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Operational Experiences on the Saturn V S-IVB Stage

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WHEN THE UNITED STATES made the decision in 1961 to undertake a manned lunar landing effort, many of the basic technological capabilities were already coming into being. On Oct. 27, 1961, the first Saturn I SA-1 booster was flight tested successfully. On Jan. 29, 1964 the Saturn I SA-5 vehicle was launched with an active second stage, the first Douglas S-IV liquid oxygen and liquid hydrogen propellant stage, using six R L 10A-3 engines. This was the first of the six completely successful flight performances of the S-IV stage.

The technical questions facing NASA space planners in 1961 and 1962 were complex. Although the use of Saturn I for a manned lunar landing was theoretically possible, it would require about six Saturn I launches, their payloads being assembled in earth orbit to form a moon ship. This procedure is called the earth orbital rendezvous (EOR) technique. Remember, at that time, no space rendezvous and docking had taken place.

By mid-1962, two key decisions were made:

1. To develop a new general purpose launch vehicle; this vehicle now known as the Saturn V was given the go-ahead in January 1962.
2. To conduct the manned lunar landing by using the lunar orbit rendezvous (LOR) technique instead of the earth orbital rendezvous technique.

The Saturn V would be composed of three propulsive stages and a small instrument unit to contain guidance and control. It could perform earth orbital missions through the use of the first two stages. However, all three stages would be required for lunar and planetary expeditions. The first, or ground stage, would have five F-1 engines developing five times the power of the Saturn I booster then under development. The upper stages would use the Rocketdyne J-2 hydrogen/oxygen engine, five in the North American Rockwell second stage, and, one in the Douglas third stage. Each such engine would develop a maximum of 225,000 lb of thrust at altitude. The Saturn V was originally sized to be capable of placing 120 tons into earth orbit or dispatching 45 tons to the moon. These performance numbers have since been uprated to more than 125 tons to earth orbit and approximately 50 tons to the moon.

As part of the original Saturn V decision, it was determined that elements of the existing Saturn I vehicle and the planned Saturn V would be combined to form a new mid-range vehicle, now called the Saturn IB. The Saturn IB would have a payload capability 50% greater than the Saturn I and would make possible the testing of the Apollo spacecraft in earth orbit earlier than would be possible by using the Saturn V.

In response to these overall plans of NASA, the Missile and Space Systems Div. of the Douglas Aircraft Co. (now the McDonnell Douglas Astronautics Co. - Western Div.) was eventually placed under contract to the NASA/ Marshall Space Flight Center to design, develop, and provide launch/ mission planning and support for:

1. Six S-IV second stages for the Saturn I Launch Vehicle.
2. Twelve S-IVB second stages for the Saturn IB Launch Vehicle.
3. Fifteen S-IVB third stages for the Saturn V Launch Vehicle.

This paper is intended to present a light, but reverent, discussion of some of the operational experiences we have had on the Saturn V/S-IVB stage, and along the way, where appropriate, we may touch on certain relevant aspects of some of our earlier work on the Thor intermediate range

ABSTRACT

This paper presents a light, but reverent, discussion of some of the Douglas operational experiences on the Saturn V/S-IVB stage. Certain relevant aspects of earlier work on the Thor intermediate range ballistic missile, the Saturn I S-IV stage, and the Uprated Saturn I S-IVB stage are also discussed.

ballistic missile, the Saturn I S-IV stage, and the Saturn IB-S-IVB stage.

In summary, Fig. 1 shows the Saturn family. A pretty impressive family when you consider the size, complexity, and power of these three vehicles.

Fig. 2 shows the stages for which we have had the responsibility of design, manufacture, test, and launch/mission planning and support. Just how we got from the 60 ft Thor to the 363 ft Saturn V provides quite a history.

Some of the technological developments go back to the Thor launch vehicle which Douglas designed in 1955, and which is still very active for the Air Force and NASA. It was on Thor that we developed the highly successful lightweight aluminum tank construction using the milled waffle pattern for integral tank stiffening. Another important technological development was the technique for handling cryogenics -- in those early days it was liquid oxygen only.

Our experience on Thor laid the ground work for the first of the Saturn stages, the S-IV (Fig. 3) of the Saturn I vehicle. The S-IV was 48 ft long, 18 ft in diameter, powered by six Pratt & Whitney RL10A-3 oxygen/hydrogen engines generating 90,000 lb of thrust -- and the stage weight at launch was 114,000 lb. Six vehicles made up the S-IV portion of the program -- all six of these vehicles were launched successfully.

Just as Thor technology led us to S-IV, the S-IV led to the S-IVB. In order that we could capitalize on the S-IV technology to the maximum, a stage diameter of 220 in. was originally chosen. This stage was first designed to coast in low earth orbit for up to 30 days and rendezvous with the Apollo and/or other S-IVB stages or tankers to be joined into a total system in earth orbit prior to injection into a lunar transfer orbit.

As the Apollo mission evolved from earth orbit rendezvous

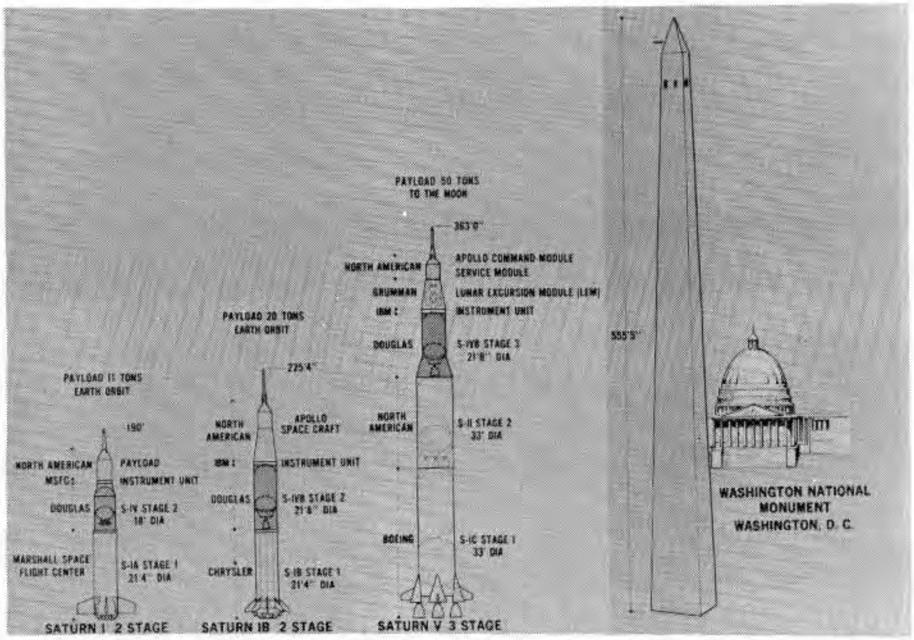

Fig. 1 - Saturn comparison

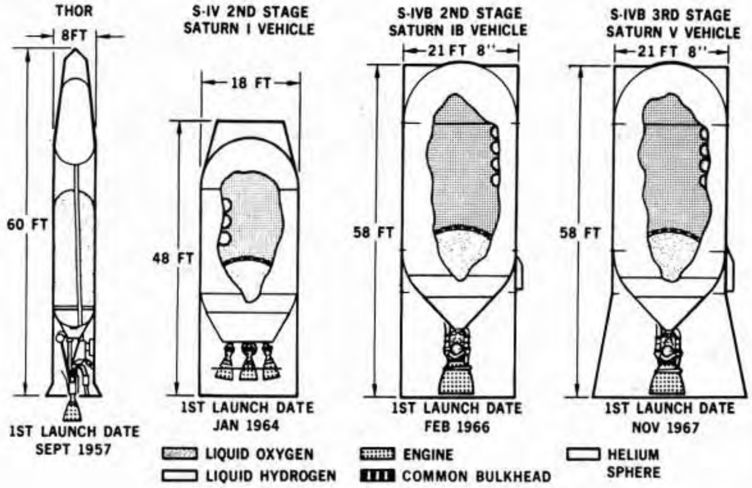

Fig. 2 - History of technology

to lunar orbit rendezvous (Fig. 4), the mission of the S-IVB changed to a four-day coast and then to its present 4-1/2 hr in low earth orbit coast with 2 hr in a translunar coast (which includes a brief stabilization period after burnout for the Apollo turn around maneuver).

During this entire design period, however, the basic stage diameter stayed at 220 in., with an interstage to adapt to the S-II diameter of 396 in. Only a short time prior to our S-IVB contract award for the Saturn V version did we change to the present 260 in. tank diameter (21.8 ft) (Fig. 5). The tank diameter of 260 in. was selected because this best matched the then-evolving use of S-IVB on Saturn IB to gain needed payload capability for earth orbital testing of Apollo components (Figs. 6 and 7).

Douglas started the Saturn S-IV program in 1960. Now, eight years later, one can ask the reasonable question: How much did we learn? What were the highlights?

To begin the story of the Saturn V/S-IVB stage program, let us refer to the program flow plan (Fig. 8) which shows you what happens to the stage from manufacturing to launch. Our detail manufacturing is at the Santa Monica, Calif. facility, from there to the Huntington Beach, Calif. now the McDonnell Douglas Astronautics Headquarters for final assembly and checkout, on to our Sacramento Test Center, also in California, for acceptance firings, and then to the John F. Kennedy Space Center, Florida, where it is stacked with the other stages to complete the Saturn V launch vehicle.

The challenges of this stage were as many for engineering, as for tooling, procurement, and manufacturing.

Our key technological experience and knowledge came from the six earlier S-IV stages: such as, the internal insulation (to reduce LH_2 boil off rates to an acceptable level) and the forward, aft domes and the common bulkhead.

Fig. 9 shows the Santa Monica facility where the domes and bulkheads are machined, contoured, and welded. Fig. 10 shows the fixture that is used for welding the nine "orange peel" segments that make up the dome and the bulkheads. It looks relatively simple today, but to get there was not. You can say we cut our eye teeth on this phase of manufacturing. The rotating fixture and "down hand" welding

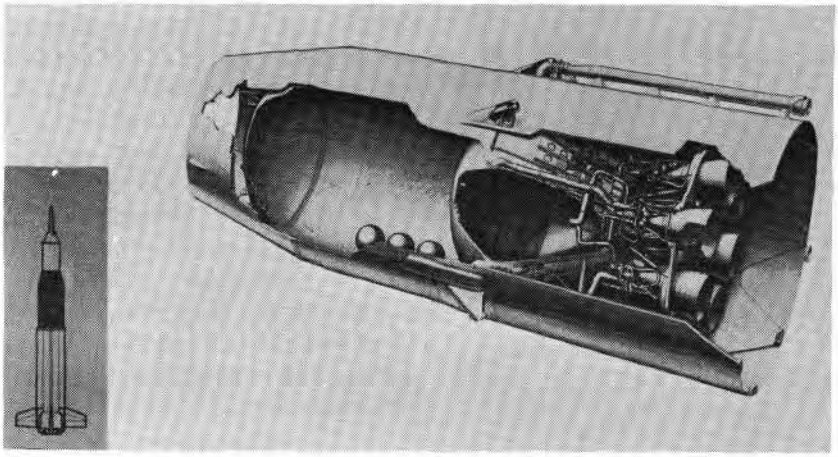

Fig. 3 - Saturn IV

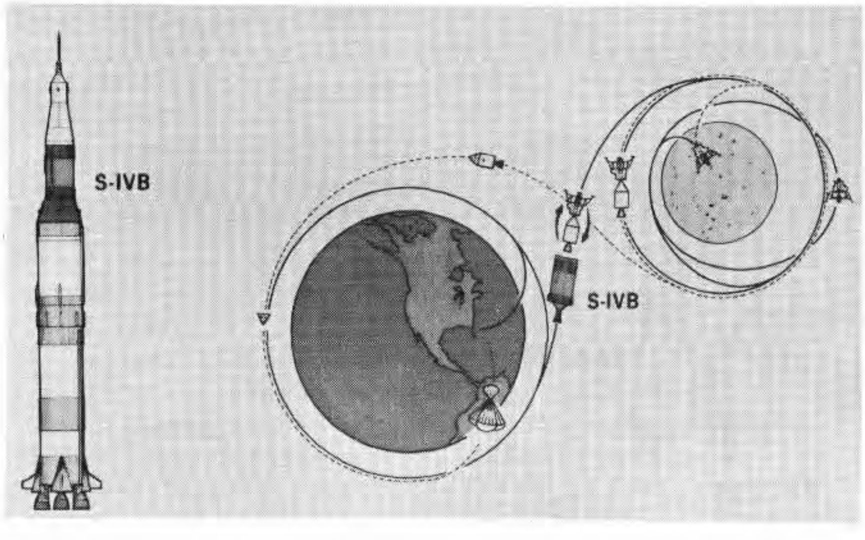

Fig. 4 - Saturn V mission profile manned lunar flight

techniques were used. This technique was selected because the molten "puddle" is held in position by gravity in the weld fixture to minimize porosity.

One strange welding problem developed. The torch head would not follow the weld seam -- as the fixture rotated, the head wandered. The problem was solved very simply when it was realized that the segments were too smoothly machined. The weld torch tracking system is based on detecting the discontinuity of induced eddy currents at the seam. Because the individual segments had been so carefully formed and sized, upon butting them together no sensable level of electrical discontinuity to the instrument resulted. Since the manufacturing people objected to the recommended "fix" of roughing up of the seams with a bastard file, they scarfed the segments and redesigned the tracking mechanism to one that had a much higher gain.

The welded common bulkhead shell of 130 in. hemispheric radius is shown in Fig. 11. Two 2014-T6 A2 aluminum shells (the forward face 0.032-in. thick and the aft face 0.055-in. thick) make up the 21.75-ft diameter bulkhead with a 1-3/4 in. thick fiberglass honeycomb core acting as a thermal barrier between the LH_2 tank and the LOX tank. This dome withstands the temperature difference of LH_2 at -423 F on one side and LOX at -297 F on the other side. It also made it possible to design a simple and shorter tank structure which reduced the total stage structural weight by 20%.

The Santa Monica facility assembles the 2,828 cu ft/ 191,000 lb/20,000 usable gallon capacity LOX tank before shipping it to the Huntington Beach facility (Fig. 12).

When the Huntington Beach facility was ready for occupancy in late 1963, we had designed and built one of the most modern aerospace plants in the country, all out of capital funds (Fig. 13).

At this location in Fig. 14 we assemble and checkout the stages. In this manufacturing area we weld the seven-segment cylindrical position of the LH_2 tank on the Panjuris

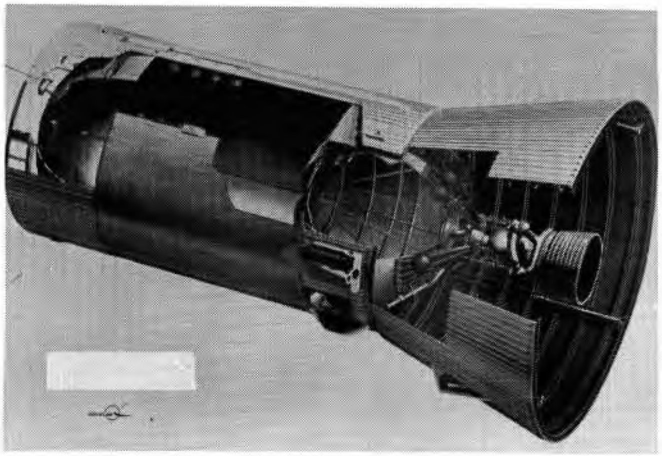

Fig. 5 - Saturn V third stage

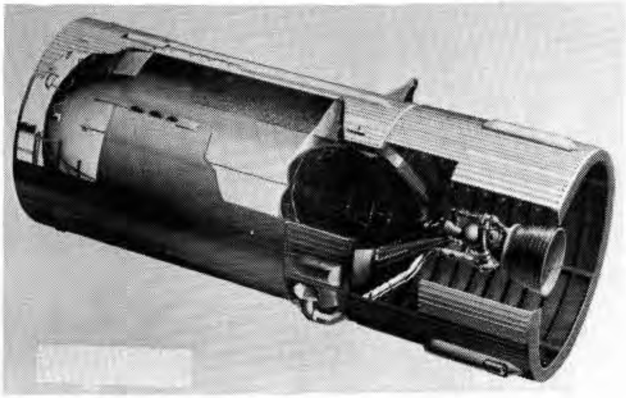

Fig. 7 - Saturn IB second stage

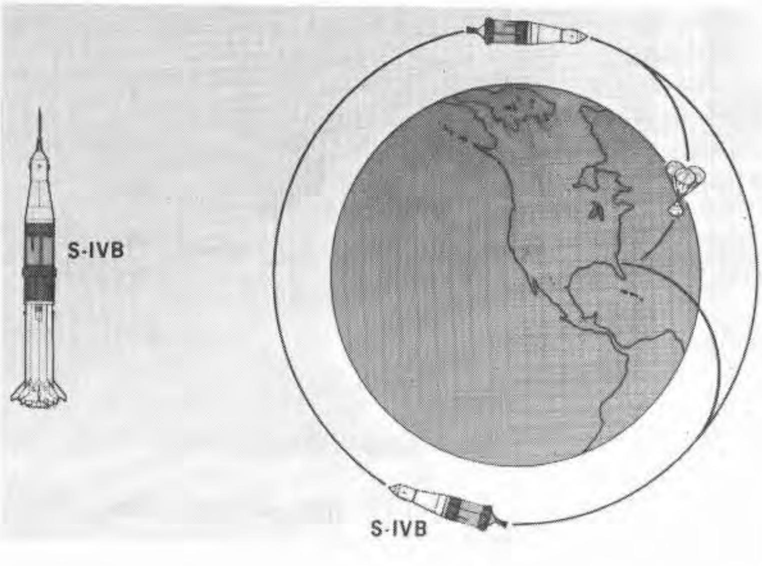

Fig. 6 - Saturn IB mission profile manned earth orbit

welder (Fig. 15). Note the waffle pattern. This pattern, machine milled from aluminum plate, was a development from the Thor program and saved tank weight and increased wall strength. Fig. 16 is the completed cylindrical section of the LH_2 tank.

The Saturn V S-IVB stage is joined in this tower at Huntington Beach (Fig. 17). The welding techniques are essentially the same for joining the LH_2 tank to the LOX tank and the forward and aft bulkheads. This completed assembly

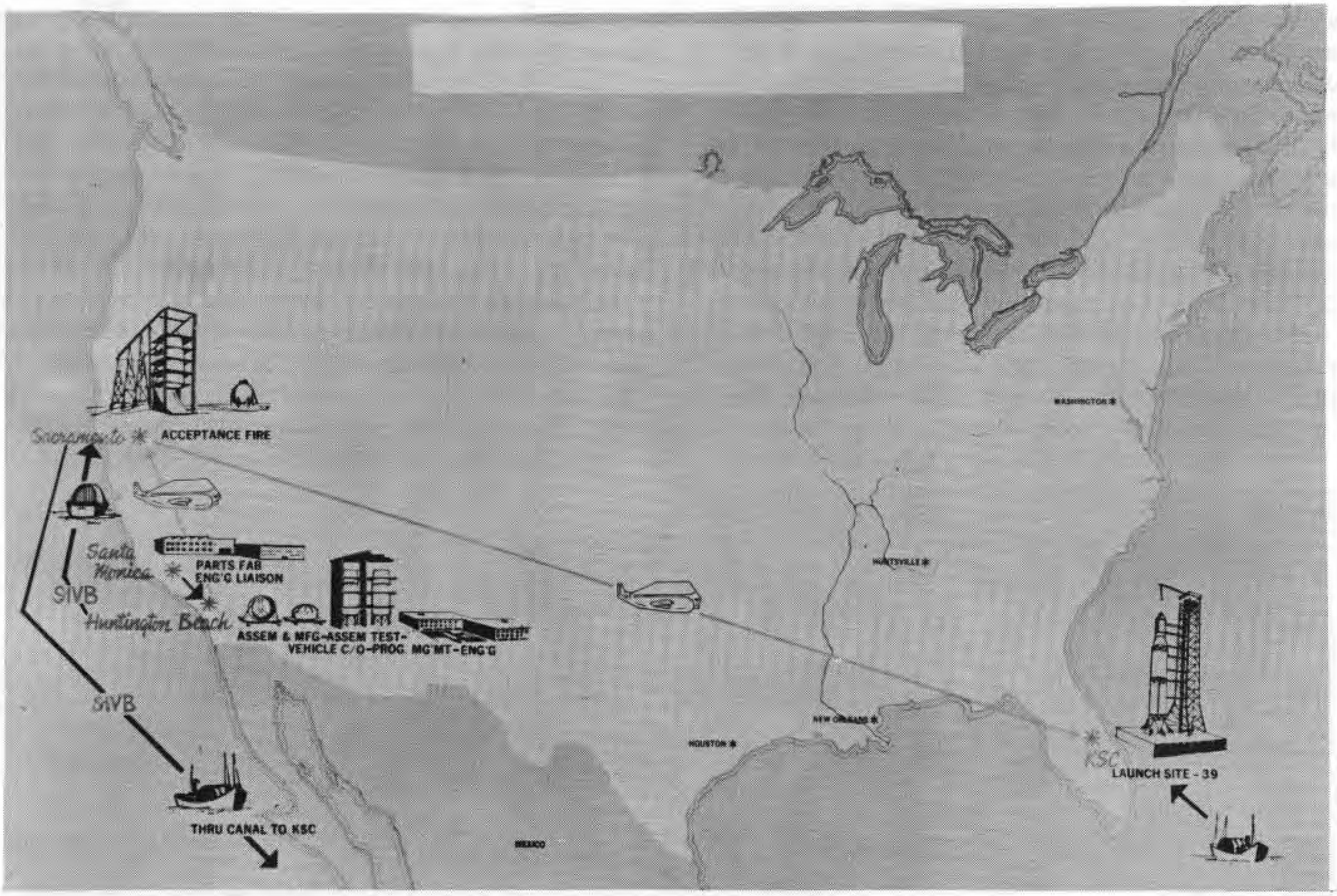

Fig. 8 - Saturn S-IVB program flow

Fig. 9 - Santa Monica facility

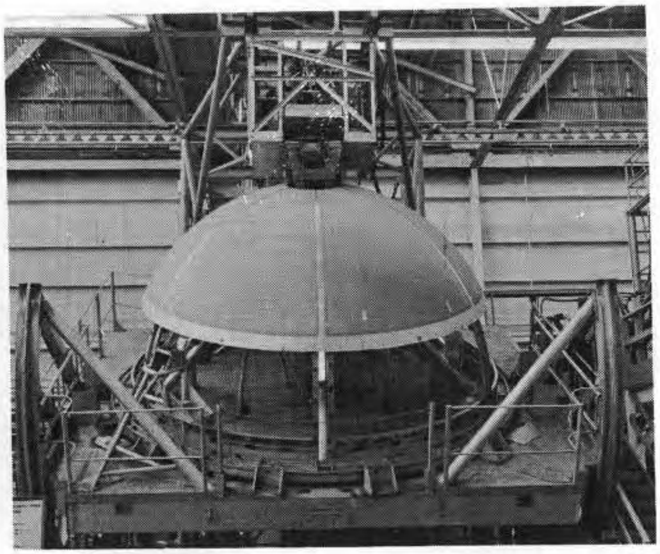

Fig. 10 - Common bulkhead fixture

Fig. 11 - Bonding forward and aft faces of common bulkhead

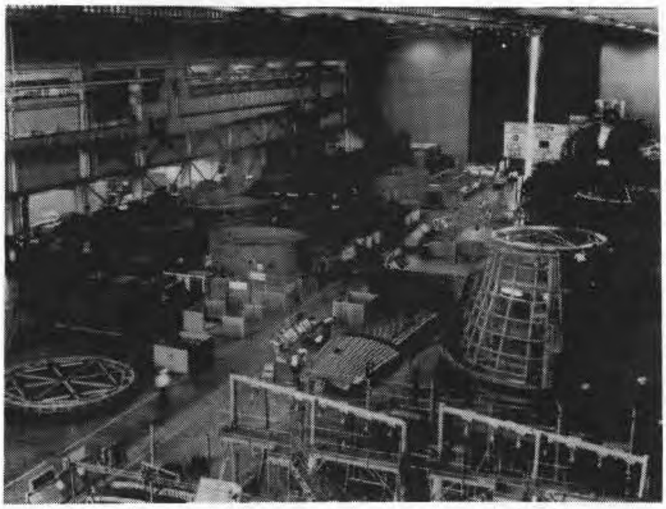

Fig. 14 - Missiles and Space Systems - one of the manufacturing areas

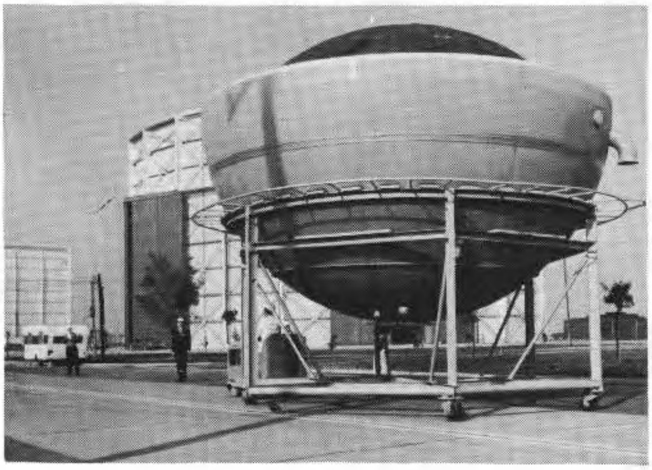

Fig. 12 - Completed LOX tank

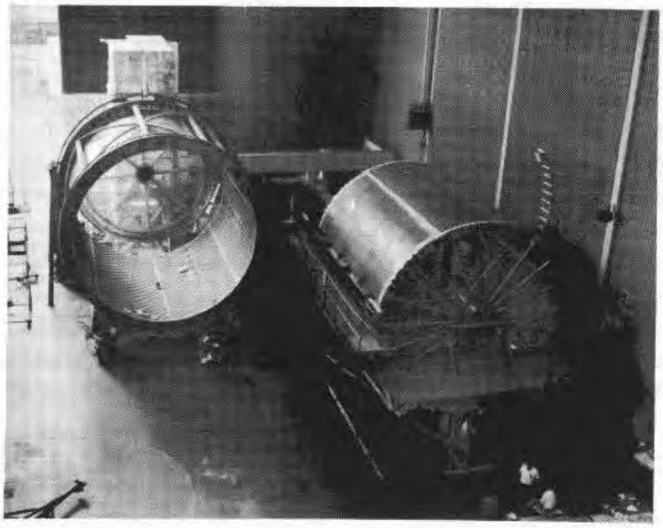

Fig. 15 - Panjuris welding of cylindrical section of tank (LH_2)

Fig. 13 - Huntington Beach facility

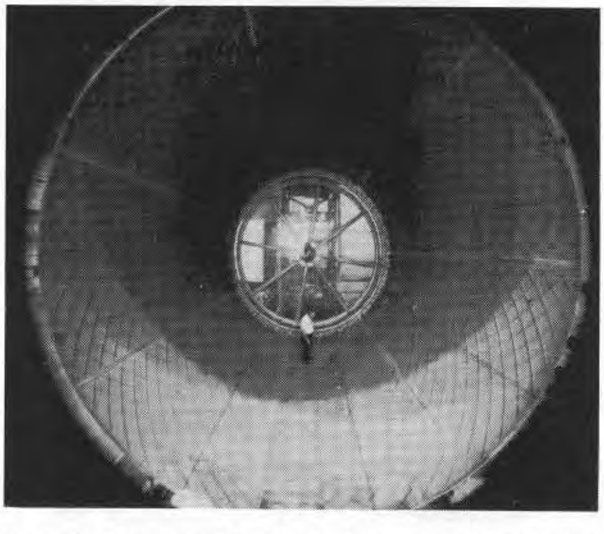

Fig. 16 - Completed cylindrical section of tank (LH_2)

is then tested hydrostatically, followed by dye check and X-ray.

You gain experience, on a program of this magnitude, the hard way and sometimes in an odd way. One such example of the unexpected was our hydrostatic test setup. We had a very elaborate setup, to control the loading of water. The system was designed for redundancy containing automatic controls and instrumentation. It failed to do the job and we damaged one of our stages due to inadvertent overpressurization. After a lengthy analysis, it was decided to use a system so old and basic that it had almost been forgotten. A standpipe -- one that extended beyond the roof so that the tank could not be overpressurized, since the system would spill the excess water overboard.

The standpipe at Huntington Beach is over 140 ft high complete with bird cage -- to prevent birds from nesting -- and an aircraft beacon for safety.

Soon after the Saturn stages were in production at the new Huntington Beach facility, the workmen complained of the pigeons flying among the rafters. Their droppings were not only contaminating the stages but the people, as well.

The project "Pigeon Elimination" got underway, and high frequency air whistles were installed in the buildings. At first they were very successful, but not for long. Back came the pigeons. Since the hazards of shooting pigeons indoors were only too obvious, a team of investigators spent considerable time with ornithologists to find a solution. In the meantime, the building doors were kept closed, but pigeons found openings where the hangar door tracks were installed. The solution turned out to be specially treated seeds that affected the pigeons' nervous systems temporarily. After eating the seeds they would sit very still for a while and then fly away. I am convinced that the birds do tell each other ("avoid eating at Douglas,") because since applying this harmless but bizarre treatment, pigeons are no longer a problem. Yet it took some time to solve. (The grain is replenished every 60 days -- just in case!)

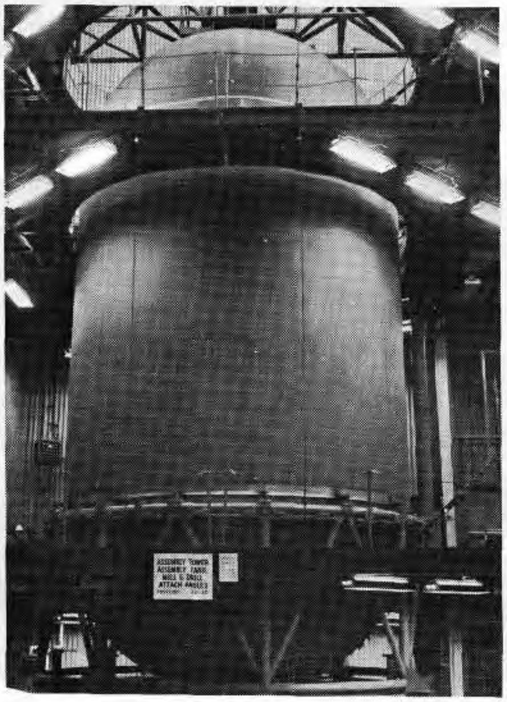

Fig. 17 - Saturn V S-IVB stage joining tower

At the start of the Saturn S-IV program in 1960, we took the somewhat controversial course of insulating, internally, the LH_2 10,446 cu ft/37,000 lb/63,000 gal capacity tank. Efficient insulation for LH_2 was an unknown quantity then; and, not much was known, for that matter, about the LH_2 characteristics when handled in large quantities.

Even when properly insulated, a LH_2 tank filled to 100%

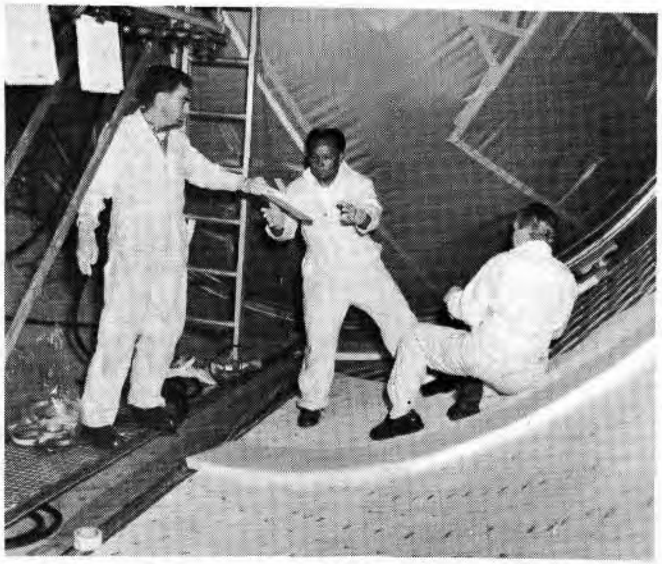

Fig. 18 - Laying insulation tile in LH_2 tank

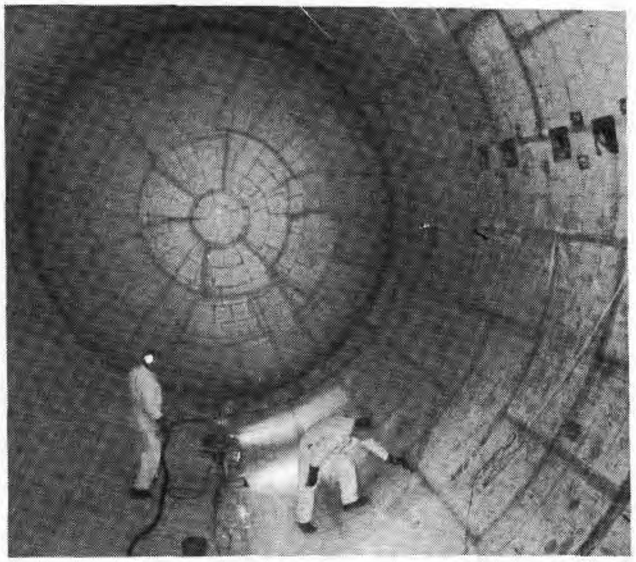

Fig. 19 - Completing interior insulation (LH_2 tank)

before launch must be replenished, at LH_2 flow rates up to 300 gpm, as required, to compensate for boiloff. In Fig. 18 you see workmen laying in the polyurethane tiles and in Fig. 19 the tank is completely insulated prior to the glass cloth liner and sealant being applied.

Countless materials were tested without success. But one investigation team came up with balsa wood as a liner. Balsa had all the right characteristics -- but S-IV tanks were 18 ft in diameter and 33 ft long -- and the S-IVB tanks were 22 ft in diameter and 40 ft long. It required lots of liner material. The balsa forests of South America were surveyed, probably by referring to the National Geographic; and, the uneasy conclusion reached was that supplies might not always be available. Testing, however, proved that balsa wood did contain flaws, and our Quality Control people assured management that balsa trees could not be grown flawlessly. However, our first test tank was lined with balsa and it worked fine. The production insulation is polyurethane tile (our version of flawless balsa) and it represents the results of a long and complicated testing program.

The first attempts to develop "flawless balsa" utilized a foam filled fiberglass honeycomb. Test results showed that the foam tended to shrink away from the sides of the honeycomb and allowed hydrogen to penetrate through to the wall. Then attempts were made at force-pressing fiberglass honeycomb a fraction of the distance through the foam, but it resulted in a shear plane located at the interface between the honeycomb and the foam which caused horizontal cracking. The most successful and the ultimately adopted configuration was a three dimensional lattice of fiberglass threads filled with the polyurethane foam. Here fiberglass threads were spaced approximately 3/16 in. apart in all three planes, forming a lattice work, and the foam allowed to rise during the foaming process. While tests on this material were highly successful, the problem was one of being able to manufacture the three dimensional lattice work. While it's easy to build a frame work of threads in two dimensions (X and Y), it took ingenuity to design a machine that could weave the final thread in the Z plane. Fig. 20 shows the "X-Y" machine where the threads are wound on special frames. The frames are stacked alternately at right angles (Figs. 21 and 22) to each other which arranges the threads in two of the three axes. Fig. 23 shows the "Z" machine threading needles. The frames with the "X and Y" threads are placed on this machine and the special needles weave the fiberglass as threads in the "Z" axes. The threaded frames are then placed

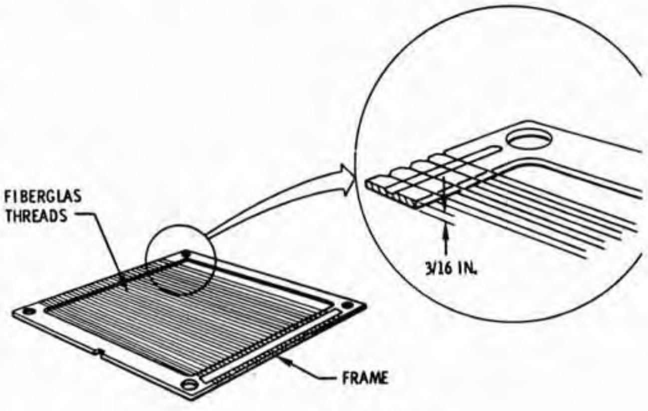

Fig. 21 - X-Y frame

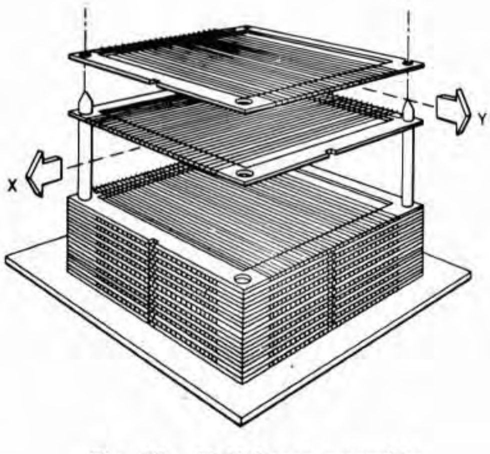

Fig. 22 - X-Y frame assembly

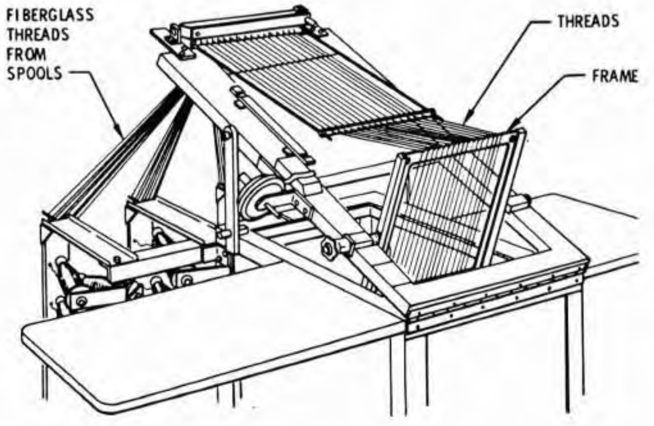

Fig. 20 - X-Y thread wrapping

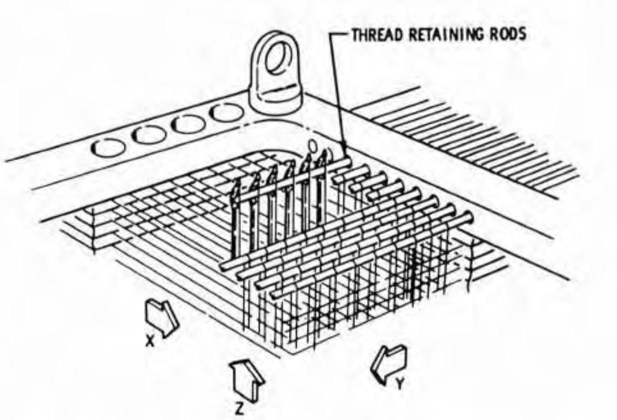

Fig. 23 - Detail - Vertical (Z) thread retaining rods

in a mold (Fig. 24) and polyurethane foam is poured over the threads. After the foam is air cured the "cones" are removed (Fig. 25) and then sawed into blocks for machining into the tiles with concave or convex contours, as necessary. Once this is accomplished, installation of the flawless balsa tile begins.

Through the years, following the successful development of internal insulation, we have often been asked whether we would do the same if we had to do it all over again. The history and experience that we have had on the S-IV and S-IVB programs have shown us that this insulation is relatively lightweight, and provides the necessary thermal characteristics for mission durations up to 4 1/2 hr in space. Most importantly we feel that it is sufficiently free from maintenance problems, sensitivity to handling, storage, repeated thermal shock, and transportation for us to stick with this configuration. While this insulation is not competitive with the newer high performance insulations for very long term storage in space, it has certainly been a reliable material for the S-IVB.

In a program such as the Saturn V, testing represents about one half of the total effort in terms of manpower and physical resources. The testing and reliability design goal is 0.95. However, what is wanted is an achieved reliability of 1.0 for each launch.

To obtain this extremely high reliability number, some specifics may help you appreciate the extent of our test program.

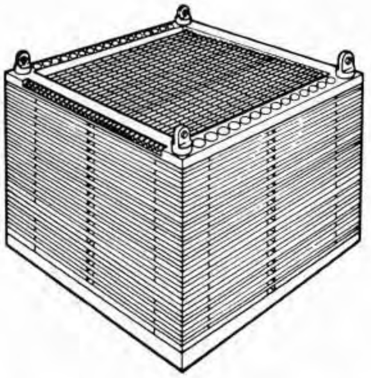

Fig. 24 - Assembly of frames and threads

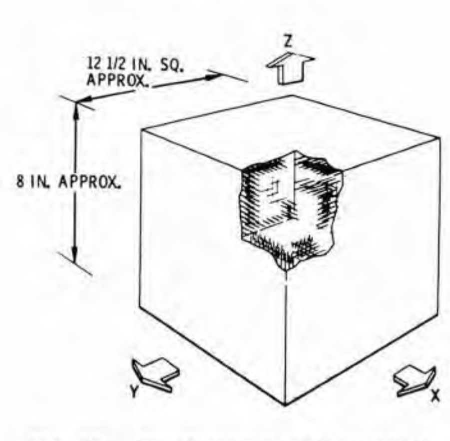

Fig. 25 - Rough trimmed foam block

There are six categories of tests: Production Acceptance Testing, Development Testing, Qualification Testing, Formal Qualification Testing, Reliability Verification Testing, and Repeat Qualification Testing.

The primary philosophy upon which this extensive test program is based is to ensure that each component, module, assembly, subassembly, and system of the stage is subjected to environments and conditions equal to or more critical than those experienced in the planned mission. The Production Acceptance Tests are established to screen out substandard parts prior to assembly into a subsystem or larger system. Development Testing evaluates hardware during the initial phases of design. Qualification Testing ensures design suitability for use on flight stages and is considered as the end result of a successful design evaluation phase. The Formal Qualification Test program is intended to demonstrate that the hardware will satisfy established requirements under various combinations of service environments. Reliability Verification Testing provides increased engineering confidence in the probability of successful flight performance. This testing includes overstressing to confirm that selected components will withstand greater stress levels than that to which they will be subjected during flight. Repeat Qualification Testing is a continuing program in which flight critical items are randomly selected from production hardware and subjected to original qualification test environments. The primary purpose of these tests is to ensure that existing performance is maintained and reliability confidence levels are maintained.

Test specifications are written encompassing the above test categories, as required. What is the operating environment for the part? What vibration levels must it withstand? Should it be tested to ultimate? These are but a few of the questions the engineer must ask himself. Just to give you some feel for the program, here are a few figures: over 4450 relays, transistors, valves, and such have been tested for the S-IVB program alone; approximately 1600 test specimens, for example, structural coupons, joints, fittings, and weld specimens were fabricated for the test program.

There are 500 major assemblies and installations for each stage and with 28 stages that means a total of 14,500 assemblies and installations. So you can see testing is a big business, and, in addition, we have 2800 vendors supplying parts to the S-IVB stage. Vendors are a vitally important segment of the Saturn community. They are located all over the United States.

Before a vendor is selected he is carefully screened before any subcontracts are signed. Full consideration is given to the complexity of the item, the need for specific technical capability in design and development areas, estimated dollar value, configuration control, and manufacturing requirements. This activity is generally initiated in the definition phase of a program. It is predicted on the (1) buy decision from the Make-Or-Buy Committee, (2) specifications, drawings, and other data for the item, (3) quantity and delivery, reliability, technical data requirements, field support, testing, quality assurance, and security requirements.

One thing we learned that was important to us and the program. The question we began asking was: Does the vendor fully understand the role he plays in Saturn? A small manufacturer, across country, building à critical component or assembly does not always fully understand the criticality of the space program, and here communication is important. Design specifications give only a small part of the story.

It was then that we instituted the Vendor Awareness Program. We developed a seminar-type program and invited a select number of vendors -- 80 companies were invited to six meetings at their own expense. One of the more valuable fallouts was that vendors, like engineers, feel their products do meet the required design criteria. Discussions on quality and reliability can sound like "motherhood;" but, when the vendors got together and started talking and comparing notes, and when they toured our facility and saw the finished product, then we felt these orientation meetings were fruitful. In many instances the vendors went back home and performed a self-audit and found means of improving their product.

One vendor found that among his second tier subvendors several were not on the Douglas approved list -- but not for long.

Other vendors completely revamped their production methods and raised their standards of reliability. No matter how large or complicated a program is, the importance of person to person communication cannot be underestimated.

Of course, before any of this could take place, the engineering design was being developed and drawings released. It is estimated that an average of 5600 drawings are required for the S-IVB stage alone -- and, on the whole every single drawing usually has an average of five changes and for some many, many more. For the ground support equipment over 13,000 drawings were required.

Transportation of the Saturn stages is quite a logistics feat. In the early days it was done by barge from Santa Monica; later from Seal Beach. On one of the first of such occasions, the stage was loaded on the transporter at Huntington Beach in the early morning hours and the trip began at about 4 mph. At that speed nothing much should happen but, as incredible as it may sound, we did run over a very mature and ripe skunk. When the transporter was returned to the Huntington Beach Facility we found that we had a 23-1/2 ft wide, 46-1/2 ft long, 22,000 lb skunk on our hands. You can imagine the actions the salvage board had to take to deodorize it. Fortunately the stage was not contaminated. And, by the time the next stage was ready to be moved, our chemists had reduced the smell to a tolerable level so that people could get near it.

Another problem of barge transport developed when our stage traveled the Mississippi. It was towed by ship through the Panama Canal up the Gulf and into the Mississippi. The stage covers had to be designed to withstand potshots from small bore rifles. It seems that someone suspected the youngsters along the river banks enjoy target practice and a barge is just an irresistibly large target.

New means of transportation evolved and I am sure you have heard of the Pregnant Guppy (Fig. 26). When the idea of air transport for the S-IV stage was first proposed, the originator, Jack Conroy, was told it could not be done. Aerodynamicists and other aircraft experts tried to reason with him that modifying a Stratocruiser to this configuration was just not practical. Despite the gloomy predictions, he went out on his own, and, with his own money built the Guppy. By September 1963, the first S-IV stage was air transported

Fig. 26 - The super guppy

Fig. 27 - Sacramento test facility

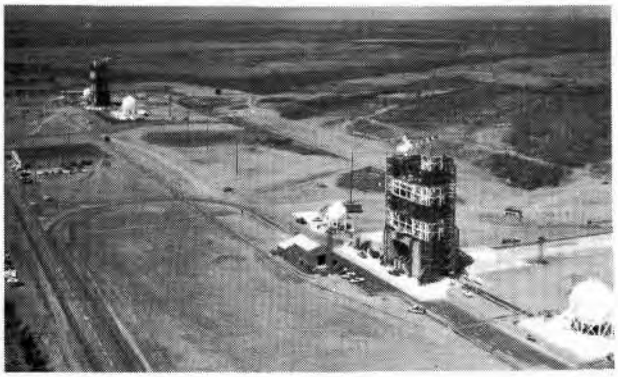

Fig. 28 - Saturn test stands

to the Sacramento Test Center. The center fuselage of the Guppy is bolted and hinged so that the stage can be installed in the plane. When someone asked how sure he was that all the bolts around the circumference of the fuselage were properly torqued, his answer was simple: "The mechanic who does it flies with me." Later, for the S-IVB stage, a new larger Super Guppy was built.

The Sacramento Test Center (Fig. 27) is where we acceptance fire the stages and conduct cryogenic testing. A closer view of the test stands is given in Fig. 28. The spherical containers to the side of the stands are the LH_2 and LO_2 storage tanks. Fig. 29 shows a static acceptance firing -- the white cloud is superheated steam, the byproduct of LH_2/LO_2 combustion.

At the outset of the Saturn program little was known about LH_2. Its uses had been limited primarily to the laboratory. Large scale handling of it, as a fuel, posed serious problems.

The combination of hydrogen and oxygen for the propellants made the moon shot feasible. Its use in upper stages results in a significant increase in performance over the propellant combination of oxygen and kerosene, then in use in first stage boosters.

How to store LH_2 at -423 F in sufficient quantities and then transfer it from large storage tanks to the stages on the test stand for acceptance firings were challenging problems to the engineers.

Special storage tanks were designed with a capacity for 90,000 gal of LH_2. Insulation was achieved by constructing two shells with the space between filled with perlite insulation and evacuated to an absolute pressure of 10 microns of mercury. Evaporation loss is held to about 0.12% by weight per day.

At the time the facility was designed, there were no fully developed and tested ground pumps that could be used to transfer LH_2 at flowrates of 2000 gpm, so pressure transfer was the method employed.

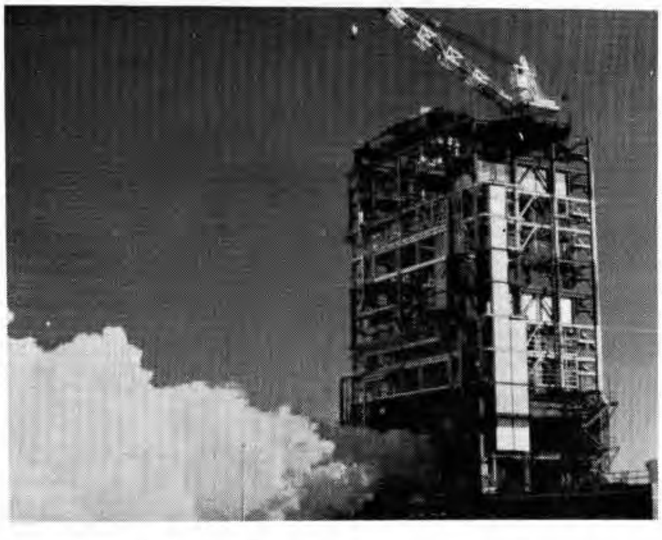

Fig. 29 - Saturn S-IVB acceptance firing

After considerable research and testing, vacuum jacketed, stainless steel transfer lines were developed. A 4 in. line, 300 ft long, transferred the bulk of the liquid, and the final portion is transferred at 500 gpm through a 2 in. topping or replenishing line.

To reduce leakage, all pipe sections are welded rather than bolted. All components of the system are joined by welding. Each weld joint is enclosed by a cylindrical stainless steel jacket which is welded between the outer portions of each vacuum jacket section of the transfer line. The resulting annulus is then filled with polyurethane foam and the "pour hole" sealed. The calculated heat transfer through this joint is approximately 75 Btu/hr.

In designing a LH_2 transfer system, consideration was given to safety. The most serious hazard with hydrogen is the danger of fire or explosion. It is a highly volatile liquid, the limits of flammability or detonability of gaseous mixtures with air or oxygen are wide, and the potential energy release per pound of reactants is very large; and it is invisible when it burns. Fortunately, it is extremely difficult to obtain detonations of hydrogen-air mixtures in the open air and radiation damage due to hydrogen fires is low.

Our Sacramento Test Center is one of the largest LH_2 handling facilities in the United States, and it was here that so much of our current knowledge of the liquid was developed.

To date we have acceptance fired six S-IV stages and 15 S-IVB stages; average duration of firing is around seven minutes for each production S-IVB stage. Prior to testing the production vehicles we had what we called the battleship program. These heavy steel tanked dummy stages were similar to the flight weight stages, and were used to test various propulsive system elements before finalizing the design. The accumulated time of all Saturn static firing tests, at this facility would be in hours rather than minutes and seconds. (To be exact -- 6 hr, approximately 275 firings.)

In the early days all the stages were checked out manually. With less complex space vehicles -- Thor-Delta for example -- this was entirely satisfactory, but Saturn is considerably more complicated. The earlier S-IV stages also were checked out manually and the pre-checkout, acceptance firing and post-checkout took an average of 1200 hr a stage.

For the Saturn V/S-IVB, checkout was automated. The average checkout time was reduced to an average of 500 hr, but the magnitude of testing was increased by 40% per stage. The advantages are obvious but there was the human element with regard to automatic checkout. In the beginning, the seasoned "switch flippers" resented the machine usurping their time honored jobs of pushing buttons and scanning gages. It was he who flipped the critical switch to stop a test or to "hold." He was a vital link in the acceptance firing loop. Now his authority was challenged by the bank of gray enamel computers. One seasoned switch flipper came into the blockhouse after the equipment was installed; he watched the blinking lights, the scanners, the recorders -- everything was working automatically, heaving out wide and endless runs of data print-outs, and he grunted, "It's the Gray Puke." The horrible name has stuck.

Problems have been experienced with the automatic system; it does only what it is told to do through pre-programming. Automatic monitoring and interrupt or cutoff routines do not interpret the state of systems. If the preset limit is 34 psia, the Gray Puke shuts the operation down and "safes" the stage at 34.000 psia, not 34.001 psia in time spans of thousandths of a second. It took several untimely cutoffs of important tests for the "slow thinking" human engineers to understand the beast and smartly program situations where slight variations of performance could be tolerated.

There are limits, however, to humanizing the computer. It is said that, during one of the early S-IVB automated checkouts and acceptance firings, a strange event took place.

Picture, if you will, a block house filled with monitoring screens and equipment; hundreds of people have been at those panels for many, many hours. In this particular static firing, the test conductor, as he now does, typed in the request to start the terminal count for this particular test and the automatic typewriter typed back, "say please." The test conductor, sure that he had made a mistake, typed in the request again. Again the typewriter wrote back, "say please." Outside on the test stand was the S-IVB stage loaded with 193,000 lb of LOX and 42,500 lb of LH_2. Nerves were pretty tense, and, the test conductor was sure he had a bad tape but before discarding it, he did type "please" and the typewriter clacked out the statement, "This is your programmer wishing you good luck."

After the static firing the stage goes through an extensive post fire check and it is prepared for shipment to the Kennedy Space Center. Fig. 30 shows the stage being loaded on the super guppy.

At this point in time the stage has gone through hundreds of hours of checkout and test. Inspection and quality control have played key roles. I have touched briefly on the many phases of the design, fabrication, testing, and checkout of the S-IVB stage. A leading partner in this total operation is Reliability and Quality Control. These are the groups who maintain high standards of performance in all elements of our stage.

If you talk to an experienced quality control man and ask him what is the most important part of his job, he will answer, "The troops understanding the problem." Why perfection, through understanding, must be maintained is best explained by the fact that on Thor, the structural welds are designed for a forgiving 10,000 psi stress level whereas on the S-IVB the welds are designed for the more critical 30,000 psi. All the stage welds are inspected by X-ray and dye penetrant. The slightest imperfection is ground out and re-welded. Another major area is the cleanliness of the LO_2 and LH_2 tank and their associated plumbing and valves. It is no exaggeration to say that virtual "surgical cleanliness" is mandatory.

Once at the Cape, (Fig. 31) the S-IVB stage is taken to the vehicle assembly building - among the largest buildings in the world, over 60 stories high. Once all the stages are "stacked," you can take the elevator to the 30th floor -- that's where our stage joins the S-II stage.

Up to now, I have been speaking primarily of hardware but there are other requirements that must be satisfied before a launch can take place.

In order to assure that the S-IVB stage is ready to support the flight mission, the stage is subjected to several readiness reviews. There are reviews which certify design integrity, reviews which look at hardware installation status, reviews of the paper work to uncover possible incomplete hardware or software work, and reviews which assure compatibility of hardware with software.

A design certification review, commonly called DCR, is conducted by the Apollo Design Certification Board chaired by Dr. Mueller, NASA Headquarters. Several preparatory reviews are held by Marshall Space Flight Center (MSFC) so that residual problems are brought to a head at NASA Headquarters. The result of the review is the certification that the design of the stage is in concert with the mission. The series of reviews of hardware installation status begin at MSFC with the Program Manager's Pre-Flight Readiness Review and Dr. von Braun's personal Pre-Flight Readiness Review. Dr. Debus also conducts his own Launch Readiness Review at KSC. General Phillips' Flight Readiness Review is the final review prior to launch.

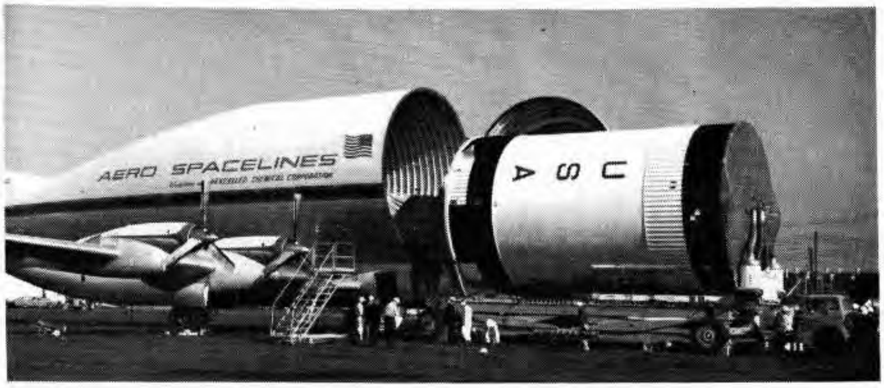

Fig. 30 - Loading stage on guppy

The detailed review to assure that the software (including checkout procedures and flight tapes) is compatible with the hardware is accomplished both at MSFC and KSC. Also included in this review is a line-by-line analysis of the checkout procedures to ensure all safety requirements are met. You might remember in the early missile days, it was not unusual for the vehicle launch to occur with open paperwork. In fact, there have been cases where engineering orders were released after the stage was launched. These reviews prevent this sort of situation.

In addition to the many important reviews held by the customer, we hold our own internal reviews. The two most important reviews we have are the Manned Flight Steering Board and the Flight Readiness Review. The manned Flight Steering Board is made up of key technical and management personnel at MDAC and is chaired by J. L. Bromberg, Vice Pres. -- Deputy General Manager, Western Div. This is a top management review of all facets including design, hardware status, and such of the stage readiness for flight.

The Vehicle Flight Readiness Review is conducted by a separate auditing organization within the company which performs this function on all key launches, static firings, and other major events across all programs.

In all these reviews, certification of readiness is documented by appropriate signatures; in other words, your job is on the line.

Prior to the command to launch, every critical component, line, and wire has been reviewed, re-reviewed, evaluated, and all work authorization and test including retest paper is signed-off before launch is finally approved. As you can see, meticulous care and infinite patience are the ingredients of the success of the Apollo Saturn Program.

If you recall the televised launch (Fig. 32) of the first Saturn V vehicles you'll remember that some of the press corps were literally shaken-up due to launch noise. The vibration levels of lift-off were pretty strong and they slightly damaged some of the press observation trailers near the launch complex. Early in the program studies were made to determine if it would be safe to launch so mighty a vehicle from the Cape area. There was talk of building a "launching island" out in the Atlantic. However, as testing and static firing data were accumulated, it was determined that a man-made launch island was not necessary. The launches of AS-501 and AS-502 proved that acoustic levels were pretty close to predicted -- it was still quite a blast.

But what happens on a Saturn V lunar mission? With the complete Saturn V stack (Fig. 33), we have the S-IC stage, the S-II (second stage), the third stage, the S-IVB, the Instrument Unit, and finally the Apollo spacecraft. All up, 363 ft high, at lift-off it weighs 6,100,000 lb or some 3000 tons. The first stage consumes 4,500,000 lb of fuel in approximately 2-1/2 minutes. Its five engines provide 7,500,000 lb of thrust. The second stage provides over 1,000,000 lb of thrust, burning 153,000 lb LH_2/789,000 lb LO_2 for 6 minutes, and the third stage, with its 225,000 lb of thrust for 2-3/4 minutes places the three module spacecraft in an earth parking orbit at about 100 miles altitude.

Three methods were originally considered to accomplish the manned lunar mission. The direct flight was a mode using a very large vehicle called Nova. Another method, previously discussed, was the earth orbital rendezvous which required separate launches of a tanker and a manned spacecraft joined by docking; this requires an extended period of days, in earth orbit. The method finally selected was the lunar orbit rendezvous, or launching the whole spacecraft from earth to parking orbit to lunar orbit and landing a section of the spacecraft on the moon while the other sections wait in orbit for the landing craft to return. This method reduces the power needed for landing on and launching from the moon.

Fig. 31 - VAB - John F. Kennedy Space Center

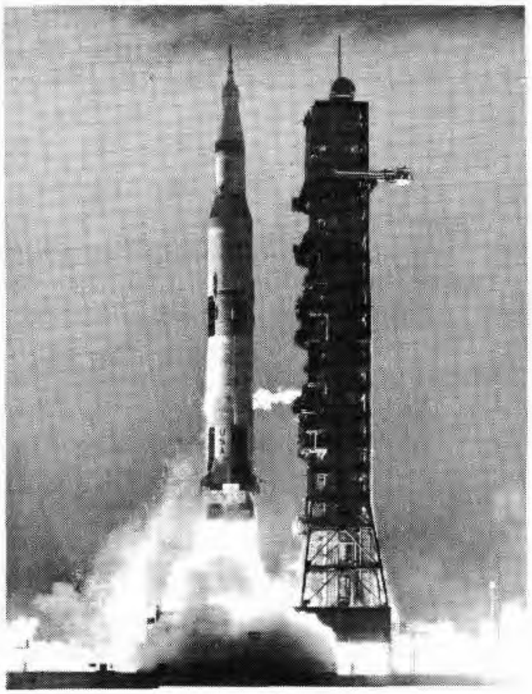

Fig. 32 - Saturn SA-501 launch

When the earth parking orbit is achieved directly after boost, the equipment will be checked during the one to three orbits to see if everything is ready for the next step. If "GO" is the decision, the S-IVB third stage will re-start and accelerate the spacecraft to the desired translunar injection velocity by burning for the second time at 225,000 lb of thrust for 5 minutes. Upon reaching a velocity of 35,460 fps, the third stage shuts down and the spacecraft is in translunar coast. Again, the equipment is checked and if it is "GO" then the docking maneuver of the Command Service Module is made; the astronauts turn the spacecraft around, aided by the S-IVB auxiliary propulsion system. The S-IVB at present is not needed from here on and is allowed to swing past the moon and enter a highly elliptical orbit around the earth or be captured by the sun.

This is a very condensed version of a very demanding program. As you can see, there is much hard work between the drawing board and a successful return trip. And, fortunately as designs materialize to "resources in being," engineers begin to speculate. One such fallout of this kind of speculation is the "Saturn I Workshop."

Back in 1962, Douglas and Marshall Space Flight Center proposed a use for the spent S-IVB Stage. The reasoning was that the S-IVB LH_2 tank contains 10,418 cu ft of empty space, therefore, since it is in orbit, "why not use it for the astronauts' living quarters?" Designing a suitable astronaut habitat from a propulsive stage turned out to be a straight

Fig. 33 - Complete Saturn V stack

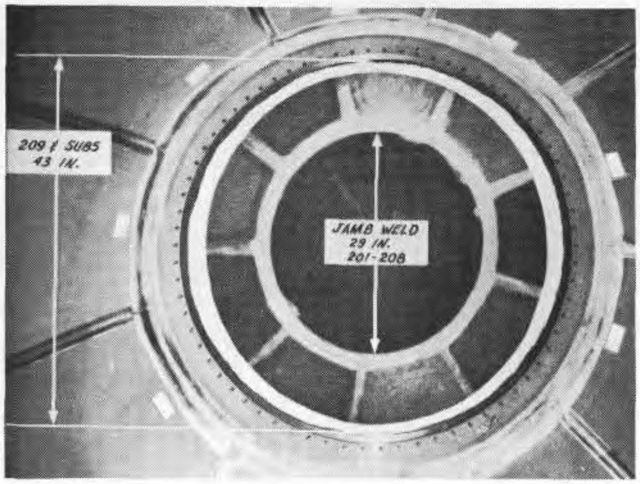

Fig. 34 - Quick opening hatch

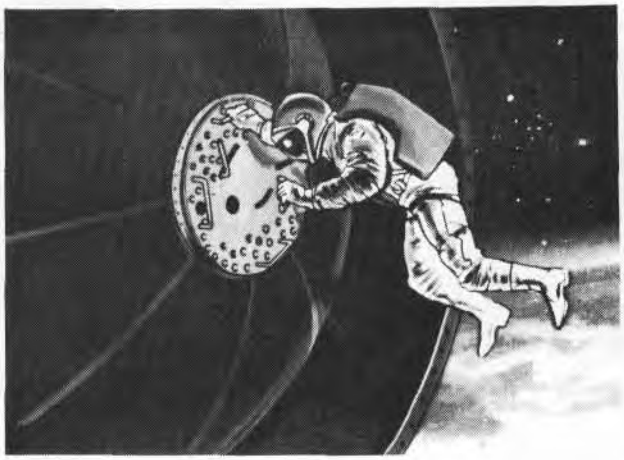

Fig. 35 - Quick opening hatch closed

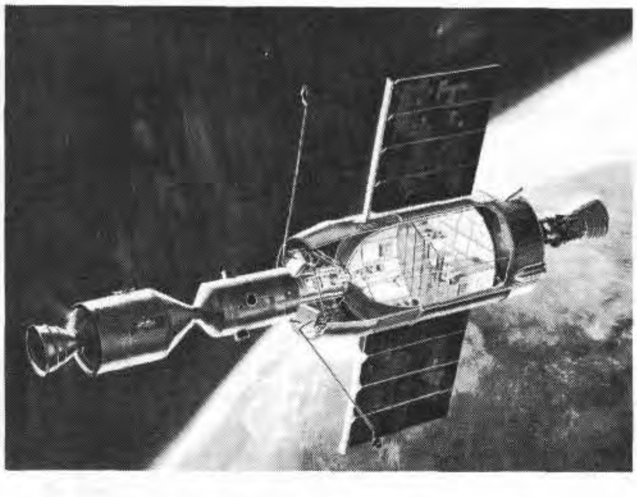

Fig. 36 - Saturn I workshop

Fig. 37 - Saturn I workshop mockup (interior)

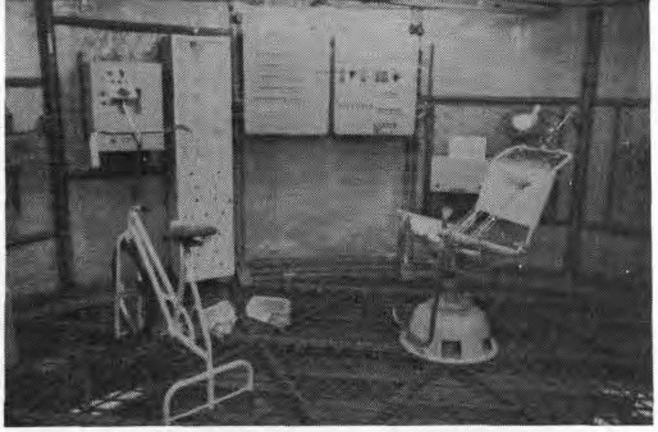

Fig. 38 - Saturn I workshop mockup (interior)

forward design process. No really tough problems had to be overcome.

But a series of coincidences developed which hastened the Saturn I Workshop thought process. In order to ensure that the separating spacecraft would not be recontacted by the spent S-IVB on the lunar mission, it was decided to dump propellant residuals remaining in the S-IVB stage through the J-2 engine. This gives enough thrust from the unlit propellants to push the S-IVB stage sufficiently far away from the spacecraft. This process expanded in detail was carried over on the workshop to evacuate the tanks of remaining propellants for astronaut habitability.

During early stage fabrication, problems developed on the jamb weld in the forward dome on the LH_2 tank; the jamb weld secures the nine gore segments to form the top of the tank.

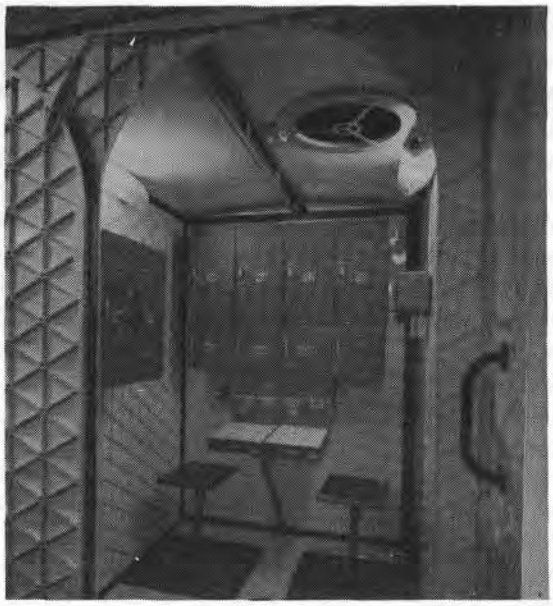

Fig. 39 - Saturn I workshop mockup (interior)

Because the centroid of the jamb ring on the S-IVB stage was not coincident with the load line from the skin membrane, local discontinuity stresses tended to cause cracks to form in the weld. Structural reinforcement or redesign, such as widening the hole became necessary.

We discussed this design change at great length. Coincidently, the feasibility of a spent stage workshop with current hardware and with minimum design changes was becoming apparent, providing the access opening could be enlarged to provide a 40 in. clear diameter for an astronaut in a pressure suit. Anticipating that a quick opening hatch would ultimately be desired, the jamb inside diameter was thus set at 43 in. (Fig. 34), and two problems were solved.

NASA approved the design change for the basic Apollo stage and provisions for a quick opening hatch design was in a unit. Fig. 35 shows the original hatch and astronaut entrance concept. This was the key change that paved the way for the Saturn I Workshop.

Fig. 36 is an artist's rendering of the workshop, the air lock module, the multiple docking adapter, and the Apollo command/service module. Note the airlock attachment to the 43 in. diameter hole in the LH_2 tank.

The purpose of the workshop is to provide a large habitable structure in space so that the astronauts can evaluate the effects of long term space flights on men and to provide a variety of experiments to be conducted in space. As you can see (Figs. 37-39), it's a pretty roomy vehicle, as noted by interior views of the proposed Saturn I Workshop.

This paper presented a discussion of some of the highlights of our Saturn operational experiences. Although we can talk lightly of these experiences, it must be clearly understood that Saturn has been, and will continue to be, one of the most demanding challenges any of us have ever undertaken.

Society of Automotive Engineers, Inc.