SATURN S-IV SPACECRAFT SYSTEM

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ABSTRACT

Vehicle stages operating in a space environment require the addition of new subsystems. The most important of these systems that must be considered are: 1) attitude stabilization in space, 2) zero g propellant storage, 3) space environmental protection, and 4) checkout in orbit. Such operational requirements have influenced the design of the S-IVB. The mission considerations for this vehicle involve the functioning of the S-IVB for hours or days in space after separation from the lower stages. Some of the potential missions for the S-IVB are Earth orbit tanking, and an escape mission requiring a parking orbit. The S-IV vehicle program is now well into the development stage. It incorporates many of the S-IVB design features. The S-IV will be fired immediately after S-I cutoff, without orbital storage or coasting in space. After placing its payload in its orbital or escape flight path, the expended S-IV will be left as a derelict coasting in space. Ultimately derelict stages in space may be banded together to form the nucleus of a space station or as a space laboratory. Douglas Aircraft Company has initiated construction of a large scale space chamber to be used in qualifying large subsystems. The evolution of vehicles into spacecraft represents one of the major design challenges facing the aerospace industry today.

INTRODUCTION

In the past, there has been a fairly clear dividing line between booster vehicles and their payloads. Boosters were built by tin benders, payloads by scientists. The old concept was that of a scientific payload, boosted into orbit by a

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piece of "hardware." Today's mission concepts are merging these two areas: the vehicle itself may be the payload. This concept arises from two considerations. First, in certain missions the vehicle must perform in space prior to placing the payload into its mission trajectory; for example, an escape mission involving an Earth parking orbit. Second, the terminal stage of a booster achieves orbital velocity in an Earth orbit boost mission or escape velocity in an escape mission. These expended stages can, if properly prepared, perform missions in themselves. These concepts require a merger of booster vehicle performance requirements to payload reliability and environmental criteria. They produce far-roaming stages designed to store their propellants in space for long periods of time; they are also designed to provide their impulsive addition to the mission energy profile after many days in orbit, as well as to function in the atmosphere of some other planet. For example, the S-IV and S-IVB vehicles may be considered payloads in themselves.

An analysis of the trajectories involved in launching toward a particular point in space shows that the launch time requirements are more relaxed if launching is accomplished from an Earth orbit rather than from Earth itself. This effect is shown for a lunar mission in Fig. 1 (see Ref. 1). Depicted here is the launch window experienced by launching toward the moon from a 300-naut mile orbit rather than from the surface of Earth. During the cycle shown, there are six periods in which a launch is possible. Each of these launch windows is of several hours duration. However, at only one particular time for each orbit within the window can the launch occur. The country's first lunar missions were conducted using a three stage Thor vehicle, boosted into a direct escape trajectory. Because of the narrow launch window, launch time was restricted to a period of 20 min. Even this length of time required readjustment of guidance parameters, as time varied in the 20-min interval. In those days, countdowns were somewhat uncertain, and the fact that the launch window was hit on every attempt is still regarded as somewhat coincidental. Because R&D countdowns can introduce substantial uncertainties in launch time, many current escape missions involve parking orbits. This greatly extends the Earth launch time window. In this type of mission, the final stage of the space vehicle will be placed, together with its payload, into a low Earth orbit. During orbit, precise trajectory information and launch time will be computed, and, at the proper time, the stage will be fired. This operation requires that new systems be added to the vehicle's terminal stage. It is interesting to review how these systems affect the S-IVB design.

1 Attitude stabilization in space. Attitude orientation may be dictated by payload peculiarities, heat transfer considerations, or the necessity for orientation prior to ignition. In the lunar orbit rendezvous mode, the S-IVB will be required to provide attitude stabilization to the Apollo/LOR vehicle during Earth parking orbit. After restart, the stage must continue to provide attitude stabilization for the Apollo turn-around maneuver. It is expected that attitude control will be provided by externally mounted storable propellant auxiliary rocket engines.

2 Zero g propellant storage. Questions arise pertaining to cryogenic venting techniques under zero g conditions when the position of the fluids in the tanks is not known. In the free coasting portion of the S-IVB s flight, it is anticipated that tank venting will be required. Two techniques under consideration are centrifugal fluid separators which permit only the gas to be vented from the tank, or ullage rockets which provide a small forward acceleration to settle the fluids to the rear of the tank just prior to a venting operation.

3 Protection against the space environment. This includes micrometeoroid impact, thermal environment, solar radiation, etc. Depending on the mission and the time the vehicle must function in space, these considerations may become major design points for the vehicle.

4 Requirement for checkout in orbit. In the lunar orbit rendezvous mode, the S-IVB will coast with the payload in Earth orbit prior to injection into a trans-lunar trajectory. The astronaut or the ground station must have knowledge of proper vehicle functioning before firing. In effect, this necessitates a countdown in orbit. Real time presentation of critical parameters associated with stage readiness to fire will be required. Similarly, certain navigation information must be transmitted to the astronauts prior to transfer from orbital to escape trajectory. For example, the stage must be re-oriented into the proper attitude in space prior to ignition so that the thrust vector is applied in the correct direction. Information on pointing the stage could be transmitted from the ground to the astronauts during the Earth orbit coast phase.

The S-IVB stage is the third stage of the Saturn C-5 vehicle. This stage is currently being designed to include provisions for operation in space. Two modes of operation for this vehicle are shown in Fig. 2.

1 Earth orbit tanking mode. Here the S-IVB and Apollo stages are placed into low Earth orbit. The S-IVB then rendezvous with a previously orbited tank and receives all or a portion of its propellants in orbit. After being filled, it boosts the Apollo stages to escape velocity. Stay time in orbit for this sort of mission is on the order of several days. During this time, the S-IVB must provide attitude control, be checked out, accept the tanker, and add its velocity to the mission profile.

2 S-IVB may be used in an escape mission that requires a parking orbit. In this mission, the S-IVB is tanked prior to liftoff and burns a portion of its propellants to place the Apollo and lunar excursion module into Earth orbit. After an orbital coasting phase, the engine is re-ignited to impart escape velocity to the payload. Ideally, in a perfectly executed mission, storage time in orbit could be as short as one-half orbit. However, if mission uncertainties develop, the stage may be required to store its propellants in orbit for much longer times.

To accomplish these two missions, the S-IVB stage is powered by liquid oxygen and liquid hydrogen and employs a single Rocketdyne J-2 engine. It is constructed almost entirely of welded 2014T-6 aluminum, using techniques proven in the Thor and S-IV programs. The hydrogen tank is internally insulated and the common bulkhead separating the hydrogen and oxygen tanks employs a bonded Fiberglas honeycomb that permits the upper and lower surface to work together as an integrated structure while effectively sealing each tank into a closed container. These operational requirements necessitate new subsystems such as engine restart, external thermal and micrometeoroid protection, and external storable attitude control system propulsive units. These are considered as factory installed kits or optional equipment, which can be added or removed as the mission dictates.

The S-IV program precedes the S-IVB. This vehicle carries roughly half the propellant of S-IVB and will be flown as the second stage of C-1 in 1963. Many of the features to be employed in S-IVB exist in the S-IV configuration. This stage is also hydrogen/oxygen powered, internally insulated, and constructed of 2014T-6 aluminum. This program is progressing well. Fig. 3 shows the six-engine firing program in progress at Sacramento. An interesting feature is the use of the ejector-diffuser system visible in the foreground of this figure. This system is employed to lower the pressure at the exit plane of the Pratt & Whitney engines to avoid nozzle separation during the sea level tests.

The missions assigned to this stage are of the bang-bang variety. That is, the S-IV will be fired immediately after S-I cutoff, without orbital storage or coasting in space. How then does the S-IV qualify as a "spacecraft system"? After adding its energy to the mission and placing the payload in its orbital or escape flight path, the expended S-IV will be left as a derelict coasting in space. Can this mass be used? It will be recalled that an Atlas/Score was launched in December 1958. The stage carried a transmitter broadcasting President Eisenhower's Christmas greetings to the world. (Here was an expended stage performing a post-injection mission.) The same type of application can be made using the large, expended stages of future spacecraft. For example, one might even consider using an expended S-IV, as Wernher von Braun has suggested, as a space way station where lost travellers of the future may find refuge, as a first aid station, and as an S.O.S. beacon. In another application, the expended stage could well serve as a spacious space laboratory, unmanned in early flights. In conjunction with an Apollo, Mercury, or Gemini capsule boosted to orbit with the stage, later laboratory missions could be manned as shown in Fig. 4. Ultimately, perhaps the derelict stages in space can be banded together to form the nucleus of a space station.

These advanced applications of final stages may require qualification and checkout in a simulated space environment. Today, NASA payloads are subjected to rigorous operational tests in simulated space environments. Since the vehicles themselves can be considered, in a sense, the payloads in future applications, more extensive space qualification of complete vehicle subsystems may be required. Anticipating this marriage of vehicle technology with payload environmental requirements, Douglas has recently initiated construction of a large scale space chamber (Fig. 5) to be used in qualifying large subsystems. This chamber will accept an entire engine section of an S-IVB and apply pressures as low as 10^{-6} torr, simultaneously with simulated solar radiation and vibration. The facility and other environmental qualification tools will be used extensively in S-IVB. The evolution of stages into spacecraft represents one of the major design challenges facing the aerospace industry today.

REFERENCE

1 Vought Astronautics, Orbital Launch Operations Report #00.26, Contract NAS8-853, 16 January 1962.

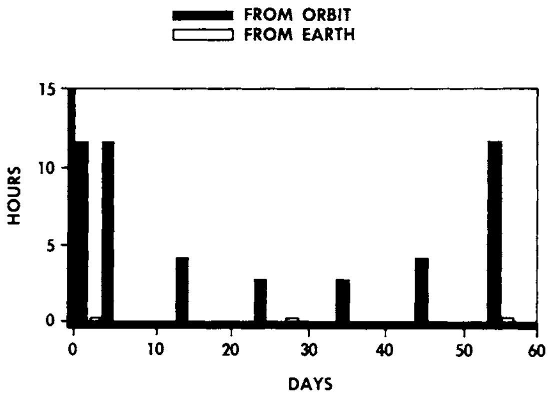

Fig. 1 Hours During Which a Lunar Launch is Possible (Booster Capability Beyond Nominal Performance = 250 ft/sec)

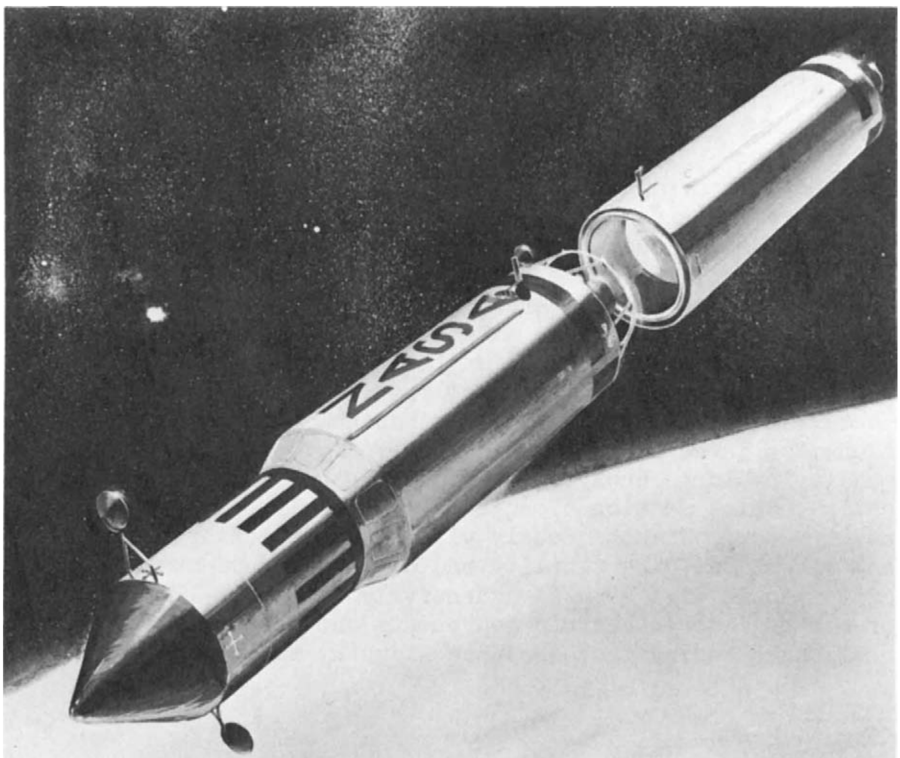

Fig. 2 S-IVB Stage of Saturn C-5 Vehicle Showing Provisions for Operation in Space.

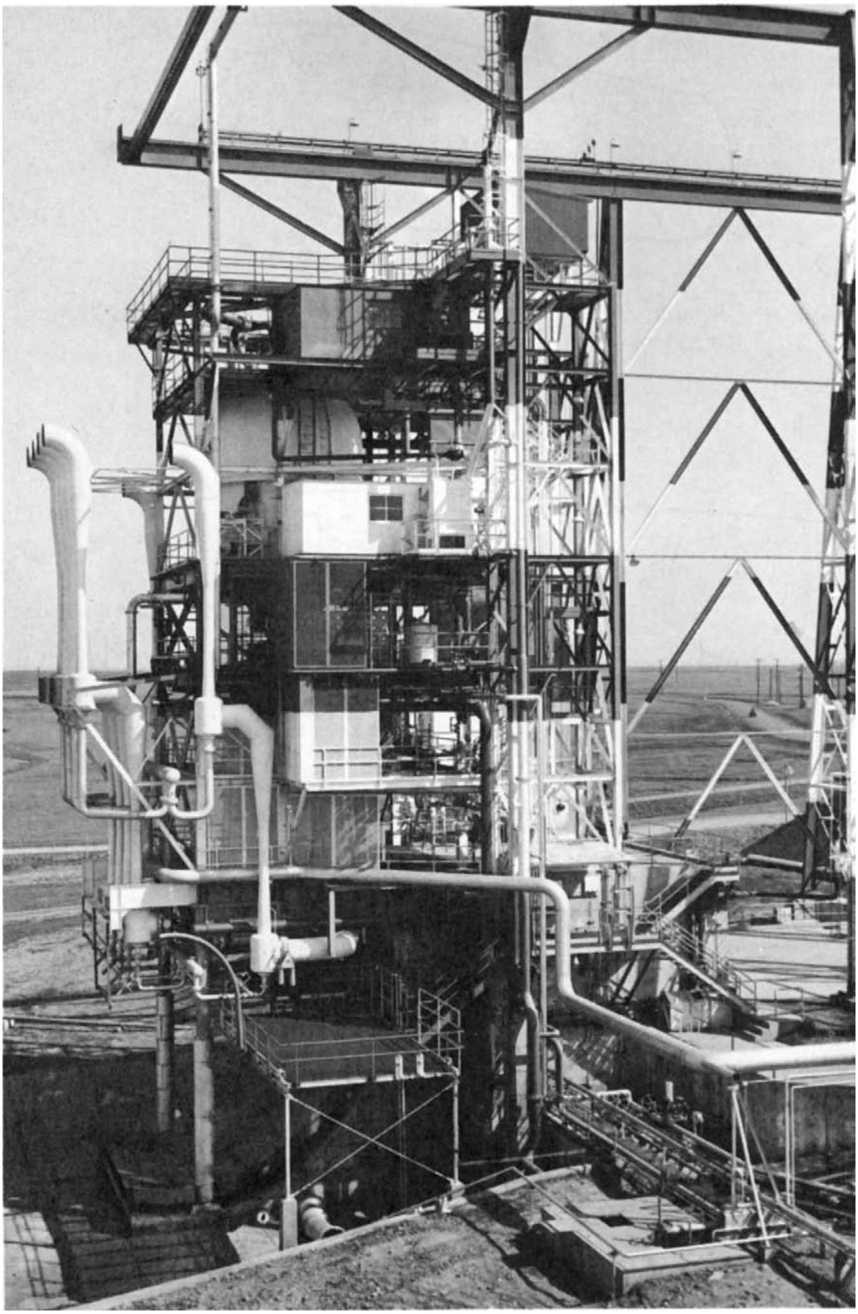

Fig. 3 Saturn S-IVB Stage Six Engine Firing Program in Progress at Sacramento, California

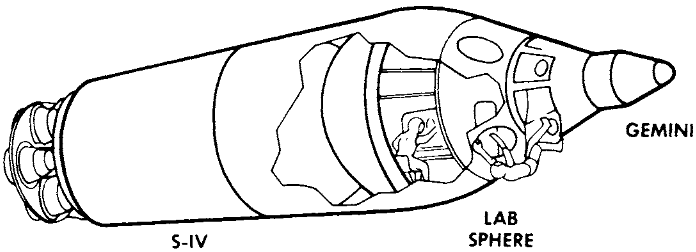

Fig. 4 Saturn S-IV Stage Intermediate Orbit Manned Space Station

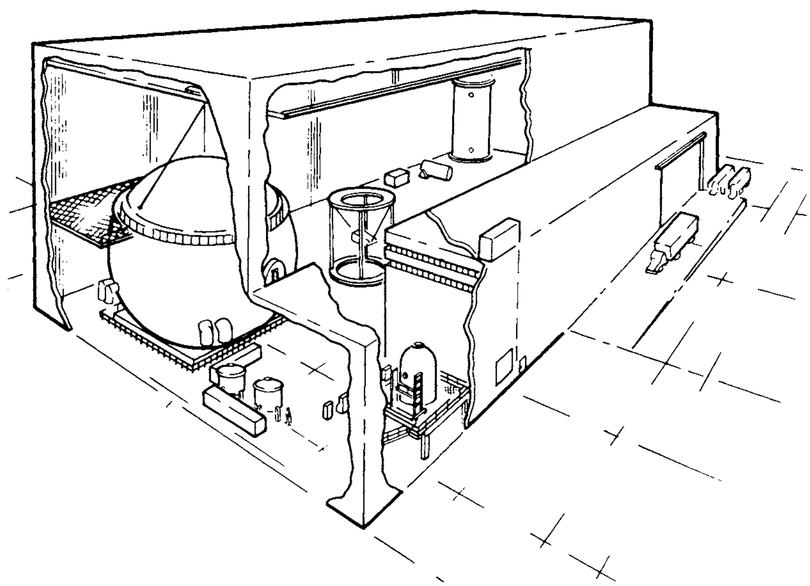

Fig. 5 Douglas Large Scale Space Chamber to be Used in Qualifying Large Subsystems