"The Saturn IB Launch Vehicle System" 7

Speech: H.D.Lowrey
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It is a pleasure to appear before you today to discuss what Chrysler Corporation Space Division is doing in our nation's space program, and to describe how we are meeting some of the engineering challenges that confront us. As all of you know, such challenges involve skill, imagination, and -- above all -- hard work, much of which goes un-noticed. So, I thank you for giving me the opportunity to speak to you --- in the hope that knowledge of what we are striving to accomplish may prove of some value to you.

Chrysler's major role in the national space program involves building booster stages for two of the three space vehicles that go by the name of Saturn. These huge rockets, believed to be the most powerful in the world, have been developed for use in the Apollo moon exploration project of the National Aeronautics and Space Administration.

The Chrysler Space Division is under contract with NASA to build 14 Saturn boosters. The first two are S-I's, which in general follow the original design developed by NASA's George C. Marshall Space Flight Center in Huntsville, Ala. The other 12 Saturn boosters are designated as S-IB's. We have successfully launched the two Saturn I boosters earlier this year.

One of the principal tasks of our engineering department is design of the S-IB, which is a new, lightweight version of the S-I stage. In assigning us this task, NASA set a design objective of removal of about 14 per cent of the stage weight at burnout -- or a little more than eight tons from the originally-designed 53-ton S-I stage. Actually, we will show a saving of slightly more than 10 tons, and how our Chrysler engineers accomplished this will form a principal part of my discussion.

To set things in proper focus, however, perhaps I should first explain the <u>why</u> of this weight removal.

The Saturn I vehicle, which uses the S-I as its first stage, had as its principal mission the placing of a micro meteoroid satellite in earth orbit. ~~the command module of the three-module Apollo spacecraft in low earth orbit~~. The c~~urrently-designed~~ S-I, was capable of placing about ~~20~~ 22,000 pounds in low earth orbit. ~~will execute this mission. This payload consists of a manned Apollo command module and the necessary structure to connect it to the first and second stages of the Saturn I vehicle.~~

To place into low earth orbit a <u>complete</u> Apollo system -- consisting of the command module plus the service module and the lunar excursion module -- requires a completely new vehicle. This vehicle ~~will~~ consists of the redesigned S-I booster stage, now called the S-IB, and a re-designed second stage, the S-IVB. This system, called the Saturn IB, will be capable of placing approximately 34,000 pounds into low earth orbit, enough for the varied missions that must be undertaken before we can safely send a three-man Apollo spacecraft to the moon's surface.

With this background behind us, let us now examine Chrysler Space Division's operations in New Orleans. As I proceed with my presentation I am going to illustrate it with slides, the first part of which is a photo of the George C. Marshall Space Flight Center's Michoud Operations.

(SLIDE 1)

This is the way the Michoud plant looked when we arrived in New Orleans late in 1961. This government-owned facility, built during World War II, was marked for the auction block when the urgency of the national space program led to the decision to reactivate it. Desirable features included its size, suitable for production of huge rockets, and its accessibility to inland waterways and deep-water routes that linked the site with NASA facilities at Huntsville and Cape Kennedy, Fla. The plant itself, however, had to undergo substantial modification to make it suitable for rocket assembly.

(SLIDE 2)

This slide is an air view of Michoud today. The original main building (point out parameters) has more than 2 million square feet of floor space -- approximately 42 acres -- and is said to be one of the largest air conditioned plants in the United States. The smaller structures in front of the main plant are Administration buildings. Chrysler operates that portion of the Michoud plant shown in yellow, while the remainder is largely occupied by NASA, The Boeing Company, and the Mason-Rust Company. The building in the right foreground (check position on slide) is the recently-completed Engineering Building. This slide includes only a portion of the 824 acres which Michoud Operations cover. Not shown is a newly-constructed dock where the boosters are loaded on barges for trips to and from Huntsville, where static test firings are conducted, and to Cape Kennedy for launching.

(SLIDE 3)

As engineers, I am sure you are interested in the Chrysler production layout. As you look at this slide, you will note that all receiving and shipping takes place in the area at the bottom or back of the plant. We have various quality control labs, engine preparation sections, tool rooms, heat treatment and weld shops, and electrical fabrication sections. The mock-up area is over to the left, then we see the assembly areas -- starting with spider and tail assembly, tank assembly, and final assembly. From this last point, the booster is moved to the center for checkout, and then to areas for modification and cleaning, painting and preparation for shipment. It took two years to put the plant in the condition shown here.

(SLIDE 4)

As I have mentioned, Chrysler Corporation Space Division is concerned with two of three Saturn configurations. These -- the Saturn I and Saturn IB -- are shown at the left of this slide. The Saturn I is 184 feet high and weighs about 60 tons empty and 560 tons fueled. The Saturn IB stands 225 feet high and weighs 640 tons when fueled. The second stages of these vehicles -- the S-IV and S-IVB -- are the responsibility of the Douglas Aircraft Company. Chrysler, I might add, is responsible for the design, manufacture, checkout, static tests & launch of the

S-IB first stages, and launches these vehicles under the direction of the National Aeronautics and Space Administration at Cape Kennedy.

The third configuration you see here is the Saturn V, a three-stage vehicle, for which the Boeing Company will build the first or booster stages in the Michoud plant. The Saturn V, which will be used for the actual moon landings, is 364 feet high, weighs 200 tons empty, and 3,000 tons fueled. It will be capable of launching a 90,000 pound payload to escape velocity.

Actually, the big difference between the Saturn IB and the Saturn V is that the Saturn V will carry the fuel required to perform all the actual elements of the lunar mission that the Saturn IB simulates in Earth orbit.

(SLIDE 5)

We now move to a slide that shows certain sectional cuts of the Chrysler S-IB boosters. The eight Rocketdyne H-1 engines, uprated to 1.6 million pounds thrust compared to 1.5 million for the S-I, are attached to an eight-legged thrust frame on the aft end of the booster and arranged in two-square patterns. The four inboard engines are rigidly attached at a 3-degree cant angle. The outboard engines are canted six degrees and mounted on gimbals which permit control of the vehicle during first-stage powered flights.

Nine tanks feed the engines. Clustered in a circle around a 105-inch diameter tank are eight 70-inch diameter tanks. The center tank and four outer ones contain liquid oxygen, while the other four outer tanks carry kerosene. The kerosene fuel containers are pressurized by gaseous helium in two 20 cu. ft. metal spheres atop the tanks. The liquid oxygen containers, on the other hand, are pressurized by gaseous oxygen that is obtained by passing liquid oxygen through heat exchangers that are part of the engine.

As I noted in the introduction, the Saturn S-IB booster is the result of a redesign by Chrysler of the S-I in which the design objective was a weight reduction of approximately eight tons so as to increase the payload capability for low earth orbit missions from about 20,000 pounds to 35,000 pounds. How, you might ask, is it possible to reduce eight tons of metal from a rocket such as the S-I? The slide I will now show you gives some of the answers.

(SLIDE 6)

First, we must know something of the missions intended for the S-I. When this booster was first designed, the most critical missions envisioned were those involving the Dynasoar and the reactor in flight test. Today, the most critical mission envisioned is the Apollo. This change in missions required a reduction in loads, bending moments at the spider beam, and fin lift loads.

Second, we must consider the matter of operating experience. There have been 7 very successful test flights of the S-I stage. These tests, fully instrumented, have yielded data on the actual flight environment as compared with the flight environment that the design engineers assumed. As might be expected, some of the assumptions were conservative and

and the actual pressures and temperatures experienced were not as severe as anticipated.

Third, refinement of analysis has been conducted. In early design studies of the S-I, for example, the circumferential members of the spider beam were assumed to carry zero loads. Today, with refined analysis, the design of these members has been evaluated and weight saving has resulted.

Fourth, design refinements are now available. In the early S-I stages, the upper and lower flanges of the spider "I" beams were of equal thickness, ignoring the difference in the compression and tensile loads. Today, these differences are exploited by removal of metal from the flange taking the tensile load.

And, finally, there are savings that resulted from system simplification. For example, the single J2 engine used in the new S-IVB has a recirculating liquid oxygen chilldown cycle, thereby eliminating the heavy LOX-GOX dispersal system which was originally part of the S-I first stage. Also, the new S-IVB second stage permits elimination of the liquid oxygen-solid oxygen system and its support structure.

In a word, it can be said that maximum use is being made of all the flight and development experience that has accrued since the original design.

With this background, let us examine the design requirements for the S-IB booster and note specifically where it was determined that weight savings could be obtained.

(SLIDE 7)

The major part of the projected 16,000 pound saving in weight, we see here, is contributed by the structure -- a total of 10,584 pounds. The spider beam assembly, at the top of the booster, is the largest contributor with 3,623 pounds lopped off. The redesigned fins contributed 2,566 pounds and refinement of the propellant tanks and tail structure resulted in savings of 1,933 and 1,747 pounds, respectively.

(SLIDE 8)

Chrysler engineers determined that 2,391 pounds could be saved by redesign of the propulsion system. Biggest contributor here, representing a 960-pound saving, was the previously mentioned elimination of the LOX/SOX system. Reductions of 361 pounds and 540 pounds resulted from changes in the LOX and fuel tank pressure systems.

(SLIDE 9)

Moving to a third area, the instrumentation unit, we found that a weight saving of 3,350 pounds was possible. One-third of this was obtained by deleting the motion picture and TV camera system, and the remainder by deleting about 60 per cent of the instrumentation and measuring equipment.

The total programmed weight saving, therefore, is 16,325 pounds.

(SLIDE 10)

Here we see, in pictorial form, the assemblies we have been discussing.

The complete stage structure is shown at the center of the picture, with blown-out sub-assemblies surrounding it.

The spider beam assembly, which was the largest contributor to the weight reduction effort, is shown just above the main assembly. This unit was the first one changed and, with the redesigned fins, makes up the only structural changes in the first S-IB booster.

All other structural changes are scheduled for the third S-IB unit. The weight reduction in electrical instrumentation will be effected in the fifth unit.

(SLIDE 11)

As most of you know, the usual approach for any design job is to establish the design criteria, perform the load analysis, prepare designs, perform the stress analysis, modify the design and start fabrication, In our program, however, we could not change any major tooling.

Therefore, instead of starting with design studies, such as would be required for a new missile concept, we established new stage criteria for the existing S-I and developed new external and internal loads. This extensive parallel effort is shown in some detail on this chart.

The preliminary design group made detailed sketches of the areas where weight savings appeared practical and a conceptual design review was held with the customer. A load review was also made with the customer, and a preliminary stress check conducted against the design changes.

Meanwhile, weights were being estimated and drafting started. These activities were bucked against each other and a 50 per cent review made with the customer, based upon compatability of stress data. Following this, the engineering documentation parts list and bills of material were created, and advance notice was given engineering for distribution, while customer sign-off occurred after the 100 per cent design review.

By use of this parallel technique, we were able to meet a very close delivery schedule with hardware fully test qualified before flight.

(SLIDE 12)

To illustrate the analysis methods used, I am showing you the whole stage assembly as a mathematical model. The bottom of the stage is shown at the right. Each line represents a major structural element. The dots are nodes or locations where either major loads are applied or where structural characteristics experience change. The tanks, for example, are shown as a single line. The actual structure is replaced by a mathematical equivalent, a composition of simple structural elements such as beam columns, plates and torque boxes.

The response of these elements to loads can be readily expressed mathematically. From these data, an algebraic matrix is formed. If each point were analyzed for six degrees of freedom, X, Y, and Z forces, and pitch, roll, and yaw moments, the matrix would indeed be formidable.

By application of some ingenious simplification, however, this matrix has been reduced to a 350 x 350 element array -- that's 350 equations with 350 unknowns. The IBM 7094 computer is capable of inverting this matrix, permitting it to yield deflection data in about 2-1/4 hours.

I don't know how many centuries would be required for a team of mathematicians to do this job manually. The computer, therefore, makes it possible to do a job that otherwise would have been impossible to accomplish in any practical sense. The deflection data combined with the load data yielded the appropriate stress information. By determination of such precise values of stress information maximum weight removal could be achieved.

(SLIDE 13)

This slide shows the application of the technique to the spider beam assembly alone. Here, again, some ingenious simplification has permitted the construction of a 72 x 72 array from what would have been a 150 x 150 array if six degrees of freedom had been assigned to each junction.

(SLIDE 14)

This slide illustrates the effect of tank operating pressures on tank weight. As is well known, the operating pressures can be used as a structural element helping to support the load. With increased operating pressures, the tank weight can be reduced while maintaining required compressive stability. The increased operating pressures, however, increase the hoop tension. The intersection of these two curves represents the optimum structural weight. This principle is used in determining the optimum tank wall thickness.

(SLIDE 15)

Here, we see where some of the weight saving occurred. The eight radial beams weighing 221 pounds each were reduced by 53.9 pounds each, for a total of 431 pounds. Six of the cross beams which weighed 103.1 pounds have been reduced 13.6 pounds each, for a total saving of 182 pounds. Two of the cross beams with clearance arches gave weight savings of 34 pounds each, for a total of 68 pounds. The 16 center LOX tanks support fittings were reduced 2.6 pounds each for a total of 42 pounds. The ends of the radial beams that formerly held the retro rockets were cut off for approximately a 50-pound saving.

(SLIDE 16)

This slide shows in summary what we achieved as compared with our initial objective. In the structure area, we have removed more weight than the design objective -- some seven tons as compared with five tons. The big difference was in the fin assembly, where complete redesign yielded rich dividends. The weight saving here, a by-product of the design, was needed for other reasons. Greater aerodynamic stability was required to protect the astronauts in the event of an abort, and new fins provided the required stability.

(SLIDE 16-A)

The propulsion system came out on target, as did the instrumentation system.

(SLIDE 16-B)

~~While we won't know, of course, until we get through building the first vehicle, it now appears that the S-IB will be 20,259 pounds lighter than the S-I -- a weight saving almost 4,000 pounds more than called for in the design objective.~~

(SLIDE 17)

The next series of slides depict the sequence of earth orbiting of a Saturn vehicle. The first slide shows the Saturn IB with an Apollo payload at lift off.

(SLIDE 18)

Here, we see the complete vehicle in flight. Incidentally, more than 50 tons of propellants are burned by each of the eight engines during the 146 seconds of propulsion.

(SLIDE 19)

At this point, the second stage is separated from the S-I booster. The S-IV second stage, you may be interested to know, is powered by six liquid hydrogen - liquid oxygen engines exerting a total of 90,000 pounds thrust.

(SLIDE 19-A)

And here, the Apollo payload is separated from the second stage.

(SLIDE 20)

This slide shows what will take place when rendezvous and docking techniques are perfected. While in orbit, two of the three astronauts will enter the lunar excursion module of the Apollo spacecraft. The module will then be separated from the Apollo for an independent flight through space, following which it will rendezvous with the Apollo, which then will return to the earth's surface.

(SLIDE 21)

Of paramount importance to all at Chrysler is that the vehicle be man-rated and that it be absolutely reliable. In spite of adverse environments resulting in a wide variety of stresses, all components and systems of the booster must function perfectly if a mission is to succeed. Every detail is important. Failure cannot be tolerated because human life is at stake. We have reliability laboratories where we can simulate the environment that components and subsystems of boosters experience in flight, including

including temperature, altitude, shock, and vibration.

Another useful reliability tool that Chrysler has developed is a model that expresses the Saturn hardware in mathematical terms. The vehicle is flown mathematically on an IBM 7090 computer. To date, we have flown ~~6000~~ many thousands of simulated flights. A summary of these flights shows those parts that would fail most frequently, the failure effects, and the time of failure. The importance of detail is highlighted. For example, our math model showed that failure of a single electrical relay would shut down all eight engines. This potential problem was corrected by adding a second relay in parallel with the first. Another potential problem uncovered by the math model involved normally closed prevalves, where the loss of control pressure would have shut down one or more engines. This problem was corrected by redesigning the valves to be normally opened instead of normally closed.

The present Saturn I and Saturn IB program consists of 10 Saturn I flight missions and 12 Saturn IB missions.

Saturn IB flights will begin ~~in 1965~~ early next year and extend into 1968, with peak activity occurring during 1966.

However, Saturn IB usefulness does not end with the presently planned vehicles and missions. "Follow-on" Saturn IB activity is now in the study stage and under consideration are investigations of additional earth-orbit flight testing, space station deployment and logistics, and lunar and interplanetary flights in a three-stage configuration.

As the space program proceeds, payload requirements will certainly grow and the Saturn IB can be uprated to meet many of these needs. Heavier payloads in earth orbit, for example, will make possible more extensive checkout of the Apollo payload, including a lunar excursion module with sufficient fuel for longer, multiple excursions from the command module and additional practice on the rendezvous maneuver. In addition, increased payload capability will enable us to launch larger, long-term space stations and to support them more economically.

Chrysler has looked at several methods by which Saturn IB payload capability can be increased to accomplish these more demanding future mission requirements. We are working closely with Marshall Space Flight Center, Douglas Aircraft, Rocketdyne, and others to select the more attractive of these methods.

As an example, we have determined that within the next 30 months the thrust of the engines of the first and second stages of the Saturn IB could be increased by 10 per cent to 220,000 pounds. Through this uprating, the payload capability for a 100-nautical-mile earth orbital mission would be increased to 43,000 pounds.

If larger earth orbital payloads are required, this capability could be increased to 51,000 pounds by using four Minuteman solid motors as strap-ons for first stage boost assist.

In order to extend the mission flexibility of Saturn IB, a third stage is required. A three-stage Saturn IB would provide the capability of sending large scientific packages on lunar or inter-planetary missions. A logical choice for a third stage is the Centaur, which is undergoing development flight tests.

Earth escape payload capability of the nominal Saturn IB with a Centaur third stage is 13,000 pounds. If the Centaur is used atop the Saturn IB with the uprated engines I've just mentioned, this escape payload capability, which is indicative of the size of payload that could be sent on a circumlunar or Mars fly-by-mission, could be increased to 16,000 pounds within the next 30 months.

Study missions which designate the Saturn IB as the booster include the Voyager Mars and Venus probes, and launch of nuclear-electric stages for outer planet exploration. These missions extend well into the 1970's and indicate a long life for the Saturn IB.

Thank you.

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