorporates two systems for flight and attitude control. During powered flight, thrust vector steering is accomplished by gimbaling the J-2 engine for pitch and yaw control and by operating the Auxiliary Propulsion System (APS) engines for roll control. Steering during coast flight is by use of the APS engines alone.

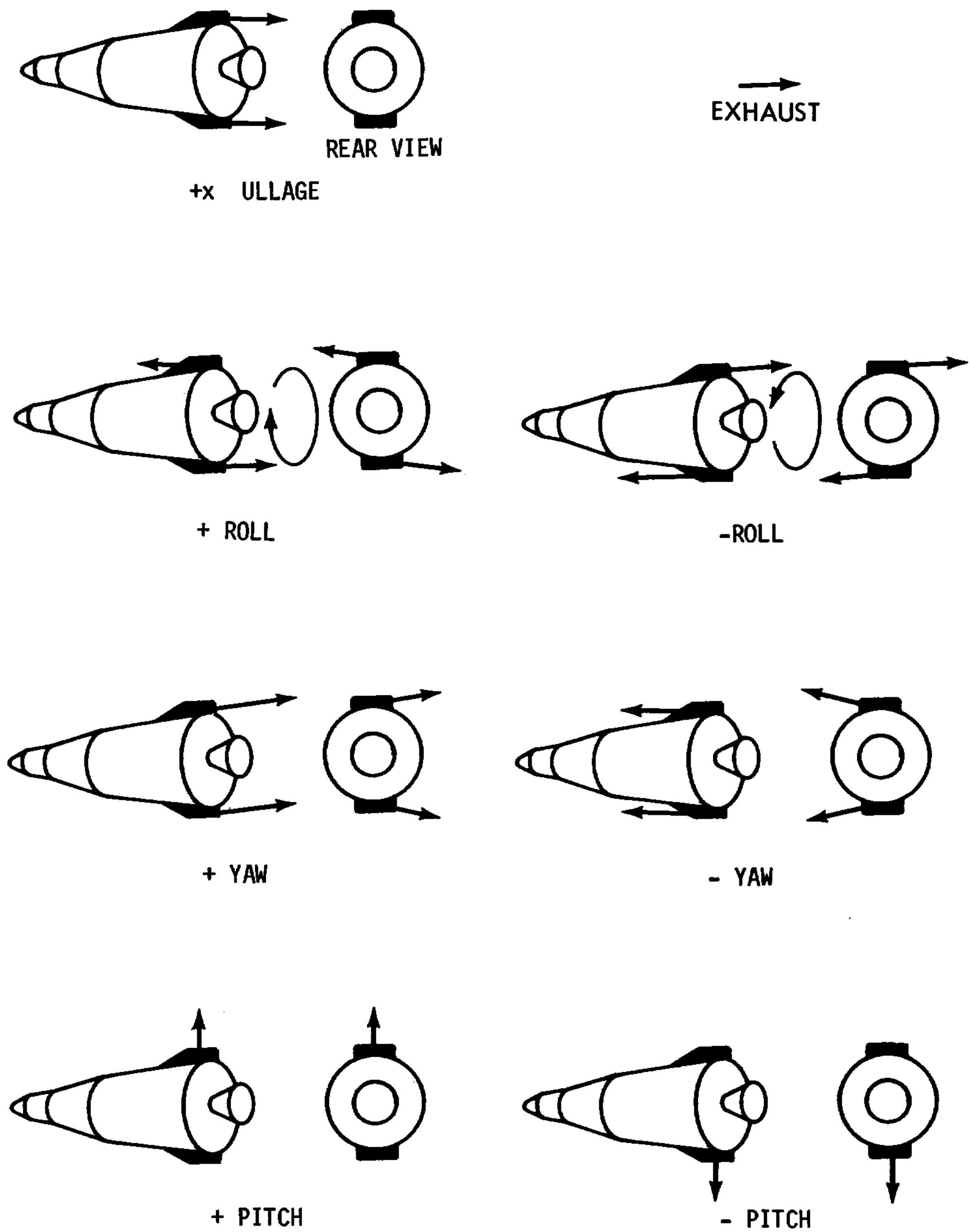
The engine is gimbaled in a $\pm$ 7.5 degree square pattern by a closed-loop hydraulic system. Mechanical feedback from the actuator to the servovalve provides the closed engine position loop.

Two actuators are used to translate the steering signals into vector forces to position the engine. The deflection rates are proportional to the pitch and yaw steering signals from the flight control computer.

AUXILIARY PROPULSION SYSTEM

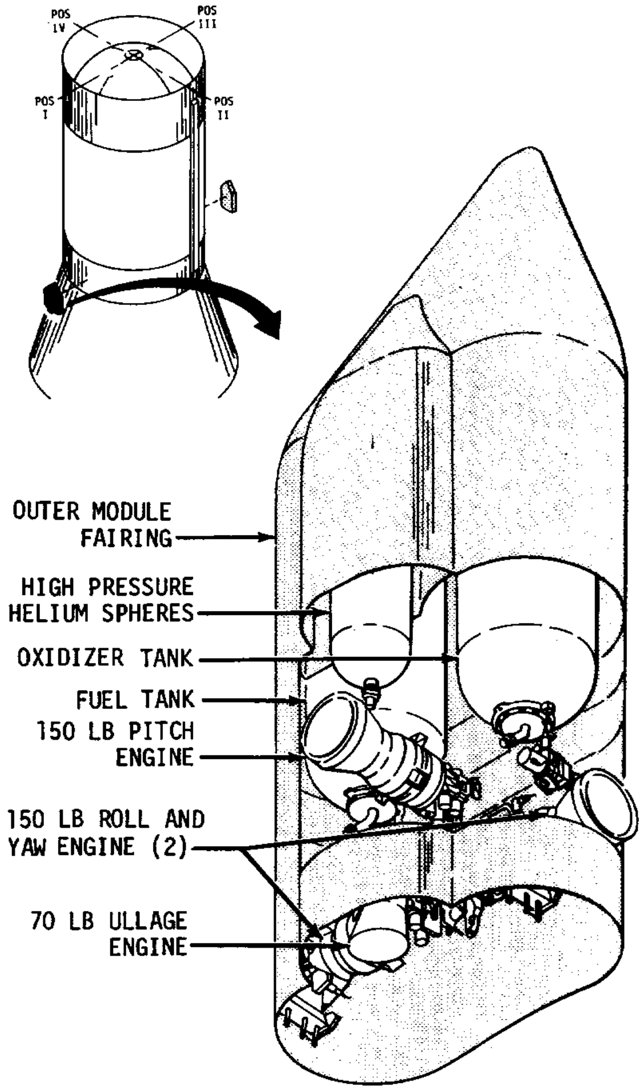
The S-IVB APS provides three-axis stage attitude control (Figure 8) and main stage propellant control during coast flight.

The APS engines are located in two modules 180° apart on the aft skirt of the S-IVB stage (Figure 9). Each module contains four engines; three 150-pound thrust control engines, and one 70-pound thrust ullage engine. Each module contains its own oxidizer, fuel, and pressurization system.



APS FUNCTIONS

Fig. 8



AUXILIARY PROPULSION SYSTEM CONTROL MODULE

Fig. 9

A positive expulsion propellant feed subsystem is used to assure that hypergolic propellants are supplied to the engines under "zero g" or random gravity conditions. Nitrogen tetroxide (N_2O_4), is the oxidizer and monomethyl hydrazine (MMH), is the fuel for these engines.

ELECTRICAL

The electrical system of the S-IVB stage is comprised of two major subsystems: the electrical power subsystem which consists of all the power sources on the stage; and the electrical control subsystem which distributes power and control signals to various loads throughout the stage.

Onboard electrical power is supplied by four silver-zinc batteries. Two are located in the forward equipment area and two in the aft equipment area. These batteries are activated and installed in the stage during the final pre-launch preparations. Heaters and instrumentation probes are an integral part of each battery.

ORDNANCE

The S-IVB ordnance systems include the separation, ullage rocket, and PDS systems.

The separation system for S-II/S-IVB is located at the top of the S-II/S-IVB interstage.

At the time of separation, four retrorocket motors mounted on the interstage structure below the separation plane fire to decelerate the S-II stage.

To provide propellant settling and thus ensure stable flow of fuel and oxidizer during J-2 engine start, the S-IVB stage requires a small acceleration. This acceleration is provided by two ullage rockets.

The S-IVB PDS provides for termination of vehicle flight. The S-IVB PDS may be safed after the launch escape tower is jettisoned.

Following S-IVB engine cutoff at orbit insertion, the PDS is electrically safed by ground command.

INSTRUMENT UNIT

GENERAL

The Instrument Unit (IU) is a cylindrical structure 21.6 ft. in diameter and 3 ft. high installed on top of the S-IVB stage (Figure 10). The IU contains the guidance, navigation, and control equipment for the Launch Vehicle. In addition, it contains measurements and telemetry, command communications, tracking, and emergency detection system components along with supporting electrical power and environmental control systems.

STRUCTURE

The basic IU structure is a short cylinder fabricated of an aluminum alloy honeycomb sandwich material. Attached to the inner surface of the cylinder are "cold plates" which serve both as mounting structure and thermal conditioning units for the electrical/electronic equipment.

NAVIGATION, GUIDANCE, AND CONTROL

The Saturn V Launch Vehicle is guided from its launch pad into earth orbit by navigation, guidance, and control equipment located in the IU. An all-inertial system using a space-stabilized platform for acceleration and attitude measurements is utilized. A Launch Vehicle Digital Computer (LVDC) is used to solve guidance equations and a Flight Control Computer (analog) is used for the flight control functions.

The three-gimbal stabilized platform (ST-124-M3) provides a space-fixed coordinate reference frame for attitude control and for navigation (acceleration) measurements. Three integrating accelerometers, mounted on the gyro-stabilized inner gimbal of the platform, measure the three components of velocity resulting from vehicle propulsion. The accelerometer measurements are sent through the Launch Vehicle Data Adapter (LVDA) to the LVDC. In the LVDC, the accelerometer measurements are combined with the computed gravitational acceleration to obtain velocity and position of the vehicle. During orbital flight, the navigational program continually computes the vehicle position, velocity, and acceleration. Guidance information stored in the LVDC (e.g., position, velocity) can be updated through the IU command system by data transmission from ground stations. The IU command system provides the general capability of changing or inserting information into the LVDC.

The control subsystem is designed to maintain and control vehicle attitude by forming the steering commands to be used by the controlling engines of the active stage.

The control system accepts guidance computations from the LVDC/LVDA Guidance System. These guidance commands, which are actually attitude error signals, are then

SATURN INSTRUMENT UNIT

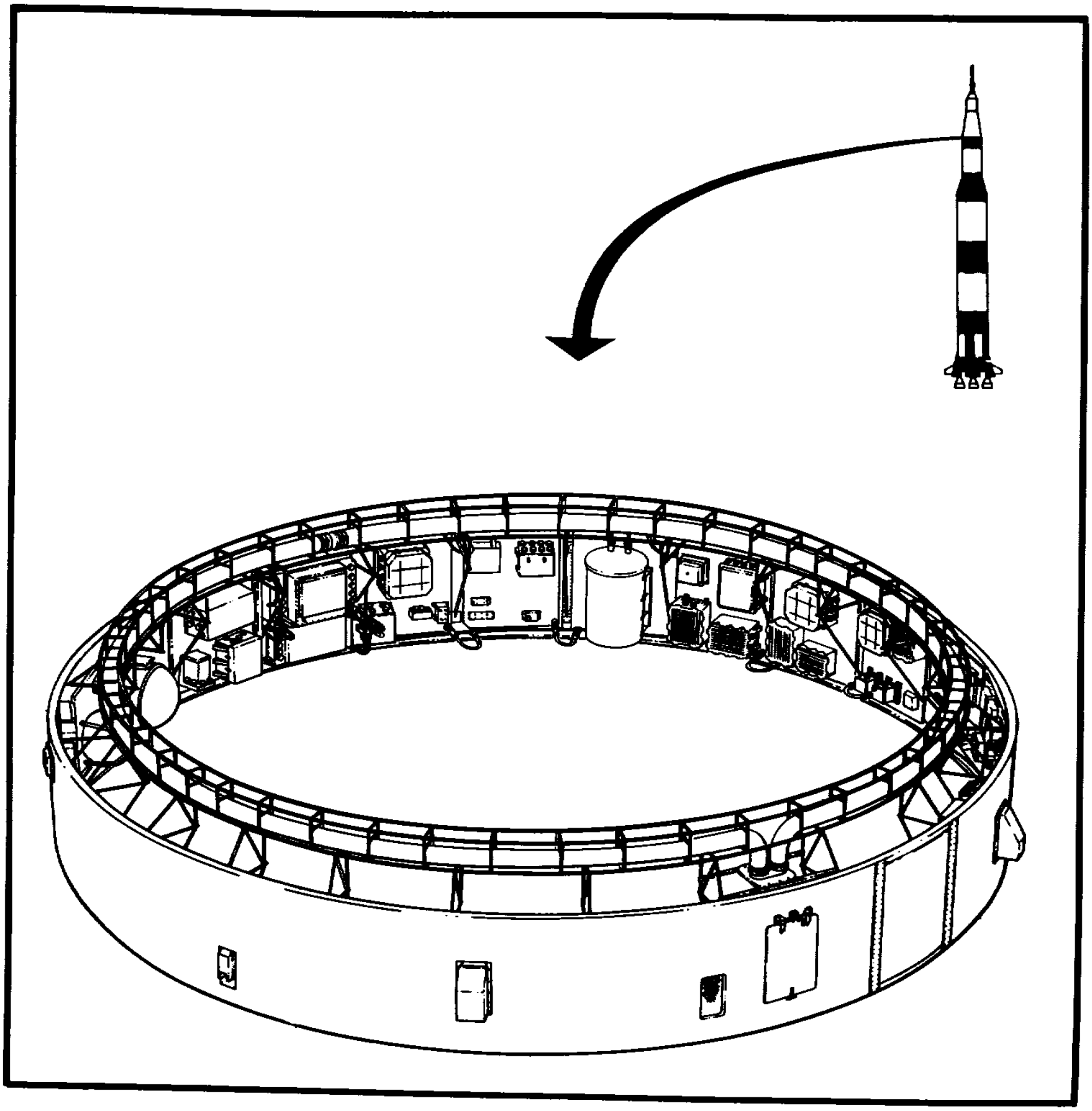


Fig. 10

combined with measured data from the various control sensors. The resultant output is the command signal to the various engine actuators and APS nozzles.

The final computations (analog) are performed within the flight control computer. This computer is also the central switching point for command signals. From this point, the signals are routed to their associated active stages and to the appropriate attitude control devices.

MEASUREMENTS AND TELEMETRY

The instrumentation within the IU consists of a measuring subsystem, a telemetry subsystem and an antenna subsystem. This instrumentation is for the purpose of monitoring certain conditions and events which take place within the IU and for transmitting monitored signals to ground receiving stations.

COMMAND COMMUNICATIONS SYSTEM

The Command Communications System (CCS) provides for digital data transmission from ground stations to the LVDC. This communications link is used to update guidance information or command certain other functions through the LVDC. Command data originates in the Mission Control Center and is sent to remote stations of the Manned Space Flight Network (MSFN) for transmission to the Launch Vehicle.

SATURN TRACKING INSTRUMENTATION

The Saturn V IU carries two C-band radar transponders and an Azusa/GLOTRAC tracking transponder. A combination of tracking data from different tracking systems provides the best possible trajectory information and increased reliability through redundant data. The tracking of the Saturn Launch Vehicle may be divided into 4 phases: powered flight into earth orbit, orbital flight, injection into mission trajectory, and coast flight after injection.

Continuous tracking is required during powered flight into earth orbit.

During orbital flight, tracking is accomplished by S-band stations of the MSFN and by C-band radar stations.

IU EMERGENCY DETECTION SYSTEM COMPONENTS

The Emergency Detection System (EDS) is one element of several crew safety systems.

There are nine EDS rate gyros installed in the IU. Three gyros monitor each of the three axes, pitch, roll, and yaw, thus providing triple redundancy.

The control signal processor provides power to and receives inputs from the nine EDS rate gyros. These inputs are processed and sent on to the EDS distributor and to the flight control computer.

The EDS distributor serves as a junction box and switching device to furnish the spacecraft display panels with emergency signals if emergency conditions exist. It also contains relay and diode logic for the automatic abort sequence.

An electronic timer in the IU allows multiple engine shutdowns without automatic abort after 30 to 40 seconds of flight.

Inhibiting of automatic abort circuitry is also provided by the vehicle flight sequencing circuits through the IU switch selector. This inhibiting is required prior to normal S-IC engine cutoff and other normal vehicle sequencing. While the automatic abort is inhibited, the flight crew must initiate a manual abort if an angular-overrate or two engine-out condition arises.

ELECTRICAL POWER SYSTEMS

Primary flight power for the IU equipment is supplied by silver-zinc batteries at a nominal voltage level of 28 ± 2 vdc. Where ac power is required within the IU it is developed by solid state dc to ac inverters. Power distribution within the IU is accomplished through power distributors which are essentially junction boxes and switching circuits.

ENVIRONMENTAL CONTROL SYSTEM

The Environmental Control System (ECS) maintains an acceptable operating environment for the IU equipment during pre-flight and flight operations. The ECS is composed of the following:

1. The Thermal Conditioning System (TCS) which maintains a circulating coolant temperature to the electronic equipment of $59° \pm 1°F$.
2. Pre-flight purging system which maintains a supply of temperature and pressure regulated air/gaseous nitrogen in the IU/S-IVB equipment area.
3. Gas bearing supply system which furnishes gaseous nitrogen to the ST-124-M3 inertial platform gas bearings.
4. Hazardous gas detection sampling equipment which monitors the IU/S-IVB forward interstage area for the presence of hazardous vapors.

SPACECRAFT LM ADAPTER

GENERAL

The Spacecraft LM Adapter (SLA) is a conical structure which provides a structural load path between the LV and SM and also supports the LM. Aerodynamically, the SLA smoothly encloses the irregularly shaped LM and transitions the space vehicle diameter from that of the upper stage of the LV to that of the Service Module. The SLA also encloses the nozzle of the service module engine.

STRUCTURE

The SLA is constructed of 1.7-inch thick aluminum honeycomb panels. The four, upper, jettisonable, or forward panels, are about 21 feet long, and the fixed lower or aft panels, about 7 feet long. The exterior surface of the SLA is covered completely by a layer of cork. The cork helps insulate the LM from aerodynamic heating during boost.

The LM is attached to the SLA at four locations around the lower panels.

SLA-SM SEPARATION

The SLA and SM are bolted together through flanges on each of the two structures. Explosive trains are used to separate the SLA and SM as well as for separating the four, upper, jettisonable SLA panels.

Redundancy is provided in three areas to assure separation; redundant initiating signals, redundant detonators and cord trains, and "sympathetic" detonation of nearby charges.

Pyrotechnic type and spring type thrusters are used in deploying and jettisoning the SLA upper panels. The four, double-piston pyrotechnic thrusters are located inside the SLA and start the panels swinging outward on their hinges. The two pistons of the thruster push on the ends of adjacent panels thus providing two separate thrusters operating each panel.

The explosive train which separates the panels is routed through two pressure cartridges in each thruster assembly.

The pyrotechnic thrusters rotate the panels 2 degrees establishing a constant angular velocity of 33 to 60 degrees per second. When the panels have rotated about 45 degrees, the partial hinges disengage and free the panels from the aft section of the SLA, subjecting them to the force of the spring thrusters. The spring thrusters are mounted on the outside of the upper panels. When the panel hinges disengage, the springs in the thruster push against the fixed lower panels to propel the panels away from the vehicle at an angle of 110 degrees to the centerline at a speed of about 5-1/2 miles per hour. The panels will then depart the area of the spacecraft.

LAUNCH ESCAPE SYSTEM

GENERAL

The Launch Escape System (LES) (Figure 11) includes the LES structure, canards, rocket motors, and ordnance. The LES provides an immediate means of separating the CM from the LV during pad or suborbital aborts up through completion of second stage ignition. During an abort, the LES must provide a satisfactory earth return trajectory and CM orientation before jettisoning from the CM. The jettison or abort can be initiated manually or automatically.

ASSEMBLY

The forward or rocket section of the system is cylindrical and houses three solid-propellant rocket motors and a ballast compartment topped by a nose cone and "Q-ball", which measures attitude and flight dynamics of the space vehicle. The 500-pound tower is made of titanium tubes attached at the top to a structural skirt that covers the rocket exhaust nozzles and at the bottom to the CM by means of explosive bolts.

A Boost Protective Cover (BPC) is attached to the tower and completely covers the CM It has 12 "blowout" ports for the CM reaction engines, vents, and an 8-inch window. This cover protects the CM from the rocket exhaust and also from the heat generated during launch vehicle boost. It remains attached to the tower and is carried away when the LES is jettisoned.

Two canards are deployed 11 seconds after an abort is initiated. The canards dynamically turn the CM so that the aft heat shield is forward. Three seconds later on extreme low-altitude aborts, or at approximately 24,000 feet on high-altitude aborts, the tower separation devices are fired and the jettison motor is started. These actions carry the LES away from the CM's landing trajectory. Four-tenths of a second after tower jettisoning the CM's earth landing system is activated and begins its sequence of operations to bring the CM down safely.

During a successful launch the LES is jettisoned by the astronauts, using the digital events timer and the "S-II Sep" light as cues.

In the event of Tower Jettison Motor failure, the Launch Escape Motor may jettison the LES.

LAUNCH ESCAPE SYSTEM

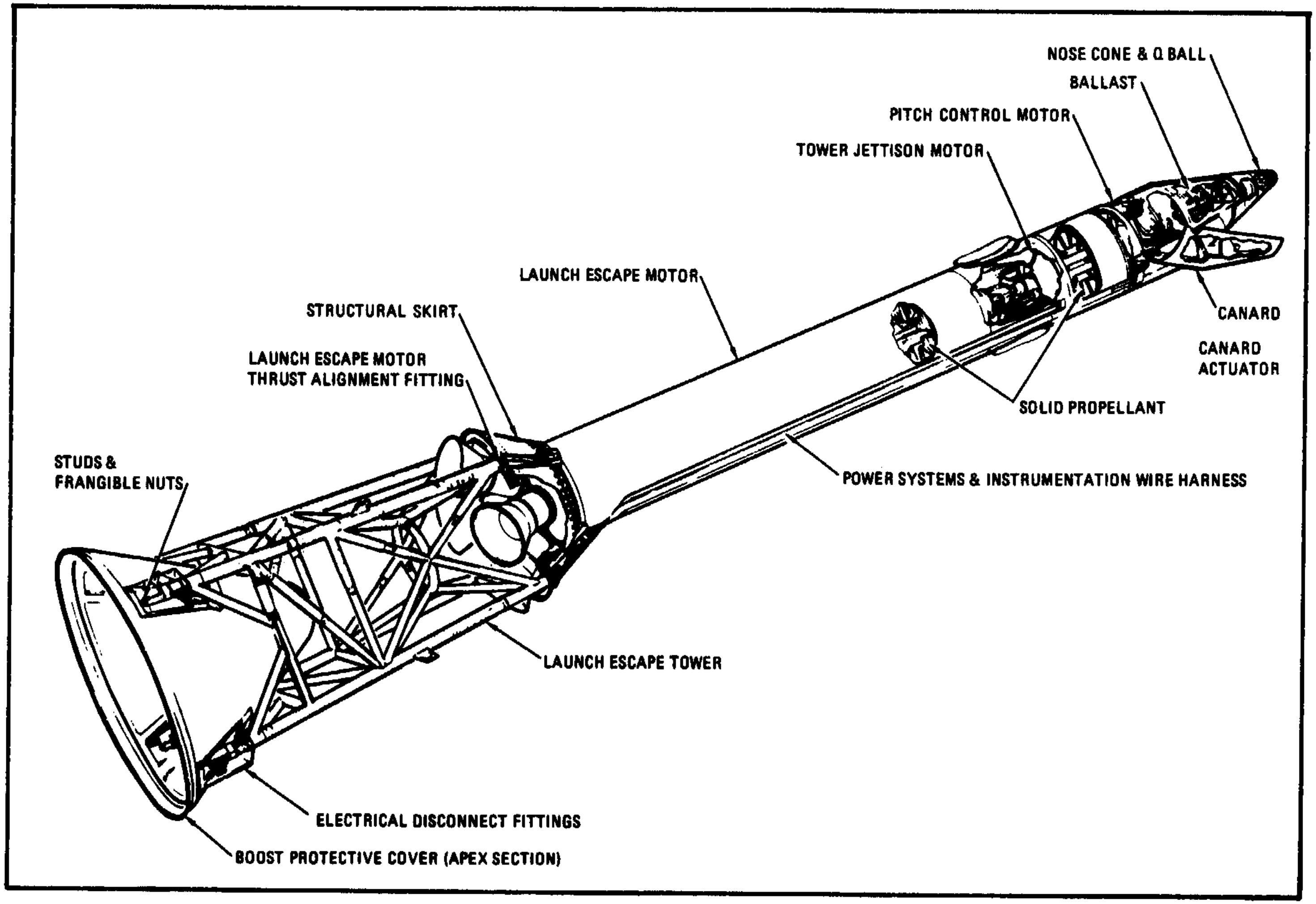


Fig. 11

PROPUSION

Three solid propellant motors are used on the LES. They are:

1. The Launch Escape Motor which provides thrust for CM abort. It weighs 4700 pounds and provides 147,000 pounds of thrust at sea level for approximately eight seconds.

2. The Pitch Control Motor which provides an initial pitch maneuver toward the Atlantic Ocean during pad or low-altitude abort. It weighs 50 pounds and provides 2400 pounds of thrust for half a second.

3. The Tower Jettison Motor, which is used to jettison the LES, provides 31,500 pounds of thrust for one second.

SERVICE MODULE

GENERAL

The Service Module (SM) (Figure 12) provides the main spacecraft propulsion and maneuvering capability during a mission. The Service Propulsion System (SPS) provides for velocity changes for translunar/transearth course corrections, lunar orbit insertion, transearth injection and CSM aborts. The Service Module Reaction Control System (SM RCS) provides for maneuvering about and along three axes. The SM provides most of the spacecraft consumables (oxygen, water, propellant, hydrogen). It supplements environmental, electrical power and propulsion requirements of the CM. The SM remains attached to the CM until it is jettisoned just before CM entry.

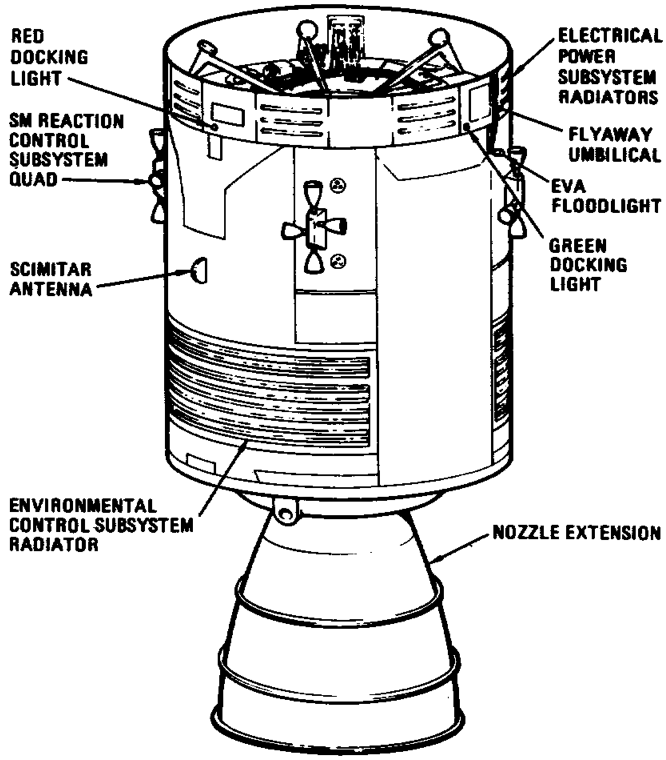
STRUCTURE

The basic structural components are forward and aft (upper and lower) bulkheads, six radial beams, four sector honeycomb panels, four reaction control system honeycomb panels, and aft heat shield, and a fairing.

The radial beams are made of solid aluminum alloy which has been machined and chem-milled to thicknesses varying between 2 inches and 0.018 inch.

The forward and aft bulkheads cover the top and bottom of the SM. Radial beam trusses extending above the forward bulkhead support and secure the CM. Three of these beams have compression pads and the other three have shear-compression pads and tension ties. Explosive charges in the center sections of these tension ties are used to separate the CM from the SM.

An aft heat shield surrounds the service propulsion engine to protect the SM from the engine's heat during thrusting. The gap between the CM and the forward bulkhead of the SM is closed off with a fairing which is composed of eight electrical power system radiators alternated with eight aluminum honeycomb panels.



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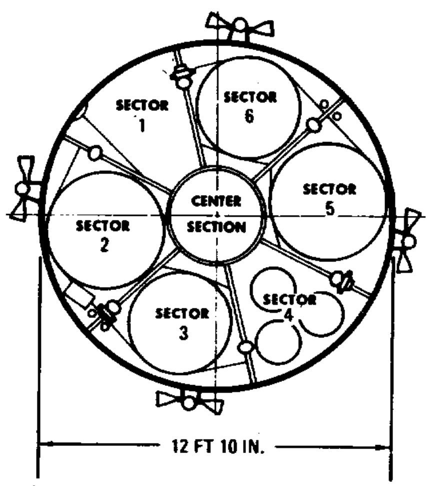
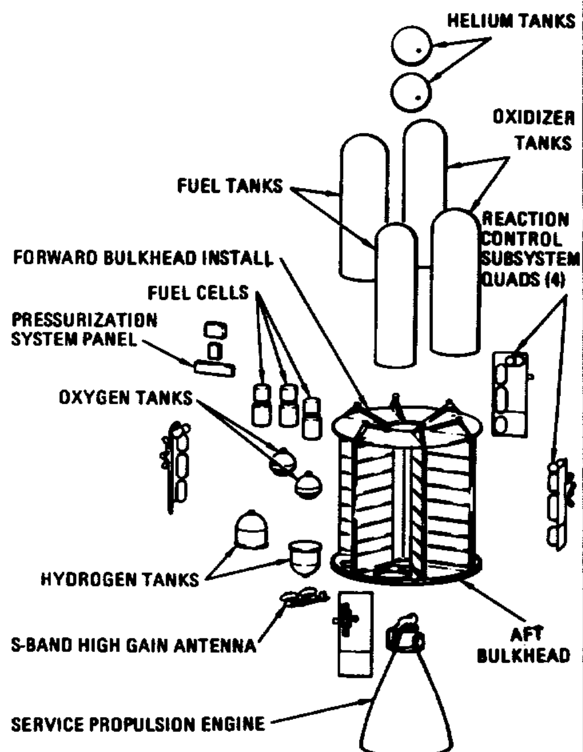


SECTOR 2 } SERVICE PROPULSION SUBSYSTEM
SECTOR 3 } OXIDIZER TANKS
SECTOR 4 OXYGEN TANKS, HYDROGEN TANKS, FUEL CELLS
SECTOR 5 } SERVICE PROPULSION SUBSYSTEM
SECTOR 6 } FUEL TANKS

CENTER SECTION - SERVICE PROPULSION ENGINE AND HELIUM TANKS

12 (b)



12 (c)

SERVICE MODULE

Fig. 12

The sector and reaction control system panels are 1-inch thick and are made of aluminum honeycomb core between two aluminum face sheets. The sector panels are bolted to the radial beams.

Radiators used to dissipate heat from the environmental control subsystem are bonded to the sector panels on opposite sides of the SM. These radiators are each about 30 square feet in area.

The SM interior is divided into six sectors and a center section (Figure 12b). Sector one is currently void. It is available for installation of scientific or additional equipment should the need arise.

Sector two has part of a space radiator and an RCS engine quad (module) on its exterior panel and contains the SPS oxidizer sump tank. This tank is the larger of the two tanks that hold the nitrogen tetroxide for the SPS engine.

Sector three has the rest of the space radiator and another RCS engine quad on its exterior panel and contains the oxidizer storage tank. This is the second of the two SPS oxidizer tanks and is fed from the oxidizer sump tank in sector two.

Sector four contains most of the electrical power generating equipment. It contains three fuel cells, two cryogenic oxygen and two cryogenic hydrogen tanks and a power control relay box. The cryogenic tanks supply oxygen to the environmental control subsystem and oxygen and hydrogen to the fuel cells.

Sector five has part of an environmental control radiator and an RCS engine quad on the exterior panel and contains the SPS engine fuel sump tank. This tank feeds the engine and is also connected by feed lines to the fuel storage tank in Sector six.

Sector six has the rest of the environmental control radiator and an RCS engine quad on its exterior and contains the SPS engine fuel storage tank which feeds the fuel sump tank in Sector five.

The center section contains two helium tanks and the SPS engine. The tanks are used to provide helium pressurant for the SPS propellant tanks.

PROPULSION

The SPS engine is a restartable, non-throttleable engine which uses nitrogen tetroxide as an oxidizer and a 50-50 mixture of hydrazine and unsymmetrical dimethylhydrazine as fuel. This engine is used for major velocity changes during the mission such as midcourse corrections, lunar orbit insertion and transearth injection. The service propulsion engine responds to automatic firing commands from the guidance and navigation system or to commands from manual controls. The engine assembly is gimbal-mounted to allow engine thrust-vector alignment with the spacecraft center of mass to preclude tumbling. Thrust vector alignment control is maintained automatically by the stablization and control system or manually by the crew.

ADDITIONAL SM SYSTEMS

In addition to the systems already described the SM has communication antennas, umbilical connections and several exterior mounted lights.

The four antennas on the outside of the SM are the S-band high-gain antenna, mounted on the aft bulkhead; two VHF omni-directional antennas, mounted on opposite sides of the module near the top; and the rendezvous radar transponder antenna, mounted in the SM fairing. The S-band high-gain antenna, used for deep space communications, is composed of four 31-inch diameter reflectors surrounding an 11-inch square reflector. At launch it is folded down parallel to the SPS engine nozzle so that it fits within the spacecraft LM adapter. After the CSM separates from the SLA the antenna is deployed at a right angle to the SM center line.

The umbilicals consist of the main plumbing and wiring connections between the CM and SM enclosed in a fairing (aluminum covering), and a "flyaway" umbilical which is connected to the launch tower. The latter supplies oxygen and nitrogen for cabin pressurization, water-gylcol, electrical power from ground equipment, and purge gas.

Seven lights are mounted in the aluminum panels of the fairing. Four (one red, one green, and two amber) are used to aid the astronauts in docking, one is a floodlight which can be turned on to give astronauts visibility during extravehicular activities, one is a flashing beacon used to aid in rendezvous, and one is a spotlight used in rendezvous from 500 feet to docking with the LM.

SM/CM SEPARATION

Separation of the SM from the CM occurs shortly before entry. The sequence of events during separation is controlled automatically by two redundant Service Module Jettison Controllers (SMJC) located on the forward bulkhead of the SM. Physical separation requires severing of all the connections between the modules, transfer of electrical control, and firing of the SMRCS to increase the distance between the CM and SM.

A tenth of a second after electrical connections are deadfaced, the SMJC's send signals which fire ordnance devices to sever the three tension ties and the umbilical. The tension ties are straps which hold the CM on three of the compression pads on the SM. Linear-shaped charges in each tension-tie assembly sever the tension ties to separate the CM from the SM. At the same time, explosive charges drive guillotines through the wiring and tubing in the umbilical.

Simultaneously with the firing of the ordnance devices, the SMJC's send signals which fire the SMRCS. Roll engines are fired for five seconds to alter the SM's course from that of the CM, and the translation (thrust) engines are fired continuously until the propellant is depleted or fuel cell power is expended. These maneuvers carry the SM well away from the entry path of the CM.

COMMAND MODULE

GENERAL

The Command Module (CM) (Figure 13) serves as the command, control and communications center for most of the mission. Supplemented by the SM, it provides all life support elements for three crewmen in the mission environments and for their safe return to earth's surface. It is capable of attitude control about three axes and some lateral lift translation at high velocities in earth atmosphere. It also permits LM attachment, CM/LM ingress and egress, and serves as a buoyant vessel in open ocean.

STRUCTURE

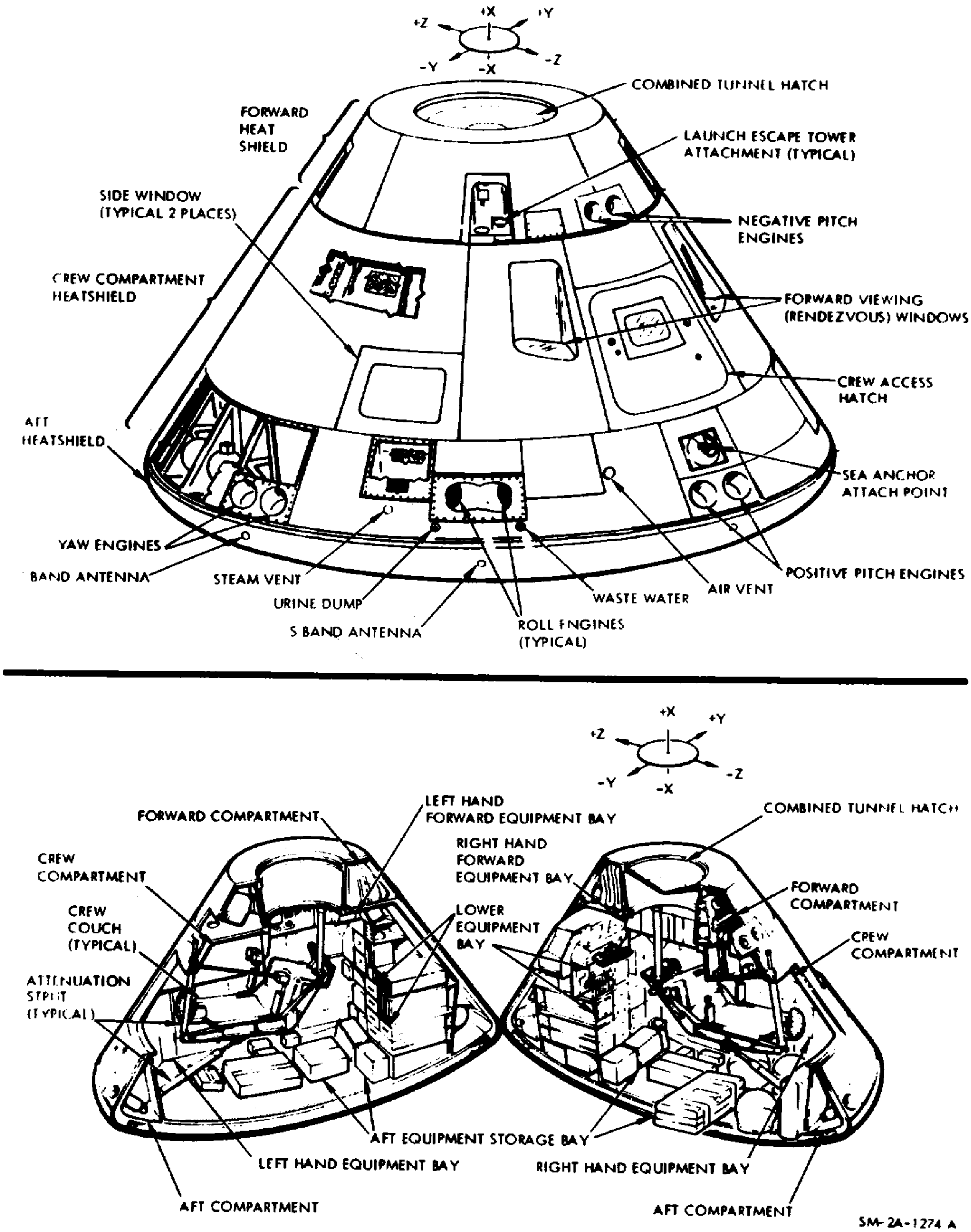
The CM consists of two basic structures joined together: the inner structure (pressure shell) and the outer structure (heat shield).

The inner structure, the pressurized crew compartment, is made of aluminum sandwich construction consisting of a welded aluminum inner skin, bonded aluminum honeycomb core and outer face sheet. The outer structure is basically a heat shield and is made of stainless steel brazed honeycomb brazed between steel alloy face sheets. Parts of the area between the inner and outer sheets is filled with a layer of fibrous insulation as additional heat protection.

THERMAL PROTECTION (HEAT SHIELDS)

The interior of the CM must be protected from the extremes of environment that will be encountered during a mission. The heat of launch is absorbed principally through the Boost Protective Cover (BPC), a fiberglass structure covered with cork which encloses the CM. The cork is covered with a white reflective coating. The BPC is permanently attached to the launch escape tower and is jettisoned with it.

The insulation between the inner and outer shells, plus temperature control provided by the environmental control subsystem, protects the crew and sensitive equipment in space. The principal task of the heat shield that forms the outer structure is to protect the crew during re-entry. This protection is provided by ablative heat shields, of varying thicknesses, covering the CM. The ablative material is a phenolic epoxy resin. This material turns white hot, chars, and then melts away, conducting relatively little heat to the inner structure. The heat shield has several outer coverings: a pore seal, a moisture barrier (a white reflective coating), and a silver Mylar thermal coating.



COMMAND MODULE

Fig. 13

FORWARD COMPARTMENT

The forward compartment is the area around the forward (docking) tunnel. It is separated from the crew compartment by a bulkhead and covered by the forward heat shield. The compartment is divided into four 90-degree segments which contain earth landing equipment (all the parachutes, recovery antennas and beacon light, and sea recovery sling, etc.), two RCS engines, and the forward heat shield release mechanism.

The forward heat shield contains four recessed fittings into which the legs of the launch escape tower are attached. The tower legs are connected to the CM structure by frangible nuts containing small explosive charges, which separate the tower from the CM when the LES is jettisoned.

The forward heat shield is jettisoned at about 25,000 feet during return to permit deployment of the parachutes.

AFT COMPARTMENT

The aft compartment is located around the periphery of the CM at its widest part, near the aft heat shield. The aft compartment bays contain 10 RCS engines; the fuel, oxidizer, and helium tanks for the CM RCS; water tanks; the crushable ribs of the impact attenuation system; and a number of instruments. The CM-SM umbilical is also located in the aft compartment.

CREW COMPARTMENT

The crew compartment has a habitable volume of 210 cubic feet. Pressurization and temperature are maintained by the ECS. The crew compartment contains the controls and displays for operation of the spacecraft, crew couches, and all the other equipment needed by the crew. It contains two hatches, five windows, and a number of equipment bays.

EQUIPMENT BAYS

The equipment bays contain items needed by the crew for up to 14 days, as well as much of the electronics and other equipment needed for operation of the spacecraft. The bays are named according to their position with reference to the couches.

The lower equipment bay is the largest and contains most of the guidance and navigation electronics, as well as the sextant and telescope, the Command Module Computer (CMC), and a computer keyboard. Most of the telecommunications subsystem electronics are in this bay, including the five batteries, inverters, and battery charger of the electrical power subsystem. Stowage areas in the bay contain food supplies, scientific instruments, and other astronaut equipment.

The left-hand equipment bay contains key elements of the ECS. Space is provided in this bay for stowing the forward hatch when the CM and LM are docked and the tunnel between the modules is open.

The left-hand forward equipment bay also contains ECS equipment, as well as the water delivery unit and clothing storage.

The right-hand equipment bay contains waste management system controls and equipment, electrical power equipment, and a variety of electronics, including sequence controllers and signal conditioners. Food also is stored in a compartment in this bay.

The right-hand forward equipment bay is used principally for stowage and contains such items as survival kits, medical supplies, optical equipment, the LM docking target, and bioinstrumentation harness equipment.

The aft equipment bay is used for storing space suits and helmets, life vests, the fecal canister, portable life support systems (backpacks), and other equipment, and includes space for stowing the probe and drogue assembly.

HATCHES

The two CM hatches are the side hatch, used for getting in and out of the CM, and the forward hatch, used to transfer to and from the LM when the CM and LM are docked.

The side hatch is a single integrated assembly which opens outward and has primary and secondary thermal seals. The hatch normally contains a small window, but has provisions for installation of an airlock.

The latches for the side hatch are so designed that pressure exerted against the hatch serves only to increase the locking pressure of the latches.

The hatch handle mechanism also operates a mechanism which opens the access hatch in the BPC. A counterbalance assembly which consists of two nitrogen bottles and a piston assembly enables the hatch and BPC hatch to be opened easily. In space, the crew can operate the hatch easily without the counter balance and the piston cylinder and nitrogen bottle can be vented after launch. A second nitrogen bottle can be used to open the hatch after landing. The side hatch can readily be opened from the outside.

In case some deformation or other malfunction prevented the latches from engaging, three jackscrews are provided in the crew's tool set to hold the door closed.

The forward (docking) hatch is a combined pressure and ablative hatch mounted at the top of the docking tunnel. The exterior or upper side of the hatch is covered with a half-inch of insulation and a layer of aluminum foil.

This hatch has a six-point latching arrangement operated by a pump handle similar to that on the side hatch and can also be opened from the outside. It has a pressure equalization valve so that the pressure in the tunnel and that in the LM can be equalized before the hatch is removed. There are also provisions for opening the latches manually if the handle gear mechanism should fail.

WINDOWS

The CM has five windows: two side, two rendezvous, and a hatch window. The hatch window is over the center couch.

The windows each consist of inner and outer panes. The inner windows are made of tempered silica glass with quarter-inch thick double panes, separated by a tenth of an inch. The outer windows are made of amorphous-fused silicon with a single pane seven tenths of an inch thick. Each pane has an antireflecting coating on the external surface and a blue-red reflective coating on the inner surface to filter out most infrared and all ultraviolet rays. The outer window glass has a softening temperature of 2800°F and a melting point of 3110°F. The inner window glass has a softening temperature of 2000°F. Aluminum shades are provided for all windows.

IMPACT ATTENUATION

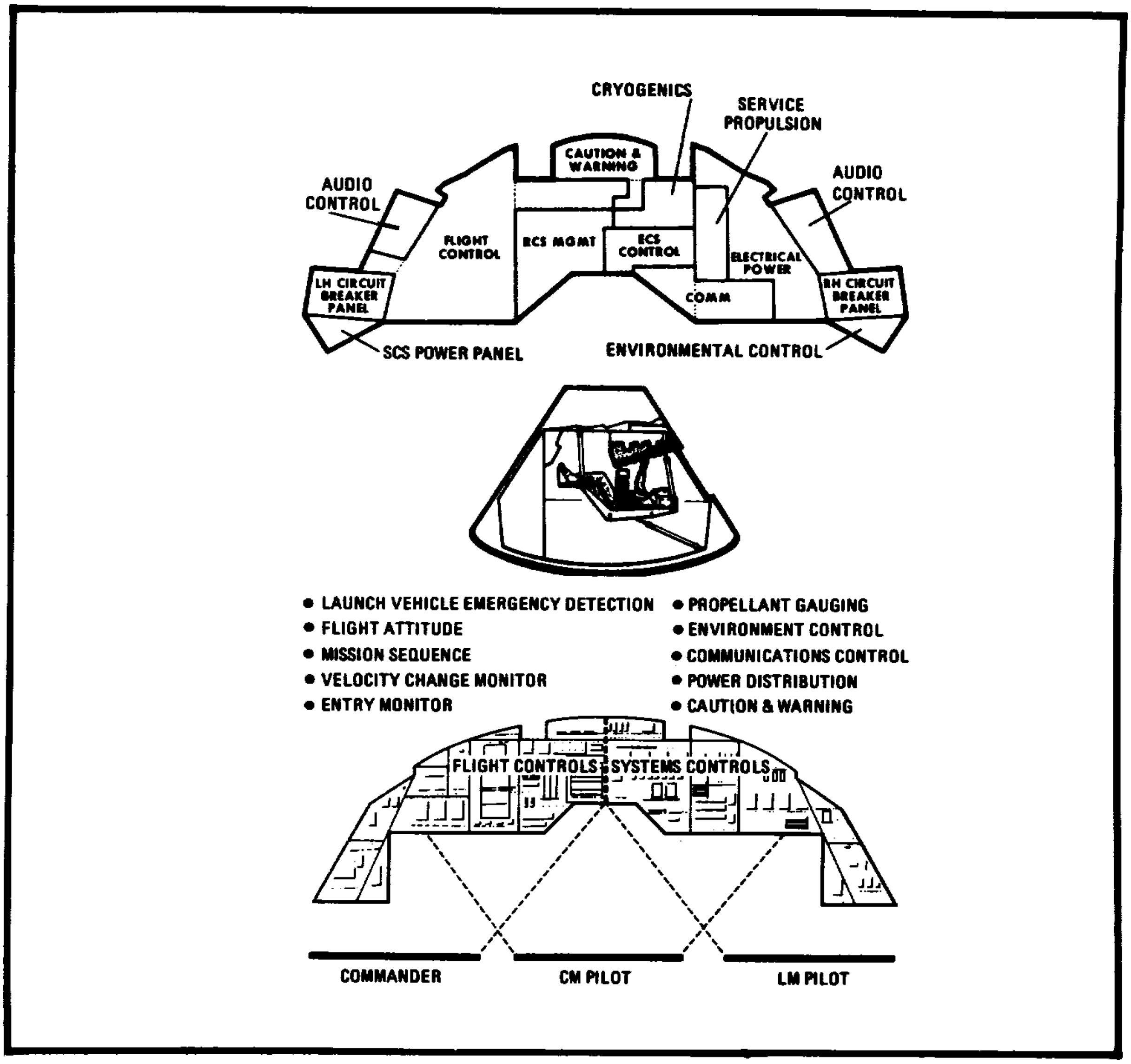
During a water impact the CM deceleration force will vary considerably depending on the shape of the waves and the dynamics of the CM's descent. A major portion of the energy (75 to 90 percent) is absorbed by the water and by deformation of the CM structure. The module's impact attenuation system reduces the forces acting on the crew to a tolerable level.

The impact attenuation system is part internal and part external. The external part consists of four crushable ribs (each about four inches thick and a foot in length) installed in the aft compartment. The ribs are made of bonded laminations of corrugated aluminum which absorb energy by collapsing upon impact. The main parachutes suspend the CM at such an angle that the ribs are the first point of the module that hits the water.

The internal portion of the system consists of eight struts which connect the crew couches to the CM structure. These struts absorb energy by deforming steel wire rings between an inner and an outer piston.

DISPLAYS AND CONTROLS

The Main Display Console (Figure 14) has been arranged to provide for the expected duties of crew members. These duties fall into the categories of Commander, CM Pilot, and LM Pilot, occupying the left, center, and right couches, respectively. The CM Pilot also acts as the principal navigator.



MAIN DISPLAY CONSOLE

Fig. 14

Flight controls are located on the left-center and left side of the Main Display Console, opposite the Commander. These include controls for such subsystems as stabilization and control, propulsion, crew safely, earth landing, and emergency detection. One of two guidance and navigation computer panels also is located here, as are velocity, attitude, and altitude indicators.

The CM Pilot faces the center of the console, and thus can reach many of the flight controls, as well as the system controls on the right side of the console. Displays and controls directly opposite him include reaction control propellant management, caution and warning, environmental control and cryogenic storage systems.

The LM Pilot couch faces the right-center and right side of the console. Communications, electrical control, data storage, and fuel cell system components are located here, as well as service propulsion subsystem propellant management.

All controls have been designed so they can be operated by astronauts wearing gloves. The controls are predominantly of four basic types: toggle switches, rotary switches with click-stops, thumbwheels, and push buttons. Critical switches are guarded so that they cannot be thrown inadvertently. In addtion, some critical controls have locks that must be released before they can be operated.

Other displays and controls are placed throughout the cabin in the various equipment bays and on the crew couches. Most of the guidance and navigation equipment is in the lower equipment bay, at the foot of the center couch. This equipment, including the sextant and telescope, is operated by an astronaut standing and using a simple restraint system. The non-time-critical controls of the environmental control system are located in the left-hand equipment bays, while all the controls of the waste management system are on a panel in the right-hand equipment bay. The rotation and translation controllers used for attitude, thrust vector, and translation maneuvers are located on the arms of two crew couches. In additon, a rotation controller can be mounted at the navigation position in the lower equipment bay.

Critical conditions of most spacecraft systems are monitored by a Caution And Warning System. A malfunction or out-of-tolerance condition results in illumination of a status light that identifies the abnormality. It also activates the master alarm circuit, which illuminates two master alarm lights on the Main Display Console and one in the lower equipment bay and sends an alarm tone to the astronauts' headsets. The master alarm lights and tone continue until a crewman resets the master alarm circuit. This can be done before the crewmen deal with the problem indicated. The Caution And Warning System also contains equipment to sense its own malfunctions.

GUIDANCE AND CONTROL

The Apollo spacecraft is guided and controlled by two interrelated systems (Figure 15). One is the Guidance, Navigation, and Control (GNCS) System. The other is the Stabilization and Control System (SCS).

The two systems provide rotational, line-of-flight, and rate-of-speed information. They integrate and interpret this information and convert it into commands for the spacecraft's propulsion systems.

GUIDANCE, NAVIGATION, AND CONTROL SYSTEM

Guidance and navigation is accomplished through three major elements. They are the inertial, optical, and computer systems.

The inertial subsystem senses any changes in the velocity and angle of the spacecraft and relays this information to the computer which transmits any necessary signals to the spacecraft engines.

The optical subsystem is used to obtain navigation sightings of celestial bodies and landmarks on the earth and moon. It passes this information along to the computer for guidance and control purposes.

The computer subsystem uses information from a number of sources to determine the spacecraft position and speed and, in automatic operation, to give commands for guidance and control.

STABILIZATION AND CONTROL SYSTEM

The Stabilization and Control System (SCS) operates in three ways: it determines the spacecraft's attitude (angular position); it maintains the spacecraft's attitude; it controls the direction of thrust of the service propulsion engine.

Both the GNCS and SCS are used by the computer in the Command Module to provide automatic control of the Spacecraft. Manual control of the spacecraft attitude and thrust is provided mainly through the SCS equipment.

Spacecraft Attitude

The Flight Director Attitude Indicators (FDAI) on the main console show the total angular position, attitude errors and their rates of change. One of the sources of total attitude information is the stable platform of the Inertial Measurement Unit (IMU). The second source is a Gyro Display Coupler (GDC) which gives a reading of the spacecraft's actual attitudes as compared with an attitude selected by the crew.

GUIDANCE AND CONTROL FUNCTIONAL FLOW

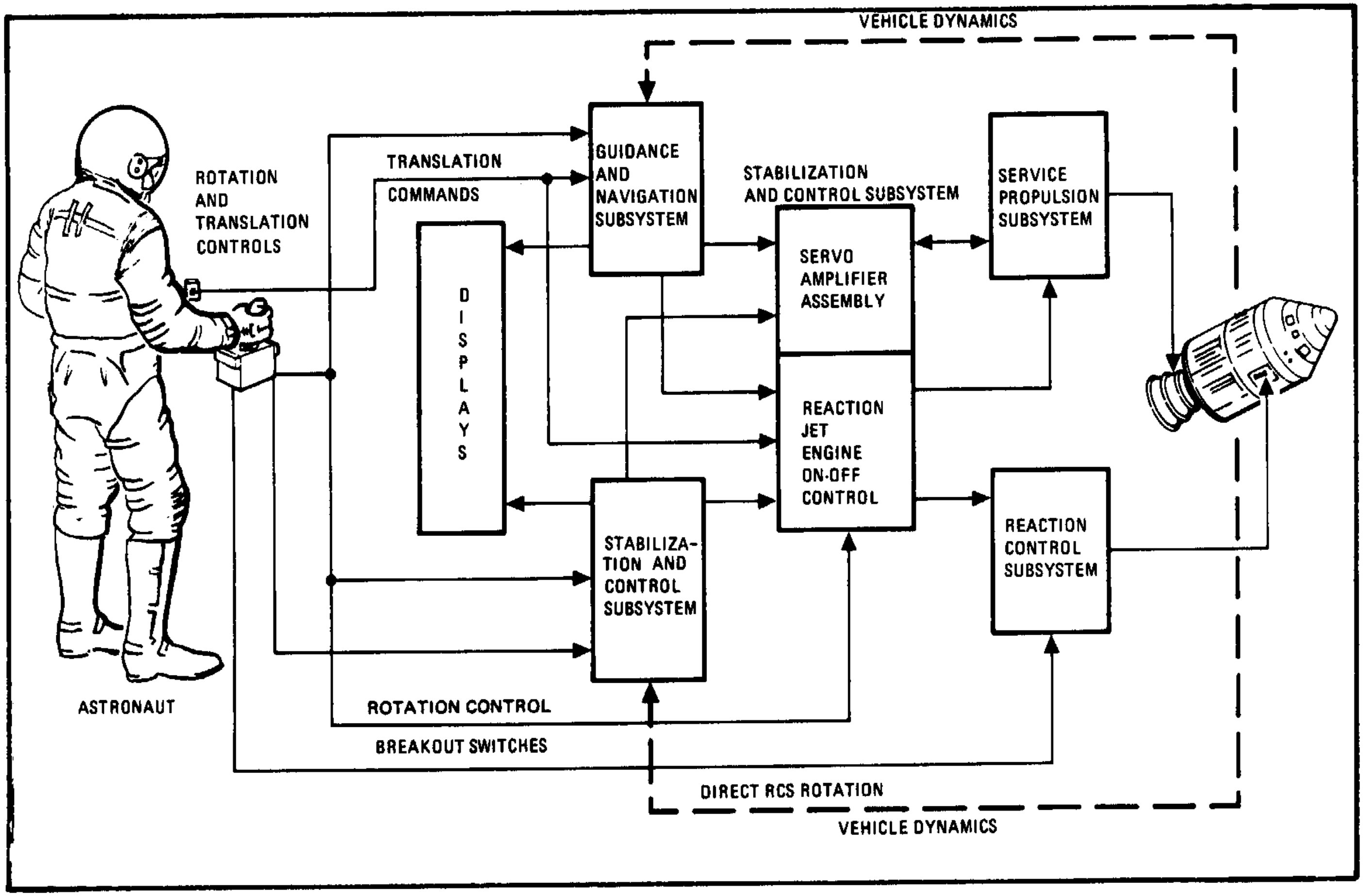


Fig. 15

Information about attitude error also is obtained by comparison of the IMU gimbal angles with computer reference angles. Another source of this information is gyro assembly No. 1, which senses any spacecraft rotation about any of the three axes.

Total attitude information goes to the Command Module Computer (CMC) as well as to the FDAI's on the console.

Attitude Control

If a specific attitude or orientation is desired, attitude error signals are sent to the reaction jet engine control assembly. Then the proper reaction jet automatically fires in the direction necessary to return the spacecraft to the desired position.

Thrust Control

The CMC provides primary control of thrust. The flight crew pre-sets thrusting and spacecraft data into the computer by means of the display keyboard. The forthcoming commands include time and duration of thrust. Accelerometers sense the amount of change in velocity obtained by the thrust.

Thrust direction control is required because of center of gravity shifts caused by depletion of propellants in service propulsion tanks. This control is accomplished through electromechanical actuators which position the gimbaled service propulsion engine. Automatic control commands may originate in either the guidance and navigation subsystem or the SCS. There is also provision for manual controls.

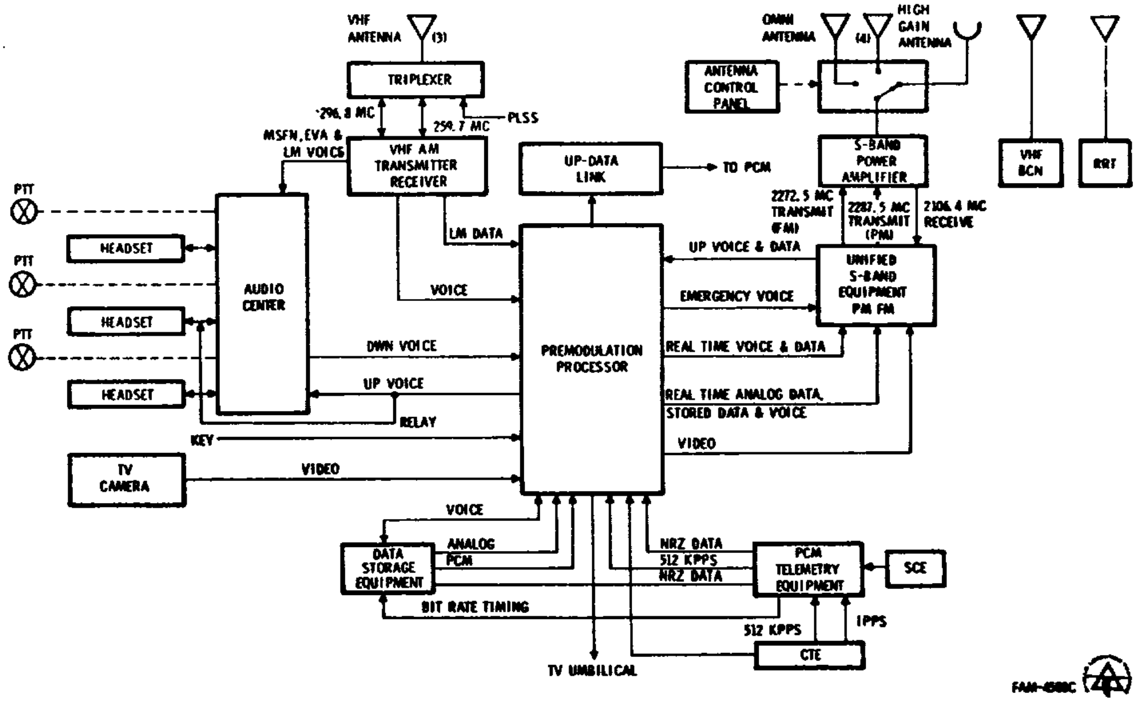
TELECOMMUNICATIONS

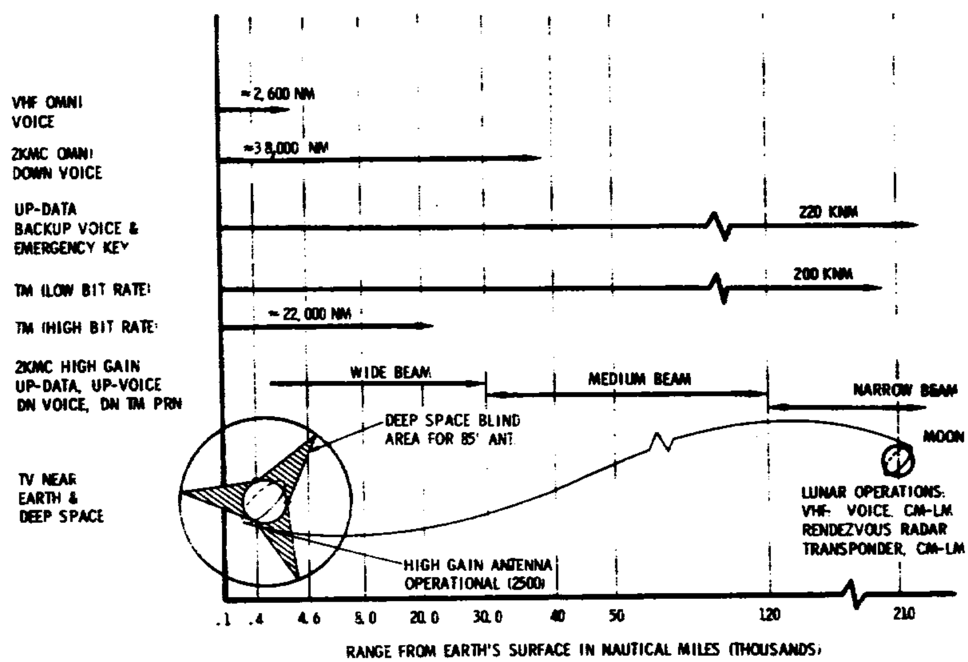
The telecommunications system (Figure 16) provides voice, television, telemetry, and tracking and ranging communications between the spacecraft and earth, between the CM and LM, and between the spacecraft and astronauts wearing the Portable Life Support System (PLSS). It also provides communications among the astronauts in the spacecraft and includes the central timing equipment for synchronization of other equipment and correlation of telemetry equipment.

For convenience, the telecommunications subsystem can be divided into four areas: intercommunications (voice), data, radio frequency equipment, and antennas.

TELECOMMUNICATIONS SYSTEM

BLOCK II





CSM COMMUNICATION RANGES

Fig. 16

INTERCOMMUNICATIONS

The astronauts' headsets are used for all voice communications. Each astronaut has an audio control panel on the main display console which enables him to control what comes into his headset and where he will send his voice.

The three headsets and audio control panels are connected to three identical audio center modules.

The audio center is the assimilation and distribution point for all spacecraft voice signals. The audio signals can be routed from the center to the appropriate transmitter or receiver, the Launch Control Center (for pre-launch checkout), the recovery forces intercom, or voice tape recorders.

Two methods of voice transmission and reception are possible: the VHF/AM transmitter-receiver and the S-band transmitter and receiver.

The VHF/AM equipment is used for voice communications with the Manned Space Flight Network during launch, ascent, and near-earth phases of a mission. The S-band equipment is used during both near-earth and deep-space phases of a mission. When communications with earth are not possible, a limited number of audio signals can be stored on tape for later transmission.

DATA

The spacecraft structure and subsystems contain sensors which gather data on their status and performance. Biomedical, TV, and timing data also are gathered. These various forms of data are assimilated into the data system, processed, and then transmitted to the ground. Some data from the operational systems, and some voice communications, may be stored for later transmission or for recovery after landing. Stored data can be transmitted to the ground simultaneously with voice or real-time data.

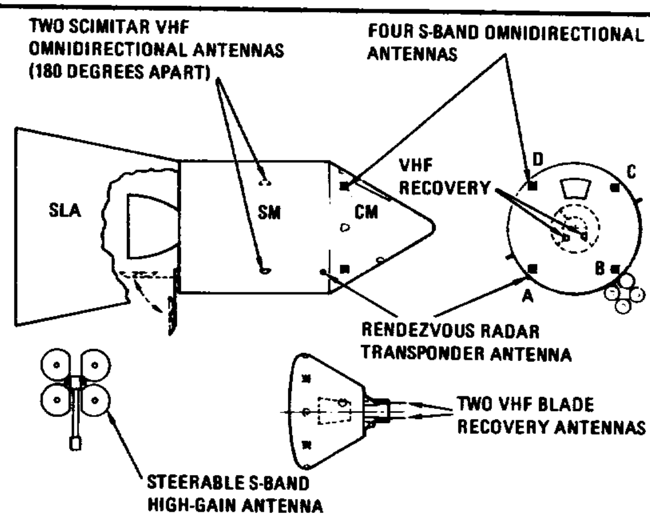
RADIO FREQUENCY EQUIPMENT

The radio frequency equipment is the means by which voice information, telemetry data, and ranging and tracking information are transmitted and received. The equipment consists of two VHF/AM transceivers in one unit, the unified S-band equipment (primary and secondary transponders and an FM transmitter), primary and secondary S-band power amplifiers (in one unit), a VHF beacon, an X-band transponder (for rendezvous radar), and the premodulation processor.

The equipment provides for voice transfer between the CM and the ground, between the CM and LM, between the CM and extravehicular astronauts, and between the CM and recovery forces. Telemetry can be transferred between the CM and the ground, from the LM to the CM and then to the ground, and from extravehicular astronauts to the CM and then to the ground. Ranging information consists of pseudo-random noise and double-doppler ranging signals from the ground to the CM and back to the ground, and, of X-band radar signals from the LM to the CM and back to the LM. The VHF beacon equipment emits a 2-second signal every five seconds for line-of-sight direction finding to aid recovery forces in locating the CM after landing.

ANTENNAS

There are nine antennas on the CSM, not counting the rendezvous radar antenna which is an integral part of the rendezvous radar transponder. These antennas are shown in Figure 17.



LOCATION OF ANTENNAS

Fig. 17

These antennas can be divided into four groups: VHF, S-band, recovery, and beacon. The two VHF antennas (called scimitars because of their shape) are omni-directional and are mounted 180 degrees apart on the SM. There are five S-band antennas, one mounted at the bottom of the SM and four located 90 degrees apart around the CM. The four smaller surface-mounted S-band antennas are used at near-earth ranges and deep-space backup. The high-gain antenna is deployable after CSM/SLA separation. It can be steered through a gimbal system and is the principal antenna for deep-space communications. The four S-band antennas on the CM are mounted flush with the surface of the CM and are used for S-band communications during near-earth phases of the mission, as well as for a backup in deep space. The two VHF recovery antennas are located in the forward compartment of the CM, and are deployed automatically shortly after the main parachutes deploy. One of these antennas also is connected to the VHF recovery beacon.

ENVIRONMENTAL CONTROL SYSTEM

The Environmental Control System (ECS) provides a controlled environment for three astronauts for up to 14 days. For normal conditions, this environment includes a pressurized cabin (five pounds per square inch), a 100-percent oxygen atmosphere, and a cabin temperature of 70 to 75 degrees fahrenheit. For use during critical mission phases and for emergencies, the subsystem provides a pressurized suit circuit.

The system provides oxygen and hot and cold water, removes carbon dioxide and odors from the CM cabin, provides for venting of waste, and dissipates excessive heat from the cabin and from operating electronic equipment. It is designed so that a minimum amount of crew time is needed for its normal operation.

The main unit contains the coolant control panel, water chiller, two water-glycol evaporators, carbon dioxide-odor absorber canisters, suit heat exchanger, water separator, and compressors. The oxygen surge tank, water glycol pump package and reservoir, and control panels for oxygen and water are adjacent to the unit.

The system is concerned with three major elements: oxygen, water, and coolant (water-glycol). All three are interrelated and intermingled with other systems. These three elements provide the major functions of spacecraft atmosphere, thermal control, and water management through four major subsystems: oxygen, pressure suit circuit, water, and water-glycol. A fifth subsystem, post-landing ventilation, also is part of the environmental control system, providing outside air for breathing and cooling prior to hatch opening.

The CM cabin atmosphere is 60 percent oxygen and 40 percent nitrogen on the launch pad to reduce fire hazard. The mixed atmosphere supplied by ground equipment will gradually be changed to pure oxygen after launch as the environmental control system maintains pressure and replenishes the cabin atmosphere.

During pre-launch and initial orbital operation, the suit circuit supplies pure oxygen at a flow rate slightly more than is needed for breathing and suit leakage. This results in the suit being pressurized slightly above cabin pressure, which prevents cabin gases from entering and contaminating the suit circuit. The excess oxygen in the suit circuit is vented into the cabin.

Spacecraft heating and cooling is performed through two water-glycol coolant loops. The water-glycol, initially cooled through ground equipment, is pumped through the primary loop to cool operating electric and electronic equipment, the space suits, and the cabin heat exchangers. The water-glycol also is circulated through a reservoir in the CM to provide a heat sink during ascent.

CM REACTION CONTROL SYSTEM

The CM Reaction Control System (RCS) is used after CM/SM separation and for certain abort modes. It provides three-axis attitude control to orient and maintain the CM in the proper entry attitude.

The system consists of two independent, redundant systems. The two systems can operate in tandem; however, one can provide all the impulse needed for the entry maneuvers, and normally only one is used.

The 12 engines of the system are located outside the crew compartment of the CM, ten in the aft compartment and two in the forward compartment. Each engine produces approximately 93 pounds of thrust.

Operation of the CM RCS is similar to that of the SM RCS. The fuel is monomethyl hydrazine and the oxidizer is nitrogen tetroxide. Helium is used for pressurization. Each of the redundant CM systems contains one fuel and one oxidizer tank similar to the fuel and oxidizer tanks of the SM system. Each CM system has one helium tank.

ELECTRICAL POWER SYSTEM

The Electrical Power System (EPS) provides electrical energy sources, power generation and control, power conversion and conditioning, and power distribution to the spacecraft throughout the mission. The EPS also furnishes drinking water to the astronauts as a by-product of the fuel cells. The primary source of electrical power is the fuel cells mounted in the SM. Each cell consists of a hydrogen compartment, an oxygen compartment, and two electrodes.

The cryogenic gas storage system, also located in the SM, supplies the hydrogen and oxygen used in the fuel cell power plants, as well as the oxygen used in the ECS.

Three silver oxide-zinc storage batteries supply power to the CM during entry and after landing, provide power for sequence controllers, and supplement the fuel cells during periods of peak power demand. These batteries are located in the CM lower equipment bay. A battery charger is located in the same bay to assure a full charge prior to entry.

Two other silver oxide-zinc batteries, independent of and completely isolated from the rest of the dc power system, are used to supply power for explosive devices for CM/SM separation, parachute deployment and separation, third-stage separation, launch escape system tower separation, and other pyrotechnic uses.

EMERGENCY DETECTION SYSTEM

The Emergency Detection System (EDS) monitors critical conditions of launch vehicle powered flight. Emergency conditions are displayed to the crew on the main display console to indicate a necessity for abort. The system includes providions for a crew-initiated abort with the use of the LES or with the SPS after tower jettison. The crew can initiate an abort separation from the LV from prior to lift-off until the planned separation time. A capability also exists for commanding early staging of the S-IVB from the S-II stage when necessary. Also included in the system are provisions for an automatic abort in case of the following time-critical conditions:

1. Loss of thrust on two or more engines on the first stage of the Launch Vehicle.

2. Excessive vehicle angular rates in any of the pitch, yaw, or roll planes.

3. Loss of "hotwire" continuity from SM to IU.

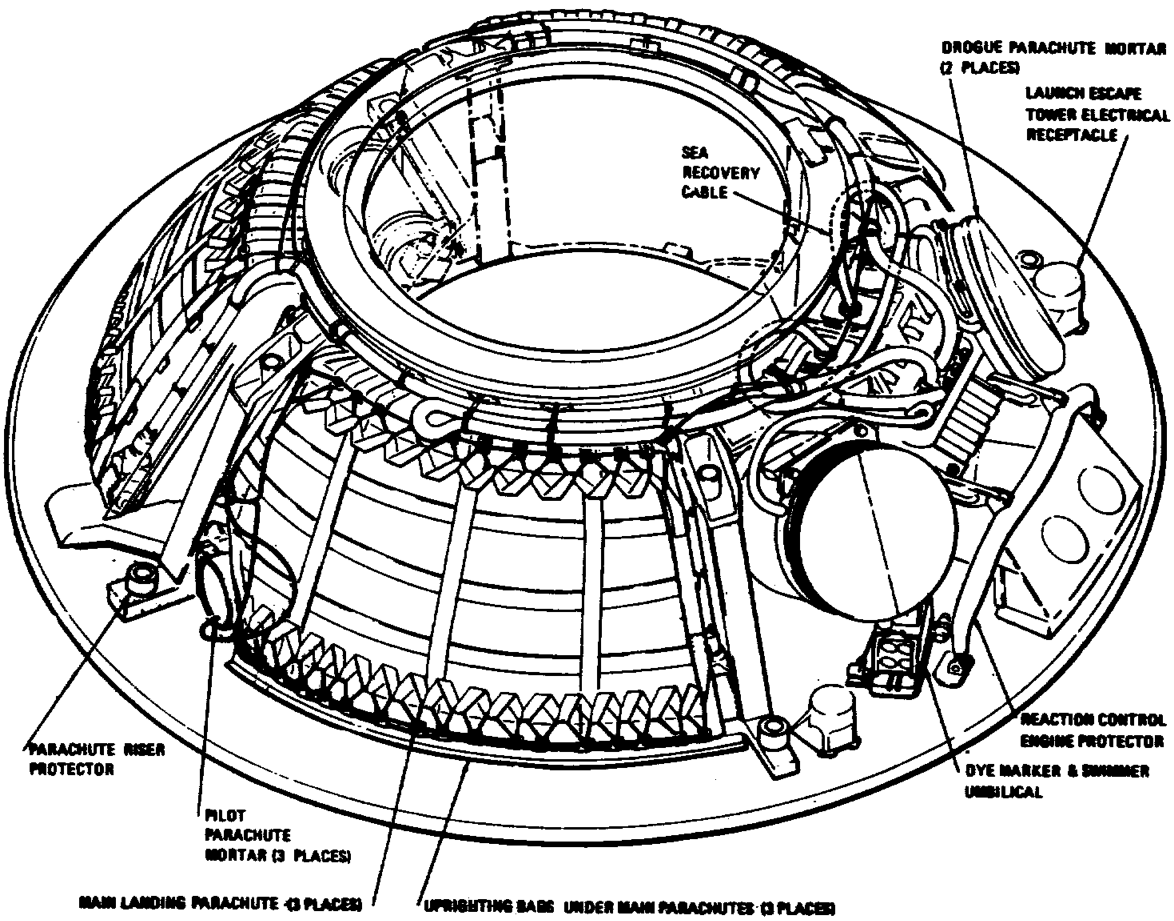
The EDS will automatically initiate an abort signal when two or more first-stage engines are out or when Launch Vehicle excessive rates are sensed by gyros in the Instrument Unit. The abort signals are sent to the master events sequence controller, which initiates the abort sequence.

The engine lights on the Main Display Console provide the following information to the crew: ignition, cutoff, engine below pre-specified thrust level, and physical stage separation. A yellow "S-II Sep" light will illuminate at second-stage first-plane separation and will extinguish at second-plane separation.

A high-intensity, red "ABORT" light is illuminated if an abort is requested by the Launch Control Center for a pad abort or an abort during lift-off via updata link. The "ABORT" light also can be illuminated after lift-off by the Range Safety Officer, or by the Mission Control Center via the updata link from the Manned Space Flight Network.

EARTH LANDING SYSTEM

The Earth Landing System (ELS) provides a safe landing for the astronauts and the CM. Several recovery aids which are activated after splashdown are part of the system. Operation normally is automatic, timed and activated by the sequential control system. All automatic functions can be backed up manually. Components and their locations are shown in Figure 18.



ELS MAJOR COMPONENT STORAGE

Fig. 18

For normal entry, about 1.5 seconds after forward heat shield jettison, the two drogue parachutes are deployed to orient the CM properly and to provide initial deceleration. At about 10,000 feet, the drogue parachutes are released and the three pilot parachutes are deployed; these pull the main parachutes from the forward section of the CM. The main parachutes initially open partially (reefed) for ten seconds, to limit deceleration prior to full-diameter deployment. The main parachutes hang the CM at an angle of 27.5 degrees to decrease impact loads at touchdown.

After splashdown, the main parachutes are released and the recovery aid subsystem is set in operation by the crew. The subsystem consists of an uprighting system, swimmer's umbilical cable, a sea dye marker, a flashing beacon, and a VHF beacon transmitter. A sea recovery sling of steel cable also is provided to lift the CM aboard a recovery ship.

The two VHF recovery antennas are located in the forward compartment with the parachutes. They are deployed automatically eight-seconds after the main parachutes. One of them is connected to the beacon transmitter, which emits a two-second signal every five-seconds to aid recovery forces in locating the CM. The other is connected to the VHF/AM transmitter and receiver to provide voice communications between the crew and recovery forces.

Three inflatable uprighting bags, stowed under the main parachutes, are available for uprighting the CM should it stabilize in an inverted floating position after splashdown.

Automatic operation of the Earth Landing System is provided by the event sequencing system located in the right-hand equipment bay of the CM. The system contains the barometric pressure switches, time delays, and relays necessary to control jettisoning of the heat shield and the deployment of the parachutes.

CREW PROVISIONS

APPAREL

The number of items a crewman wears varies during a mission. There are three basic conditions: unsuited, suited, and extravehicular. Unsuited, the crewman breathes the cabin oxygen and wears a bioinstrumentation harness, a communication soft hat, a constant-wear garment, flight coveralls, and booties.

Under the space suit, the astronaut wears the bioinstrumentation harness, communications soft hat, and constant-wear garment. The extravehicular outfit, designed primarily for wear during lunar exploration, includes the bioinstrumentation harness, a fecal containment system, a liquid-cooled garment, the communication soft hat, the space suit, a portable life support system (backpack), an oxygen purge system, a thermal/meteoroid garment, and an extravehicular visor.

The bioinstrumentation harness has sensors, signal conditioners, a belt, and wire signal carriers. These monitor the crewman's physical condition and the information is telemetered to the ground.

The constant-wear garment is an undergarment for the suit and flight coveralls. Made of porous cotton cloth, it is a one-piece, short-sleeved garment with feet similar to those on long underwear. It is zippered from waist to neck and has openings front and rear for personal hygiene. Pockets at the ankles, thighs, and chest hold passive-radiation dosimeters. Spare garments are stowed on the aft bulkhead.

The flight coverall is the basic outer garment for unsuited operations. It is a two-piece, Teflon-cloth garment with pockets on the shins and thighs for personal equipment.

The communication soft hat is worn when suited. It has two earphones and two microphones, with voice tubes on two mounts that fit over the ears. An electical cable runs from the hat to the communications cable. A lightweight headset is worn when crewmen are not in their suits.

Booties worn with the flight coveralls are made of Beta cloth, with Velcro hook material bonded to the soles. During weightlessness, the Velcro hook engages Velcro pile patches attached to the floor to hold the crewman in place.

SPACE SUIT

The space suit protects the astronaut from the hostile environment of space. It provides atmosphere for breathing and pressurization, protects him from heat, cold, and micrometeroroids, and contains a communications link.

The suit is worn by the astronauts during all critical phases of the mission, during periods when the CM is unpressurized, and during all operations outside the CM and LM, whether in space or on the Moon.

The suit system must provide an artificial atmosphere (100-percent oxygen for breathing and for pressurization to 3.7 psi), adequate mobility, micrometeorite and visual protective systems, and the ability to operate on the lunar surface for periods of three hours. Design of the Apollo spacecraft and suits will permit the crew to operate - with certain restraints - in a decompressed cabin for periods as long as 115 hours.

The complete space suit is called the Pressure Garment Assembly (PGA). It is composed of a number of items assembled into two configurations: extravehicular (for outside the spacecraft) and intravehicular. The addition of the backpack to the extravehicular space suit makes up the Extravehicular Mobility Unit (EMU). The backpack (called the Portable Life Support System PLSS) supplies oxygen, electrical power, communications, and liquid cooling.

The intravehicular space suit consists of : fecal containment subsystem, constant-wear garment, biomedical belt, urine collection transfer assembly, torso limb suit, integrated thermal/micrometeoroid garment, pressure helmet, pressure glove, and communications carrier.

In the extravehicular configuration, the constant wear garment is replaced by the liquid-cooling garment and four items are added to the intravehicular suit: extravehicular visor, extravehicular glove, lunar overshoe, and a cover which fits over umbilical connections on the front of the suit.

The pressure suit is a white garment that weighs about 60 pounds with the integrated thermal/micrometeoroid garment. The latter weighs about 19 pounds.

The basic components of the suit, or PGA, are the torso limb suit, the pressure helmet, the pressure glove, the integrated thermal/micrometeoroid garment, and the extravehicular glove.

A cable and hose assembly connects the space suits to the spacecraft. The cable provides a communications capability and the two hoses carry oxygen. There are three fluorel-coated hose assemblies. The communications cable assembly consists of a cable and control head. The cables run next to the two hoses of the assembly.

FOOD AND WATER

Food supplies are designed to supply each astronaut with a balanced diet of approximately 2800 calories a day. The food is either freeze-dried or concentrated and is carried in vacuum-packaged plastic bags. Each bag of freeze-dried food has a one-way-valve through which water is inserted and a second valve through which food passes. Concentrated food is packaged in bite-size units and needs no reconstitution. Several bags are packaged together to make one meal bag. The meal bags have red, white, and blue dots to identify them for each crewman, as well as labels to identify them by day and meal.

The food is reconstituted by adding hot or cold water through the one-way valve. The astronaut kneads the bag and then cuts the neck of the bag and squeezes the food into his mouth.

Drinking water comes from the water chiller to two outlets: the water meter dispenser, and the food preparation unit. The dispenser has an aluminum mounting bracket, a 72-inch coiled hose, and a dispensing valve unit in the form of a button-actuated pistol. The pistol barrel is placed in the mouth and the button is pushed for each half-ounce of water. The meter records the amount of water drunk. A valve is provided to shut off the system in case the dispenser develops a leak or malfunction.

Food preparation water is dispensed from a unit which has hot (150°F) and cold (50°F) water. Cold water comes directly to the unit from the water chiller. Hot water is accumulated in a 38-ounce tank which contains three heaters that keep the water at 150° F.

COUCHES AND RESTRAINTS

The astronaut couches are individually adjustable units made of hollow steel tubing and covered with a heavy, fireproof, fiberglass cloth. The couches rest on a head beam and two side-stabilizer beams supported by eight attenuator struts (two each for the Y and Z axes and four for the X axis) which absorb the impact of landing.

These couches support the crewmen during acceleration and deceleration, position the crewman at their duty stations, and provide support for translation and rotation hand controls, lights, and other equipment. A lap belt and shoulder straps are attached to the couches.

The couches can be folded or adjusted into a number of seat positions. The one used most is the 85-degree position assumed for launch, orbit entry, and landing. The 170-degree (flat-out) position is used primarily for the center couch, so that crewmen can move into the lower equipment bay. The armrests on either side of the center couch can be folded footward so the astronauts from the two outside couches can slide over easily. The hip pan of the center couch can be disconnected and the couch can be pivoted around the head beam and laid on the aft bulkhead floor of the CM. This provides both room for the astronauts to stand and easier access to the side hatch for extravehicular activity.

Two armrests are attached to the back pan of the left couch and two armrests are attached to the right couch. The center couch has no armrests. The translation and rotation controls can be mounted to any of the four armrests. A support at the end of each armrest rotates 100 degrees to provide proper tilt for the controls. The couch seat pan and leg pan are formed of framing and cloth, and the foot pan is all steel. The foot pan contains a boot restraint device which engages the boot heel and holds it in place.

The couch restraint harness consists of a lap belt and two shoulder straps which connect to the lap belt at the buckle. The shoulder straps connect to the shoulder beam of the couch.

Other restraints in the CM include handholds, a hand bar, hand straps, and patches of Velcro which hold crewmen when they wear sandals.

The astronauts sleep in bags under the left and right couches with heads toward the hatch. The two sleeping bags are lightweight Beta fabric 64 inches long, with zipper openings for the torso and 7-inch diameter neck openings. They are supported by two longitudinal straps that attach to storage boxes in the lower equipment bay and to the CM inner structure. The astronauts sleep in the bags when unsuited and restrained on top of the bags when they have space suits on.

HYGIENE EQUIPMENT

Hygiene equipment includes wet and dry cloths for cleaning, towels, a toothbrush, and the waste management system.

The waste management system controls and disposes of waste solids, liquids, and gases. The major portion of the system is in the right-hand equipment bay. The system stores feces, removes odors, dumps urine overboard, and removes urine from the space suit.

OPERATIONAL AIDS

These include data files, tools, workshelf, cameras, fire extinguishers, oxygen masks, medical supplies, and waste bags.

The CM has one fire extinguisher, located adjacent to the left-hand and lower equipment bays. The extinguisher weighs about eight pounds. The extinguishing agent is an aqueous gel expelled in two cubic feet of foam for approximately 30 seconds at high pressure. Fire ports are located at various panels so that the extinguisher's nozzle can be inserted to put out a fire behind the panel.

Oxygen masks are provided for each astronaut in case of smoke, toxic gas, or other hostile atmosphere in the cabin while the astronauts are out of their suits. Oxygen is supplied through a flexible hose from the emergency oxygen/repressurization unit in the upper equipment bay.

Medical supplies are contained in an emergency medical kit, about 7 x 5 x 5 inches, which is stored in the lower equipment bay. It contains oral drugs and pills (pain capsules, stimulant, antibiotic, motion sickness, diarrhea, decongestant, and aspirin), injectable drugs (for pain and motion sickness), bandages, topical agents (first-aid cream, sun cream, and an antibiotic ointment), and eye drops.

SURVIVAL EQUIPMENT

Survival equipment, intended for use in an emergency after earth landing, is stowed in two rucksacks in the right-hand forward equipment bay.

One of the rucksacks contains a three-man rubber life raft with an inflation assembly, carbon-dioxide cylinder, a sea anchor, dye marker, and a sunbonnet for each crewman.

The other rucksack contains a beacon transceiver, survival lights, desalter kits, machete, sun glasses, water cans, and a medical kit.

The survival medical kit contains the same type of supplies as the emergency medical kit: six bandages, six injectors, 30 tablets, and one tube of all-purpose ointment.

MISCELLANEOUS EQUIPMENT

Each crewman is provided a toothbrush, wet and dry cleansing cloths, ingestible toothpaste, a 64-cubic inch container for personal items, and a two-compartment, temporary storage bag.

A special tool kit is provided which also contains three jack screws for contingency hatch closure.

LAUNCH COMPLEX

GENERAL

Launch Complex 39 (LC-39), located at Kennedy Space Center, Florida, is the facility provided for the assembly, checkout, and launch of the Apollo/Saturn V Space Vehicle. Assembly and checkout of the vehicle is accomplished on a Mobile Launcher, in the controlled environment of the Vehicle Assembly Building. The space vehicle and the Mobile Launcher are then moved, as a unit, by the Crawler-Transporter to the launch site. The major elements of the launch complex shown in Figure 19 are the Vehicle Assembly Building (VAB), the Launch Control Center (LCC), the Mobile Launcher (ML), the Crawler-Transporter (C/T), the crawlerway, the Mobile Service Structure (MSS), and the launch pad.

LC-39 FACILITIES AND EQUIPMENT

Vehicle Assembly Building

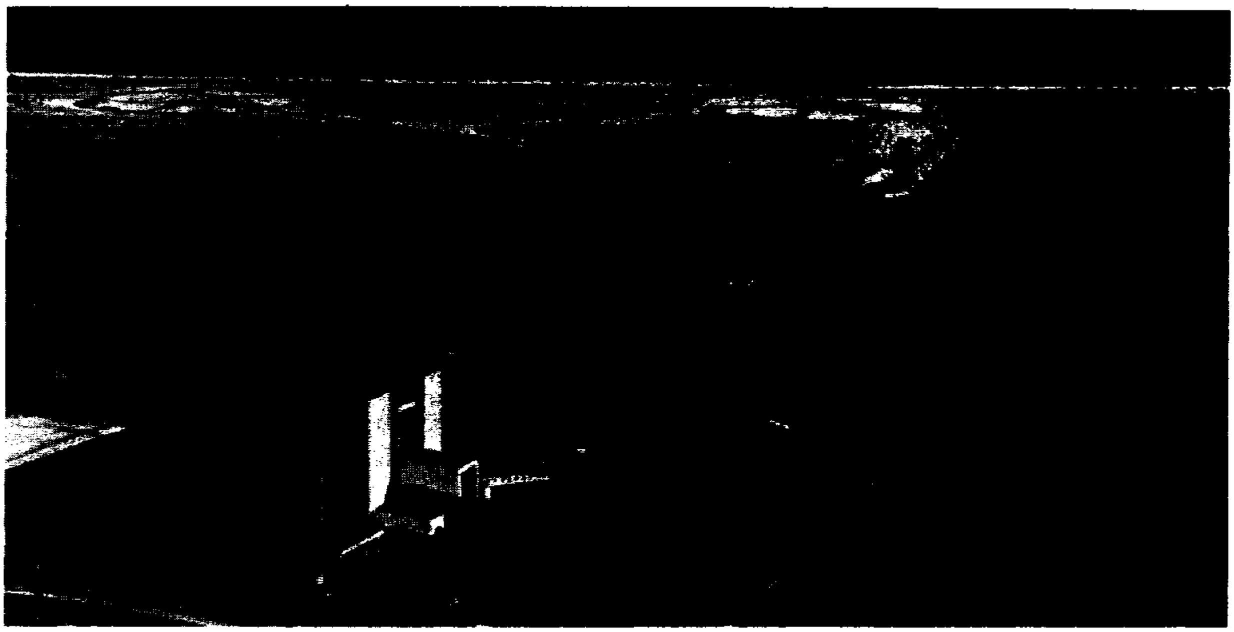
The VAB provides a protected environment for receipt and checkout of the propulsion stages and IU, erection of the vehicle stages and spacecraft in a vertical position on the ML, and integrated checkout of the assembled space vehicle.

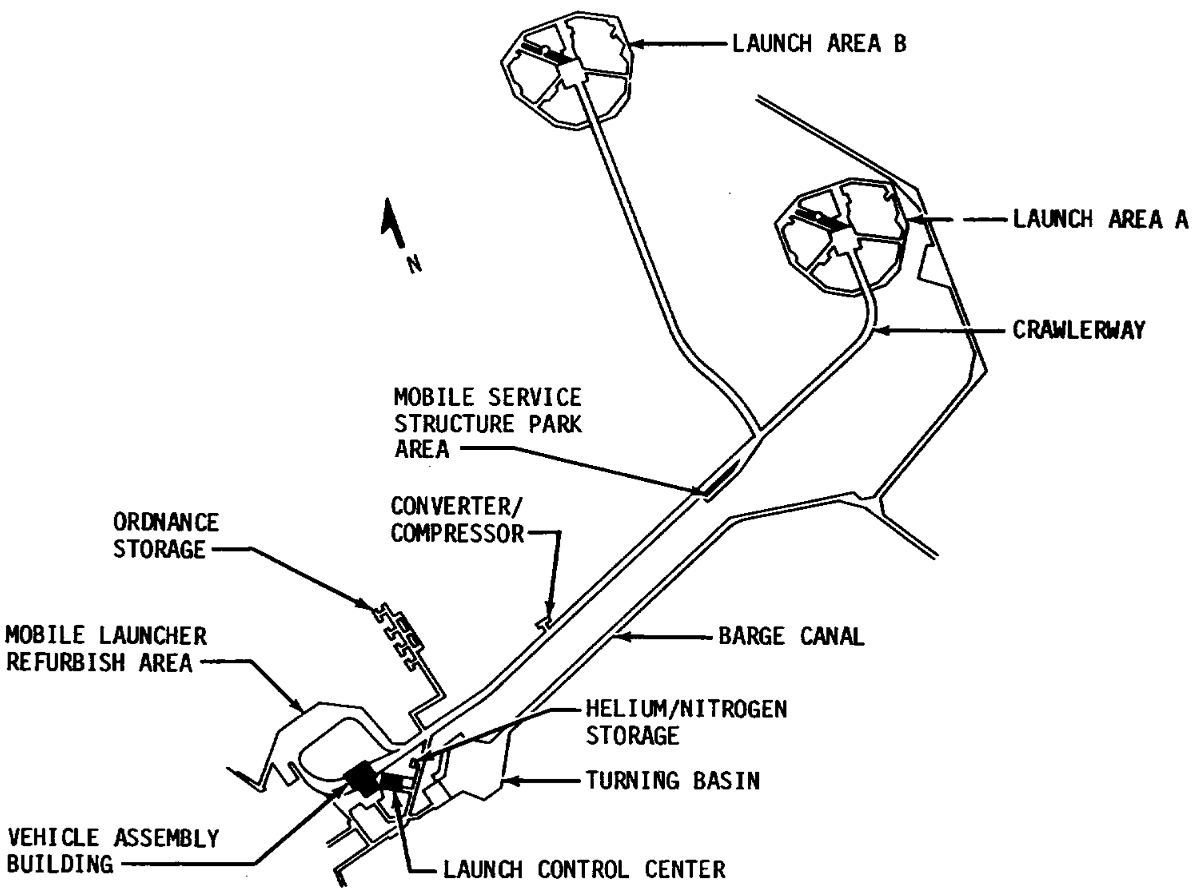
The VAB, as shown in Figure 20, is a totally-enclosed structure covering eight acres of ground. It is a structural steel building approximately 525 feet high, 518 feet wide, and 716 feet long.

The principal operational elements of the VAB are the low bay and high bay areas. A 92-foot wide transfer aisle extends through the length of the VAB and divides the low and high bay areas into equal segments (Figure 20).

The low bay area provides the facilities for receiving, uncrating, checkout, and preparation of the S-II stage, S-IVB stage, and the IU.

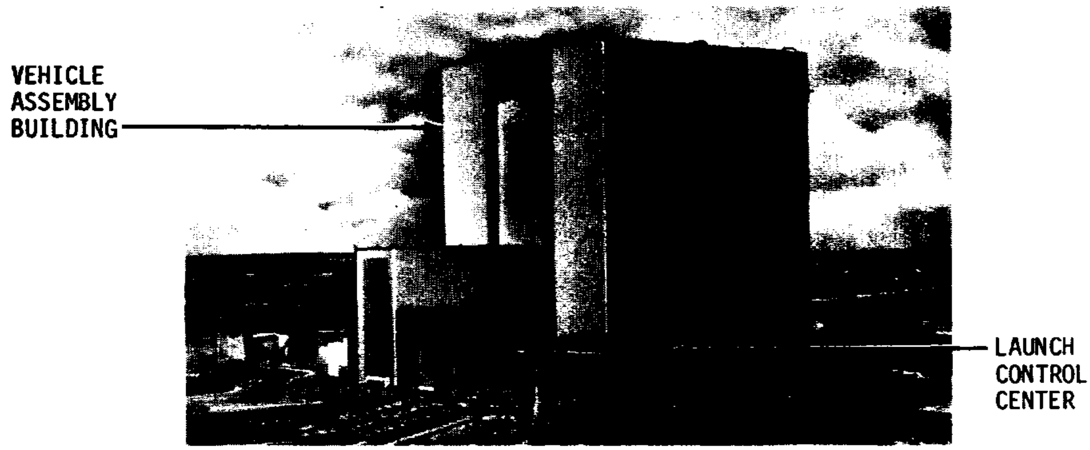
The high bay area provides the facilities for erection and checkout of the S-IC stage; mating and erection operations of the S-II stage; S-IVB stage, IU, and spacecraft; and integrated checkout of the assembled space vehicle. The high bay area contains four checkout bays, each capable of accommodating a fully-assembled Apollo/Saturn V Space Vehicle.





LAUNCH COMPLEX 39

Fig. 19



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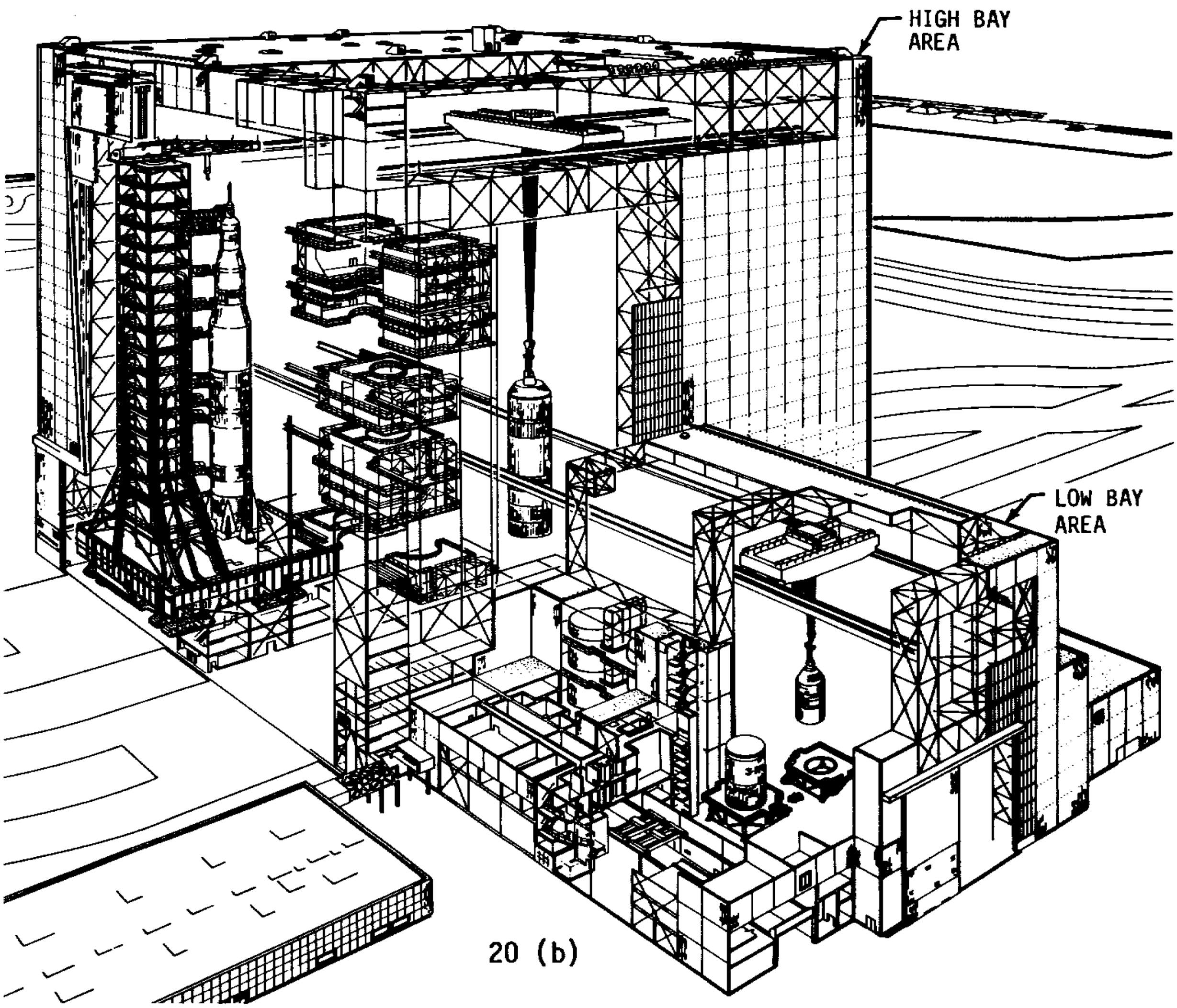


20 (b)

VEHICLE ASSEMBLY BUILDING

Fig. 20

Launch Control Center

The LCC, Figure 20, serves as the focal point for overall direction, control, and monitoring of space vehicle checkout and launch. The LCC is located adjacent to the VAB and at a sufficient distance from the launch pad (three miles) to permit the safe viewing of lift-off without requiring site hardening.

The LCC is a four-story structure. The ground floor is devoted to service and support functions. The second floor houses telemetry and tracking equipment, in addition to instrumentation and data reduction facilities.

The third floor is divided into four separate but similar control areas, each containing a firing room, a computer room, a mission control room, a test conductor platform area, a visitor gallery, and offices. The four firing rooms, one for each high bay in the VAB, contain control, monitoring, and display equipment for automatic vehicle checkout and launch.

The display rooms, offices, Launch Information Exchange Facility (LIEF) rooms, and mechanical equipment are located on the fourth floor.

The power demands in this area are large and are supplied by two separate systems, industrial and instrumentation. This division between power systems is designed to protect the instrumentation power system from the adverse effects of switching transients, large cycling loads, and intermittent motor starting loads. Communication and signal cable troughs extend from the LCC via the enclosed bridge to each ML location in the VAB high bay area. Cableways also connect to the ML refurbishing area and to the Pad Terminal Connection Room (PTCR) at the launch pad. Antennas on the roof provide an RF link to the launch pads and other facilities at KSC.

Mobile Launcher

The ML (Figure 21) is a transportable steel structure which, with the C/T, provides the capability to move the erected vehicle to the launch pad. The ML is divided into two functional areas, the launcher base and the umbilical tower. The launcher base is the platform on which a Saturn V vehicle is assembled in the vertical position, transported to a launch site, and launched. The umbilical tower provides access to all important levels of the vehicle during assembly, checkout, and servicing. The equipment used in the servicing, checkout, and launch is installed throughout both the base and tower sections of the ML.

The launcher base is a steel structure 25 feet high, 160 feet long, and 135 feet wide. The upper deck, designated level 0, contains, in addition to the umbilical tower, the four hold-down arms and the three tail service masts. There is a 45-foot square opening through the ML base for first stage exhaust.

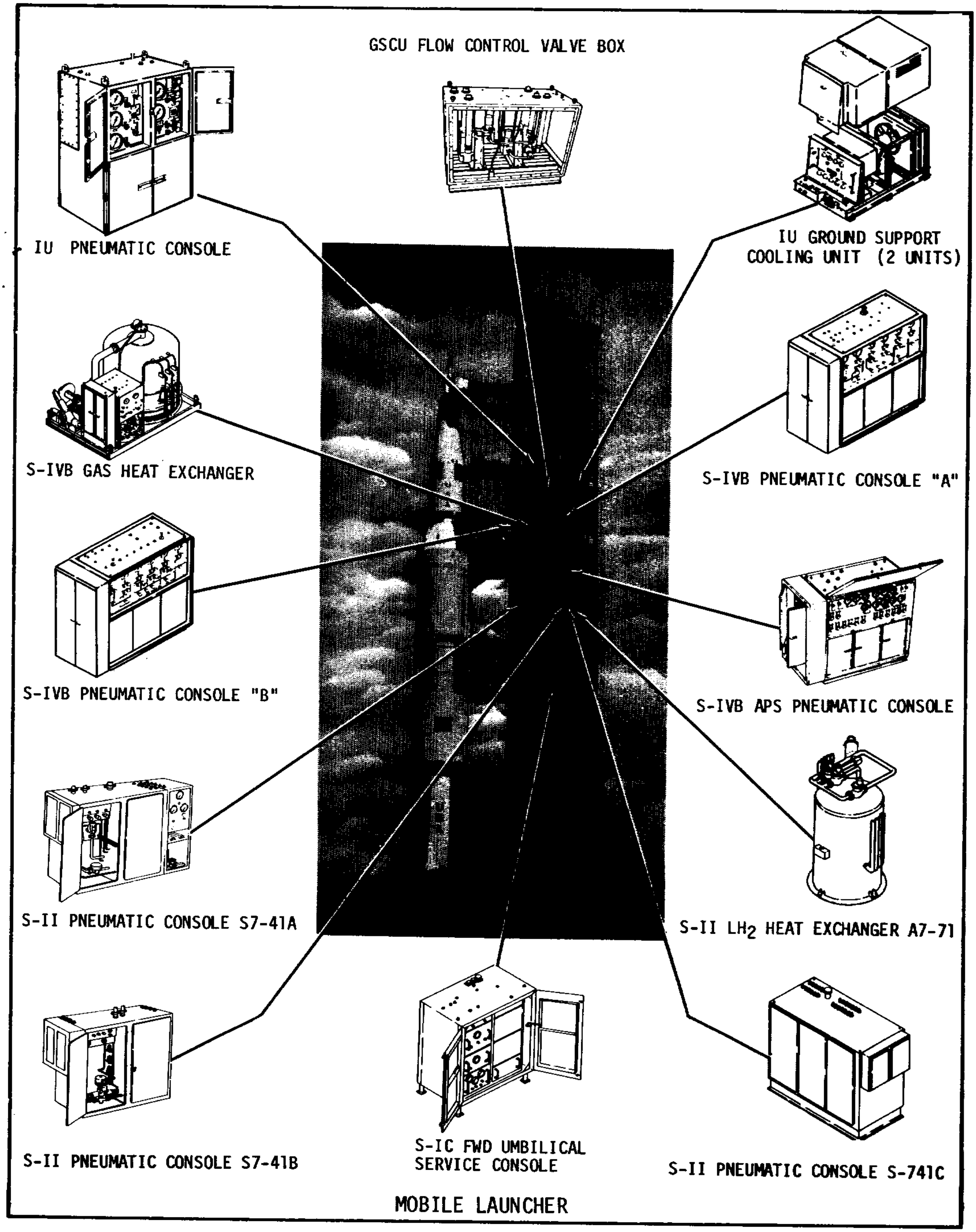

GSCU FLOW CONTROL VALVE BOX
IU PNEUMATIC CONSOLE
IU GROUND SUPPORT COOLING UNIT (2 UNITS)
S-IVB GAS HEAT EXCHANGER
S-IVB PNEUMATIC CONSOLE "A"
S-IVB PNEUMATIC CONSOLE "B"
S-IVB APS PNEUMATIC CONSOLE
S-II PNEUMATIC CONSOLE S7-41A
S-II LH_2 HEAT EXCHANGER A7-71
S-II PNEUMATIC CONSOLE S7-41B
S-IC FWD UMBILICAL SERVICE CONSOLE
S-II PNEUMATIC CONSOLE S-741C
MOBILE LAUNCHER

Fig. 21

The base has provisions for attachment to the C/T, six launcher-to-ground mount mechanisms, and four extensible support columns. All electrical/mechanical interfaces between vehicle systems and the VAB or the launch site are located through or adjacent to the base structure. The base houses such items as the computer systems test sets, digital propellant loading equipment, hydraulic test sets, propellant and pneumatic lines, air conditioning and ventilating systems, electrical power systems, and water systems.

Fueling operations at the launch area require that the compartments within the structure be pressurized with a supply of uncontaminated air.

The primary electrical power supplied to the ML is divided into four separate services: instrumentation, industrial, in-transit, and emergency. Emergency power is supplied by a diesel-driven generator located in the ground facilities. It is used for obstruction lights, emergency lighting, and for one tower elevator. Water is supplied to the ML for fire, industrial, and domestic purposes.

The umbilical tower is an open steel structure, 380 feet high, which provides the support for eight umbilical service arms, one access arm, 18 work and access platforms, distribution equipment for the propellant, pneumatic, electrical, and instrumentation subsystems, and other ground support equipment. Two high-speed elevators service 18 landings, from level A of the base to the 340-foot tower level. The structure is topped by a 25-ton hammerhead crane. Remote control of the crane is possible from numerous locations on the ML.

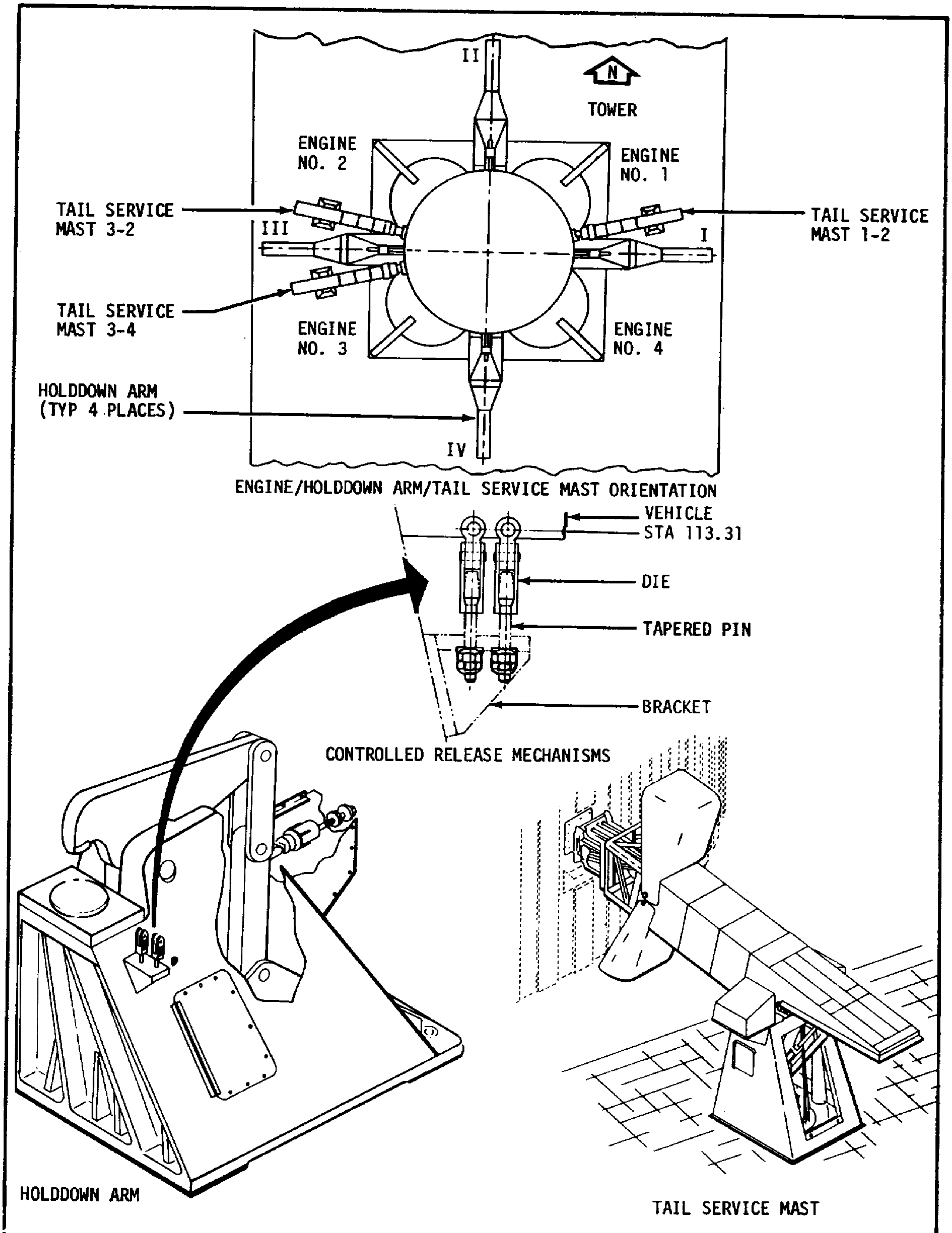
The four holddown arms (Figure 22) are mounted on the ML deck, 90° apart around the vehicle base. They position and hold the vehicle on the ML during the VAB checkout, movement to the pad, and pad checkout. The vehicle base is held with a pre-loaded force of 700,000 pounds at each arm.

At engine ignition, the vehicle is restrained until proper engine thrust is achieved. The unlatching interval for the four arms should not exceed 0.050 seconds. If any of the separators fail to operate in 0.180 seconds, release is effected by detonating an explosive nut link.

At launch, the holddown arms quickly release, but the vehicle is prevented from accelerating too rapidly by the controlled-release mechanisms (Figure 22).

Each controlled-release mechanism basically consists of a tapered pin inserted in a die which is coupled to the vehicle. Upon vehicle release, the tapered pin is drawn through the die during the first six inches of vehicle travel.

There are provisions for as many as 16 mechanisms per vehicle. The precise number is determined on a mission basis.



HOLDDOWN ARMS/TAIL SERVICE MAST

Fig. 22

The three Tail Service Mast (TSM) assemblies (Figure 22), support service lines to the S-IC stage and provide a means for rapid retraction at vehicle lift-off. The TSM assemblies are located on level 0 of the ML base. Each TSM is a counterbalanced structure which is pneumatically/electrically controlled and hydraulically operated. Retraction of the umbilical carrier and vertical rotation of the mast is accomplished simultaneously to ensure no physical contact between the vehicle and mast. The carrier is protected by a clam-shell hood which is closed by a separate hydraulic system as the mast rotates.

The nine service arms provide access to the launch vehicle and support the service lines that are required to sustain the vehicle, as described in Figure 23. The service arms are designated as either pre-flight or in-flight arms. The pre-flight arms are retracted and locked against the umbilical tower prior to lift-off. The in-flight arms retract at vehicle lift-off. Carrier withdrawal and arm retraction is accomplished by pneumatic and/or hydraulic systems.

Launch Pad

The launch pad (Figure 24), provides a stable foundation for the ML during Apollo/ Saturn V launch and pre-launch operations and an interface to the ML for ML and vehicle systems. There are presently two pads at LC-39 located approximately three miles from the VAB area. Each launch site is approximately 3000 feet across.

The launch pad is a cellular, reinforced concrete structure with a top elevation of 42 feet above grade elevation.

Located within the fill under the west side of the structure (Figure 25) is a two-story concrete building to house environmental control and pad terminal connection equipment. On the east side of the structure, within the fill, is a one-story concrete building to house the high-pressure gas storage battery. On the pad surface are elevators, staircase, and interface structures to provide service to the ML and the MSS. A ramp, with a five percent grade, provides access from the crawlerway. This is used by the C/T to position the ML/Saturn V and the MSS on the support pedestals. The azimuth alignment building is located on the approach ramp in the crawlerway median strip. A flame trench 58 feet wide by 450 feet long, bisects the pad. This trench opens to grade at the north end. The 700,000-pound, mobile, wedge-type flame deflector is mounted on rails in the trench.

The Pad Terminal Connection Room (PTCR) (Figure 25) provides the terminals for communication and data link transmission connections between the ML or MSS and the launch area facilities and between the ML or MSS and the LCC. This facility also accommodates the electronic equipment that simulates functions for checkout of the facilities during the absence of the launcher and vehicle.

1 S-IC Intertank (preflight). Provides lox fill and drain interfaces. Umbilical withdrawal by pneumatically driven compound parallel linkage device. Arm may be reconnected to vehicle from LCC. Retract time is 8 seconds. Reconnect time is approximately 5 minutes.

2 S-IC Forward (preflight). Provides pneumatic, electrical, and air-conditioning interfaces. Umbilical withdrawal by pneumatic disconnect in conjunction with pneumatically driven block and tackle/lanyard device. Secondary mechanical system. Retracted at T-20 seconds. Retract time is 8 seconds.

3 S-II Aft (preflight). Provides access to vehicle. Arm retracted prior to liftoff as required.

4 S-II Intermediate (in-flight). Provides LH_2 and lox transfer, vent line, pneumatic, instrument cooling, electrical, and air-conditioning interfaces. Umbilical withdrawal systems same as S-IVB Forward with addition of a pneumatic cylinder actuated lanyard system. This system operates if primary withdrawal system fails. Retract time is 6.4 seconds (max).

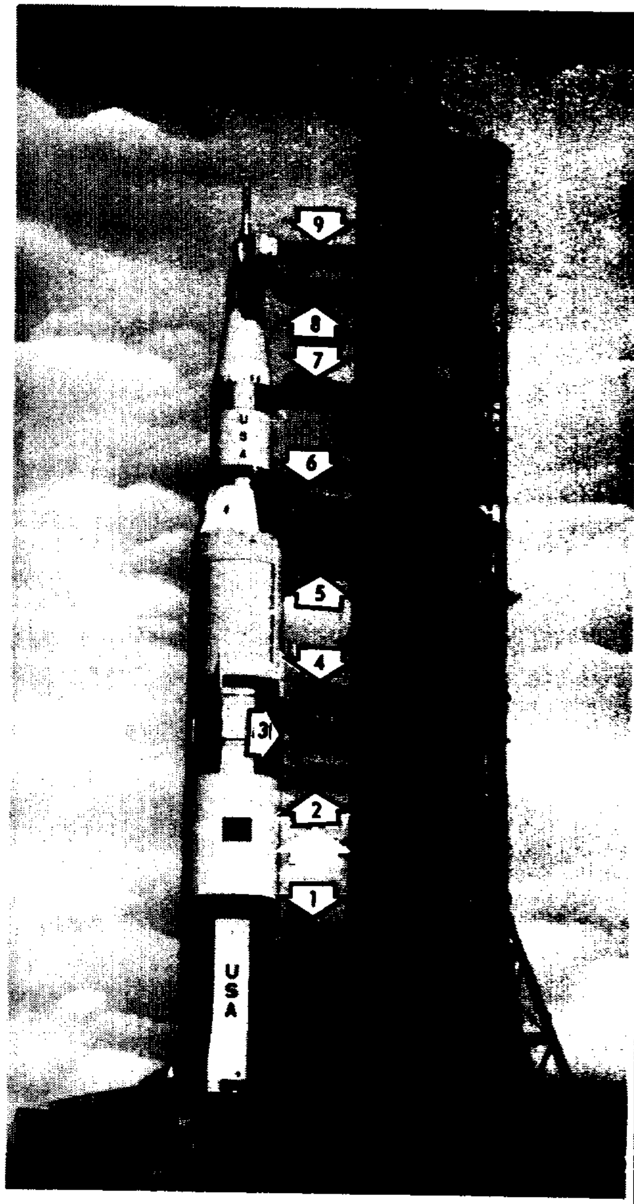
5 S-II Forward (in-flight). Provides GH_2 vent, electrical, and pneumatic interfaces. Umbilical withdrawal systems same as S-IVB Forward. Retract time is 7.4 seconds (max).

6 S-IVB Aft (in-flight). Provides LH_2 and lox transfer, electrical, pneumatic, and air-conditioning interfaces. Umbilical withdrawal systems same as S-IVB Forward. Also equipped with line handling device. Retract time is 7.7 seconds (max).

7 S-IVB Forward (in-flight). Provides fuel tank vent, electrical, pneumatic, air-conditioning, and preflight conditioning interfaces. Umbilical withdrawal by pneumatic disconnect in conjunction with pneumatic/hydraulic redundant dual cylinder system. Secondary mechanical system. Arm also equipped with line handling device to protect lines during withdrawal. Retract time is 8.4 seconds (max).

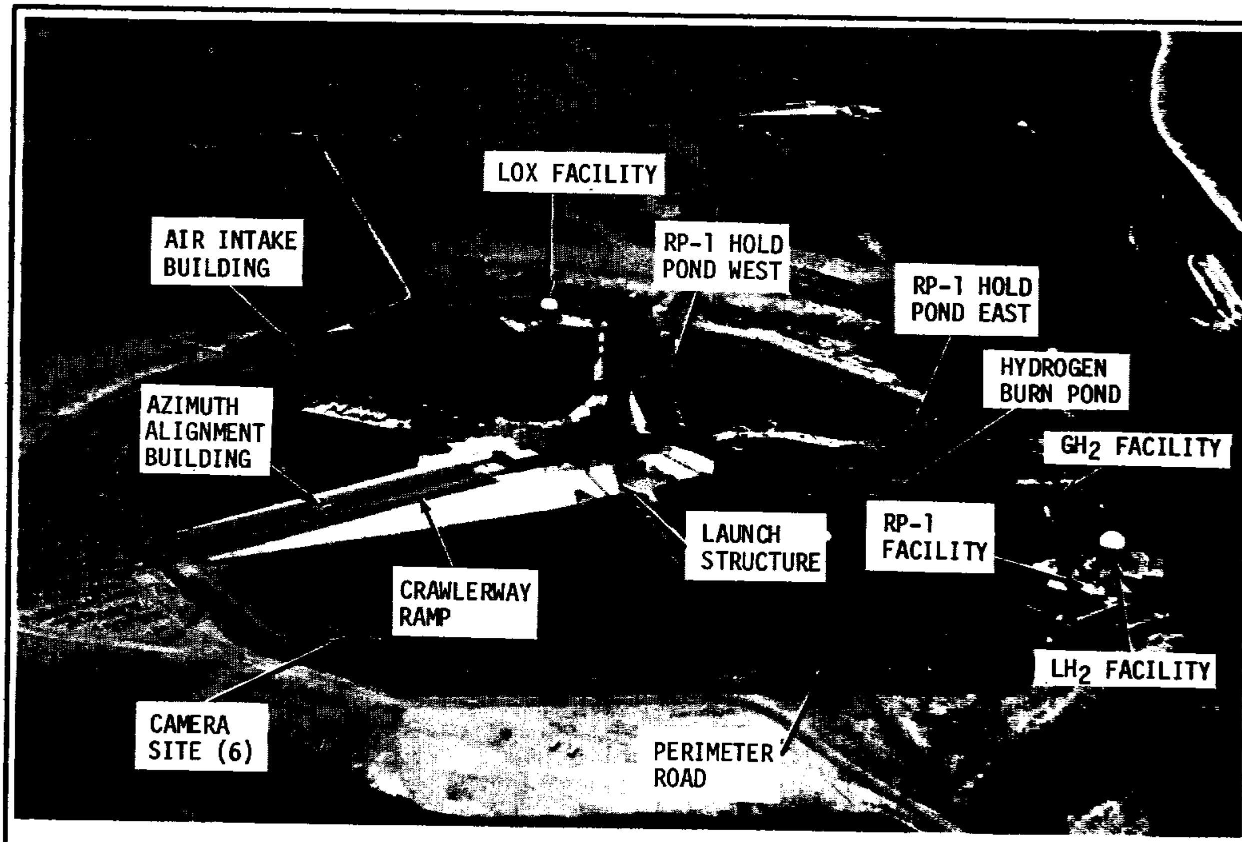
8 Service Module (in-flight). Provides air-conditioning, vent line, coolant, electrical, and pneumatic interfaces. Umbilical withdrawal by pneumatic/mechanical lanyard system with secondary mechanical system. Retract time is 9.0 seconds (max).

9 Command Module Access Arm (preflight). Provides access to spacecraft through environmental chamber. Arm may be retracted or extended from LCC. Retracted 12° park position until T-4 minutes. Extend time is 12 seconds from this position.



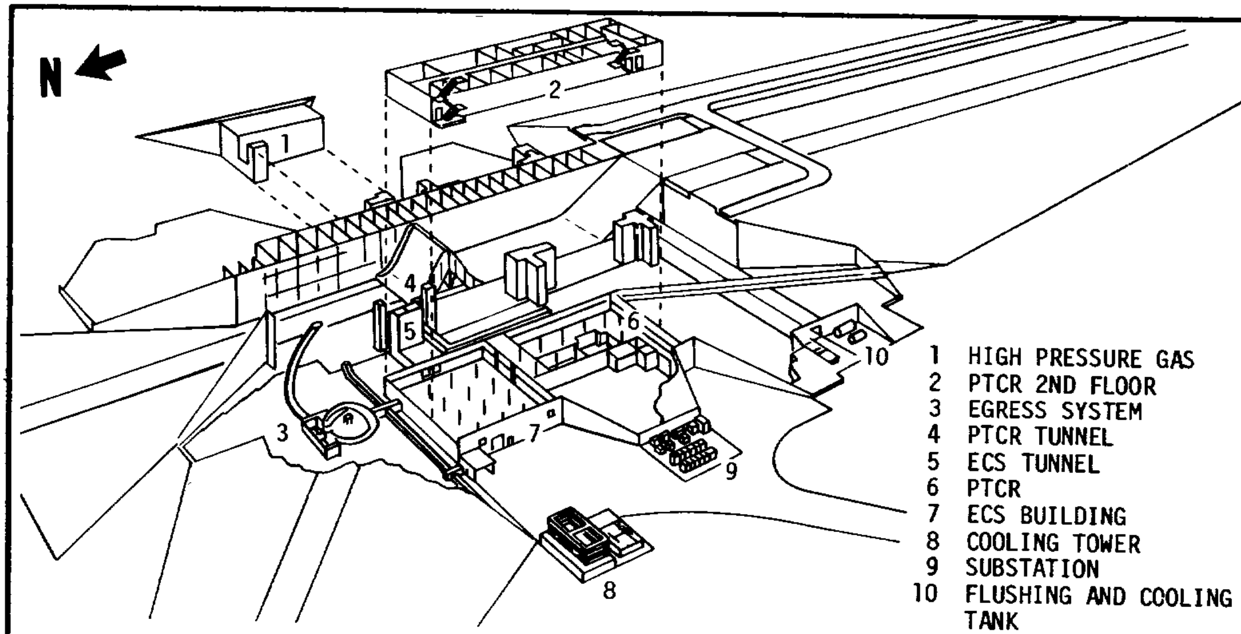
MOBILE LAUNCHER SERVICE ARMS

Fig. 23



LAUNCH PAD A, LC-39

Fig. 24



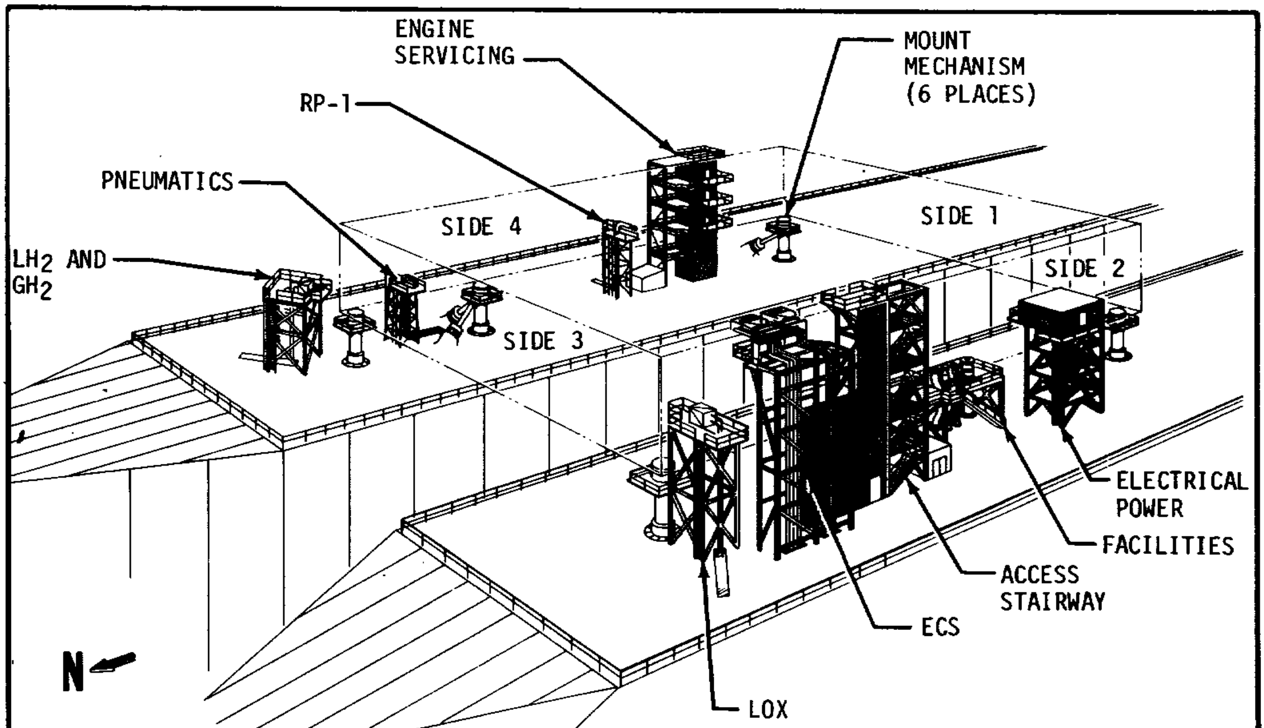
LAUNCH STRUCTURE EXPLODED VIEW

Fig. 25

The Environmental Control System (ECS) room, located in the pad fill west of the pad structure and north of the PTCR (Figure 25), houses the equipment which furnishes temperature and/or humidity-controlled air or nitrogen for space vehicle cooling at the pad. The ECS room is 96 feet wide by 112 feet long and houses air and nitrogen handling units, liquid chillers, air compressors, a 3000-gallon water/glycol storage tank, and other auxiliary electrical and mechanical equipment.

The high-pressure gas storage facility at the pad provides the launch vehicle with high-pressure helium and nitrogen.

The launch pad interface structure (Figure 26) provides mounting support pedestals for the ML and MSS, an engine access platform, and support structures for fueling, pneumatic, electric power, and environmental control interfaces.



LAUNCH PAD INTERFACE SYSTEM

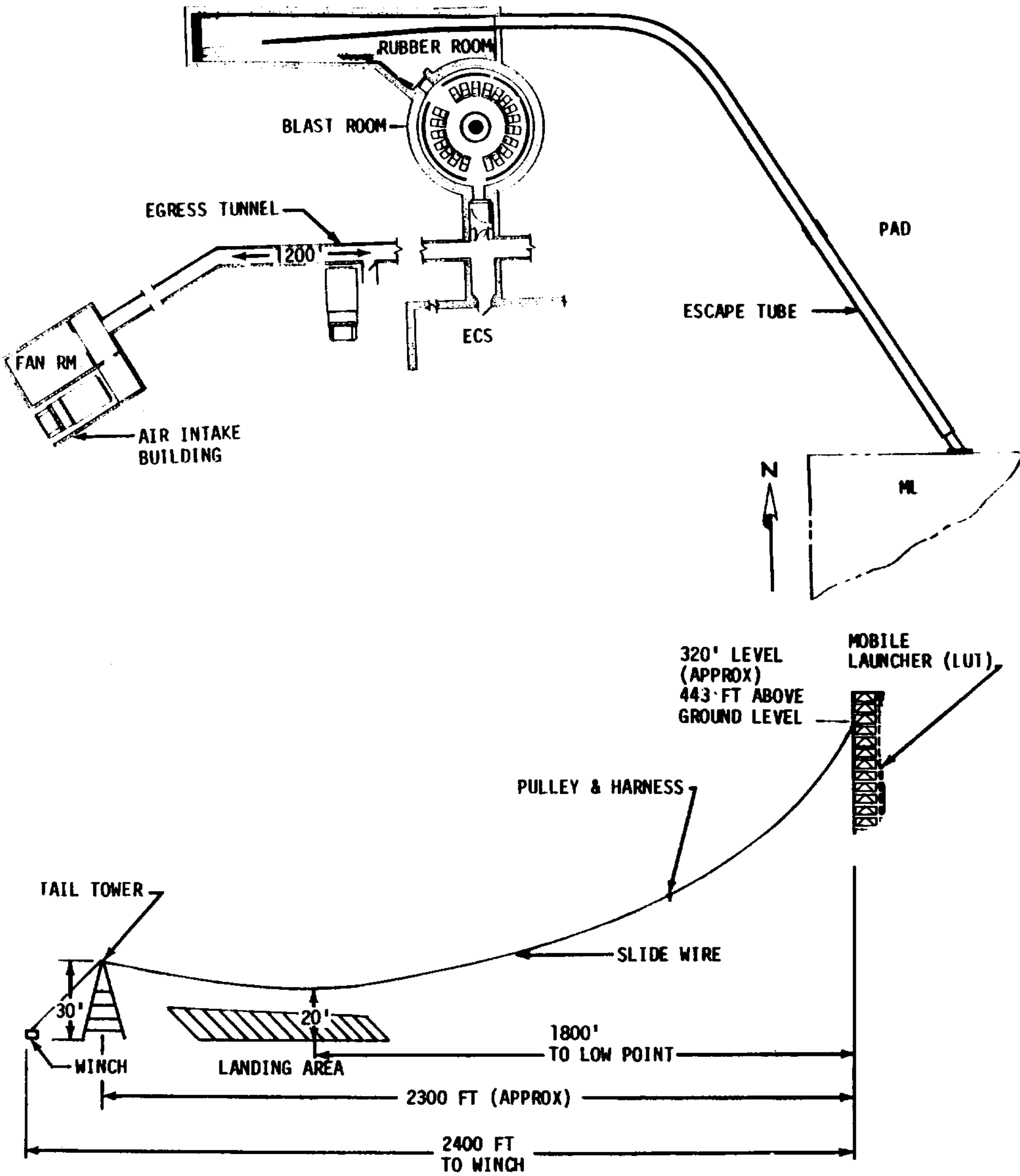
Fig. 26

Apollo Emergency Ingress/Egress and Escape System

The Apollo emergency ingress/egress and escape system provides access to and from the Command Module (CM) plus an escape route and safe quarters for the astronauts and service personnel in the event of a serious malfunction prior to launch. The system includes the CM access arm, two 600-feet per minute elevators from the 340-foot level to level A of the ML, pad elevator No. 2, personnel carriers located adjacent to the exit of pad elevator No. 2, the escape tube, and the blast room.

The CM access arm provides a passage for the astronauts and service personnel from the spacecraft to the 320-foot level of the tower. Egressing personnel take the high-speed elevators to level A of the ML, proceed through the elevator vestibule and corridor to pad elevator No. 2, move down this elevator to the bottom of the pad, and enter armored personnel carriers which remove them from the pad area.

When the state of the emergency allows no time for retreat by motor vehicle, egressing personnel upon reaching level A of the ML,slide down the escape tube into the blast room vestibule, commonly called the "rubber room" (Figure 27).



EGRESS SYSTEM

Fig. 27

Entrance to the blast room is gained through blast-proof doors controllable from either side. The blast room floor is mounted on coil springs to reduce outside acceleration forces to between 3 and 5 g's. Twenty people may be accommodated for 24 hours. Communication facilities are provided in the room,including an emergency RF link.

An underground air duct from the vicinity of the blast room to the remote air intake facility permits egress from the pad structure to the pad perimeter. Provision is made to decrease air velocity in the duct to allow personnel movement through the duct.

An alternate emergency egress system employs a slide wire from the vicinity of the 320-foot level of the ML to a 30-foot tower on the ground,approximately 2500 feet west of the launcher. Egressing personnel slide down the wire on individual seat assemblies suspended from the wire. Speeds of approximately 50 miles per hour are attained at the low point approximately 20 feet above ground level. A ferrule at the low point activates a braking mechanism which causes a controlled deceleration of each seat assembly to a safe stop. Up to 11 persons may be accommodated by the system.

Fuel System Facilities

The RP-1 facility consists of three 86,000-gallon steel storage tanks, a pump house, a circulating pump, a transfer pump, two filter-separators, an 8-inch stainless steel transfer line, RP-1 foam generating building, and necessary valves, piping, and controls. Two RP-1 holding ponds (Figure 24), 150 feet by 250 feet, with a water depth of two feet,are located north of the launch pad, one on each side of the north-south axis. The ponds retain spilled RP-1 and discharge water to drainage ditches.

The LH facility (Figure 24) consists of one 850,000-gallon spherical storage tank, a vaporizer/heat exchanger which is used to pressurize the storage tank to 65 psi, a vacuum-jacketed, 10-inch, invar transfer line, and a burn pond venting system. Internal tank pressure provides the proper flow of LH from the storage tank to the vehicle without using a transfer pump. Liquid hydrogen boil-off from the storage and ML areas is directed through vent-piping to bubble-capped headers submerged in the burn pond where a hot wire ignition system maintains the burning process.

LOX System Facility

The LOX facility (Figure 24) consists of one 900,000-gallon spherical storage tank, a LOX vaporizer to pressurize the storage tank, main fill and replenish pumps, a drain basin for venting and dumping of LOX, and two transfer lines.

Azimuth Alignment Building

The azimuth alignment building (Figure 24) houses the auto-collimator theodolite which senses, by a light source, the rotational output of the stable platform in the Instrument

Unit of the launch vehicle. This instrument monitors the critical inertial reference system prior to launch.

Photography Facilities

These facilities support photographic camera and closed circuit television equipment to provide real-time viewing and photographic documentation coverage. There are six camera sites in the launch pad area. These sites cover pre-launch activities and launch operations from six different angles at a radial distance of approximately 1300 feet from the launch vehicle. Each site has four engineering, sequential cameras and one fixed, high-speed metric camera (CZR).

Pad Water System Facilities

The pad water system facilities furnish water to the launch pad area for fire protection, cooling, and quenching. Specifically, the system furnishes water for the industrial water system, flame deflector cooling and quench, ML deck cooling and quench, ML tower fogging and service arm quench, sewage treatment plant, Firex water system, liquid propellant facilities, ML and MSS fire protection, and all fire hydrants in the pad area.

Mobile Service Structure

The MSS (Figure 28) provides access to those portions of the space vehicle which cannot be serviced from the ML while at the launch pad. The MSS is transported to the launch site by the C/T where it is used during launch pad operations. It is removed from the pad a few hours prior to launch and returned to its parking area 7000 feet from the nearest launch pad. The MSS is approximately 402 feet high and weighs 12 million pounds. The tower structure rests on a base 135 feet by 135 feet. At the top, the tower is 87 feet by 113 feet.

The structure contains five work platforms which provide access to the space vehicle. The outboard sections of the platforms open to accept the vehicle and close around it to provide access to the launch vehicle and spacecraft. The lower two platforms are vertically adjustable to serve different parts of the launch vehicle. The upper three platforms are fixed but can be disconnected from the tower and relocated as a unit to serve different vehicle configurations. The second and third platforms from the top are enclosed and provide environmental control for the spacecraft.

The MSS is equipped with the following systems: air conditioning, electrical power, various communication networks, fire protection, compressed air, nitrogen pressurization, hydraulic pressure, potable water, and spacecraft fueling.

MOBILE SERVICE STRUCTURE

Fig. 28

CRAWLER TRANSPORTER

Fig. 29

Crawler-Transporter

The C/T (Figure 29) is used to transport the ML, including the space vehicle, and the MSS to and from the launch pad.

The C/T is capable of lifting, transporting, and lowering the ML or the MSS, as required, without the aid of auxiliary equipment. The C/T supplies limited electric power to the ML and the MSS during transit.

The C/T consists of a rectangular chassis which is supported through a suspension system by four, dual-tread, crawler-trucks. The overall length is 131 feet and the overall width is 114 feet. The unit weighs approximately six million pounds. The C/T is powered by self-contained, diesel-electric generator units. Electric motor-driven pumps provide hydraulic power for steering and suspension control. Air conditioning and ventilation are provided where required.

The C/T can be operated with equal facility in either direction. Control cabs are located at each end. The leading cab, in the direction of travel, has complete control of the vehicle. The rear cab, however, has override controls for the rear trucks only.

Maximum C/T speed is 2 mph unloaded, 1 mph with full load on level grade, and 0.5 mph with full load on a five percent grade. It has a 500-foot minimum turning radius and can position the ML or the MSS on the facility support pedestals within $\pm$ two inches.

VEHICLE ASSEMBLY AND CHECKOUT

The Launch Vehicle propulsive stages and the IU are, upon arrival at KSC, transported to the VAB by special carriers. The S-IC stage is erected on an ML in one of the checkout bays in the high bay area. Concurrently, the S-II and S-IVB stages and the IU are delivered to preparation and checkout cells in the low bay area for inspection, checkout, and pre-erection preparations. All components of the Launch Vehicle, including the Apollo Spacecraft and Launch Escape System, are then assembled vertically on the ML in the high bay area.

Following assembly, the space vehicle is connected to the LCC via a high-speed data link for integrated checkout and a simulated flight test. When checkout is completed, the C/T picks up the ML with the assembled space vehicle and moves it to the launch site via the crawlerway.

At the launch site, the ML is emplaced and connected to system interfaces for final vehicle checkout and launch monitoring. The MSS is transported from its parking area by the C/T and positioned on the side of the vehicle opposite the ML. A flame deflector is moved on its track to its position beneath the blast opening of the ML to deflect the blast from the S-IC stage engines. During the pre-launch checkout, the final system checks are completed, the MSS is removed to the parking area, propellants are loaded, various items of support equipment are removed from the ML, and the vehicle is readied for launch. After vehicle launch, the C/T transports the ML to the parking area near the VAB for refurbishment.

MISSION MONITORING, SUPPORT, AND CONTROL

GENERAL

Mission execution involves the following functions: pre-launch checkout and launch operations; tracking the space vehicle to determine its present and future positions; securing information on the status of the flight crew and space vehicle systems (via telemetry); evaluation of telemetry information; commanding the space vehicle by transmitting real-time and updata commands to the onboard computer; voice communication between flight and ground crews; and recovery operations.

These functions require the use of a facility to assemble and launch the space vehicle (see Launch Complex); a central flight control facility; a network of remote stations located strategically around the world; a method of rapidly transmitting and receiving information between the space vehicle and the central flight control facility; a real-time data display system in which the data is made available and presented in usable form at essentially the same time that the data event ocurred; and ships/aircraft to recover the spacecraft on return to earth.

The flight crew and the following organizations and facilities praticipate in mission control operations:

1. Mission Control Center (MCC), Manned Spacecraft Center (MSC), Houston, Texas. The MCC contains the communication, computer, display, and command systems to enable the flight controllers to effectively monitor and control the space vehicle.

2. Kennedy Space Center (KSC), Cape Kennedy, Florida. The space vehicle is launched from KSC and controlled from the Launch Control Center (LCC), as described previously. Pre-launch, launch, and powered flight data are collected at the Central Instrumentation Facility (CIF) at KSC from the launch pads, CIF receivers, Merritt Island Launch Area (MILA), and the down-range Air Force Eastern Test Range (AFETR) stations. This data is transmitted to MCC via the Apollo Launch Data System (ALDS). Also located at KSC (ETR) is the Impact Predictor (IP), for range safety purposes.

3. Goddard Space Flight Center (GSFC), Greenbelt, Maryland. GSFC manages and operates the Manned Space Flight Network (MSFN) and the NASA communications (NASCOM) networks. During flight, the MSFN is under operational control of the MCC.

4. George C. Marshall Space Flight Center (MSFC), Huntsville, Alabama. MSFC, by means of the Launch Information Exchange Facility (LIEF) and the Huntsville Operations Support Center (HOSC), provides launch vehicle systems real-time support to KSC and MCC for pre-flight, launch, and flight operations.

A block diagram of the basic flight control interfaces is shown in Figure 30.

VEHICLE FLIGHT CONTROL CAPABILITY

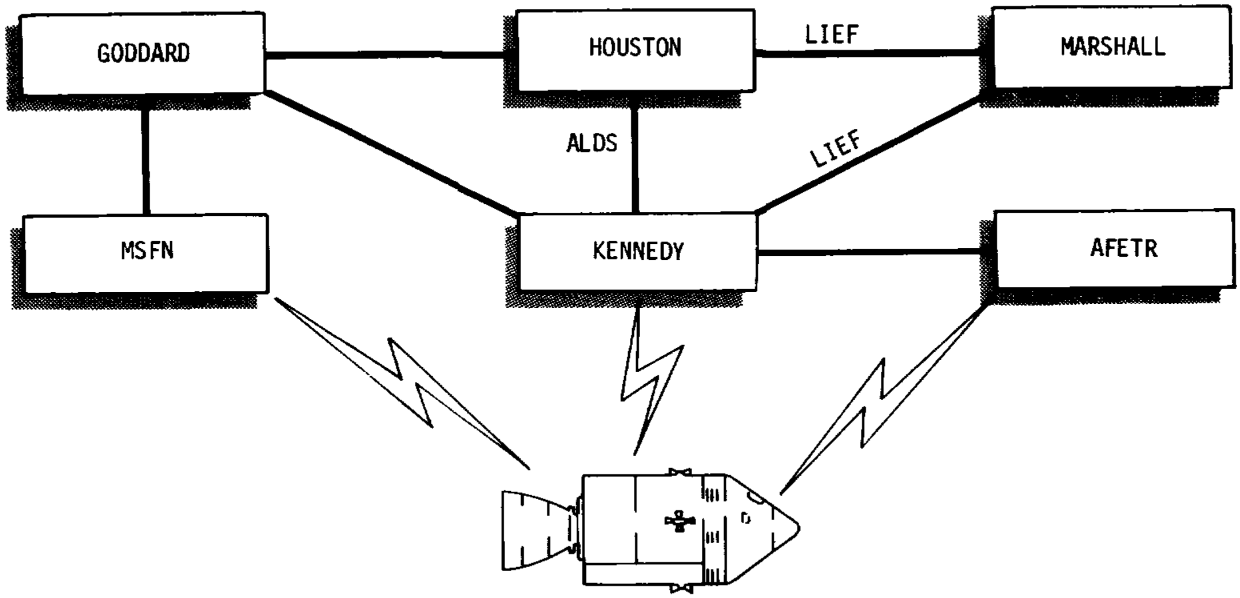
Flight operations are controlled from the MCC. The MCC has two flight control rooms. Each control room, called a Mission Operations Control Room (MOCR), is used independently of the other and is capable of controlling individual Staff Support Rooms (SSR's) located adjacent to the MOCR. The SSR's are manned by flight control specialists who provide detailed support to the MOCR. Figure 31 outlines the organization of the MCC for flight control and briefly describes key responsibilities. Information flow within the MOCR is shown in Figure 32.

The consoles within the MOCR and SSR's permit the necessary interface between the flight controllers and the spacecraft. The displays and controls on these consoles and other group displays provide the capability to monitor and evaluate data concerning the mission and, based on these evaluations, to recommend or take appropriate action on matters concerning the flight crew and spacecraft.

Problems concerning crew safety and mission success are identified to flight control personnel in the following ways:

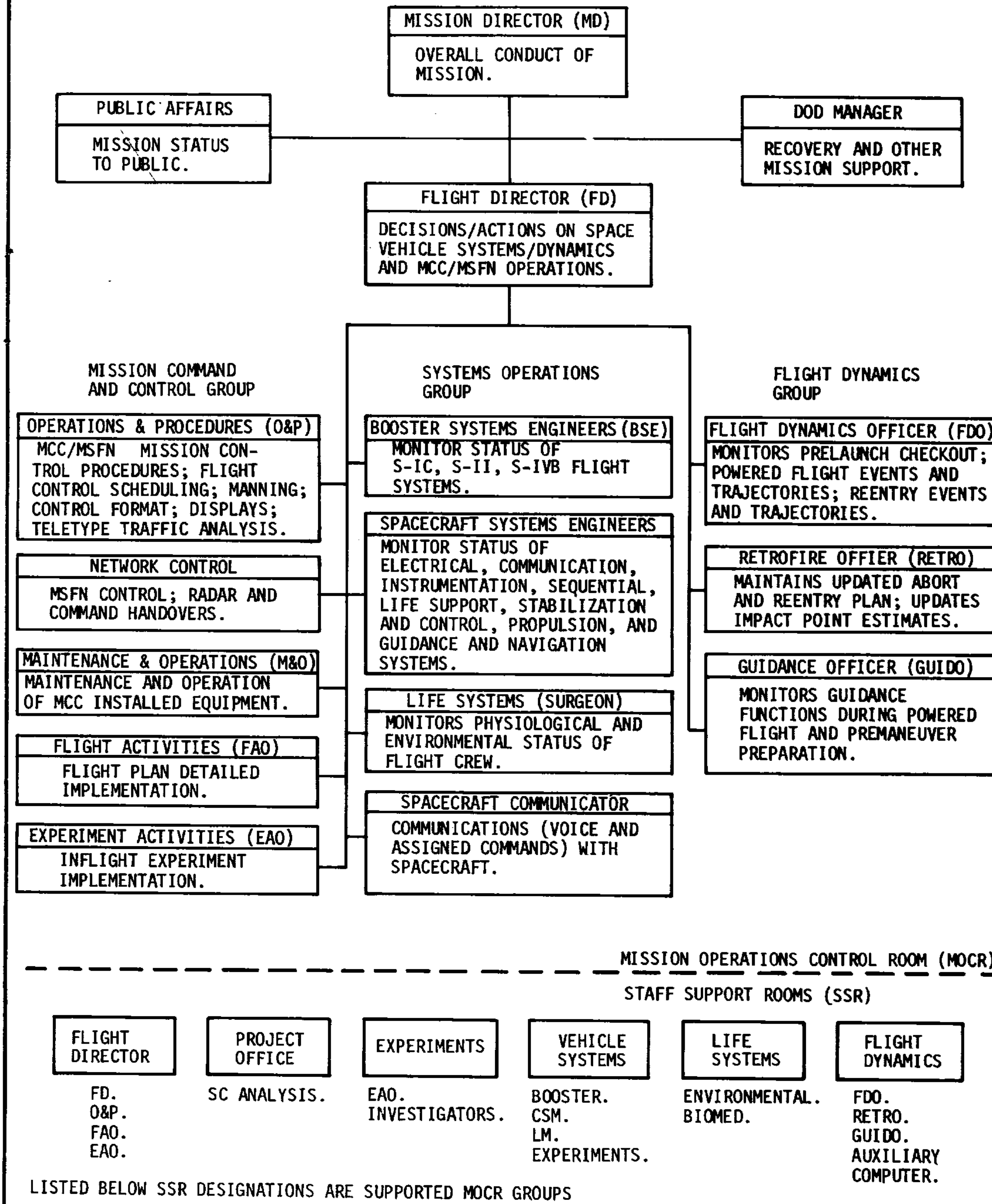
1. Flight crew observations;
2. Flight controller real-time observations;
3. Review of telemetry data received from tape recorder playback;
4. Trend analysis of actual and predicted values;
5. Review of collected data by systems specialists;
6. Correlation and comparision with previous mission data;
7. Analysis of recorded data from launch complex testing.

The facilities at the MCC include an input/output processor designated as the Command, Communications, and Telemetry System (CCATS) and a computational facility, the Real-Time Computer Complex (RTCC). Figure 33 shows the MCC functional configuration.



BASIC TELEMETRY, COMMAND, AND COMMUNICATION INTERFACES FOR FLIGHT CONTROL

Fig. 30



MCC ORGANIZATION

Fig. 31

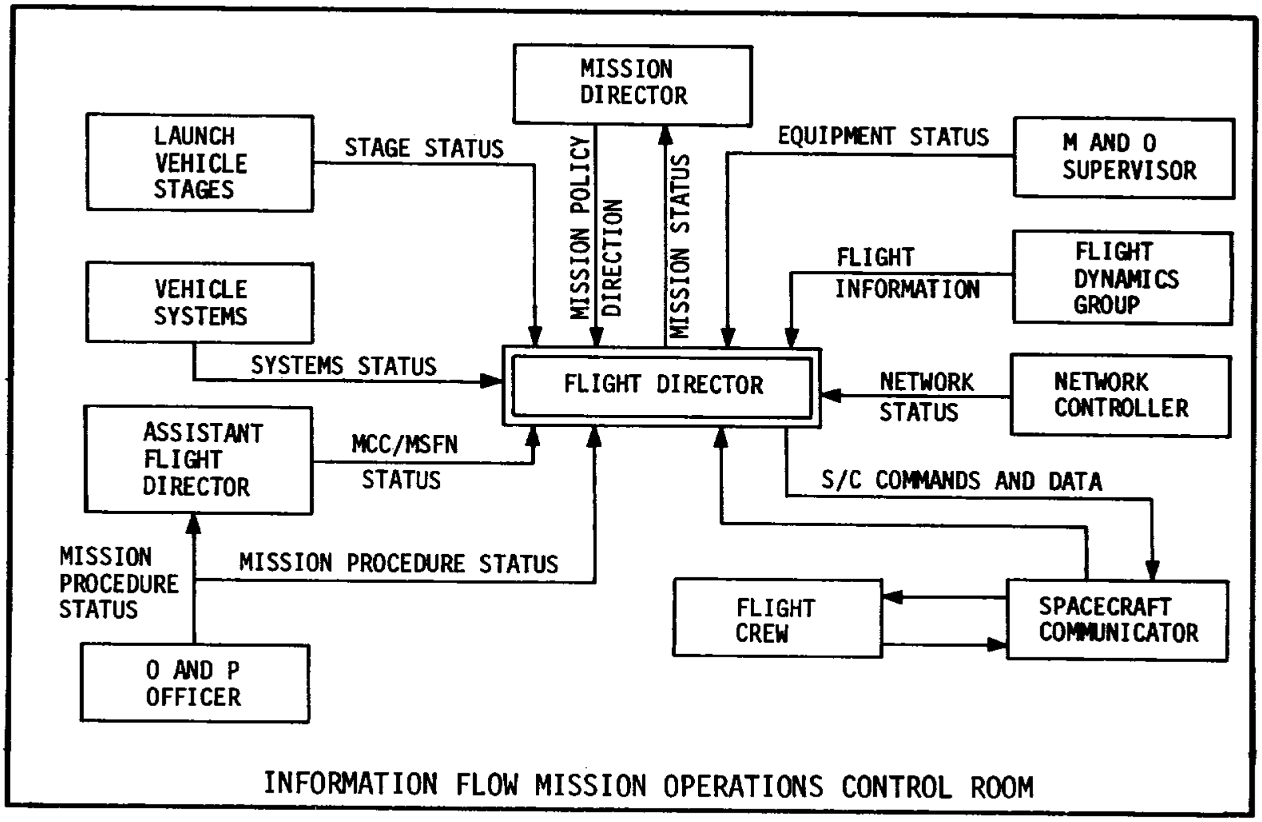
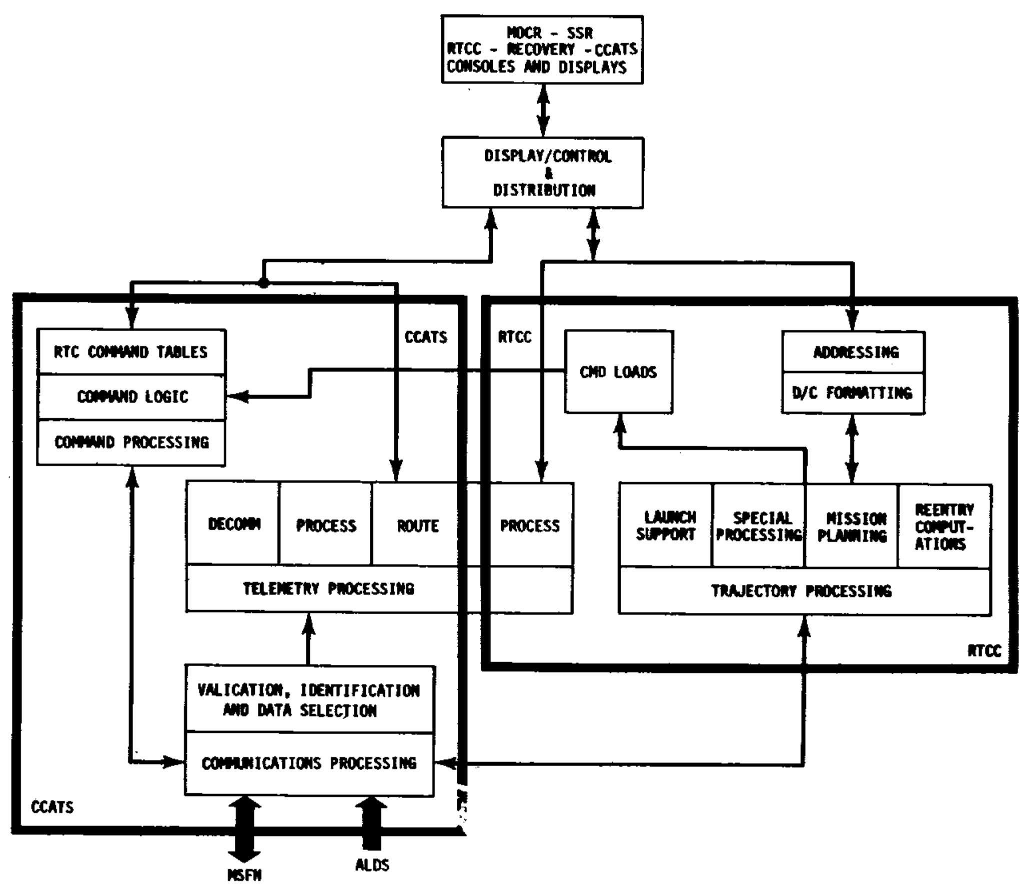

MISSION DIRECTOR
LAUNCH VEHICLE STAGES
STAGE STATUS
MISSION POLICY DIRECTION
MISSION STATUS
EQUIPMENT STATUS
M AND O SUPERVISOR
VEHICLE SYSTEMS
FLIGHT INFORMATION
FLIGHT DYNAMICS GROUP
SYSTEMS STATUS
FLIGHT DIRECTOR
NETWORK STATUS
NETWORK CONTROLLER
ASSISTANT FLIGHT DIRECTOR
MCC/MSFN STATUS
S/C COMMANDS AND DATA
MISSION PROCEDURE STATUS
MISSION PROCEDURE STATUS
FLIGHT CREW
SPACECRAFT COMMUNICATOR
O AND P OFFICER
INFORMATION FLOW MISSION OPERATIONS CONTROL ROOM

Fig. 32



MCC FUNCTIONAL CONFIGURATION

Fig. 33

The CCATS consists of three Univac 494 general purpose computers.. Two of the computers are configured so that either may handle all of the input/output communications for two complete missions. One of the computers acts as a dynamic standby. The third computer is used for nonmission activities.

The RTCC is a group of five IBM 360, large-scale, general purpose computers. Any of the five computers may be designated as the Mission Operations Computer (MOC). The MOC performs all the required computations and display formatting for a mission. One of the remaining computers will be a dynamic standby. Another pair of computers may be used for a second mission or simulation.

Space Vehicle Tracking

From lift-off of the launch vehicle to insertion into orbit, accurate position data are required to allow the Impact Predictor (IP) to function effectively as a Range Safety device, and the RTCC to compute a trajectory and an orbit. These computations are required by the flight controllers to evaluate the trajectory, the orbit, and/or any abnormal situations to ensure safe recovery of the astronauts. The launch tracking data are transmitted from the AFETR site to the IP and thence to the RTCC via high-speed data communications circuits. The IP also generates spacecraft inertial positions and inertial rates of motion in real-time.

During boost the trajectory is calculated and displayed on consoles and plotboards in the MOCR and SSR's. Also displayed are telemetry data concerning status of launch vehicle and spacecraft systems. If the space vehicle deviates excessively from the nominal flight path, or if any critical vehicle condition exceeds tolerance limits, or if the safety of the astronauts or range personnel is endangered, a decision is made to abort the mission.

During the orbit phase of a mission, all stations that are actively tracking the spacecraft will transmit the tracking data through GSFC to the RTCC by teletype. If a thrusting maneuver is performed by the spacecraft, high-speed tracking data is also transmitted.

Command System

The Apollo ground command systems have been designed to work closely with the telemetry and trajectory systems to provide flight controllers with a method of "closed-loop" command. The astronauts and flight controllers act as links in this operation.

To prevent spurious commands from reaching the space vehicle, switches on the Command Module console block uplink data from the onboard computers. At the appropriate times, the flight crew will move the switches from the "BLOCK" to the "ACCEPT" positions and thus permit the flow of uplink data.

With a few exceptions, commands to the space vehicle fall into two categories: real-time commands, and command loads (also called computer loads, computer update, loads, or update).

Real-time commands are used to control space vehicle systems or subsystems from the ground. The execution of a real-time command results in immediate reaction by the affected system. Real-time commands are stored prior to the mission in the Command Data Processor (CDP) at the applicable command site. The CDP, a Univac 642B, general-purpose digital computer, is programmed to format, encode, and output commands when a request for uplink is generated.

Command loads are generated by the real-time computer complex on request of flight controllers. Command loads are based on the latest available telemetry and/or trajectory data.

Flight controllers typically required to generate a command load include the Booster Systems Engineer (BSE), the Flight Dynamics Officer (FDO), the Guidance Officer (GUIDO), and the Retrofire Officer (RETRO).

Display and Control System

The MCC is equipped with facilities which provide for the input of data from the MSFN and KSC over a combination of high-speed data, low-speed data, wide-band data, teletype, and television channels. These data are computer processed for display to the flight controllers.

Several methods of displaying data are used including television (projection TV, group displays, closed circuit TV, and TV monitors), console digital readouts, and event lights. The display and control system interfaces with the RTCC and includes computer request, encoder multiplexer, plotting display, slide file, digital-to-TV converter, and telemetry event driver equipments.

A control system is provided for flight controllers to exercise their respective functions for mission control and technical management. This system is comprised of different groups of consoles with television monitors, request keyboards, communications equipment, and assorted modules added as required to provide each operational position in the MOCR with the control and display capabilities required for the particular mission.

CONTINGENCY PLANNING AND EXECUTION

Planning for a mission begins with the receipt of mission requirements and objectives. The planning activity results in specific plans for pre-launch and launch operations, pre-flight training and simulation, flight control procedures, flight crew activities, MSFN and MCC support, recovery operations, data acquisition and flow, and other mission-related operations. Numerous simulations are planned and performed to test procedures and train flight control and flight crew teams in normal and contingency operations.

MCC Role in Aborts

After launch and from the time the space vehicle clears the ML, the detection of slowly-deteriorating conditions which could result in an abort is the prime responsibility of MCC; prior to this time, it is the prime responsibility of LCC. In the event such conditions are discovered, MCC requests abort of the mission or, circumstances permitting, sends corrective commands to the vehicle or requests corrective flight crew actions.

In the event of a noncatastrophic contingency, MCC recommends alternate flight procedures, and mission events are rescheduled to derive maximum benefit from the modified mission.

VEHICLE FLIGHT CONTROL PARAMETERS

In order to perform flight control monitoring functions, essential data must be collected, transmitted, processed, displayed, and evaluated to determine the space vehicle's capability to start or continue the mission.

Parameters Monitored by LCC

The launch vehicle checkout and pre-launch operations monitored by the Launch Control Center (LCC) determine the state of readiness of the launch vehicle, ground support, telemetry, range safety, and other operational support systems. During the final countdown, hundreds of parameters are monitored to ascertain vehicle, system, and component performance capabilities. Among these parameters are the "redlines." The redline values must be within the predetermined limits or the countdown will be halted. In addition to the redlines, there are a number of operational support elements such as ALDS, range instrumentation, ground tracking and telemetry stations, and ground support facilities which must be operational at specified times in the countdown.

Parameters Monitored by Booster Systems Group

The Booster Systems Group (BSG) monitors launch vehicle systems (S-IC, S-II, S-IVB, and IU) and advises the flight director and flight crew of any system anomalies. It is responsible for confirming in-flight power, stage ignition, holddown release, all engines go, engine cut-offs, etc. BSG also monitors attitude control, stage separations, and digital commanding of LV systems.

Parameters Monitored by Flight Dynamics Group

The Flight Dynamics Group monitors and evaluates the powered flight trajectory and makes the abort decisions based on trajectory violations. It is responsible for abort planning, entry time and orbital maneuver determinations, rendezvous planning, inertial alignment correlation, landing point prediction, and digital commanding of the guidance systems.

The MOCR positions of the Flight Dynamics Group include the Flight Dynamics Officer (FDO), the Guidance Officer (GUIDO), and the Retrofire Officer (RETRO). The MOCR positions are given detailed, specialized support by the Flight Dynamics SSR.

The surveillance parameters measured by the ground tracking stations and transmitted to the MCC are computer processed into plotboard and digital displays. The Flight Dynamics Group compares the actual data with pre-mission, calculated, nominal data and is able to determine mission status.

Parameters Monitored by Spacecraft Systems Group

The Spacecraft Systems Group monitors and evaluates the performance of spacecraft electrical, optical, mechanical, and life support systems; maintains and analyzes consumables status; prepares the mission log; coordinates telemetry playback; determines spacecraft weight and center of gravity; and executes digital commanding of spacecraft systems.

The MOCR positions of this group include the Command and Service Module Electrical, Environmental, and Communications Engineer (CSM EECOM), the CSM Guidance, Navigation, and Control Engineer (CSM GNC), the Lunar Module Electrical, Environmental, and Communications Engineer (LM EECOM), and the LM Guidance, Navigation, and Control Engineer (LM GNC). These positions are backed up with detailed support from the Vehicle Systems SSR.

Parameters Monitored by Life Systems Group

The Life Systems Group is responsible for the well-being of the flight crew. The group is headed by the Flight Surgeon in the MOCR. Aeromedical and environmental control specialists in the Life Systems SSR provide detailed support to the Flight Surgeon. The group monitors the flight crew health status and environmental/biomedical parameters.

MANNED SPACE FLIGHT NETWORK

The Manned Space Flight Network (MSFN) is a global network of ground stations, ships, and aircraft designed to support manned and unmanned space flights. The network provides tracking, telemetry, voice and teletype communications, command, recording, and television capabilities. The network is specifically configured to meet the requirements of each mission.

MSFN stations are categorized as lunar support stations (deep-space tracking in excess of 15,000 miles), near-space support stations with Unified S-Band (USB) equipment, and near-space support stations without USB equipment.

Figure 34 shows the geographical location of each station.

MSFN stations include facilities operated by NASA, the United States Department of Defense (DOD), and the Australian Department of Supply (DOS).

The DOD facilities include the Eastern Test Range (ETR), Western Test Range (WTR), White Sands Missile Range (WSMR), Range Instrumentation Ships (RIS), and Apollo Range Instrumentation Aircraft (A/RIA).

NASA COMMUNICATION NETWORK

The NASA Communications (NASCOM) network (Figure 35) is a point-to-point communications systems connecting the MSFN stations to the MCC. NASCOM is managed by the Goddard Space Flight Center, where the primary communications switching center is located. Three smaller NASCOM switching centers are located at London, Honolulu, and Canberra. Patrick AFB, Florida and Wheeler AFB, Hawaii serve as switching centers for the DOD eastern and western test ranges, respectively. The MSFN stations throughout the world are interconnected by landline, undersea cable, radio, and communications satellite circuits. These circuits carry teletype, voice, and data in real-time support of the missions.

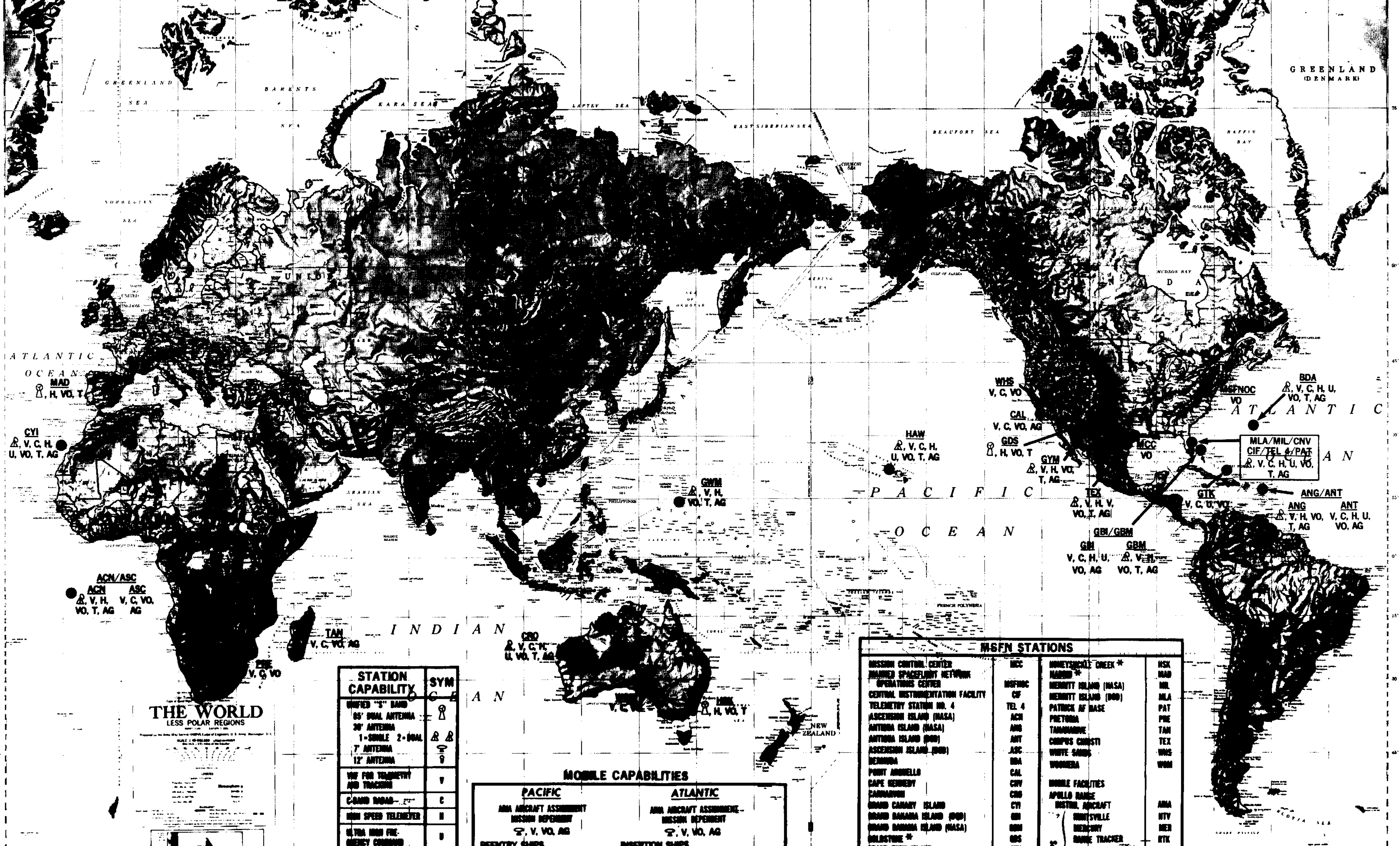
Each MSFN USB land station has a minimum of five voice/data circuits and two teletype circuits. The Apollo insertion and injection ships have a similar capability through the communications satellites.

APOLLO LAUNCH DATA SYSTEM (ALDS)

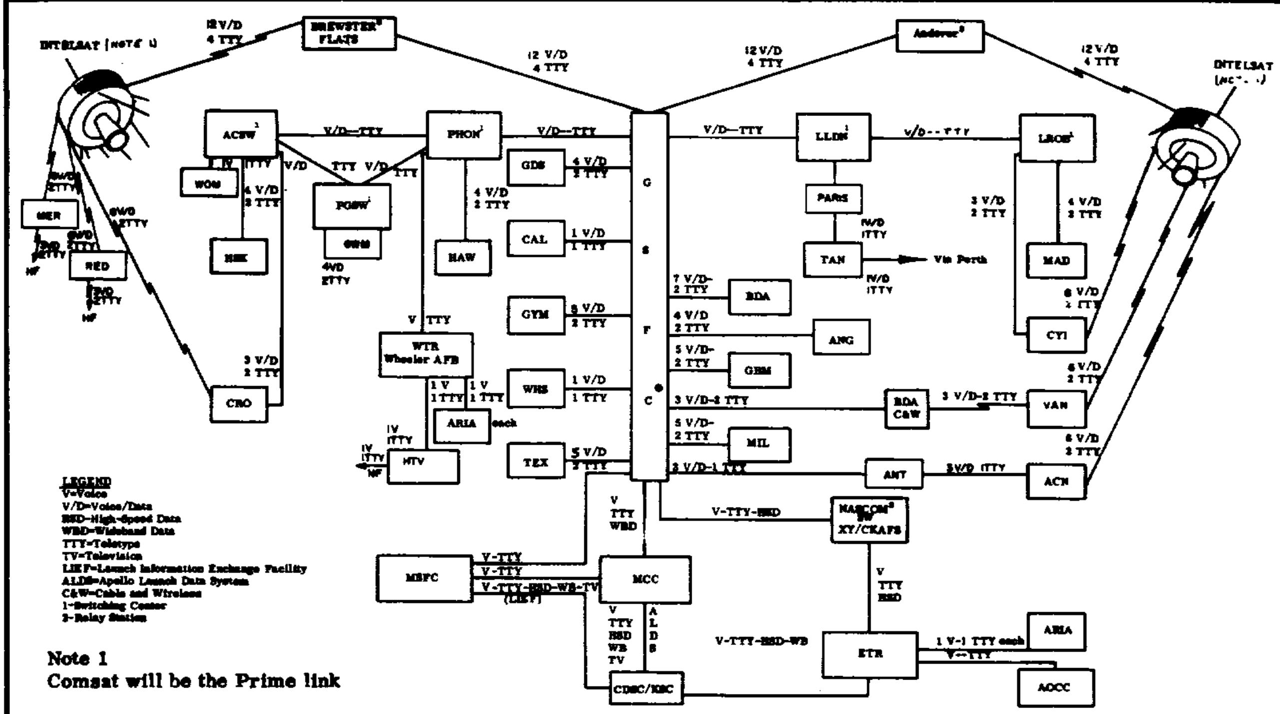
The Apollo Launch Data System (ALDS) between KSC and MSC is controlled by MSC and is not routed through GSFC. The ALDS consists of wide-band telemetry, voice coordination circuits, and a high-speed circuit for the Countdown and Status Transmission System (CASTS). In addition, other circuits are provided for launch coordination, tracking data, simulations, public information, television, and recovery.

MSFC SUPPORT FOR LAUNCH AND FLIGHT OPERATIONS

The Marshall Space Flight Center (MSFC), by means of the Launch Information Exchange Facility (LIEF) and the Huntsville Operations Support (HOSC), provides real-time support of launch vehicle pre-launch, launch, and flight operations. MSFC also provides support, via LIEF, for post-flight data delivery and evaluation.



THE WORLD
LESS POLAR REGIONS
GREENLAND (DENMARK)
ATLANTIC OCEAN
PACIFIC OCEAN
INDIAN OCEAN
MAD
H, VO, T
CYI
V, C, H, U, VO, T, AG
ACN/ASC
ACN
V, H, VO, T, AG
ASC
V, C, VO, AG
TAN
V, C, VO, AG
PRE
V, C, VO
CRO
V, C, H, U, VO, T, AG
HSK
H, VO, T
GWM
V, H, VO, T, AG
HAW
V, C, H, U, VO, T, AG
WHS
V, C, VO
CAL
V, C, VO, AG
GDS
H, VO, T
GYM
V, H, VO, T, AG
TEX
V, H, V, VO, T, AG
MCC
VO
MSFNOC
VO
BDA
V, C, H, U, VO, T, AG
MLA/MIL/CNV
CIF/TEL 4/PAT
V, C, H, U, VO, T, AG
GTK
V, C, U, VO
ANG/ANT
ANG
V, H, VO, T, AG
ANT
V, C, H, U, VO, AG
GBI/GBM
GBI
V, C, H, U, VO, AG
GBM
V, H, VO, T, AG
NEW ZEALAND
STATION CAPABILITY
SYM
UNIFIED "S" BAND
85' DUAL ANTENNA
30' ANTENNA
1=SINGLE 2=DUAL
7' ANTENNA
12' ANTENNA
VHF FOR TELEMETRY AND TRACKING
V
C-BAND RADAR
C
HIGH SPEED TELEMETER
H
ULTRA HIGH FREQUENCY COMMAND
U
MOBILE CAPABILITIES
PACIFIC
ARIA AIRCRAFT ASSIGNMENT MISSION DEPENDENT
V, VO, AG
ATLANTIC
ARIA AIRCRAFT ASSIGNMENT MISSION DEPENDENT
V, VO, AG
MSFN STATIONS
MISSION CONTROL CENTER
MCC
MANNED SPACEFLIGHT NETWORK OPERATIONS CENTER
MSFNOC
CENTRAL INSTRUMENTATION FACILITY
CIF
TELEMETRY STATION NO. 4
TEL 4
ASCENSION ISLAND (NASA)
ACN
ANTIGUA ISLAND (NASA)
ANG
ANTIGUA ISLAND (DOD)
ANT
ASCENSION ISLAND (DOD)
ASC
BERMUDA
BDA
POINT ARGUELLO
CAL
CAPE KENNEDY
CNV
CARNARVON
CRO
GRAND CANARY ISLAND
CYI
GRAND BAHAMA ISLAND (DOD)
GBI
GRAND BAHAMA ISLAND (NASA)
GBM
GOLDSTONE *
GDS
HONEYSUCKLE CREEK *
HSK
MADRID *
MAD
MERRITT ISLAND (NASA)
MIL
MERRITT ISLAND (DOD)
MLA
PATRICK AF BASE
PAT
PRETORIA
PRE
TANANARIVE
TAN
CORPUS CHRISTI
TEX
WHITE SANDS
WHS
WOOMERA
WOM
MOBILE FACILITIES
APOLLO RANGE
INSTRU. AIRCRAFT
ARIA
HUNTSVILLE
HTV
MERCURY
MER
RANGE TRACKER
RTK



ACN	ASCENSION IS. (NASA STATION)
ACSW	CANBERRA SWITCHING STA.
ANG	ANTIGUA ISLAND
ANT	AFETR SITE ANTIGUA ISLAND
AOCC	AIRCRAFT OPERATIONS CONTROL CENTER
ARIA	APOLLO RANGE INSTRUMENTATION AIRCRAFT
BDA	BERMUDA
CAL	CALIFORNIA (VANDENBERG AFB)
CDSC	COMMUNICATION DISTRIBUTION SWITCHING CENTER
CRO	CARNARVON, AUSTRALIA
CYI	GRAND CANARY ISLAND
ETR	EASTERN TEST RANGE
GBM	GRAND BAHAMA IS.
GDS	GOLDSTONE, CALIFORNIA
GSFC	GODDARD SPACE FLIGHT CENTER
GWM	GUAM
GYM	GUAYMAS, MEXICO
HAW	HAWAII
HSK	HONEYSUCKLE CR. AUST.
HTV	USNS HUNTSVILLE
LLDN	LONDON SWITCHING CENTER
LROB	MADRID, SPAIN SWITCHING CENTER
MAD	MADRID, SPAIN
MER	USNS MERCURY
MCC	MISSION CONTROL CENTER
MIL	MERRITT ISLAND, FLA.
MSFC	MARSHALL SPACE FLIGHT CENTER
PGSW	GUAM SWITCHING CENTER
PHON	HONOLULU SWITCHING STA.
RED	USNS REDSTONE
TAN	TANANARIVE, MALAGASY
TEX	CORPUS CHRISTI, TEXAS
VAN	USNS VANGUARD
WHS	WHITE SANDS, NEW MEXICO
WOM	WOOMERA, AUSTRALIA
WTR	WESTERN TEST RANGE

TYPICAL MISSION COMMUNICATIONS NETWORK

Fig. 35

In-depth real-time support is provided for pre-launch, launch, and flight operations from HOSC consoles manned by engineers who perform detailed system data monitoring and analysis.

Pre-launch flight wind monitoring analysis and trajectory simulations are jointly performed by MSFC and MSC personnel located at MSFC during the terminal countdown. Beginning at T-24 hours, actual wind data is transmitted periodically from KSC to the HOSC. These measurements are used by the MSFC/MSC wind monitoring team in vehicle flight digital simulations to verify the capability of the vehicle with these winds.

In the event of marginal wind conditions, contingency data are provided MSFC in real-time via the Central Instrumentation Facility (CIF). DATA-CORE and trajectory simulations are performed on-line to expedite reporting to KSC.

During the pre-launch period, primary support is directed to KSC. At lift-off primary support transfers from KSC to the MCC. The HOSC engineering consoles provide support as required to the Booster Systems Group for S-IVB/IU orbital operations by monitoring detailed instrumentation for the evaluation of system in-flight and dynamic trends, assisting in the detection and isolation of vehicle malfunctions and providing advisory contact with vehicle design specialists.

ABREVIATIONS AND ACRONYMS

ac	Alternating Current
AFB	Air Force Base
AFETR	Air Force Eastern Test Range
ALDS	Apollo Launch Data System
AM	Amplitude Modulation
APS	Auxiliary Propulsion System
ARIA	Apollo Range Instrumentation Aircraft
AS	Apollo Saturn
ASI	Augmented Spark Igniter
BPC	Boost Protective Cover
BSE	Booster Systems Engineer
CASTS	Countdown and Status Transmission System
CCATS	Communications, Command, and Telemetry System
CCS	Command Communications System
CDP	Command Data Processor (MSFN Site)
CIF	Central Instrumentation Facility
CM	Command Module
COAS	Crewman Optical Alignment Sight
CSM	Command Service Module
C/T	Crawler/Transporter
CWG	Constant-Wear Garment
DATA-CORE	CIF Telemetry Conversion System
dc	Direct Current
DOD	Department of Defense
DOS	Department of Supply (Australia)
ECS	Environmental Control System
EDS	Emergency Detection System
ELS	Earth Landing System
EMS	Entry Monitor System
EMU	Extravehicular Mobility Unit
EPS	Electrical Power System
ETR	Eastern Test Range
EV	Extravehicular
EVA	Extravehicular Activity
FCC	Flight Control Computer (IU, analog)
FDAI	Flight Director Attitude Indicator
FDO	Flight Dynamics Officer
g	Force of gravity (local)
GDC	Gyro Display Coupler
GH_2	Gaseous Hydrogen

GN_2	Gaseous Nitrogen
GNCS	Guidance, Navigation, and Control System
GOX	Gaseous Oxygen
GSE	Ground Support Equipment
GUIDO	Guidance Officer
GSFC	Goddard Space Flight Center
H_2	Hydrogen
HF	High Frequency
HOSC	Huntsville Operations Support Center
ICG	Inflight Coverall Garment
IMU	Inertial Measurement Unit
IP	Impact Predictor (at KSC)
IU	Instrument Unit
KSC	Kennedy Space Center
LC	Launch Complex
LCC	Launch Control Center
LCG	Liquid-Cooling Garment
LEA	Launch Escape Assembly
LEB	Lower Equipment Bay
LES	Launch Escape System
LET	Launch Escape Tower
LH	Liquid Hydrogen
LIEF	Launch Information Exchange Facility
LM	Lunar Module
LN_2	Liquid Nitrogen
LOX	Liquid Oxygen
LV	Launch Vehicle
LVDA	Launch Vehicle Data Adapter
LVDC	Launch Vehicle Digital Computer
MCC	Mission Control Center
MILA	Merritt Island Launch Area
ML	Mobile Launcher
MMH	Monomethyl Hydrazine
MOC	Mission Operations Computer
MOCR	Mission Operations Control Room
MSC	Manned Spacecraft Center
MSFC	Marshall Space Flight Center
MSFN	Manned Space Flight Network
MSS	Mobile Service Structure
NASCOM	NASA Communications Network
N_2O_4	Nitrogen Tetroxide

NPSH	Net Positive Suction Head
O_2	Oxygen
OMR	Operations Management Room
OSR	Operations Support Room
PDS	Propellant Dispersion System
PGA	Pressure Garment Assembly
PLSS	Portable Life Support System
PTCR	Pad Terminal Connection Room
PU	Propellant Utilization
RCS	Reaction Control System
RETRO	Direction Opposite to Velocity Vector
RF	Radio Frequency
RIS	Range Instrumentation Ship
RP-1	Rocket Propellant (refined kerosene)
RTCC	Real Time Computer Complex
SC	Apollo Spacecraft
SCS	Stabilization and Control System
SECS	Sequential Events Control System
SLA	Spacecraft Lunar Module Adapter
SM	Service Module
SPS	Service Propulsion System
SSR	Staff Support Room
SV	Space Vehicle
TCS	Thermal Conditioning System
TSM	Tail Service Mast
TV	Television
USB	Unified S-band
UHF	Ultra-High Frequency
VAB	Vehicle Assembly Building
VHF	Very High Frequency
WSMR	White Sands Missile Range
WTR	Western Test Range

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