THE SATURN S-II

NORTH AMERICAN AVIATION, INC. SPACE and INFORMATION SYSTEMS DIVISION

THE S-II

The S-II is the second stage of NASA's Apollo moon-landing rocket — the giant Saturn V. The most powerful hydrogen-fueled booster under production, the S-II is destined for Apollo manned lunar missions and will help power three Americans to the moon. The S-II is being developed and manufactured at Seal Beach, Calif., by North American's Space and Information Systems Division, Downey, Calif., under the technical direction of NASA's Marshall Space Flight Center, Huntsville, Ala.

SIZE

The S-II stands 81-1/2 feet high, has a 33-foot diameter, and weighs 80,000 pounds empty and 1,025,000 pounds loaded. It is constructed primarily of an aluminum alloy (2014-T6 aluminum). With its five Rocketdyne J-2 engines of 200,000 pounds thrust each, the S-II develops a total thrust of one million pounds. Graphically, a Polaris missile could spin lengthwise on a string inside the S-II, and a Minuteman missile would reach the S-II's chest. (Figure 1)

LIQUID HYDROGEN FUEL

The S-II is powered by a combination of liquid hydrogen and liquid oxygen propellants. Liquid hydrogen is a colorless, tasteless, odorless gas. Its atom is the lightest known. When reduced to a temperature of 423 degrees below zero Fahrenheit, it becomes a liquid. Because liquid hydrogen offers a maximum amount of energy per pound, it becomes possible to lift payloads which would require three or more stages using other fuels. In its liquid state, hydrogen forms the newest of the nation's space fuels.

S-II ASSEMBLY

Starting at the top is the forward skirt to which the upper S-IVB (third stage) connects. Below it, occupying more than half the total length of the stage, is the 288,750-gallon liquid hydrogen tank. The domed top of the tank is called the forward (liquid hydrogen) bulkhead. The tank's cylindrical sides comprise the six liquid hydrogen cylinders. Below this tank is the common or intermediate bulkhead that forms the bottom of the liquid hydrogen tank and the top of the 93,750-gallon liquid oxygen tank. Actually, it is two bulkheads in one: the aft common bulkhead and the forward common bulkhead. The bottom of the liquid oxygen tank is called the aft (liquid oxygen) bulkhead. A bolting ring attaches the liquid oxygen tank to the S-II structure. Below the aft bulkhead is the thrust structure and the aft skirt assembly. Then comes the heat shield, and the interstage which attaches to the bottom first stage (S-IC) of the Saturn V. (Figure 2)

NEW TECHNIQUES

The construction of a rocket so big, yet so delicate, called for revolutionary tooling techniques. New and precise methods had to be devised, tested, and retested.

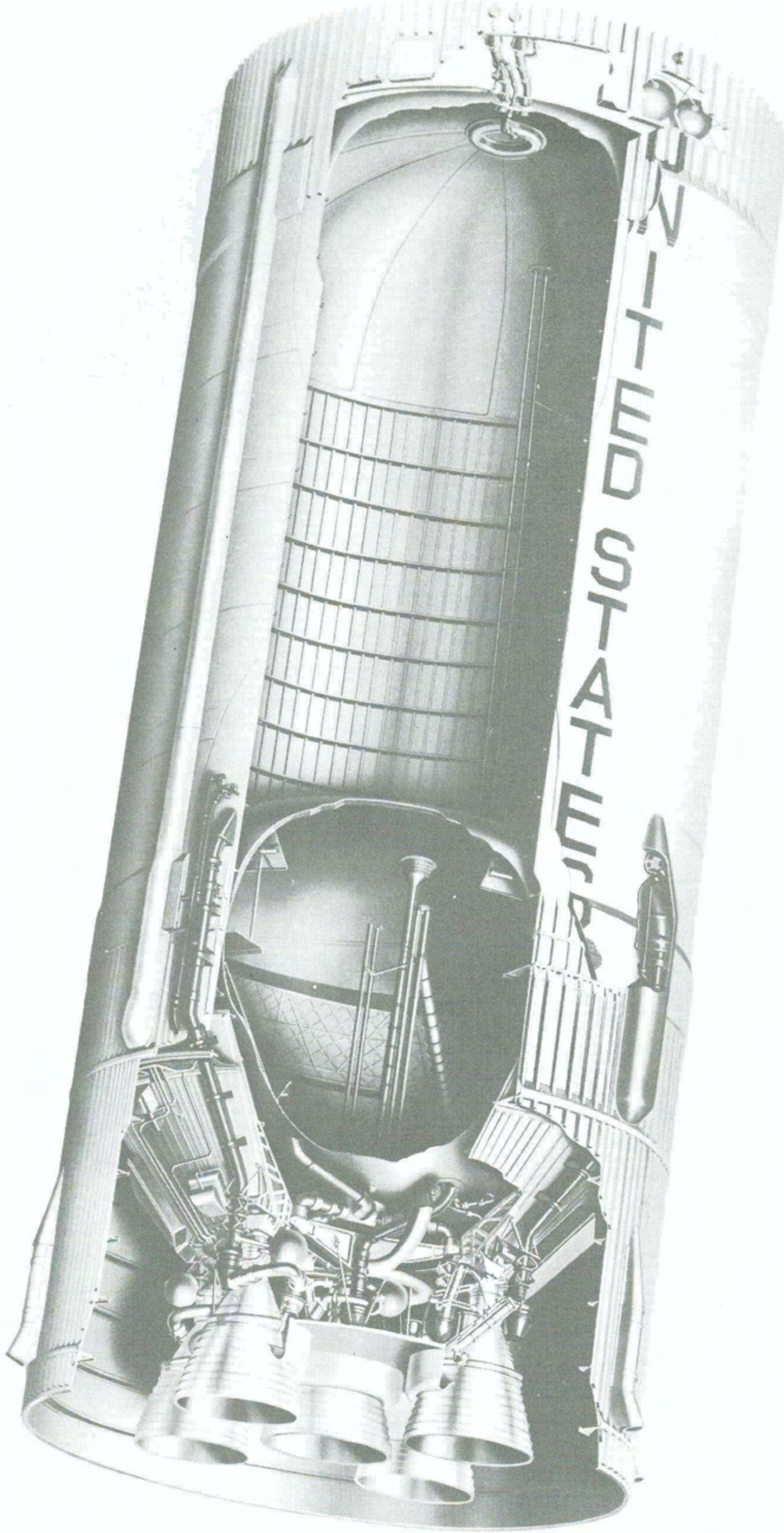
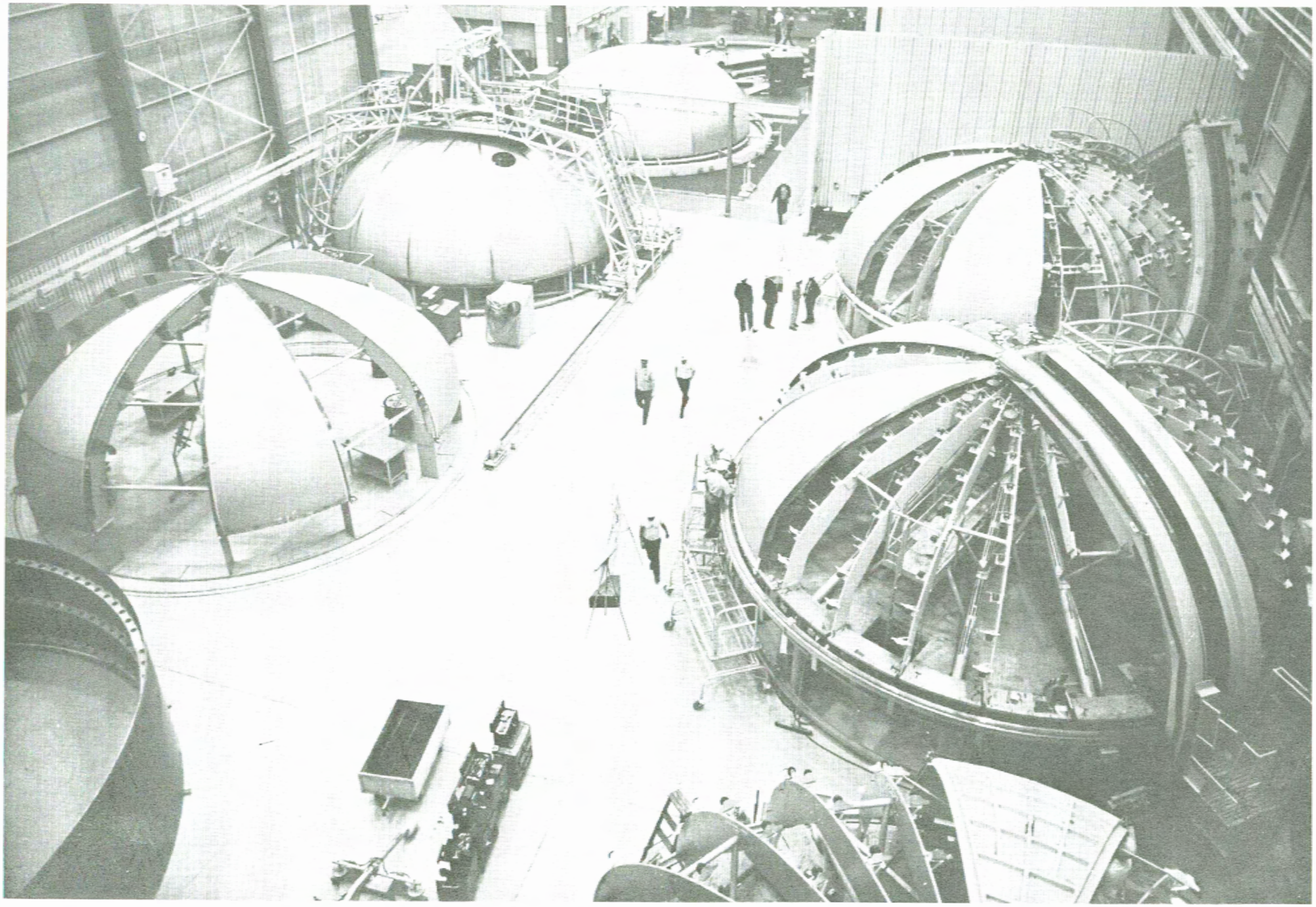


Figure 1. SATURN S-II CUTAWAY - Drawing of the S-II stage shows interior of the liquid oxygen tank (above engines) and the liquid hydrogen tank. The five J-2 engines develop a thrust of one million pounds.



SPACE HARDWARE - Resembling giant beanie caps, two futuristic domes (left rear) are completed propellant "bulkheads" for the Saturn V Apollo moon-landing rocket's second stage in production at North American's Space Division, Downey, Calif. Bulkheads are partitions that bottle up, insulate and separate space propellants that will power the launch vehicle. The second stage (called the S-II) is being developed by North American for NASA's Marshall Space Flight Center, Huntsville, Ala.

One such new technique developed by North American specialists is skate welding. The automatic skate welder is operated by an electrical weld package that regulates and remembers every welding operation. This welder literally skates over the part to be welded on a track that is held in position by vacuum-operated suction cups. An operator following the automatic welder can adjust the programed weld procedure. The track is precisely positioned on the sheets to be welded and remains fixed throughout the trim, weld, and subsequent X-ray inspection. Each of these three procedures is accomplished by mounting the respective head on the track.

A unique welding technique was introduced to prevent entrapped gas bubbles in the fabrication of the S-II. It requires trimming, polishing, deburring and vacuum cleaning. Operators may not touch a cleaned joint surface before welding, because fingers deposit undesirable chemical particles on the edges to be welded which eventually would dissolve in the molten weld metal. These bubbles would solidify in the weld metal, causing a defect in the weld bead.

More than 2,500 feet of seams on the S-II must be welded. To accomplish this, revolutionary giant weld fixtures were designed to accommodate final assembly of the stage, bulkheads, and cylinders. Five bulkhead fixtures were required: one for the forward bulkhead, two for the forward common bulkhead, one for both the aft common bulkhead and the aft bulkhead, and one for the assembled common bulkhead to the liquid hydrogen cylinder. Bulkheads are made up of gores. (A gore is shaped like a slice of pie. Twelve aluminum gores comprise one bulkhead.) One weld fixture — called the "dollar" welder — is used to weld three-foot diameter domed sections, which resemble large silver dollars, at the apex of the bulkheads. Another fixture — called the thick-to-thin welder — is used to weld the two segments of the aft common bulkhead together.

All of these welding fixtures, except the thick-to-thin section welders, are located in the bulkhead fabrication building at Seal Beach. The thick-to-thin welders, which are required for certain two-piece gores, were transferred to North American's Slauson facility in Los Angeles because of space limitations. Some of these tools are shown in Figure 3. Figure 4 shows a welded aft common bulkhead on its welding fixture. Figure 5 shows the aft common bulkhead and the forward common bulkhead welding fixtures inside the bulkhead fabrication building.

FACILITIES

The bulkhead fabrication building is a 154- by 300- by 50-foot-high structured steel frame building with a 30-foot wide staging area. Inside are two cab-operated, interlocking bridge cranes; an electrically-powered gantry crane to position the bulkheads in the autoclave; sliding walls and roofs; and other massive tooling.

The autoclave is the largest pressure cooker in the world. Actually, it is a hemispherical, covered, pressure vessel, 38 feet in diameter by 20 feet high, used to bond and cure the core insulation between the aft common and forward common bulkheads.

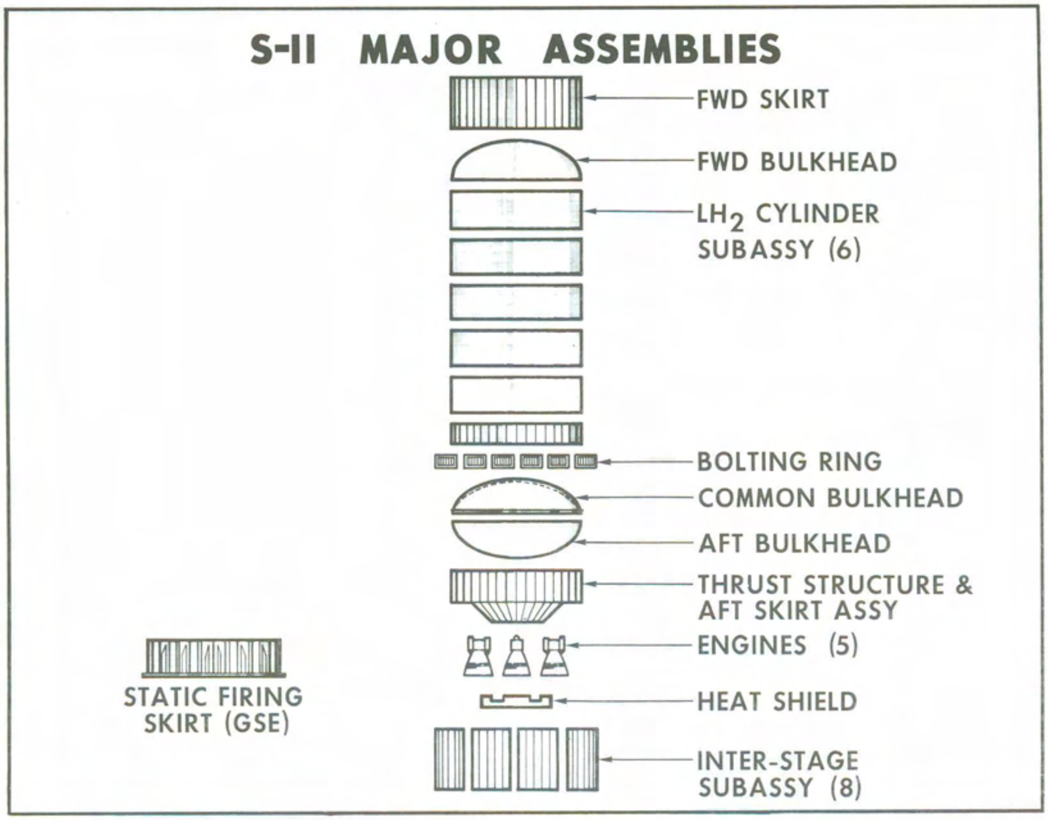


Figure 2.

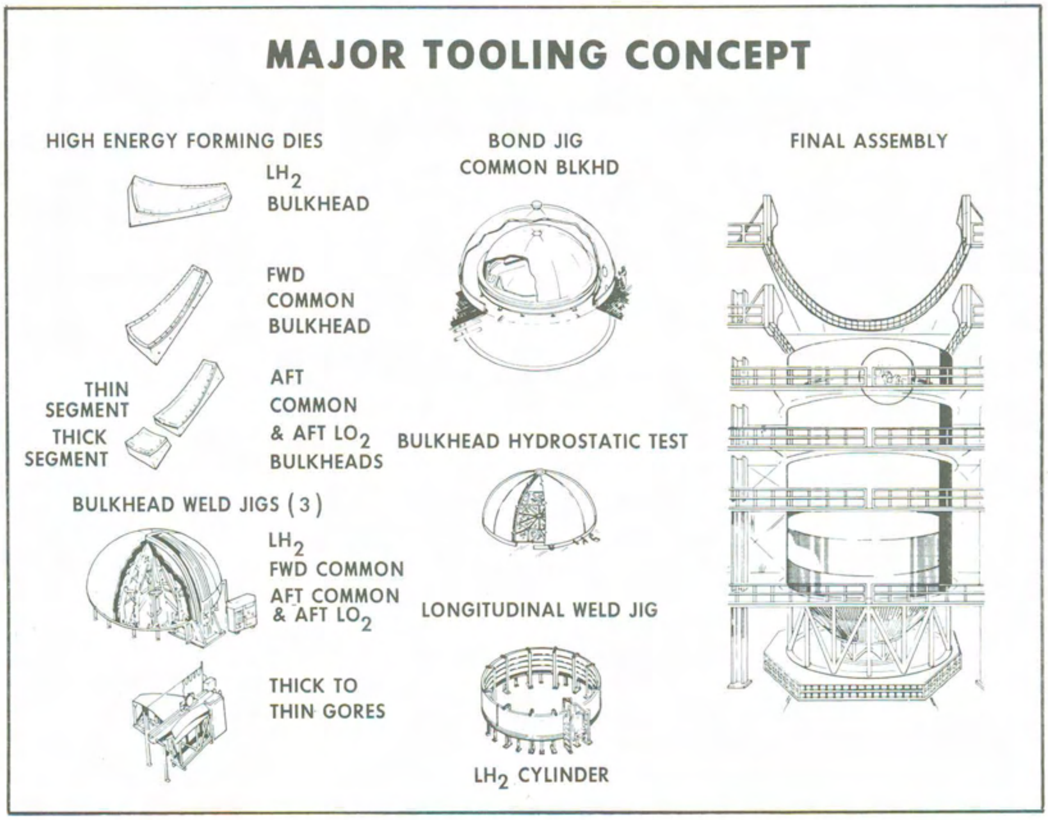


Figure 3.

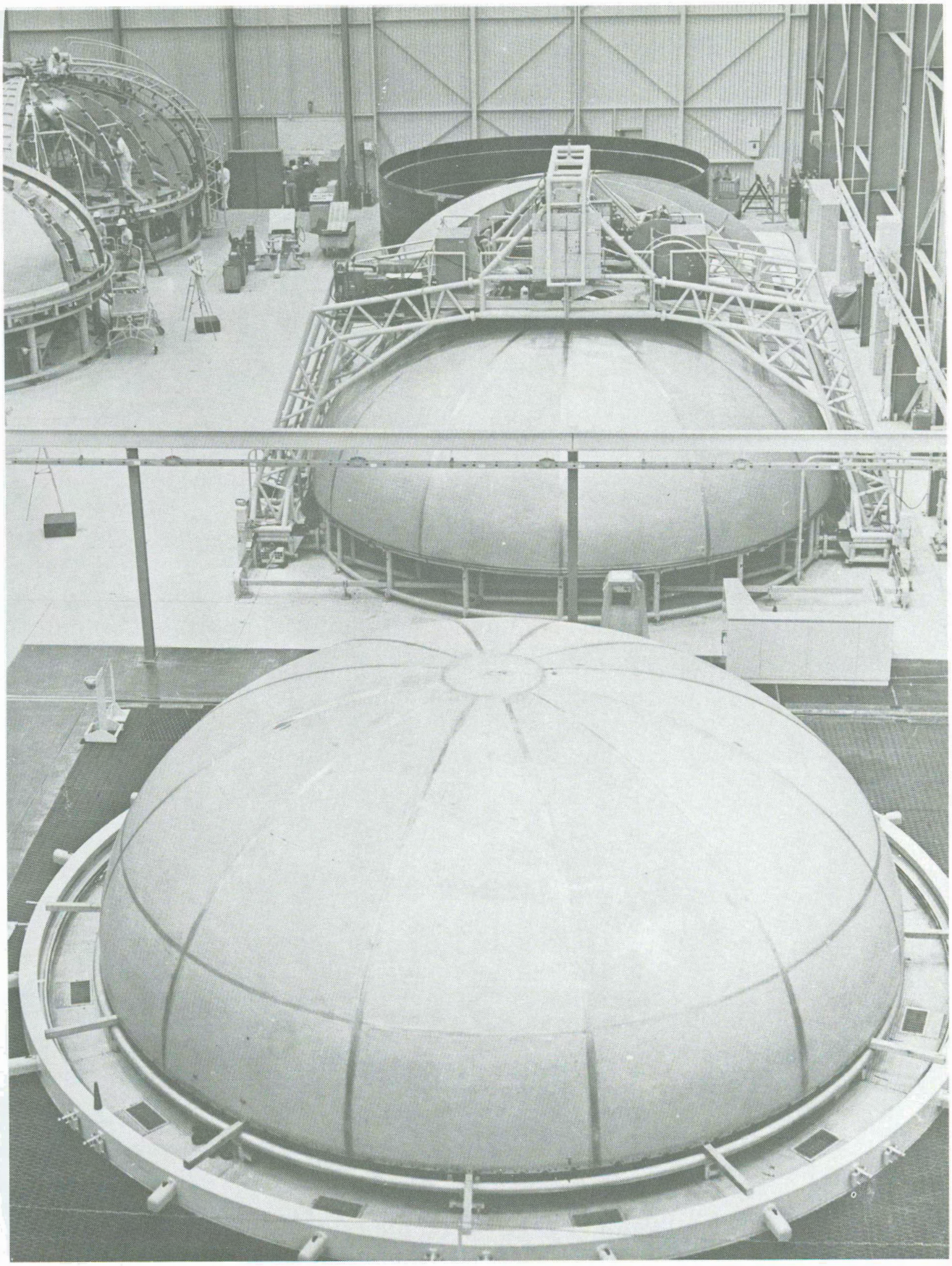


Figure 4. AFT COMMON BULKHEAD - The first S-II bulkhead which will be used for static tests is shown on the welding fixture at North American's Seal Beach facility. Horizontal and vertical lines indicate the chemical preparation used to protect the weld areas. Lines also indicate how the bulkhead was fabricated.

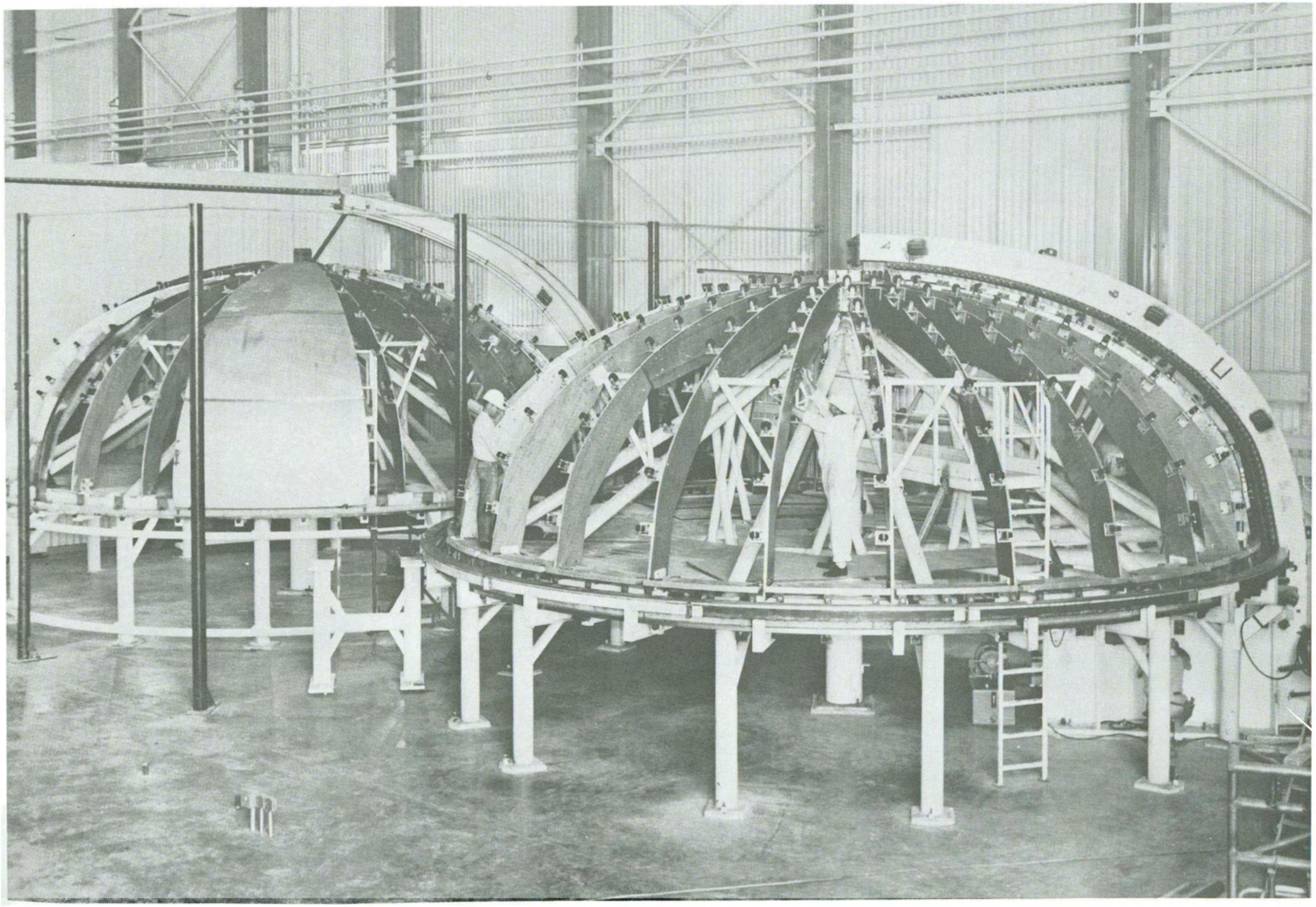


Figure 5. WELDING FIXTURES - The aft common bulkhead (left) and the forward common bulkhead jigs are being prepared to receive the gores.

The autoclave's bonding temperature is 340 degrees Fahrenheit and its pressure is 50 pounds per square inch, augmented by a 10-pound-per-square-inch vacuum pulled between the two bulkheads.

Near the bulkhead fabrication building is the 120-foot-high vertical assembly building. In this facility, the major components of the S-II are welded together and its flight systems are installed.

This building includes four vertical assembly stations, (each about 110 feet high and 35 feet in diameter) opening in floors for welding, insulation, system installation, and combined systems checkout. It also includes two hydrostatic test stations for liquid oxygen tank and liquid hydrogen tank hydrostatic (water-pressure) testing.

Another Seal Beach facility is the water conditioning plant which contains tanks and equipment to furnish demineralized water, heat detergent solution and trichloroethylene for the hydrostatic testing and cleaning operation. It includes water pumps and a storage tank for fire fighting, and compressors and equipment to furnish air at 100 pounds of pressure per square inch.

The structural static test facility includes a test tower with hydraulic struts for structural testing on an initial test stage. The tower, 138 feet high, will be enclosed on three sides.

Other facilities include the service building, which houses supporting personnel, and another building for the pneumatic test, paint, and packaging operation.

All of these facilities contain revolutionary tooling to accommodate the various components of the S-II. These components are described below.

THRUST STRUCTURE

The five J-2 engines are installed on the thrust structure, a riveted, skin-stringer and internal frame construction which resembles a miniature amphitheater. This part is fabricated in four panels and has a machined cylindrical skirt. A heat shield atop the thrust structure protects the base area of the stage against recirculation of hot engine exhaust gases and heat from the exhaust. The heat shield is of lightweight construction protected by low-density ablative material. This structure fits partially into the aft interstage assembly and around combustion chamber of the engines; the assembly is shown in Figures 6 and 7.

INTERSTAGE

The interstage, fabricated at North American's Tulsa plant, is of riveted, semi-monocoque, skin-stringer construction. (Semimonocoque means that the S-II's skin is

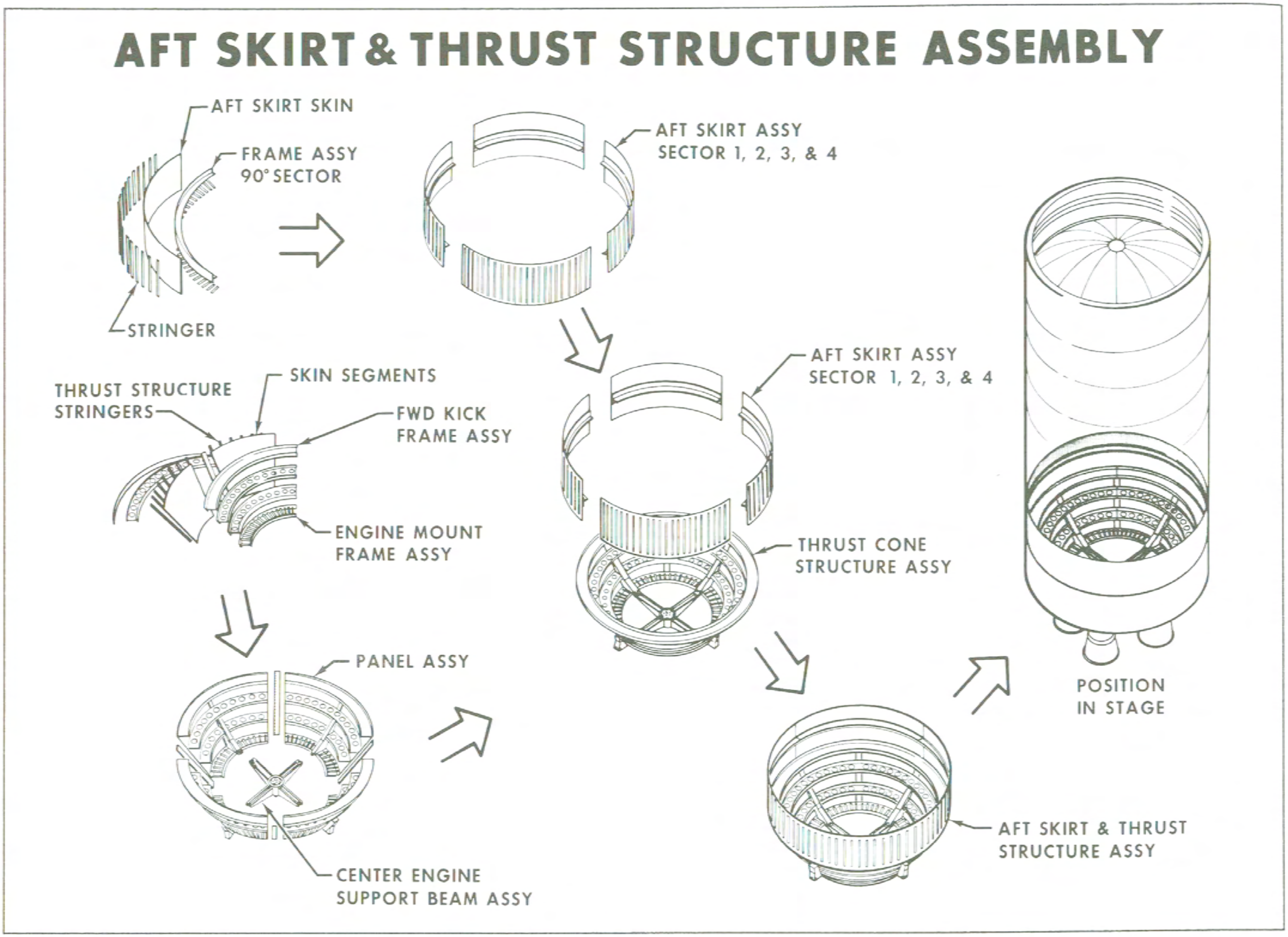
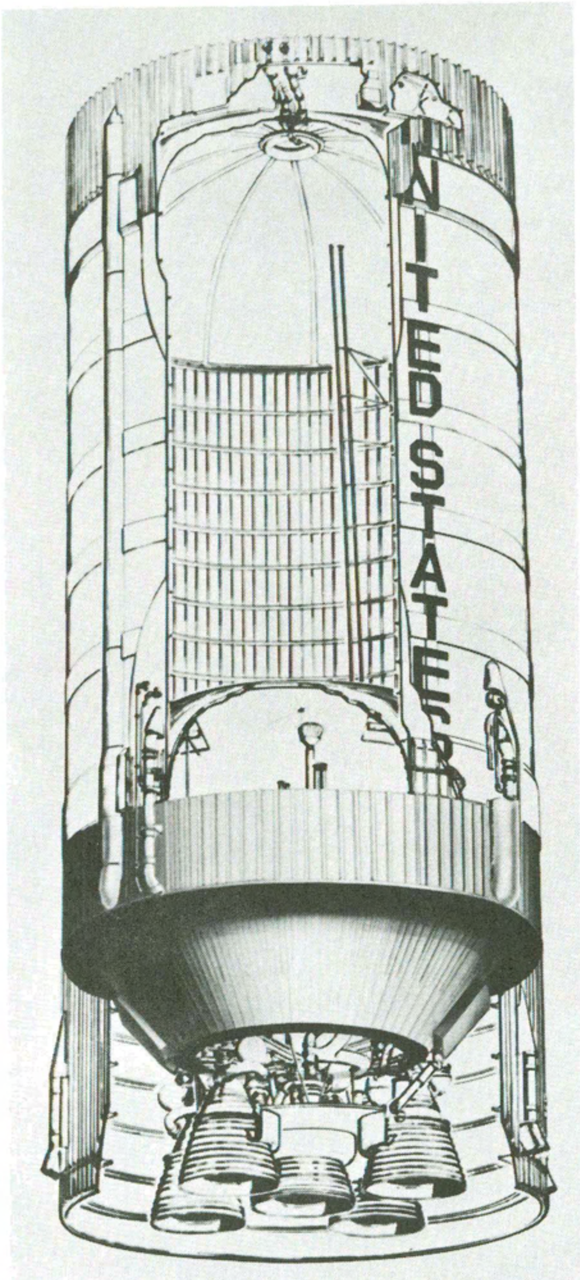

AFT SKIRT & THRUST STRUCTURE ASSEMBLY
AFT SKIRT SKIN
FRAME ASSY
90° SECTOR
STRINGER
AFT SKIRT ASSY
SECTOR 1, 2, 3, & 4
THRUST STRUCTURE
STRINGERS
SKIN SEGMENTS
FWD KICK
FRAME ASSY
ENGINE MOUNT
FRAME ASSY
AFT SKIRT ASSY
SECTOR 1, 2, 3, & 4
THRUST CONE
STRUCTURE ASSY
PANEL ASSY
CENTER ENGINE
SUPPORT BEAM ASSY
POSITION
IN STAGE
AFT SKIRT & THRUST
STRUCTURE ASSY

Figure 6.



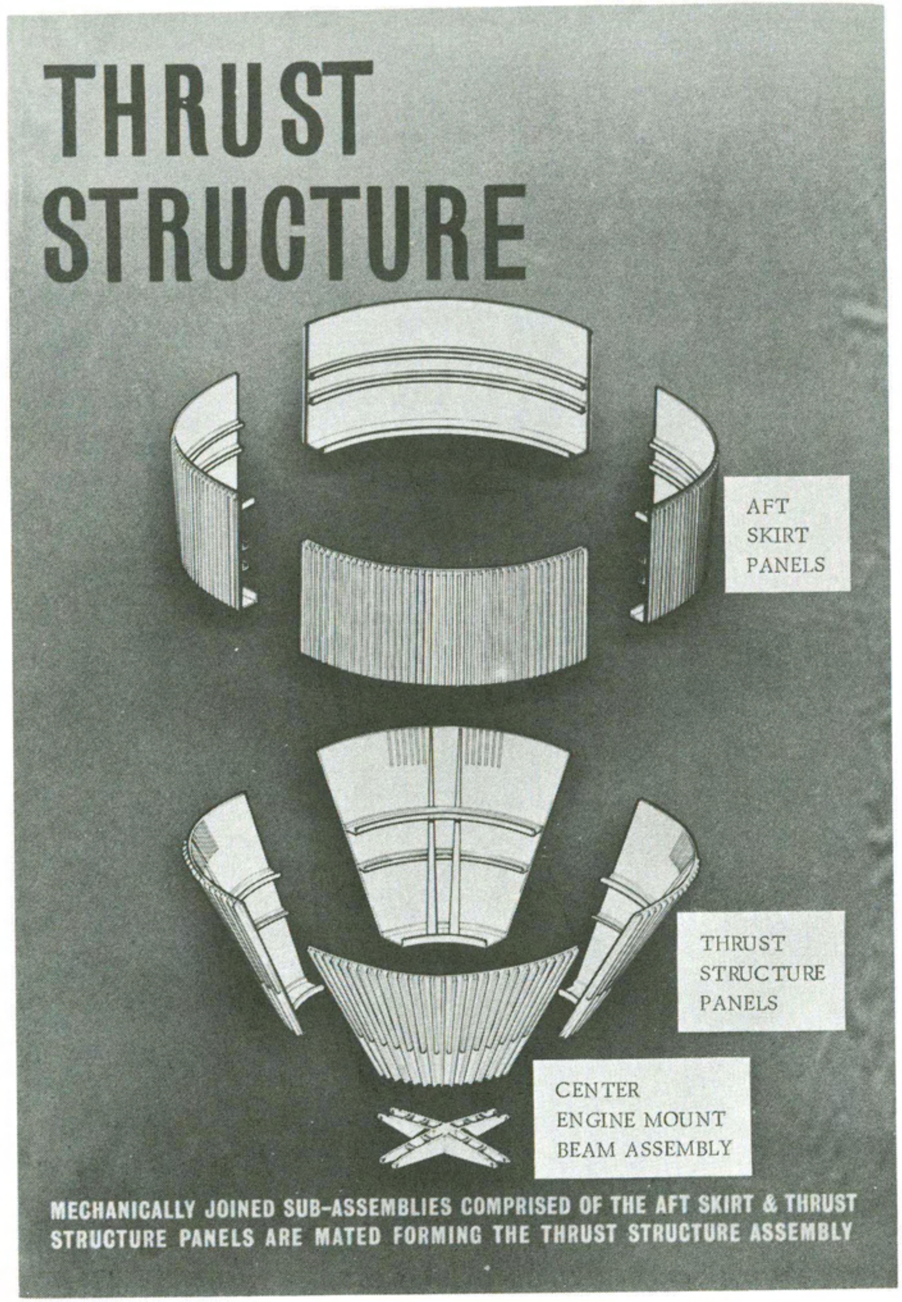

THRUST STRUCTURE
AFT SKIRT PANELS
THRUST STRUCTURE PANELS
CENTER ENGINE MOUNT BEAM ASSEMBLY
MECHANICALLY JOINED SUB-ASSEMBLIES COMPRISED OF THE AFT SKIRT & THRUST STRUCTURE PANELS ARE MATED FORMING THE THRUST STRUCTURE ASSEMBLY

Figure 7.

primarily without an internal framework). The interstage is 219 inches long with a 396-inch diameter and has a 30- by 30-inch access door. A master mating gauge is used to drill the bolt pattern so that the interstage fits to the S-IC stage below. An aft skirt and thrust structure delivered to Seal Beach for use on the static test stage will be used by engineering development laboratory personnel for stress-load testing.

FORWARD AND AFT SKIRTS

The forward skirt also is a riveted, semimonocoque, skin-stringer structure. It is 137 inches long and has a 30- by 30-inch access door. It is fabricated in four panels with external longerons and subassembled internal frames. The aft skirt, similar in construction, is 88 inches long.

A master mating gauge is used to drill the bolt pattern to ensure that the skirts mate precisely to the upper and lower stages.

BOLTING RING

The bolting ring supports the liquid oxygen tank by attaching it to the S-II structure with 600 bolts. A top flange of the ring connects to the first liquid hydrogen tank cylinder and a bottom flange connects to the aft skirt. The "J" section of the common bulkhead is welded to the first cylinder.

CYLINDERS

Each of the six liquid hydrogen cylinders comprises four panels welded together. Five of the cylinder panels are 8.3 feet high and 27 feet long, the other panel is 28 inches high. Longitudinal and circumferential stiffeners are machine-milled on the inside surface to a rectangular grid pattern. The original thickness of the panel is two inches. It is milled to approximately a quarter-inch thickness between the stiffeners.

In order to prevent boil-off of the -423 degree Fahrenheit liquid hydrogen, insulation is bonded to the external surface of each cylinder. This insulation is made of phenolic honeycomb filled with isocyanate foam. Two laminate nylon external sealing skins are bonded to the honeycomb insulation.

These cylinders are welded together during final assembly of the S-II in the vertical assembly building. Figures 8 and 9 show these cylinders.

LH_2 CYLINDER PANELS

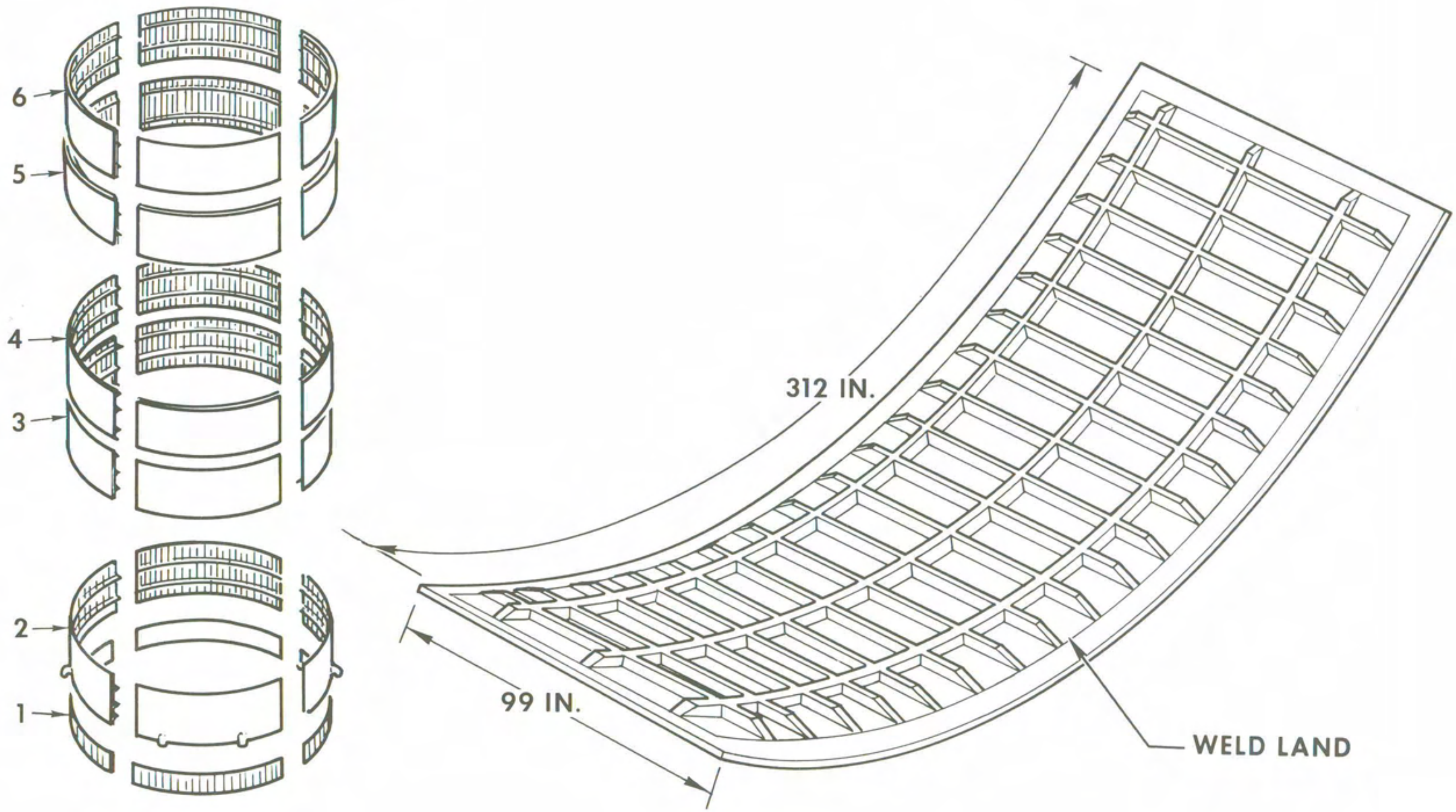


Figure 8.

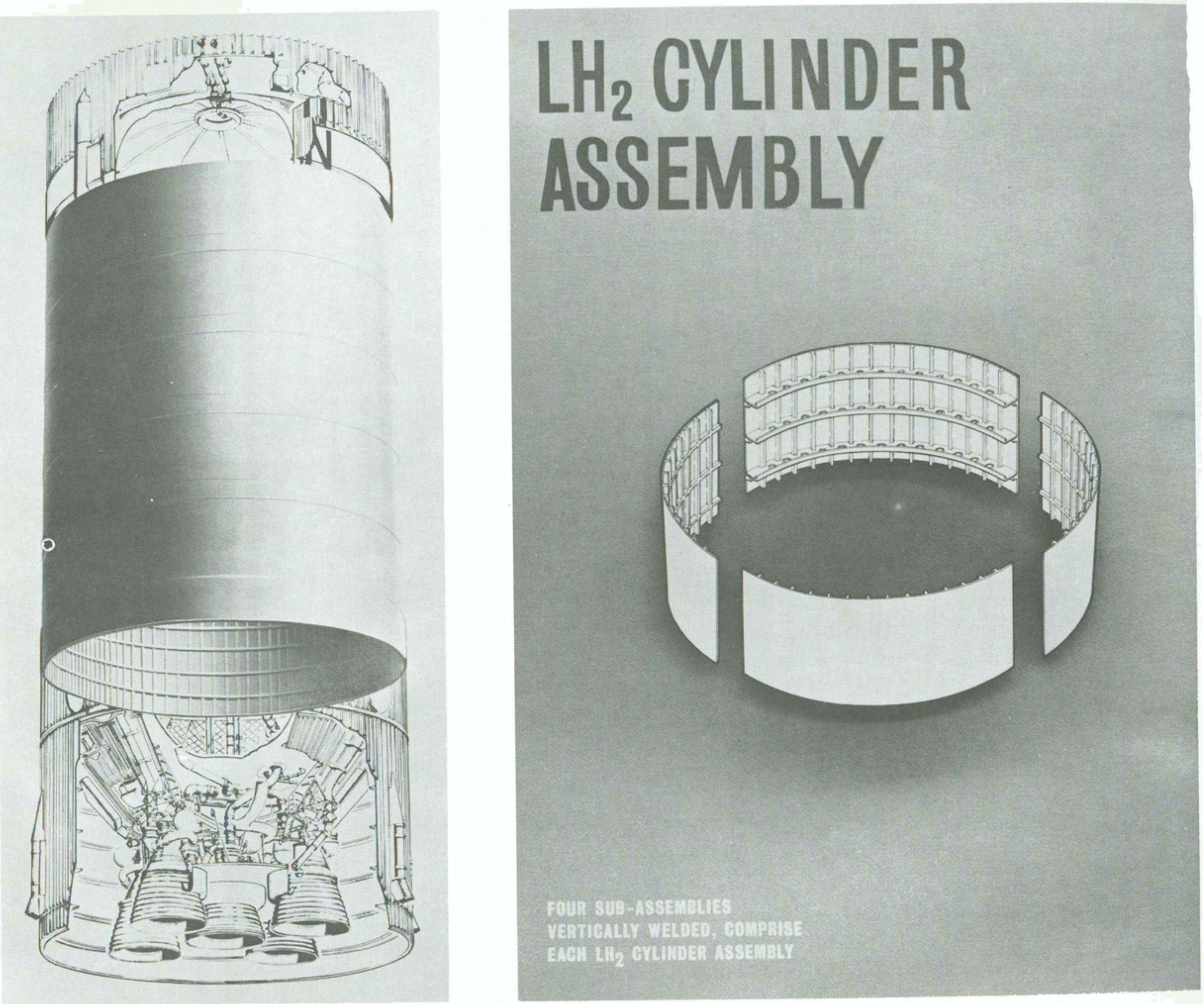

LH2 CYLINDER ASSEMBLY
FOUR SUB-ASSEMBLIES
VERTICALLY WELDED, COMPRISE
EACH LH2 CYLINDER ASSEMBLY

Figure 9.

BULKHEADS

All of the bulkheads (Figure 10) are the same size with one exception. The forward common bulkhead is slightly larger since it must fit over the aft common bulkhead. The 12 gores that comprise each bulkhead are approximately 20 feet long and 103 inches wide. They vary in thickness along the weld land (longitudinal area where the gores are welded together) from one-half inch to one-eighth inch. They are welded together on an electrically controlled, hydraulic bulkhead weld fixture.

The common bulkhead may be likened to two giant domes, one placed inside the other, open end down, with a layer of insulation (of varying thickness) sandwiched between them (Figures 11 and 12). The top dome is the forward common bulkhead and the bottom dome the aft common bulkhead. The aft common bulkhead gore is different from the other bulkhead gores in that each of its gores is composed of a thick section (resembling a waffle) at the wide end and a thin section. These are welded together on the thick-to-thin welding fixture.

The forward common bulkhead (sometimes called the lower LH_2 bulkhead, Figure 13) consists of a thin dome with a J-section on its periphery that allows for expansion of the bulkhead when it is filled with liquid hydrogen. The section resembles a "J," and the lower lip is welded to the liquid hydrogen cylinder.

In order to bond the phenolic honeycomb insulation to the aft common and forward common bulkheads, several operations are performed. The aft common bulkhead is placed first on the bonding fixture, a dome-shaped tool resembling the bulkhead. Then the honeycomb core insulation, in numerous sections, is fitted to the bulkhead. The sections are then tapered to exact thickness specifications by machining, the thickest part being 4.75 inches. They are then bonded and cured in the autoclave. The cured insulation is removed and stored so the bulkhead can be lifted by the huge 50-ton gantry crane, inverted, and transferred to the processing room. The bulkhead is inverted by a mechanical and pneumatic turn-over sling.

In the processing room, which resembles a huge sunken bath, the bulkhead is lifted onto a circular wall and receives a spray bath with a solution of 24 percent sulfuric acid, detergent, and water. This prepares it for receiving the adhesive which holds the honeycomb. After the adhesive is put on the bulkhead, insulation cores are placed over it. The entire assembly is lifted onto the autoclave which pressurizes and cures the adhesives. Full pressure and heat is applied by the autoclave for an hour only, although several hours are required before and after full pressure and heat to prevent too rapid a temperature change, which could cause buckling of the bulkhead.

When the aft common bulkhead is removed from the autoclave and placed on the bonding fixture again, the forward common bulkhead is mated to it. To ensure a perfect fit, several impression checks are taken. Then the forward common bulkhead receives a