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EVOLUTIONARY STEPS IN S-IVB DEVELOPMENT

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ABSTRACT

The injection stage of a multistage launch vehicle must be partially a velocity stage and partially a spacecraft; it must not only boost the payload, it must also perform cooperative mission operations with the payload after orbital insertion. These hybrid requirements result in intrinsic stage versatility which permits consideration of new and challenging missions for the stage which were unanticipated during initial design.

Basically, the S-IVB can evolve in two directions: stage propulsive applications and spent-stage applications. Propulsive applications are envisioned in which S-IVB's, modified for multiple starts, can be utilized to accomplish Hohmann-orbit transfers, synchronous-orbit injection, and planetary-escape missions. Spent stage uses are currently being studied in great detail; of immediate interest is the orbital workshop application in which a specially modified S-IVB, injected into orbit unmanned, is later occupied by astronauts who will perform experiments in the environmentally controlled stage for 28 days. The experience gained in the early workshop missions can be used in later, more demanding space station missions lasting for a year, with 6- to 9-man crews and with a potential requirement for artificial gravity.

The basic mission of the 1-year stations will be to provide precursor information for the operational space station and interplanetary missions which will follow in the last half of the next decade. The S-IVB can be used to support lunar operations. With some modifications, the S-IVB can deliver

cargo to the surface of the moon and, once having landed, provide shelter on the surface in a manner similar to the use of the spent stage in orbit. An S-IVB with cargo can be placed into lunar orbit to support operations on the lunar surface or to conduct space-station type experiments from lunar orbit where the stage could serve as a workshop. This type of evolution is of highest importance to our national space program because it permits attainment of higher reliabilities through use of more mature equipment and operational procedures, continuity of industrial teams, and realization of cost benefits as a result of multiple production of various elements of hardware.

The S-IVB, a stage designed for a particular mission, has utility far beyond that initially required. There seem to be important reasons to capitalize on that utility in the accomplishment of the nation's objectives.

INTRODUCTION

The injection stage of a multistage launch vehicle must be partially a velocity stage and partially a spacecraft; it must not only boost the payload, it must also perform cooperative mission operations with the payload after orbital insertion. These hybrid requirements result in intrinsic stage versatility which permits consideration of new and challenging missions for the stage which were unanticipated during initial design. For example, in the case of the Agena program, the final stage serves as payload carrier and provides for payload stabilization and system support. The S-IVB, in its Apollo mission, must perform the payload injection maneuver, then stabilize the payload during three orbits, restart to provide final escape velocity, and then, after translunar injection, provide payload stabilization for the Apollo transposition maneuver. We have already seen, in the case of the Saturn program, how the expended stage injected into Earth orbit can perform the functions of an elementary space station, the Apollo applications (AAP) orbital workshop.

There are other new uses for the stage which have been suggested that are of equal or greater importance. This paper will discuss some of the evolutionary developments of the S-IVB which have been suggested and will show how these can be applied to many of the missions which will be important to the nation in the years immediately ahead.

The S-IVB can evolve in two basic directions. It can be developed into a propulsive stage which will satisfy missions even more demanding than Apollo and it can, following its use as an orbital workshop, be developed into an even more advanced mission support module. (Figure 1.)

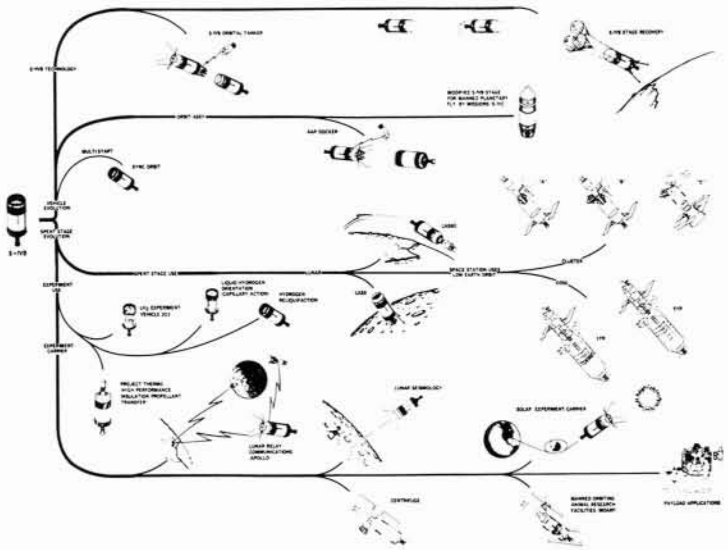

S-IVB
S-IVB TECHNOLOGY
S-IVB ORBITAL TANKER
S-IVB STAGE RECOVERY
AAP DOCKER
MULTISTART
SYNC ORBIT
VEHICLE EVOLUTION
SPENT STAGE EVOLUTION
SPENT STAGE USE
LUNAR
SPACE STATION USES LOW EARTH ORBIT
CLUSTER
EXPERIMENT USE
EXPERIMENT CARRIER
LIQUID HYDROGEN ORIENTATION CAPILLARY ACTION
HYDROGEN RELIQUEFACTION
PROJECT THERMO HIGH PERFORMANCE INSULATION PROPELLANT TRANSFER
LUNAR RELAY COMMUNICATIONS APOLLO
LUNAR SEISMOLOGY
SOLAR EXPERIMENT CARRIER
CENTRIFUGE
PAYLOAD APPLICATIONS

FIGURE 1

PROPULSIVE APPLICATIONS

HOHMANN TRANSFER

The S-IVB is currently designed to inject its payload into low Earth orbit, in the Apollo mission, with approximately 70% of its propellant remaining. After as many as three orbits, the tanks are repressurized and the stage supplies escape velocity to the payload. Through changes to the propulsion system and tank pressurization system (Figure 2), provisions can be made for a third S-IVB start. The third start permits the stage to increase its payload to Earth orbit; rather than injecting payload directly in orbit, the mission can include a parking orbit and a Hohmann transfer to the final orbit. The three burns required are injection into Earth orbit, injection into the transfer orbit, and final circularization. This type of mission, depicted in Figure 3, shows the effect of this multiple burn on payload for various parking-orbit altitudes.

TERRAIN COMPENSATING LANDING LEG SYSTEM FEATURES

S-IVB-3405

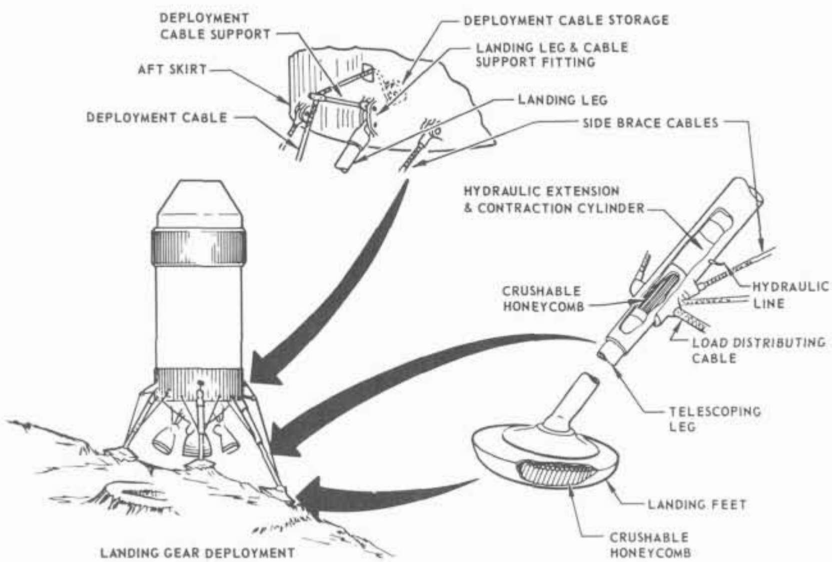


FIGURE 2

SATURN V HOHMANN TRANSFER PAYLOAD CAPABILITY

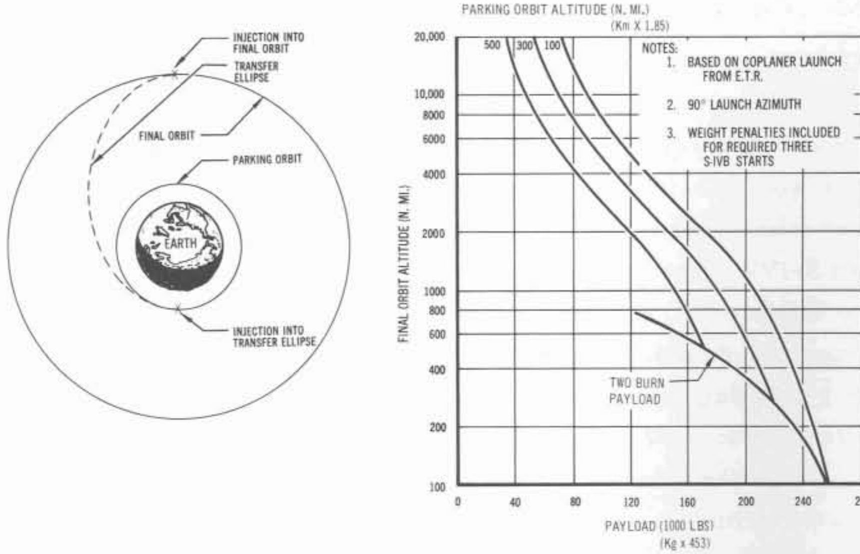


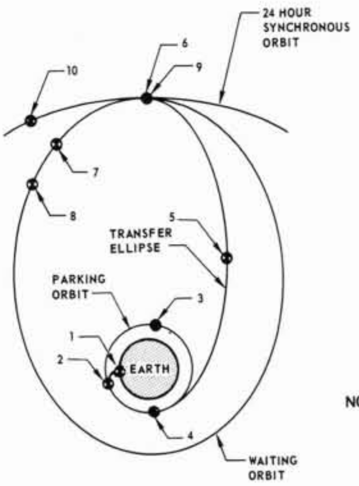
FIGURE 3

SYNCHRONOUS ORBIT

It has been found that the three-burn S-IVB is also a suitable configuration for synchronous-orbit injection. Figure 4 shows how such a mission might be accomplished. Here, the three burns of the S-IVB are used for Earth-orbit injection, injection into the transfer ellipse, and injection into an elliptical orbit with apogee at synchronous altitude. One form of this particular mission envisions circularization of the payload using the service module; however, the third burn of the S-IVB could also provide circularization. The payload capability of the Saturn V, using a three-burn S-IVB to synchronous orbit, is shown in Figure 5 as a function of hover-point longitude, launch azimuth, and time in Earth parking orbit.

SATURN V SYNCHRONOUS ORBIT MISSION PROFILE

S-IVB-2918



SEQUENCE OF EVENTS

1 LAUNCH FROM ETR
2 INJECT S-IVB AND SPACECRAFT INTO PARKING ORBIT
3 COAST IN PARKING ORBIT
4 ORBITAL LAUNCH (2ND S-IVB START) AND INJECTION INTO TRANSFER ELLIPSE
5 COAST IN TRANSFER ELLIPSE
6 S-IVB IGNITION (3RD S-IVB START), INJECTION INTO WAITING ORBIT
7 COAST IN WAITING ORBIT
8 JETTISON OF S-IVB
9 SERVICE MODULE IGNITION AND INJECTION INTO 24 HOUR SYNCHRONOUS ORBIT
10 OPERATIONS IN SYNCHRONOUS ORBIT

NOTES:

- PARKING ORBIT ALTITUDE = 100 N. MI.
- SYNCHRONOUS ORBIT ALTITUDE = 19, 351 N. MI.
- NOT DRAWN TO SCALE

FIGURE 4

SATURN V SYNCHRONOUS ORBIT MISSION

S-IVB-2921

PAYLOAD & COAST TIME SENSITIVITIES TO HOVER POINT LONGITUDE

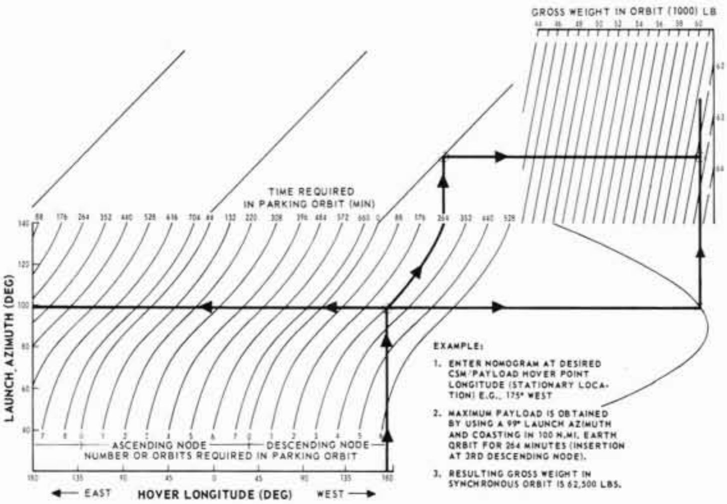


FIGURE 5

PLANETARY-ESCAPE MISSIONS

Another category of modification has been defined which permits the S-IVB to provide escape velocity for manned planetary missions. These modifications were defined in a recent study accomplished for Marshall Space Flight Center (MSFC). In this mission, several modified S-IVB's are injected with full propellant tanks into low Earth orbit. These modified stages are then remotely assembled and docked to an independently launched planetary spacecraft. Once all stages have been mated and checked out, the modified S-IVB's fire in sequence and provide escape velocity to the payload. Figure 6 shows an overview of the types of modifications required for this mission. These modifications permit the stage to coast in orbit for periods of a month or so. Figure 7 shows the performance which can be expected in this mission; note that three modified S-IVB's can boost approximately 190,000 lb in a Mars flyby mission (1977). One of these stages can boost 120,000 lb to Venus in the same time period.

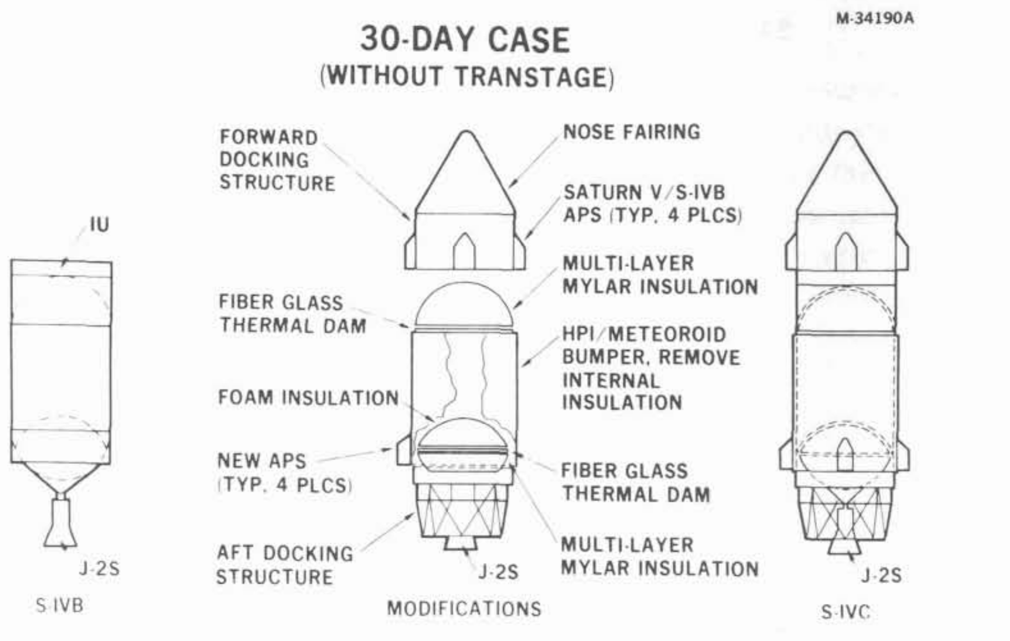


FIGURE 6

M-34185A

OLV PERFORMANCE

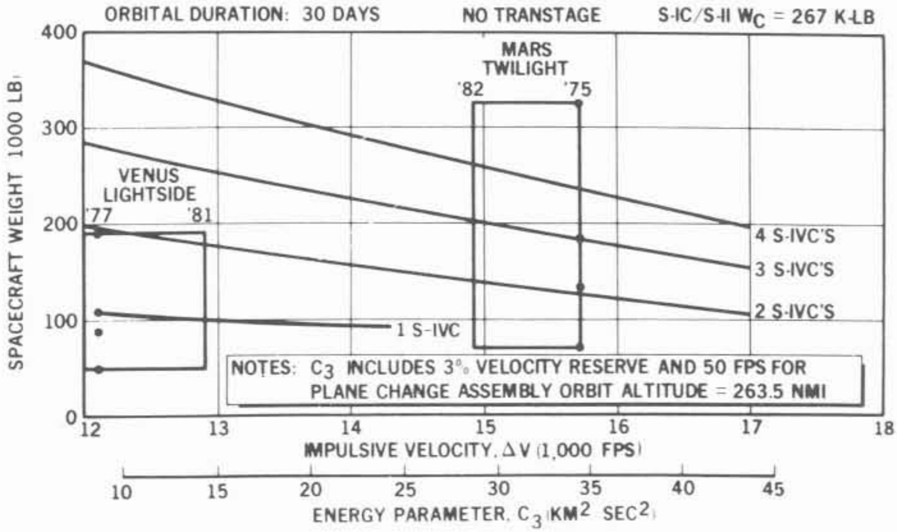


FIGURE 7

SPENT STAGE USES

WORKSHOP

The first spent-stage use of the S-IVB will be the orbital workshop application. The workshop is an elementary space station. In this mission, a specially modified S-IVB, as the second stage of an uprated Saturn I, injects itself into orbit unmanned. It is later occupied and activated by astronauts who are placed in orbit with a separate uprated Saturn I launch. Since the stage is initially fueled (but empty when it reaches orbit), only that equipment which is not adversely affected by LH_2 can be preinstalled in the hydrogen tank; other equipment must be brought in by the astronauts who activate the stage. Figure 8 shows the elements of the orbital workshop. The vehicle must be modified to provide a deployable meteoroid bumper which protects the stage for its extended stay in orbit, a quick opening hatch in the forward LH_2 dome to permit easy access for the astronauts, mobility aids and

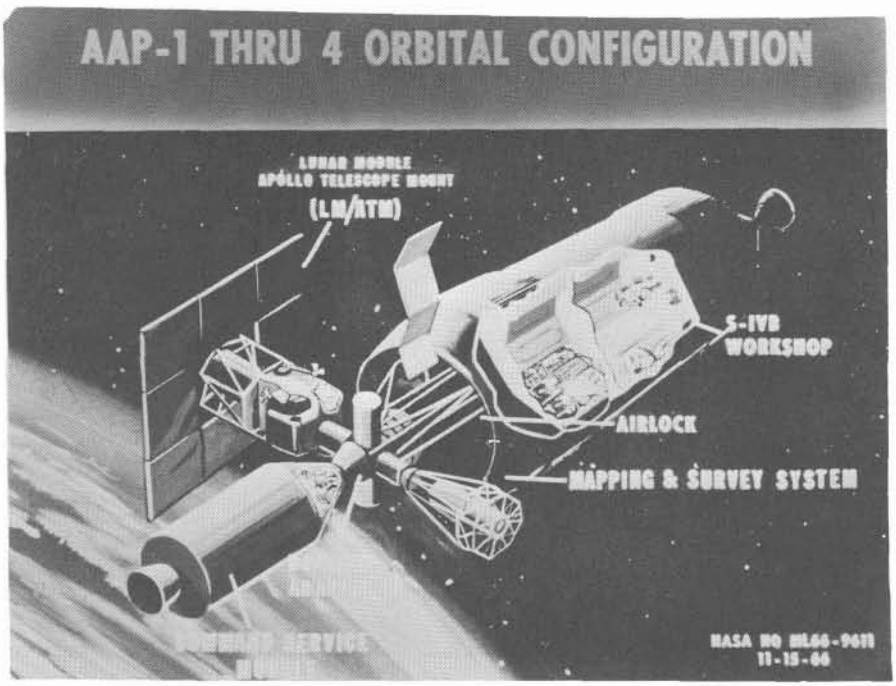


FIGURE 8

restraints for astronaut motion inside the tank, crew quarters bounded by a floor and ceiling and partitioned into five rooms, devices which permit sealing of the normal tank opening after it is occupied, and a thermal-control system to direct the conditioned air properly. After entry into the tank, the astronauts will install certain fabric separation panels; compartment doors; habitation equipment including food lockers, sanitation devices, and sleeping restraints; equipment for performing experiments; and thermal-control fans and lights.

An element of the mission planned for the first workshop vehicle is shown in Figure 9. The first launch places a command module/service module and lunar mapping and survey system into orbit; the second launch inserts the orbital workshop into low Earth orbit. After the basic LMMS mission is complete, the experiment module and the command module dock to the MDA and the astronauts enter and occupy the stage for 28 days. The life-support

SAA CLUSTER MISSION
FIRST PHASE

M-31087

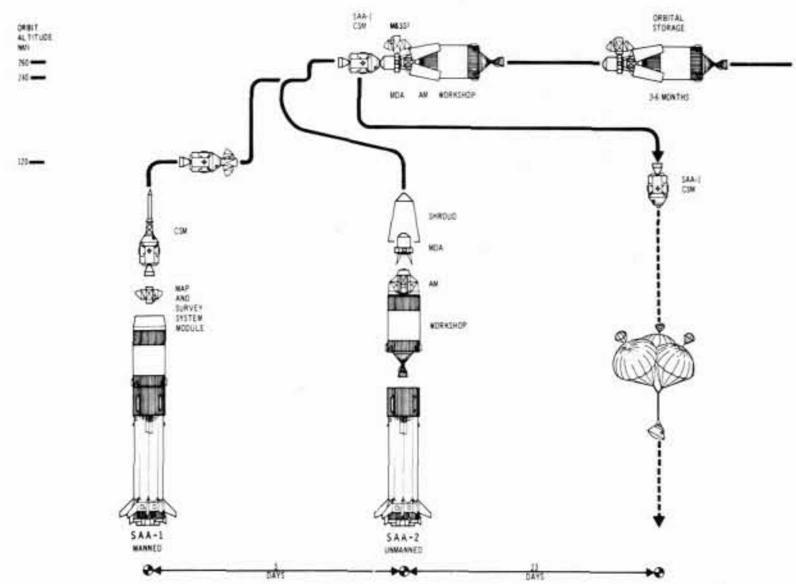


FIGURE 9

systems and space-station facility functions are furnished by the airlock module.

Categories of experiments to be performed within the tank include the following:

1. Evaluation of crew quarters design: space allocation, personnel hygiene operations, food preparation, sleeping accommodations, illumination, environmental control, etc.
2. Biomedical monitoring and experimentation.
3. Maintenance of an orbiting space station, including evaluation of work-sleep-recreation scheduling.
4. Technology experiments: electron arc welding, flammability, assembly and disassembly of hardware, etc.
5. Evaluation of astronaut aids: foot and hand holds, mobility rails, restraints, etc.

After 28 days, the astronauts return to Earth, but the workshop remains in orbit. Several months later, it will be revisited and reactivated for a longer time and important solar astronomy objectives will be completed.

SPACE STATION DEVELOPMENTS

The experience gained in the early workshop missions can be used in later, more demanding space-station missions. Douglas is currently conducting a study for MSFC in which the spent-stage concepts are being applied to missions of escalated requirements, in particular Earth-orbit space-station missions lasting for a year with six- to nine-man crews and with a potential requirement for artificial gravity. These requirements are being analyzed with two basic configuration approaches known as "Cluster C" and Earth orbital space station (EOSS). In the Cluster C mission (Figure 10) a modified S-IVB is launched into low Earth orbit in much the same manner as the currently planned workshop stage. However, this vehicle is equipped with advanced versions of the airlock module and multiple docking adapter and has internal tank provisions which are suited to the larger crew size and the more advanced functions of the mission. The subsystems carried in the

M-38917

AWS-LO CLUSTER 'C' C-C-3C

"OG" OPERATIONS

FIRST LAUNCH: MANNED CSM AND EXPERIMENT/SUPPLY MODULE.

SECOND LAUNCH: UNMANNED SIVB SS-II INTERMEDIATE AM WITH INSTALLED COMMAND CONTROL CENTER AND CREW QUARTERS. LH TANK WITH TWO DECKS AND CENTRAL CORE ACCESS. INTERMEDIATE SUBSYSTEMS. SOLAR PANEL POWER.

LATER LAUNCHES: ADDITIONAL EXPERIMENTS, RESUPPLY AND CREW ROTATION.

"AG" OPERATIONS

THIRD LAUNCH: UNMANNED "AG" MODULE LAUNCH TO RENDEZVOUS WITH SECOND LAUNCH. SPENT STAGE CARRIES CONSUMABLES AND EXPERIMENTS.

"AG" MODULE: SIVB LONG NOSE CONE WITH DOCK CAP CONNECTED TO EXPERIMENTS VOLUME. SPENT STAGE SIVB. LH TANK ACCESS. REDUNDANT APS POWER FOR SPINUP/DOWN. PASSIVE DAMPERS EXTENDED.

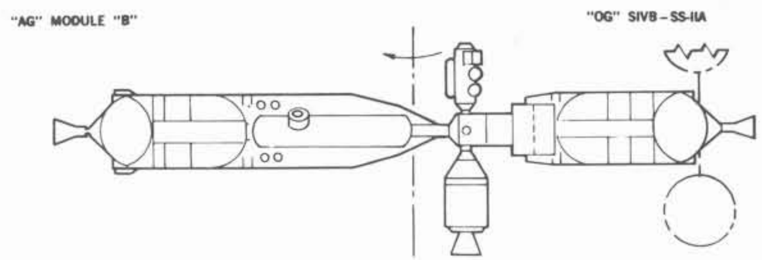


FIGURE 10

airlock module are suitably modified for a 1-year mission using resupply every 3 months.

A second spent S-IVB will be launched on an uprated Saturn I launch vehicle into the proximity of the first workshop; these two vehicles will rendezvous and dock, thus providing additional payload capacity and volume for experiments and living quarters and services for the crew. If artificial gravity is required, the two vehicles will rotate around their CG, with the second vehicle being primarily the "artificial gravity module" in that it contains the peculiar elements of stabilization and control demanded by this mode. Note that this vehicle has a particularly long nose fairing so that the radius of rotation is maximum.

As in the case of the first workshop missions described earlier, much of the equipment to be located inside the tanks must be installed by the astronauts after stage orbital insertion, since the S-IVB vehicles are launched and act initially as a propulsive stage.

The alternate configuration being studied for the advanced versions of the workshop, the EOSS, envisions a specially modified S-IVB-derived space station launched into orbit as the payload of a Saturn V vehicle (Figure 11). This mission mode has the advantage that equipment can be preinstalled prior to launch and assembly time in orbit by astronauts is practically eliminated. The particular mission requirements are similar to those described above. For example, 6- to 9-man crews are required for periods of 1 year and intermittent resupply can be considered. The lessons learned in the early workshop mission will also be applicable here, since subsystems, tank fittings, operations, and other elements of the early missions can be used to advantage. This mission also involves two basic launches. The first places the space station itself into orbit on a Saturn V and the second places

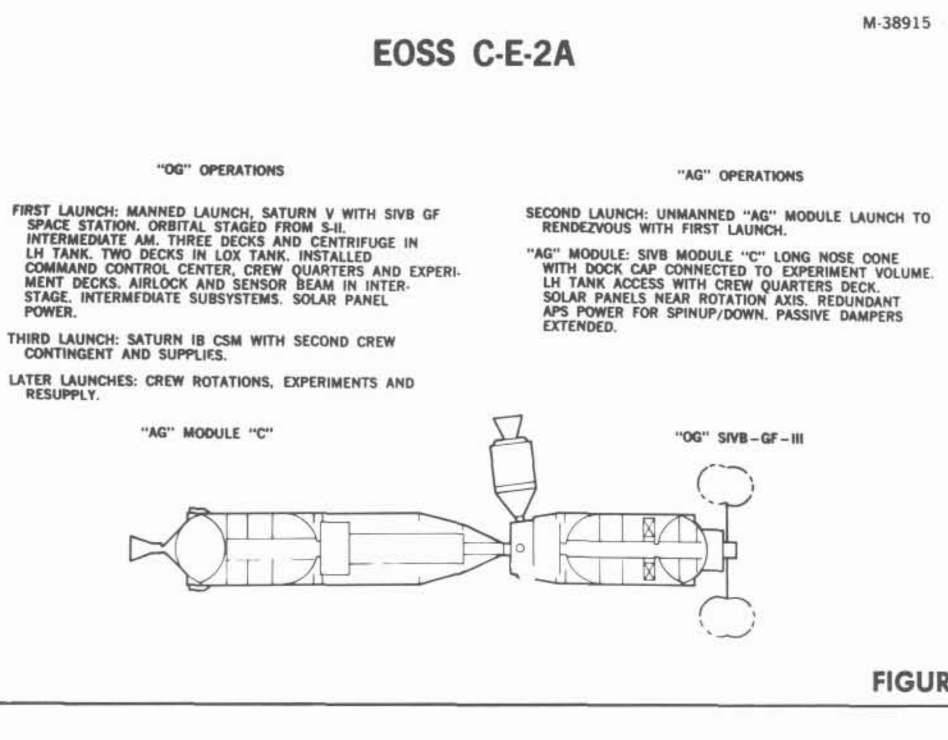


FIGURE 11

a "Module C" in orbit using an uprated Saturn I launch. This second module provides an artificial-g counterweight and artificial-g services in addition to added volume and experiment capability.

The basic mission of the 1-year station of either the Cluster C or EOSS configuration will be to provide precursor information for the operational space stations to follow and for interplanetary missions which will undoubtedly occur in the last half of the next decade. Thus, in the sense that the workshop will provide early experience for the Cluster C or EOSS, these versions will, in turn, provide subsystem, operations, and experiments in support of more advanced missions to follow.

LASS and LASSO

Independent Douglas studies show that the S-IVB can be used to support lunar operations. With some modifications, the S-IVB can deliver cargo to the surface of the moon and, once having landed, provide shelter on the surface in a manner similar to the use of spent stage in orbit. This mission is known as the Lunar Application Spent Stage (LASS) and is depicted in Figure 12.

The baseline mission profile for the unmanned LASS lunar logistics/shelter vehicle consists of a direct ascent launch to injection into a 110-hour lunar transfer. The launch phase will employ standard S-IC and S-II stages, as well as first burn of the modified S-IVB. Throughout most of the 4-1/2 day coast, the vehicle will be maintained in a solar alignment by the attitude control system. The vehicle will be aligned toward the sun (solar radiation impinging on the J-2 engine thrust structure) to reduce the amount of fuel boiloff and to prevent freezing of the LO_2. Appropriate mid-course corrections, ullages, vents, and navigational operations will also be made. A direct-descent powered braking phase to the lunar surface will be performed using a terminal guidance system in conjunction with the propulsion system to direct the vehicle toward the lunar beacon. The lunar landing will utilize two phases of braking. Phase I (full-thrust operation of three engines) will cancel the impact velocity and steer to the beacon. Phase II (throttling

KEY MISSION FEATURES

S-IVB-3381

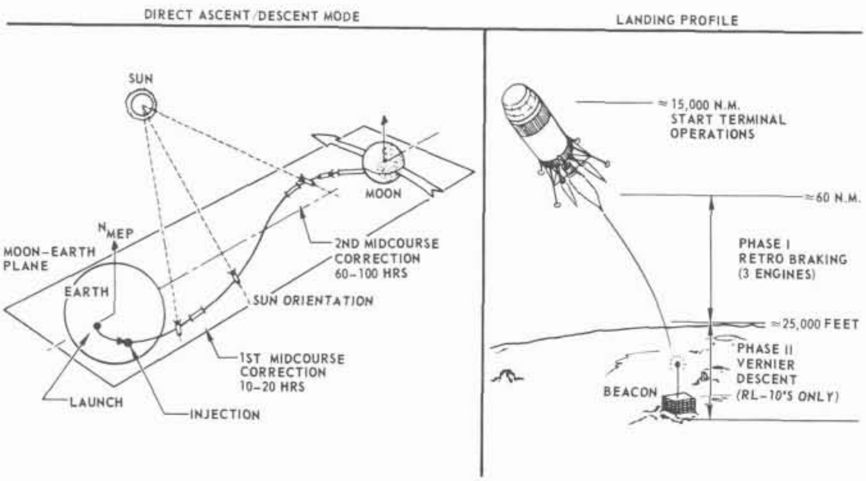


FIGURE 12

operation of the RL-10 engines) will provide the terminal cutoff conditions. The powered phases of landing will begin at approximately 60 nmi and end at approximately a 10-ft altitude with a velocity of 0 to 5 fps. The velocity at touchdown will be approximately 10 fps.

It has been found after detailed study that the vehicle can land approximately 27,000 lb of cargo above the empty stage. This compares very favorably with new vehicles designed particularly for the mission and offers the definite advantage of the potential use of spent-stage workshop techniques to provide cost-effective structures on the lunar surface.

It is important to describe the landing system, since this is one of the keys to the use of the S-IVB on the lunar surface. Figure 13 depicts the landing system currently being considered. In this quadruped system, comparison of the first leg which contacts the surface forces hydraulic fluid into the opposite leg, thus extending the down-slope leg. Crushable honeycomb pads

MUTIPLE START KITS

S-IVB-2796

DUAL RESTART CONFIGURATION

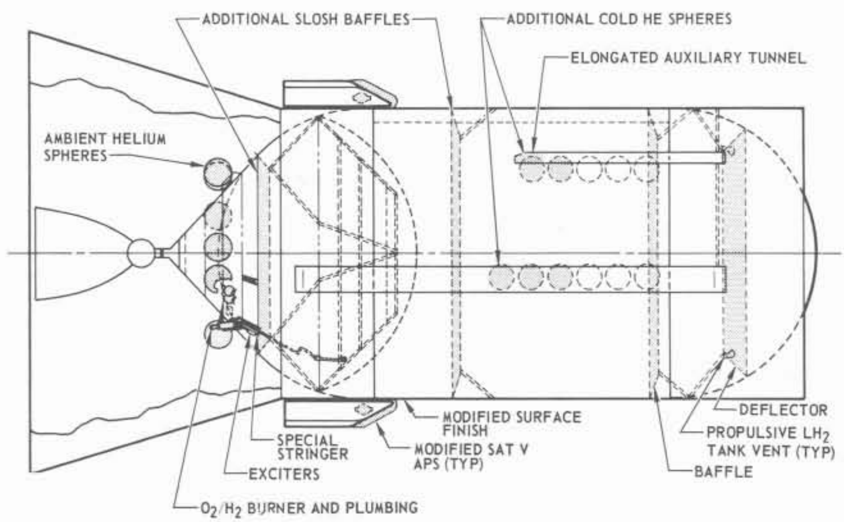


FIGURE 13

are used to absorb final shock. This system is being tested analytically using landing criteria, and the stage has been found to be stable during the landing maneuver.

The LASS in orbit (LASSO), an S-IVB with cargo, can be placed into lunar orbit to support operations on the lunar surface or to conduct space station type experiments from lunar orbit. There are several methods of conducting this mission. In one of these, a command module/offloaded service module and S-IVB are injected into a translunar path with the second burn of the S-IVB. The S-IVB points toward the sun during the translunar coast to minimize boiloff, and its engine starts again in the vicinity of the moon to place the stage and its payload in lunar orbit. This mission which involves only a single Saturn V launch could carry 18,000 lb of scientific equipment as well as expendables to support 3 men for 30 days in lunar orbit. The stage, of course, could serve as a workshop-type space station. More complex missions can be envisioned immediately in which dual launches are required, and payload will rise dramatically with these multiple-launch approaches.

Thus, there is a continuity to the potential evolution of the S-IVB. Multiple start, long duration coast, and adaptation to orbital operations appear to be the keys to extending the propulsive applications of the stage. With these kinds of modifications, the stage can perform missions of higher payload, synchronous-orbit flights and can even boost manned planetary missions. The other main path of evolution appears to be more complex, demanding uses of the spent stage to provide a framework for experiments and, potentially, space stations of increasing importance and sophistication. This type of evolution is of highest importance to our national space program because it permits the following:

1. Attainment of higher reliabilities through use of more mature equipment and operational procedures.
2. Continuity of industrial teams.
3. Realization of cost benefits as a result of multiple production of various elements of hardware.

The S-IVB, a stage designed for a particular mission, has utility far beyond that initially required. There seem to be important reasons to capitalize on that utility in the accomplishment of the nation's objectives.