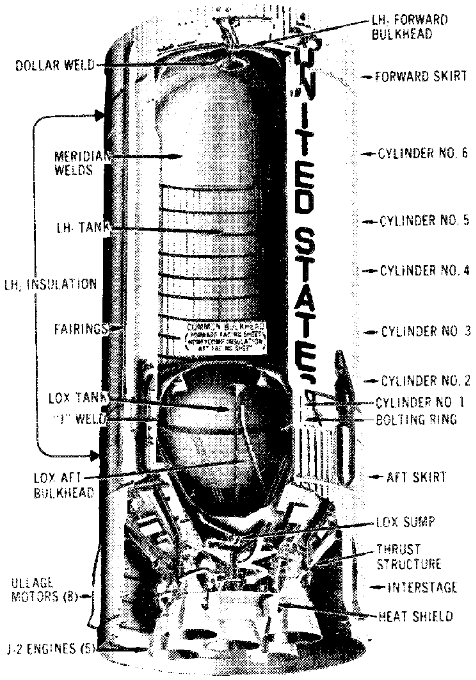
SECOND STAGE FACT SHEET



WEIGHT: 95,000 lb. (dry)
1,037,000 lb. (loaded)
DIAMETER: 33 ft.
HEIGHT: 81 ft. 7 in.
BURN TIME: 6 min. approx. (actually 395 sec.)
VELOCITY: 15,300 miles per hour at burnout (approx.)
ALTITUDE AT BURNOUT: 114.5 miles

MAJOR STRUCTURAL COMPONENTS

AFT INTERSTAGE	THRUST STRUCTURE	COMMON BULKHEAD	LH_2 FORWARD BULKHEAD
AFT SKIRT	AFT LOX BULKHEAD	LH_2 CYLINDER WALLS	FORWARD SKIRT

MAJOR SYSTEMS

PROPULSION: Five J-2 engines
Thrust: More than 1,000,000 lb. (225,000 maximum each engine)
Propellant: LH2—260,000 gal. (153,000 lb.)
LOX—83,000 gal. (789,000 lb.)

ELECTRICAL: 6 electrical bus systems, four 28-volt DC flight batteries, and motor-operated power transfer switches

ORDNANCE: Provides, in operational sequence, ignition of eight ullage motors before ignition of five main engines, explosive separation of second stage interstage skirt, explosive separation of second stage from third stage, and ignition of four retrorockets to decelerate second stage for complete separation

MEASUREMENT: Instrumentation, telemetry, and radio frequency subsystems

THERMAL CONTROL: A ground-operated system that provides proper temperature control for equipment containers in the forward and aft skirt

FLIGHT CONTROL: Gimbaling of the four outboard J-2 engines as required for thrust vector control, accomplished by hydraulic-powered actuators which are electrically controlled from signals initiated in the flight control computer of the instrument unit (atop the Saturn V third stage)

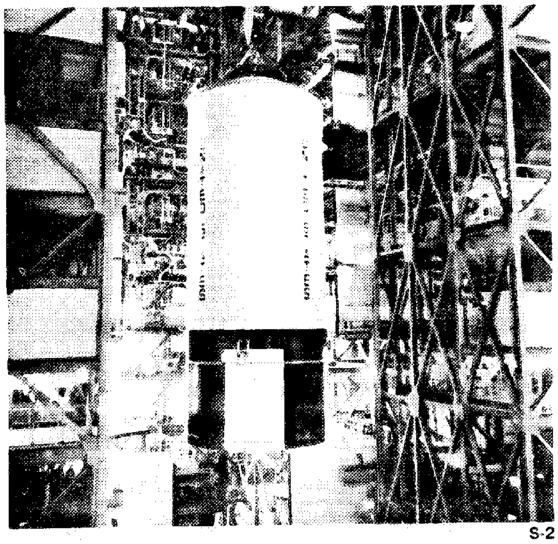
SECOND STAGE

SECOND STAGE DESCRIPTION

The second stage of the Saturn V is the most powerful hydrogen-fueled launch vehicle under production. Manufactured and assembled by North American Aviation's Space Division, it employs the cryogenic (ultra-low temperature) propellants of liquid hydrogen and liquid oxygen, which must be contained at temperatures of -423 and -297 degrees Fahrenheit, respectively.

For the lunar mission, the second stage takes over from the Saturn V's first stage at an altitude of approximately 200,000 feet (38 miles) and boosts its payload of the third stage and Apollo spacecraft to approximately 606,000 feet (114.5 miles). When its five J-2 engines ignite, the stage is pushing more than one million pounds, a load greater than that of any U.S. booster prior to the Saturn program. Speed of the stage ranges from 6,000 miles per hour to 15,300 miles per hour.

The beginning of second stage boost is a two-step process. When all the F-1 engines of the first stage have cut off, the first stage separates. Eight ullage rocket motors located around the bottom of the second stage then fire for approximately 4 seconds to give positive acceleration to the stage prior to ignition of the five J-2 engines. About 30 seconds after the first stage separation, the part of the second stage structure on which the ullage rockets are located (the aft interstage) is separated by firing explosive charges. This second separation is a precise maneuver: the 18-foot-high interstage must slip past the engines without touching them. With the stage traveling at great speed, the interstage must clear the engines by only a little more than 3 feet.



S-2

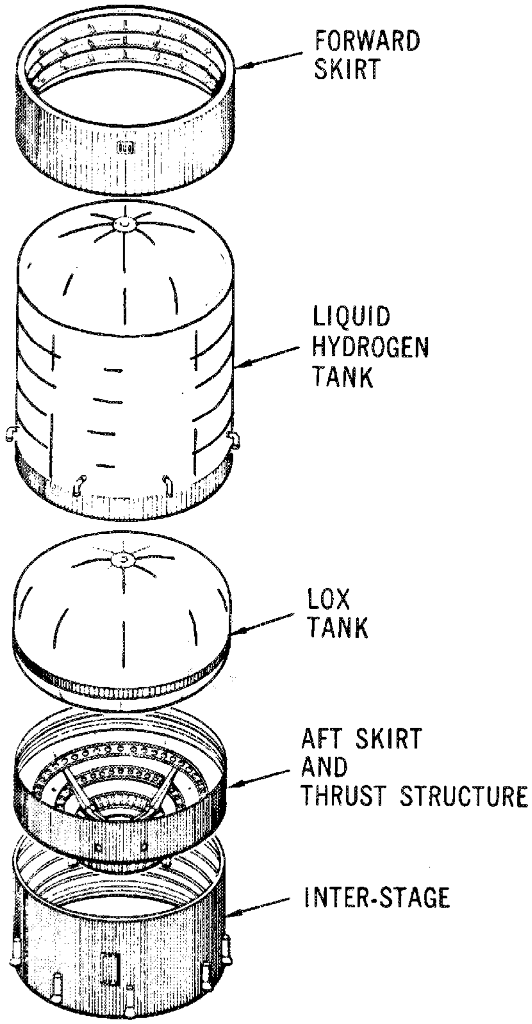
Mating—A completed second stage is mated to a first stage at Kennedy Space Center, Fla. This particular stage was used for facilities checkout.

The second stage burns for about 6 minutes, pushing its payload into space. At the end of boost, all J-2 engines cut off at once, the stages separate, and the J-2 engine on the third stage begins firing to take it and the Apollo spacecraft into a parking earth orbit. The 81-foot 7-inch second stage is basically a container for its 942,000 pounds of propellant with engines attached at the bottom. Propellants represent more than 90 per cent of the stage's total weight. Despite this great weight of propellant and the stresses the stage must take during launch and boost, the stage is primarily without an internal framework. It is constructed mostly of lightweight aluminum alloys ribbed in such a fashion that it is rigid enough to withstand the pressures to which it is subjected. Special lightweight insulation had to be developed to keep its cryogenic propellants from warming and thus turning to gas and becoming totally useless as propellant. The insulation that helps maintain a difference of about 500 degrees between outside (70 to 80-degree normal Florida temperature) and inside (-423° F of liquid hydrogen) is only about 1-1/2 inches thick around the hydrogen tank.

A unique feature of the second stage is its common bulkhead, a single structure which is both the top of the liquid oxygen tank and the bottom of the liquid hydrogen tank. This bulkhead was a critical item in the development of the stage. The relatively thin bulkhead, consisting of two aluminum facing sheets separated by a phenolic honeycomb core insulation, must maintain a temperature difference of 126 degrees between the two sides. The insulation which accomplishes this varies from one-tenth of an inch thickness at the girth to 4-3/4 inches thickness at the apex of the bulkhead. Development of the common bulkhead resulted in a weight saving of approximately 4 tons and more than 10 feet in stage length.

STRUCTURE

The second stage structure consists of an interstage, which links it with the first stage; a thrust structure and aft skirt assembly, which supports and houses the five J-2 engines; an ellipsoidal liquid oxygen tank; a bolting ring, which attaches the liquid oxygen tank to the second stage structure; six aluminum cylinder walls, which are welded



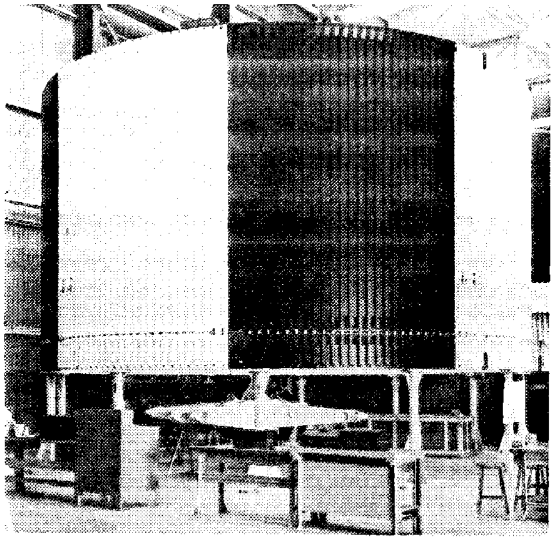
S-3

Second Stage Subassemblies

together to form the liquid hydrogen tank; a forward domed bulkhead; and the forward skirt, which connects with the Saturn V third stage. Another important part of the structure is the 60-foot systems tunnel located on the outside of the liquid hydrogen cylinder walls through which all electrical wires between the aft skirt and the forward skirt are routed.

Interstage

The interstage, fabricated at NAA's Tulsa plant, is a semimonocoque structure. Semimonocoque means that the skin has a minimum of internal framework. The interstage is slightly over 18 feet in height and 33 feet in diameter. The structure has internal circumferential supporting frames and external hat



S-4

Interstage

sections positioned vertically to provide structural rigidity.

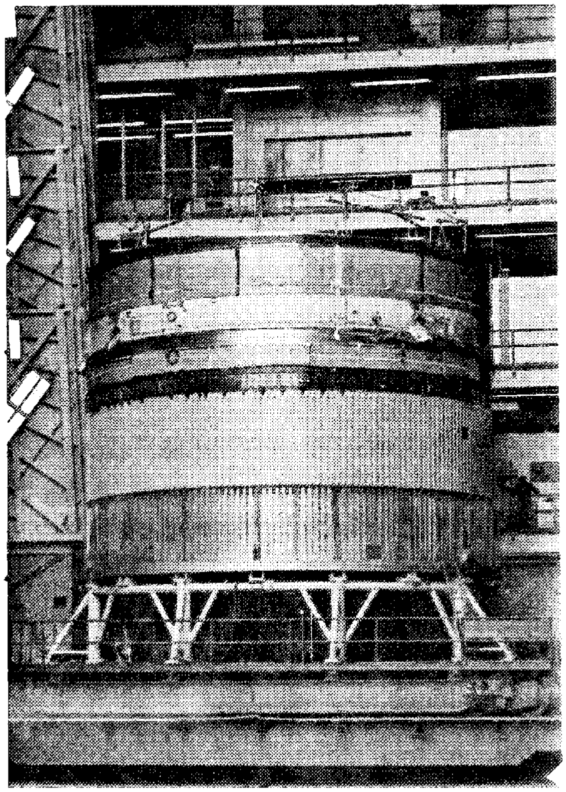
After first stage burnout and initial separation, eight rocket motors attached equidistantly around the interstage are fired for approximately 4 seconds. These motors, called ullage motors (an old brewer's term referring to the gaseous zone in a tank above the liquid), provide positive acceleration and therefore pressure to force the stage's propellants into the feed lines to the J-2 engines. This is called the ullage maneuver. The interstage is separated from the second stage approximately 30 seconds after it separates from the first stage. The two-step separation of the interstage is called dual-plane separation.

Aft Skirt

Like the interstage, the aft skirt (as well as the thrust structure and forward skirt) is manufactured at NAA's Tulsa facility and delivered to Seal Beach for final assembly. The aft skirt is 7 feet in height and is semimonocoque construction fabricated from aluminum alloy. It is fabricated in four panels with external stringers and subassembled internal frames.

Thrust Structure

The thrust structure consists of four panels of riveted skin-stringer and internal frame construction, which, when assembled, forms an inverted cone decreasing in size from the 33-foot diameter of the upper ring to approximately 18 feet at the



S-5

Stacking Stage—Aft skirt, thrust structure, and common bulkhead move on transfer table to new station for further buildup of stage.

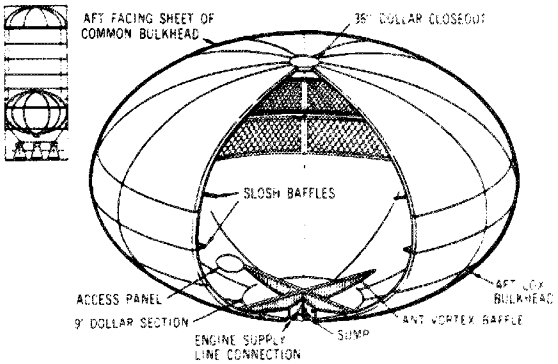
lower ring. Four support rings along with an outer skin stiffened with hat sections comprise the basic structure. In addition, eight thrust longerons (two to each panel) extend upward along the conical surface of the thrust structure. The lower circumferential ring rests directly over the line of thrust of each of the four outboard engines while the center engine support beam assembly is directly over the thrust line of the center engine. A rigid heat shield mounted around the five J-2 engines to a frame connecting to the thrust structure protects the base area of the stage against recirculation of hot engine exhaust gases and heat from the exhaust. This heat shield is of lightweight construction protected by low-density ablative (heat-resistant) material.

Although assembled separately, the aft skirt and thrust structure when joined become a structural entity and together support the five engines and withstand and distribute the thrust and boost structural loads.

In addition to engines and engine accessories, the interstage, aft skirt, and thrust structure house electrical and mechanical equipment such as signal conditioners and controllers, telemetry electronics, flight control electronics, service and connecting umbilicals, electrical power control units, power distribution panels and batteries, inverters, propellant management electronics, propellant plumbing, ordnance installations, and hydraulic pumps and accumulators. Equipment that is not required after second-plane separation is in the interstage which is separated 30 seconds after ignition. Equipment necessary for flight operations is located on the aft skirt, thrust structure, and forward skirt.

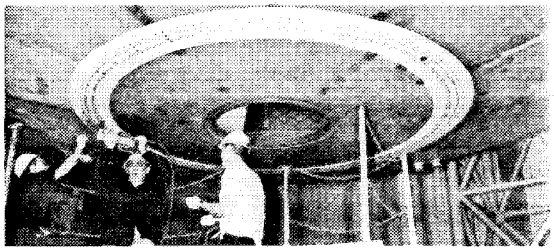
Liquid Oxygen Tank

The liquid oxygen (LOX) tank is an ellipsoidal container 22 feet high and fabricated from ellipsoidal-shaped top and aft halves. The top half of the LOX tank is known as the common bulkhead and is actually two bulkheads separated by phenolic honeycomb insulation and bonded together to form both the upper portion of the liquid oxygen tank and the lower portion of the liquid hydrogen tank.



Second Stage LOX Tank

All of the LOX tank bulkheads are formed by welding together 12 high-energy-formed curved sections (gores), each approximately 20 feet long and 8 feet



S-11

Tank Fabrication—Workmen close out dollar section of propellant tank.

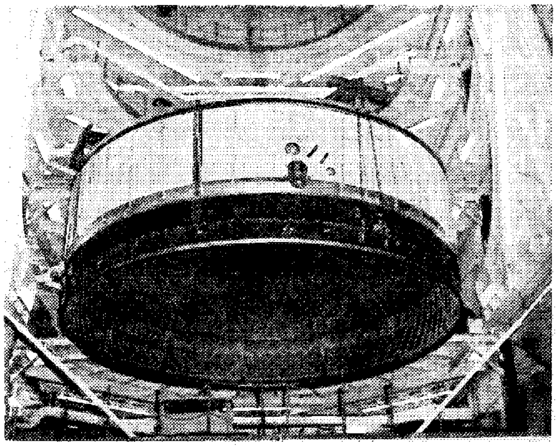
wide. When the gores are welded together, an opening is formed at the apex of the bulkhead. The apex is closed by welding the 12 gores to a circular section called a dollar section.

AFT LOX BULKHEAD

The aft LOX bulkhead, like the aft facing sheet of the common bulkhead, is composed of 12 thin aluminum gores welded to mechanically milled waffle panels. The waffle panels are sheets into which diagonal ribs are machined to form a series of diamonds. The waffle panels are used around the middle (widest part of the LOX tank) to provide structural strength. Baffles adjacent to the aft facing sheet of the common bulkhead prevent wave action (sloshing) during flight. At the lower apex of the LOX tank, anti-vortex baffles, consisting of a 14-foot cruciform (four fins arranged in a cross) and 12 smaller baffles, are installed over the sump and engine supply line connections. The smaller baffles are essentially thin metal plates extending from the center of the cruciform, three between each pair of fins.

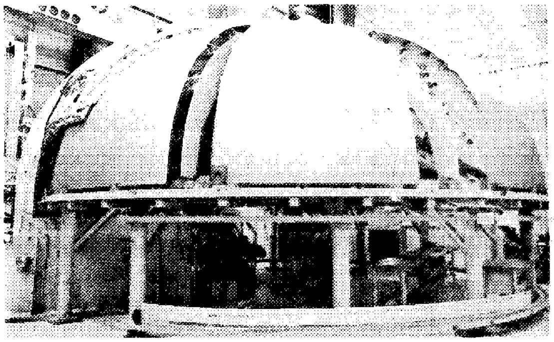
COMMON BULKHEAD

The common bulkhead may be likened to two giant domes, one placed inside the other, open end down, with a layer of insulation sandwiched between. The top dome is called the forward facing sheet and the bottom, the aft facing sheet. The forward facing sheet has a J-shaped periphery, which is welded to the No. 1 liquid hydrogen tank cylinder. In final assembly, a 15-inch, 12-section bolting ring is bolted to the aft skirt and the No. 1 liquid hydrogen tank cylinder. A total of 636 bolts attach the bolting ring to the liquid oxygen tank.



S-8

Bulkhead—Common bulkhead shows aft facing sheet (in sling preparatory to mating).



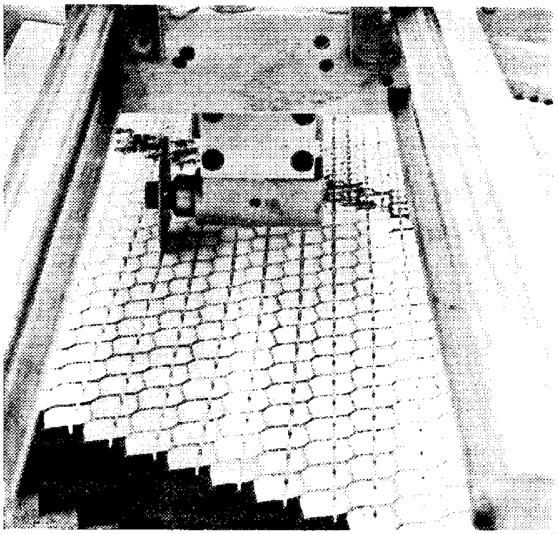
S-13

Gore Section of Aft Facing Sheet of Common Bulkhead Before Assembly

Insulating and joining the forward and aft facing sheets into a common bulkhead is a process of several operations. First the aft facing sheet is placed on a bonding fixture and numerous sections of honeycomb phenolic insulation are fitted and tapered to exact but varying thicknesses. Then the insulation is cemented to the aft facing sheet in a multistage bonding operation which includes chemical processing of the aft facing sheet, application of adhesive, and pressurizing and curing in the autoclave. After mating the forward facing sheet over the insulated aft facing sheet, impression checks are made to assure a perfect fit. The forward facing sheet is then chemically processed, the insulation placed on the exposed top of the aft facing sheet is prepared with adhesive, and the entire bulkhead assembly is joined and placed in the autoclave for pressurizing and curing. In both bonding operations, checks are performed with ultrasonic equipment to ensure that the adhesive has completely covered the surface.

Liquid Hydrogen Tank

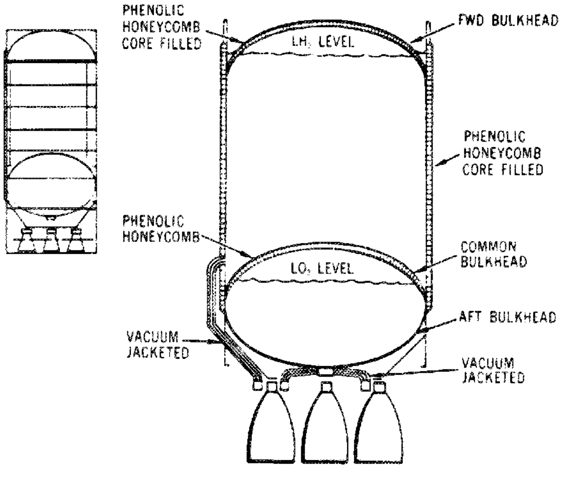
The liquid hydrogen cylinder walls comprise the main bulk of the second stage. Five of the cylinder walls measure slightly over 8 feet in height each, while the sixth, the No. 1 cylinder, is 27 inches high. Each of the six cylindrical sections is comprised of four curved, machined aluminum skins. Numerically machine-milled into the inside of the curved skins are stringers and ring frames. Riveted to the circumferential ring frames are flanged aluminum frames which extend inward for approximately 7 inches. In addition to structural rigidity, the frames act as slosh baffles for the liquid hydrogen.



S-7

Honeycomb Insulation

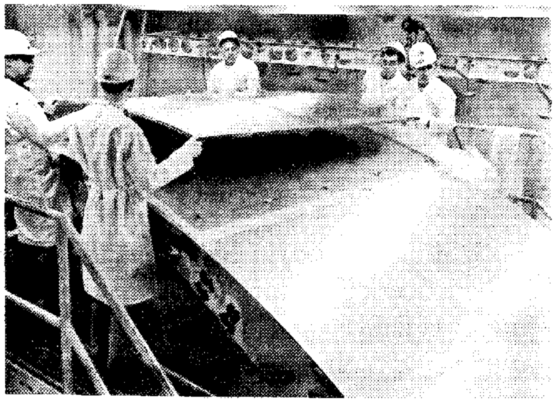
Special lightweight insulation and insulating techniques had to be developed to contain the cryogenic propellants of the second stage. The stage insulation helps maintain the liquid hydrogen at -423 degrees Fahrenheit and the liquid oxygen at -297 degrees Fahrenheit.



Second Stage Insulation

Insulation

The insulation varies in thickness in different parts of the stage. On the cylinder walls of the liquid hydrogen tank, it is only about 1-1/2 inches thick. On the common bulkhead, which separates the liquid hydrogen and liquid oxygen tanks, it varies from a tenth of an inch thick at the edges to about 4-3/4 inches thick at the apex of the bulkhead.



S-10

Insulating—Workers apply insulation to LH$_2$ cylinder panel.

The LH$_2$ tank wall insulation is formed of a phenolic honeycomb filled with a heat-resistant foam of isocyanate. The honeycomb is sealed top and bottom with a phenolic laminate and a layer of Tedlar plastic film. The helium is forced through passages (grooves) cut into the foam and honeycomb. The purge is continuous from the start of hydrogen loading until just before launch.

Systems Tunnel

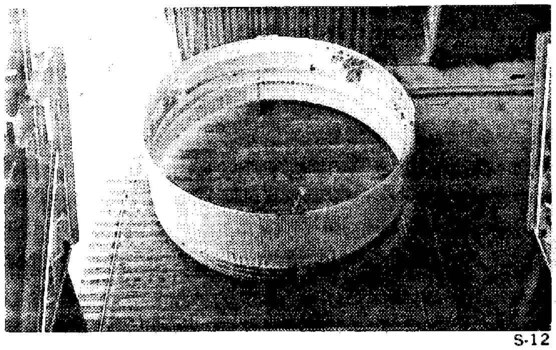
The systems tunnel is semicircular, approximately 22 inches wide, and almost 60 feet long. It is attached vertically to the outside wall cylinders, protecting and supporting instrumentation, wiring, and tubing, which connect system components located at both ends of the stage.

Forward Skirt Assembly

Of semimonocoque construction, the forward skirt is assembled from four curved sections with a height of 11-1/2 feet and has four internal support rings. Hat sections attached vertically to the outer skin stiffen the completed assembly and provide structural support for the third stage and Apollo payload. The forward ring has provisions for attachment to the mating ring of the third stage while skin and vertical members of the skirt attach to the forward end of the liquid hydrogen tank structure.

Final Assembly

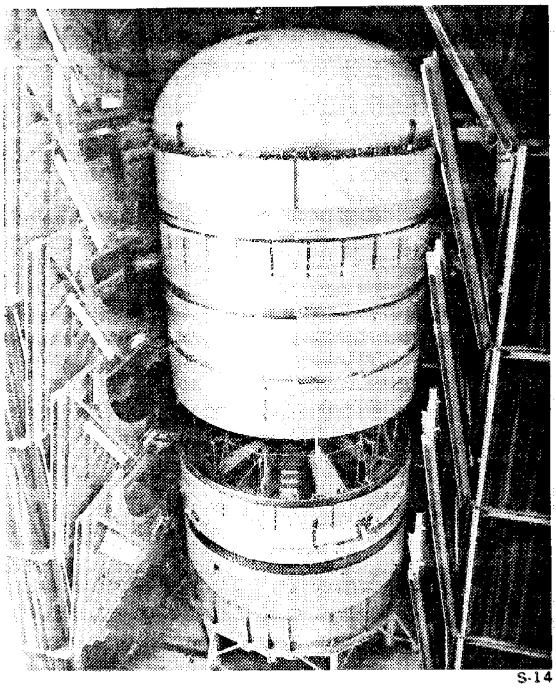
The second stage of the Saturn V launch vehicle assumes its shape in the vertical assembly building of NAA's Seal Beach facility. Assembly in the vertical position is based on a building-block concept. In this position, subassembly loading, circumferential exactness, and station locating is benefited by the even gravitational force exerted during each assembly operation. Constant checks and verification of station planes and stage alignment are maintained during each joining procedure by special scopes, levels, and traditional plumb bobs.


S-12

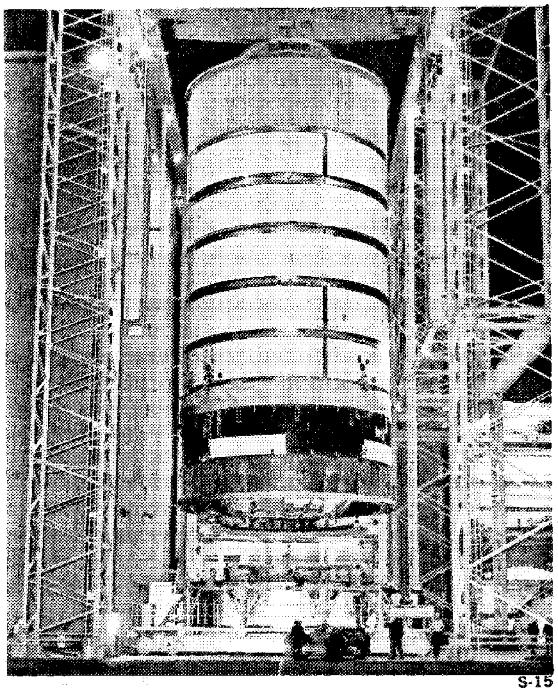
Second Stage Forward Skirt

Another reason for vertical assembly involves the welding of cylinders and bulkhead. If the stage were welded while in a horizontal position, temperature diversion over the circumference could result in harmful expansion near the top of the stage.

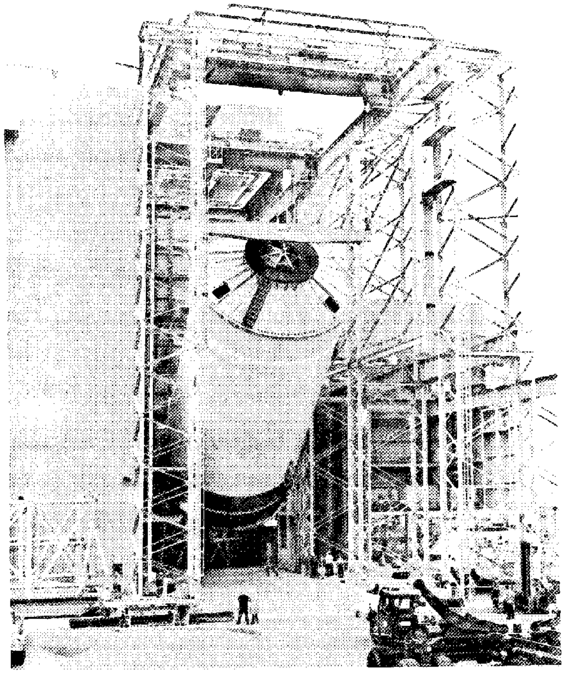
To facilitate movement of the huge components and of the stage itself, a motorized transfer table rolls from outside to inside the building. Essentially, the assembly sequence begins with the welding of the lower two cylinders. Then the common bulkhead is welded to that assembly. Next the uppermost cylinder is welded to the LH_2 forward bulkhead. The aft LOX bulkhead and the aft facing sheet of the common bulkhead are welded together to form the liquid oxygen tank, and the thrust structure and aft skirt are then assembled to it. The remaining cylinders are then welded to the stage, and the forward skirt is then mated to the stage stack. The interstage is fit-checked to the thrust structure before interstage systems are installed. Throughout the assembly and welding operations, hydrostatic, X-ray, dye penetrant, and other tests and quality control devices are performed to ensure that specifications are met. The liquid hydrogen portion of the second stage as well as the liquid oxygen tank are given a thorough cleaning after assembly. After each bulkhead is welded to its components, it is hydrostatically tested. After completion of stack weld operations, the entire stage is pneumostatically tested. After completion of these tests, the liquid hydrogen and liquid oxygen tanks are thoroughly cleaned.


S-14

Vertical Assembly of Stage

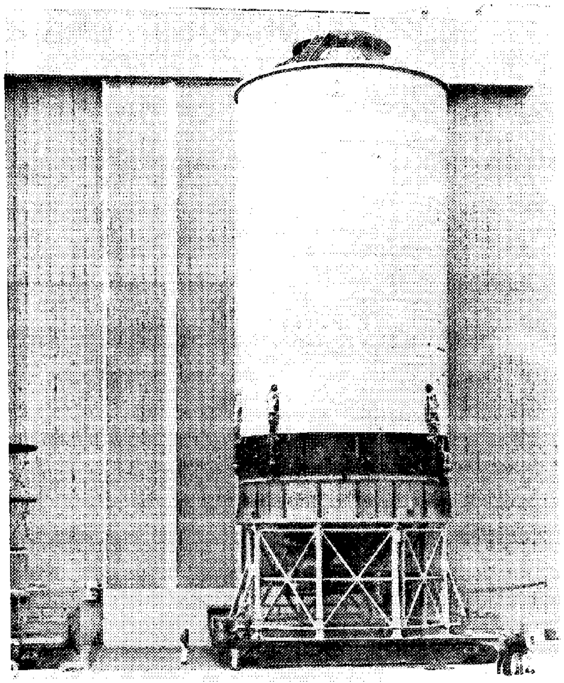

S-15

Move is Made—Flight stage is moved onto transporter to new station in vertical assembly building at Seal Beach.



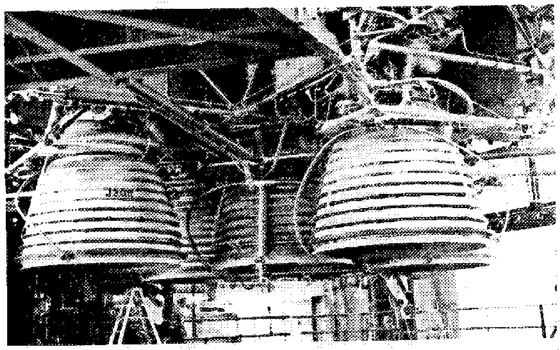
S 16

Repositioning—Second stage is turned horizontally for checkout operation.



S-18

Stage Complete—Flight stage moves on transfer table from assembly building to checkout building.



S-17

Engine Installation—J-2 engines are mounted in stage.

After assembly, the stage is moved to a vertical checkout building for final checks on all stage systems.

PROPELLANT SYSTEM

The propellant system is composed of seven subsystems: purge, fill and replenish, venting, pressurization, propellant feed, recirculation, and propellant management.

Purge Subsystem

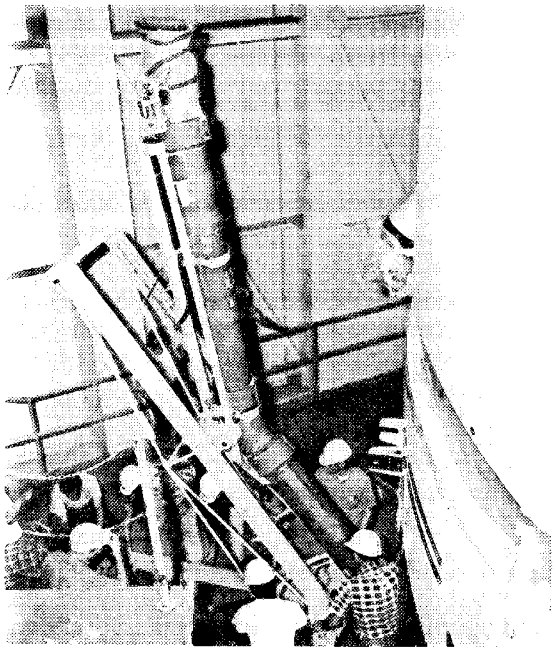
The purge subsystem uses helium gas to clear the propellant tanks of contaminants before they are loaded. The important contaminants are oxygen in the liquid hydrogen tank (liquid hydrogen will freeze oxygen which is impact-sensitive) and moisture in the liquid oxygen tank.

The tanks are purged with helium gas from ground storage tanks. The tanks are alternately pressurized and vented to dilute the concentration of contaminants. The operation is repeated until samples of the helium gas emptied from the tanks show that contaminants have been removed or reduced to a safe level.

Fill and Replenish Subsystem

Filling of the propellant tanks on the second stage is a complex and precise task because of the nature of the cryogenic liquids and the construction of the stage.

Because the metal of the stage is at normal outside temperature, it must be chilled gradually before pumping the ultra-cold propellants into the tanks. The filling operation thus starts with the introduction of cold gas into the tanks, lines, valves, and other components that will come into contact with the cryogenic fluids. The cold gas is circulated until



S-19

Channel Installed—Feed line from LH_2 tank to one of the five engines is installed.

the metal has become chilled enough to begin pumping in the propellants. The filling and replenishing subsystem operation consists of five phases:

Childown—Propellants are first pumped into the tank at the rate of 500 gallons per minute for LOX and 1,000 gallons per minute for LH_2. Despite the preliminary chilling by cold gas, the tanks are still so much warmer than the propellants that much of the latter boils off (converts to gaseous form) when it first goes into the tank. Filling continues at this rate until enough of the propellants remain liquid so that the tanks are full to the five per cent level.

Fast Fill—As soon as tank sensors report that the liquid has reached the five per cent level, the filling rate is increased to 5,000 gallons per minute for LOX and 10,000 gallons per minute for LH_2. This rate continues until the liquid level in the tank reaches the 98 per cent level.

Slow-Fill—Propellant tanks are filled at the rate of 1,000 gallons per minute for both LOX and LH_2 until the 100 per cent level is reached.

Replenishment—Because filling begins many hours before a scheduled liftoff and the cryogenic liquids are constantly boiling off, filling continues almost up to liftoff (160 seconds before liftoff for LOX and 70 seconds before liftoff for LH_2). Tanks are filled at the rate of up to 200 gallons per minute for LOX and up to 500 gallons per minute for LH_2, depending on signals from sensors in the tanks on the liquid level.

101 Per Cent Shutdown—A sensor in each tank will send a signal to indicate that the 101 per cent level (over the proper fill level) has been reached; this signal causes immediate shutdown of filling operations.

Filling is accomplished through separate connections, lines, and valves. The ground part of the connections is covered by special shrouds in which helium is circulated during filling operations. This provides an inert atmosphere around the coupling between the ground line and the tanks.

The coupling of the fill line and the tanks is engaged manually at the start of filling operations; it is normally disengaged remotely by applying pneumatic pressure to the coupling lock and actuating a push-off mechanism. A backup method involves a remotely attached lanyard in which the vertical rise of the vehicle will unlock the coupling. The fill valves are designed so that loss of helium pressure or electrical power will automatically close them.

Liquid oxygen is the first propellant to be loaded onto the stage. It is pumped from ground storage tanks. Liquid hydrogen is transferred to the stage by pressurizing the ground storage tanks with gaseous hydrogen. The liquid hydrogen tank is chilled before the liquid oxygen is loaded to avoid structural stresses.

After filling is completed, the fill valves and the liquid oxygen debris valves in the coupling are closed, but the liquid hydrogen debris valve is left open. The liquid oxygen fill line is then drained and purged with helium. The liquid hydrogen line is purged up to the coupling. When a certain signal is received (first stage thrust-commit), the liquid hydrogen debris valve is closed and the coupling is separated from the stage.

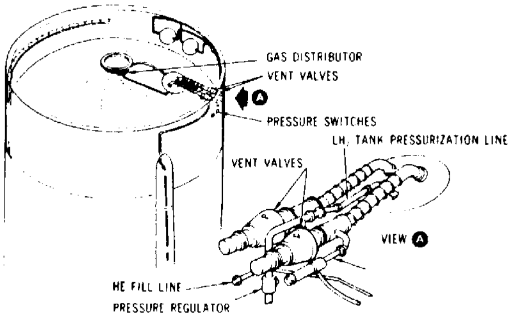
The tanks can be drained by pressurizing them, opening the valves, and reversing the filling operation.

Venting Subsystem

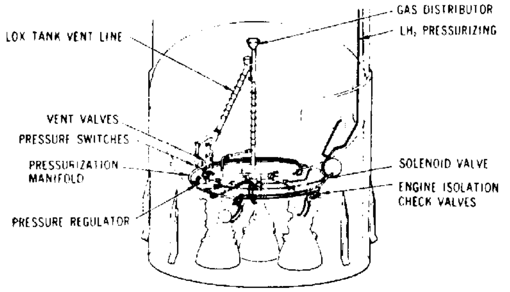
The venting subsystem is used during loading and flight operations. While the propellant tanks are being loaded, the vent valves (two for each tank) are opened by electrical signals from ground equipment to allow the gas created by propellant boil-off to leave the tanks. The valves are spring-loaded to be normally closed, but a relief valve will open them if pressure in the tanks reaches an excessive level. Each valve is capable of venting enough gas to relieve the pressure in its tank; two are provided in each tank as backup.

Pressurization

Pressurization of the propellant tanks is a three-stage process. Before launch, pressurization is obtained with gaseous helium from ground support equipment. After J-2 engine start, the pressurization is maintained with gaseous oxygen and gaseous hydrogen converted from the liquid oxygen and hydrogen.



LH$_2$ PRESSURIZATION SYSTEM—FWD



LH$_2$ & LOX PRESSURIZATION SYSTEM AFT

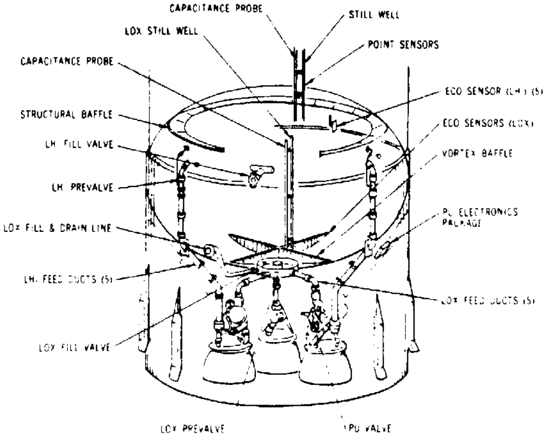
S-20

Propellant Pressurization System

Before launch, both the liquid hydrogen and liquid oxygen tanks are pressurized with gaseous helium which flows directly into the stage pressurization lines from ground storage tanks. Pressure switches, which sense ullage pressure, maintain the required pressurization level (37 to 39 psia for liquid oxygen and 31 to 33 psia for liquid hydrogen). This pressurization is maintained until liftoff; boil-off of the liquid propellants maintains adequate pressure until the stage's engines are ignited. A fitting on the upper manifold of the engines permits gaseous hydrogen (converted from its liquid state) to flow through a common manifold, a pressurization line, and regulator back to pressurize the liquid hydrogen tank to the desired levels. Some of the liquid oxygen is bled through a heat exchanger before reaching the combustion chamber, converted to a gaseous state, and diverted to a pressurization line and a regulator where it flows back to pressurize the liquid oxygen tank. The flow of pressurant gas into the LH$_2$ tank is automatically stepped up after 250 seconds of a J-2 engine firing, and the greater flow of gas and the increase of pressure continues for the rest of the firing period.

Propellant Feed Subsystem

The purpose of the propellant feed subsystem is simple: transfer the liquid propellants from their tanks to the five J-2 engines.



S-21

Feed System Components

Each tank has five prevalves which control or stop the flow through separate feed lines to the engines. Solenoids control helium pressure to open and close the valves; if pressure or electrical power is lost, the valves will automatically stay open.

The feed lines (except the center engine liquid oxygen line) are 8 inches in diameter and are vacuum-jacketed and insulated. The center engine liquid oxygen line is also 8 inches in diameter but is not insulated. Thermocouples (temperature measuring devices) in the vacuum jackets permit periodic vacuum checks; rupture discs in the jackets relieve excessive pressure. The feed lines also have bellows to allow for thermal expansion and freedom of movement.

Recirculation Subsystem

The main purpose of the recirculation subsystem is to keep the liquid propellants in the engine pumps. The subsystem, by keeping the propellants moving through lines, valves, and pumps, also keeps these parts chilled.

The LH_2 recirculation subsystem pumps the propellants through the feed lines and valves and back to the LH_2 tank through a single return line. The pumps are powered from a 56-volt DC battery system located in the interstage; the batteries are ejected with the interstage approximately 30 seconds after first plane separation. Before liftoff, power for the LH_2 recirculation subsystem is supplied by ground equipment.

The LOX recirculation system works on the basis of a thermal syphon; heat entering the system is used to provide pumping action by means of fluid density differences across the system. Helium gas is used to supplement the density differences and thereby improve the pumping action.

Recirculation of oxygen begins at the start of tanking; LH_2 recirculation begins just before launch. The propellants continue to circulate through first stage firing and up until just before the first stage and second stage separate. While the subsystems are operating, the LH_2 prevalves which lead to the combustion chambers are closed; as soon as the recirculation subsystem stops, the LH_2 prevalves open and the engines ignite.

Propellant Management System

The propellant management system controls loading, flow rates, and measurement of the propellants. It includes propellant utilization, propellant loading, propellant mass indication, engine cutoff, and propellant level monitoring subsystems.

PROPELLANT UTILIZATION SUBSYSTEM

The propellant utilization subsystem controls the flow rates of liquid hydrogen and liquid oxygen in such a manner that both will be depleted simultaneously. It controls the mixture ratio so as to minimize propellant residuals (propellant left in the tanks) at engine cutoff. Propellant utilization bypass valves at the liquid oxygen turbopump outlets control flow of liquid oxygen in relation to the liquid hydrogen remaining. Control of the engine mixture ratio increases the stage's payload capability. The propellant utilization subsystem is interrelated with the propellant loading subsystem and uses some of the same tank sensors and ground checkout equipment.

PROPELLANT LOADING SUBSYSTEM

The loading subsystem is used to control propellant loading and maintain the quantity of propellants in the tanks. Capacitance probes (sensors) running the full length of the propellant tanks sense liquid mass in the tanks and send signals to an airborne computer, which relays them to a ground computer to control loading. They also send signals to an airborne computer for the propellant utilization subsystem's control of flow rates.

PROPELLANT MASS INDICATION SUBSYSTEM

The propellant mass indication subsystem is integrated with the propellant loading subsystem and is used to send signals to the flight telemetry system for transmission to the ground. It utilizes propellant loading sensors to determine propellant levels.

ENGINE CUTOFF SUBSYSTEM

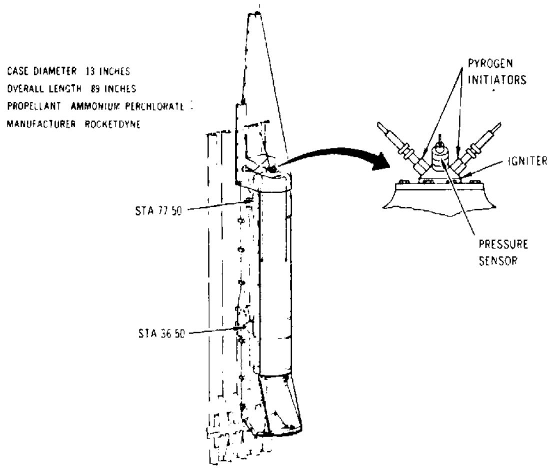
The main function of the engine cutoff subsystem is to signal the depletion point of either propellant. It is an independent subsystem and consists of five sensors in each propellant tank and associated electronics. The sensors will initiate a signal to shut down the engines when two out of five sensors in the same tank signal that propellant is depleted.

PROPELLANT LEVEL MONITORING SUBSYSTEM

The propellant level monitoring subsystem checks the level of propellants in both tanks to provide checkpoints for the sensors used in the propellant utilization and loading subsystems and to monitor propellant levels during firing. These functions are performed by sensors mounted on continuous stillwells adjacent or parallel to the full-length capacitance probes in each tank. There are 14 sensors on each stillwell to indicate various levels in the tanks.

ULLAGE MOTORS

The solid propellant ullage motors are used to provide artificial gravity by momentarily accelerating the second stage forward after first stage burnout. This moment of forward thrust is required in the weightless environment of outer space to make certain that the liquid propellant is in proper position to be drawn into the pumps prior to starting of the second stage engines.



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Ullage Motor

Eight ullage motors are utilized on the stage where they are attached around the periphery of the interstage structure between the first and second stages. Each ullage motor measures 12.5 inches in diameter by 89 inches long and each provides 22,500 pounds of thrust for approximately 4 seconds. The motors utilize Flexadyne solid propellant in a formulation developed specifically to provide high performance and superior mechanical properties under operating conditions encountered in space. Ullage motor nozzles are canted 10 degrees to reduce exhaust impingement against the interstage structure.

THERMAL CONTROL SYSTEM

Thermal control is provided by a ground-operated system which maintains proper temperatures for the equipment containers in the forward and aft skirt areas. Tempered air is used to cool the containers before propellant loading. With preparation for loading, the air is changed to nitrogen for container inerting and heating. Separate thermal control systems are provided for the forward and aft skirt areas. Each of the units contains a single manifold connected to each container, individual fixed-flow orifices, and individual relief holes from each container. Container insulation and thermal inertia preclude excessive temperature changes.

FLIGHT CONTROL SYSTEM

Flight control of the second stage is maintained by gimbaling the four rocket thrust engines for thrust vector (direction) control. These are the four outboard engines; the fifth J-2 engine located in the center of the cluster is stationary.

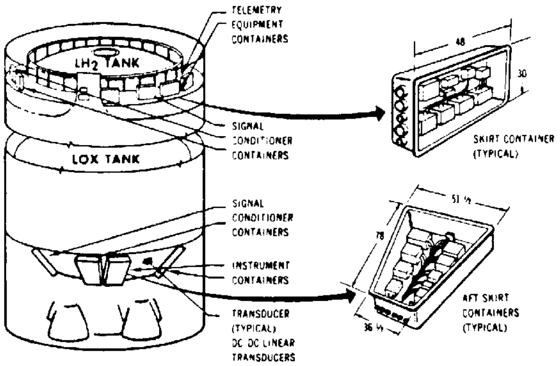
Each outboard engine has a separate engine actuation system to provide the force to position the engine. Gimbaling is achieved by hydraulic-powered actuators controlled by electrical signals generated through a flight control computer located in the instrument unit just above the third stage. Hydraulic power for operating each of the gimbaling actuators is supplied by individual engine-driven hydraulic pumps. Each system is self-contained and operates under a pressure of 3,500 psi. The components of each hydraulic system are attached to the thrust structure above each of the outboard engines. The main hydraulic pump is driven by the liquid oxygen turbopump on the respective engine. Two servoactuators that control each engine programmed for gimbaling are located on the engine outboard side. One is on the pitch plane, and the other on the yaw plane. Each actuator will gimbal the engine plus or minus 7 degrees in pitch or yaw and plus or minus 10 degrees in combination to correct for roll errors at a minimum rate of 8 degrees per second.

During flight, the guidance system continuously determines an optimum vehicle steering command based on the vehicle's position, velocity, and acceleration. This system, located in the instrument unit, has a guidance signal processor which delivers attitude correction signals to the flight control computer in the instrument unit. These signals are shaped, scaled, and summed electronically. These summed error signals are then directed to the servoactuator amplifiers, which, in turn, drive their respective servoactuators in the second stage. These signals cause the servoactuators to position the engines.

MEASUREMENT SYSTEM

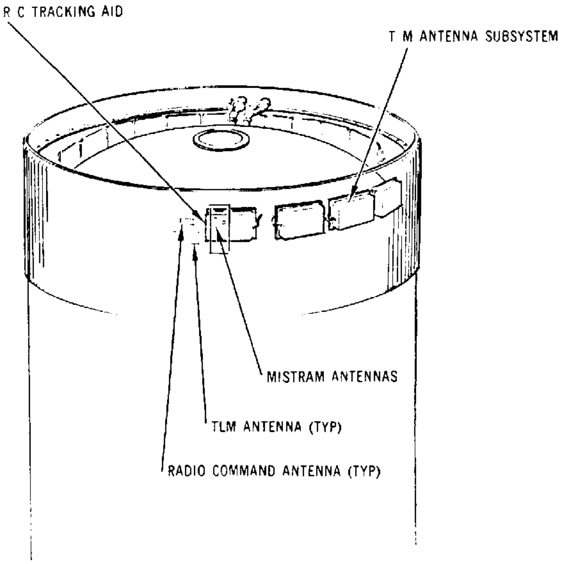
A wide variety of transducers and signal conditioners is used in the instrumentation system, which feeds signals to a high-level telemetering system for transmission to the ground. The various instrumentation sensors monitor pressure, temperature, and propellant flow rates within the tanks. Other sensors record the amount of vibration and noise, and flight position and acceleration.

Tied into the measurement system are telemetry and radio frequency subsystems which transmit the performance signals to ground receiving stations for immediate (real-time) and postflight vehicle performance evaluation. Antennas which serve the telemetry and radio frequency subsystems are flush-mounted on the forward skirt and are omnidirectional in coverage.



S-23

Telemetry System



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Radio Frequency System

ELECTRICAL SYSTEM

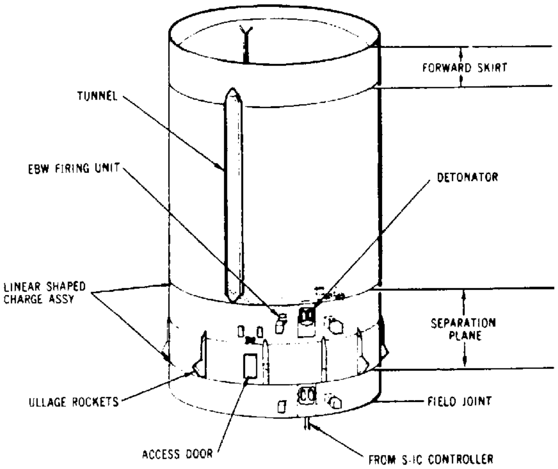
In flight, the second stage electrical system is powered by four 28-volt DC batteries which operate four DC bus systems. The main DC bus powers electrical controls for the pressurization and propellant management systems, J-2 engine control, and the electrical sequence controller. The instrumentation DC bus powers instrumentation and telemetry. The ignition and recirculation bus systems provide the electrical supply for those flight operations.

Both the main and instrumentation bus systems are powered by individual 28-volt DC silver-oxide/zinc batteries. The recirculation DC bus system is powered by two series-connected 28-volt DC silver-oxide/zinc batteries. This supplies electrical power to five recirculation pump-motor inverters. The inverters convert the 56 volts to three-phase, 400 cps, quasi-square wave power to the AC induction motors on the liquid hydrogen recirculation pump systems. The ignition system receives its electrical power from a tap on the recirculation system flight batteries through a power transfer switch.

Each of the flight electrical power bus systems has a power transfer switch—an electro-mechanical device for transferring the systems from ground service equipment power (prelaunch) to stage battery power for flight. Before flight, the electrical power system and its electrical controls are energized from regulated ground service equipment power.

ORDNANCE SYSTEM

The separation of the first and second stages is a dual-plane separation. With depletion of the first stage propellants, an engine cutoff signal is initiated. A linear-shaped charge utilizing exploding bridgewire initiators physically severs the two stages.



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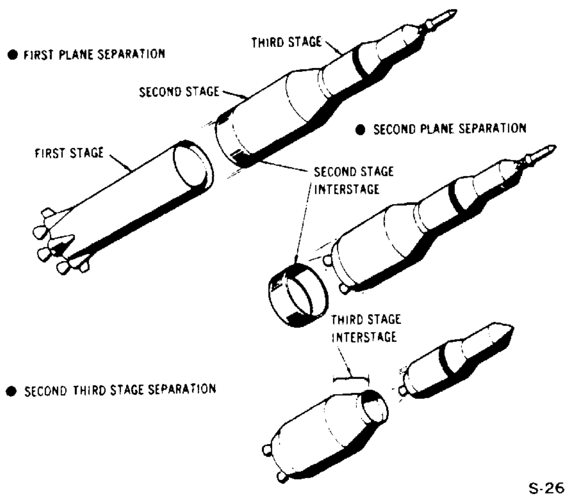
Ordnance System

Simultaneously, retrorockets on the first stage are ignited to decelerate the first stage and complete the separation, and in order to assure good propellant flow to the five J-2 engines of the second stage after first stage separation, eight solid-propellant ullage motors located on the second stage's aft interstage are fired to establish positive vehicle acceleration and proper propellant settling. When the outboard engines of the second stage reach 90 per cent of maximum thrust, a signal is transmitted which initiates interstage separation. An explosive charge separates the interstage from the aft skirt of the second stage.



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Separation System

Approximately 10 seconds before second stage propellant depletion, a signal activates the separation system which will sever the second stage from the third. An interstage connecting the second and third stage has four retrorockets which are fired to decelerate the second stage.

GROUND SUPPORT

Ground support operations play an important part in getting the second stage ready for operation. Among the vital operations in this area are checkout (performed mostly with complex electronic equipment and computerized routines which stimulate stage systems and analyze responses), leak detection and insulation purge, and engine compartment conditioning.

Leak Detection and Insulation Purge

The purpose of this system is to detect hydrogen, oxygen, or air leaks; to dilute and remove leaking gases; and to prevent air from liquifying during tanking operations.

Any operation involving liquid hydrogen can be extremely hazardous; liquid hydrogen in the presence of oxygen can explode or create a fire. The low-temperature atmosphere of liquid hydrogen causes air to liquify and solidify against the hydrogen tank wall if there is any leak in the tank insulation. The organic portion of the insulation will become impact-sensitive when drenched in liquid air or oxygen; insulation saturated with cryopumped air will add weight to the stage and could cause damage during draining because of a pressure buildup created by the liquified air returning to a gas. For these reasons, detection, control, and elimination of any hydrogen leaks from the stage and ground equipment are of great importance.

The leak detection system checks out the liquid hydrogen tank, tank insulation, and the common bulkhead. The areas to be checked are divided (tank wall, forward bulkhead, and common bulkhead), each with inlet and outlet taps. A gas analyzer determines the concentration of hydrogen in the purge gas (helium) after it has been forced through the insulation, and thus indicates any leakage.

From the start of hydrogen loading until launch, the insulation and core of the common bulkhead are continuously purged of hazardous gases.

Vacuum equipment is used for evacuation to prevent pressure buildup in the insulation and bulkheads by removing trapped gases. The insulation purge prevents air from entering the insulation in the event of damage during cryogenic operations.

Engine Compartment Conditioning

The purpose of this system is to purge the engine and interstage areas of explosive mixtures and to maintain proper temperature in critical regions of the aft compartment of the second stage. The compartment is purged before tanking and while the propellants are loaded.

The system consists of a 13-inch diameter feed line, manifold, ducts, and a series of vents surrounding the engine compartment and skirt area. The system provides temperature control for the hydraulic systems and certain components on the J-2 engines. The purge gas is forced through orifices in the manifold to the following areas requiring warming: the area between the thrust structure and the liquid oxygen tank, the bottom of the thrust structure including the lower surface of the thrust cone, the aft skirt and interstage, and the top surface of the heat shield.

The vent holes are located under the supporting hat sections on the outside of the aft skirt; this prevents wind, rain, and dust from entering the engine compartment. The vents are located so that the flow pattern provides good thermal control and expels hazardous gases.

The aft skirt and interstage are purged with warm (80 to 250 degrees) nitrogen. The nitrogen is sent through the feed line into the manifold, and then through ducts to the temperature-sensitive areas. By maintaining a 98 per cent nitrogen atmosphere in the engine compartment, desired temperatures are maintained and the danger of fire or explosion resulting from propellant leaks are minimized.