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LUNAR APPLICATIONS OF A SPENT S-IVB/IU STAGE (LASS)

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DOUGLAS MISSILE & SPACE SYSTEMS DIVISION

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ABSTRACT

Support of lunar exploration missions is a major consideration in future space program planning. The spent Saturn V/S-IVB/IU can support both lunar-orbit and lunar-landing operations. This paper investigates lunar applications of the spent stage, and incorporates data generated during Company-funded studies. Investigated here is the feasibility of using a launch vehicle employing standard S-IC and S-II boost stages to deliver a modified S-IVB/IU and large discretionary payloads to a lunar orbit (LASSO) and/or the lunar surface (LASS). Operations in Earth orbit and direct-ascent trajectories are examined, and consideration is given to the use of the spent stage as a shelter in a manner similar to the presently planned Earth orbital workshop operations. Both the LASSO and LASS concepts are recommended for consideration in future lunar exploration plans. These concepts are capable of placing a gross wet weight of 101, 400 lb in lunar orbit or landing 63, 580 lb on the lunar surface respectively. The effective payload capability can be enhanced by proper integration of translunar mission subsystems with the subsystems required for lunar orbit or surface operations. The vehicles can be available within 3 years, with current-technology hardware sufficient for performing the missions described.

CREDITS

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The concepts and objectives described within this paper reflect the opinions of the authors and do not necessarily constitute endorsement by the NASA or any other U. S. Government organization.

INTRODUCTION

After the Apollo Lunar Module (LM) landings, support of lunar exploration missions will be a major consideration in development planning of future space programs. The Lunar Applications of a Spent S-IVB/Instrumentation Unit (IU) (Saturn V) Stage (LASS) can support both lunar orbit and lunar landing operations. An Airlock Module (AM) will provide the necessary life support for a 3-man operation in the Command Service Module (CSM) and S-IVB hydrogen tank. It is also planned that, with resupply, the mission may be extended for periods much longer in duration. Many complex experiments will be performed during the mission. More sophisticated versions of the workshop or space station are also being studied to provide support for as long as a full year in orbit. Most of the subsystems and components used in this mission have been developed for the Apollo, Gemini, or other space programs. Much of this Earth-orbital technology and hardware can be directly applied to lunar orbit as well as to surface missions.

Mission requirements, system characteristics and stage modifications for using the spent S-IVB/IU in a lunar orbit (LASSO Configuration) or for lunar landing (LASS Configuration) and a summary of the work that has already been accomplished in this area are discussed in this paper.

A wide range of missions is possible using the LASS concept as based on a Saturn V launch, appropriate mid-course corrections, and braking into a lunar orbit or to the lunar surface. Several possible missions are described. The earlier potential LASSO mission can be accomplished using a Saturn V version of the S-IVB workshop and AM. This configuration is capable of supporting 3 men and 18, 000 lb of scientific equipment for 30 days in lunar orbit. The Service Propulsion System (SPS) of the Service Module (SM) is used for the mid-course corrections and lunar orbit braking. With some modification to the stage and IU, the braking and midcourse corrections can be accomplished by the S-IVB.

The LASSO configurations have the capability of placing a gross weight of 101, 400 lb into lunar orbit. Of this amount, 69, 200 lb represents discretionary payload. The LASS configuration selected as the optimum lunar lander proved capable of landing the complete S-IVB/IU plus approximately 27, 300 lb of useful cargo (total landed dry weight of 61, 580 lb) on the lunar surface. These large payload capabilities will permit a host of potential manned scientific missions and experiments to be performed. With the possibility of carrying large quantities of expendables, long-term manned lunar orbiting and surface missions could be a reality in the early and mid-1970's. The design of the S-IVB for use in this manner to support lunar missions may be altered during the final design to accommodate modifications for other mission applications.

EVOLUTION OF A S-IVB LUNAR ORBITING AND LUNAR LANDING VEHICLE

The natural evolution of the spent S-IVB/IU for lunar applications is presented in Figure 1. The chronological development is shown starting with the uprated Saturn I/S-IVB-AM Earth-orbital workshop cluster mission to be launched in the near future. (1) The second evolutionary step shown employs the Saturn V vehicle, is the earliest potential lunar orbital LASSO mission (1970), and requires no modifications to the S-IVB, because the SPS is used for translunar mid-course corrections and lunar orbit braking. The next logical development is the J-2S engine hardware go-ahead and its substitution for the J-2 engine which allows attainment of large lunar orbit payloads via the LASSO concept. Here the J-2S does the job performed at the SPS. It is envisioned that the LASSO vehicle will evolve from an initially dependent configuration using CSM subsystems to provide near-term capability and satisfy mission requirements. In a totally independent configuration, all required subsystems are incorporated in the LASSO vehicle. The LASSO evolution is portrayed as satisfying missions in the 1970-to-1980 era.

The fulfillment of the LASS concept is reached with the evolution of the lunar landing vehicle at about 1973 to 1975. This configuration would require the addition of landing legs, throttleable engine(s), and terminal landing radars. A similar version was studied by Douglas in 1962.[2, 3] In this early concept, a modifed S-IV was landed on the moon and a Saturn V was used as the boost vehicle; the S-IV was the fourth stage and could land approximately 25, 000 lb of discretionary payload.

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SPENT STAGE EVOLUTION

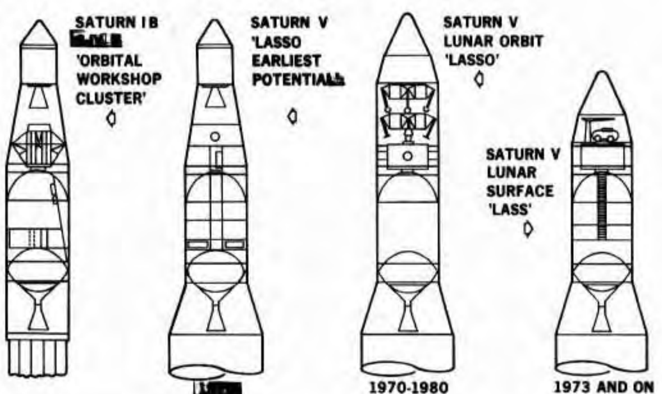


FIGURE 1

Baseline Configurations

Three baseline launch vehicle configurations are shown in Figure 2 to orient the reader prior to subsequent detailed discussions. Each employs the unmodified S-IC and S-II boost stages. The principal features of each required subsystem are presented to show the logical evolution of the baseline configurations from the present Earth-orbital workshop to the lunar orbit or landing concepts.

Baseline 1 is a Saturn V adaptation of the AS-211 mission and consists of an S-IVB, IU, AM, manned CSM, spacecraft-LM Adapter (SLA), and scientific cargo. The CSM is used to make the

S-IVB-3581A

BASELINE CONFIGURATIONS

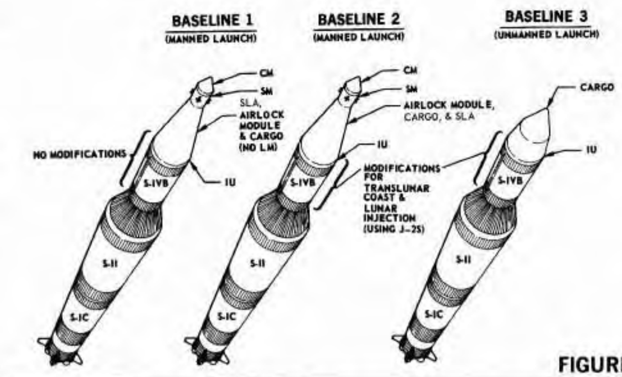


FIGURE 2

mid-course corrections and lunar orbit braking. The S-IVB/IU is used for translunar injection in a normal lunar orbit rendezvous (LOR) manner.

Baseline 2 is a manned configuration which uses the J-2S engine for translunar trajectory corrections and lunar orbit braking but has considerably more discretionary payload-carrying capability than Baseline 1. Specifically implied in this baseline configuration is the utilization of those subsystems in the CSM which would satisfy LASSO requirements, examples being fuel cells, thermal conditioning systems, communications, and so forth.

Baseline 3 is a cargo-carrying version that operates independently with its own systems (J-2S engine used in both Baselines 2 and 3). This concept, for which two possible payloads are presented, can be either manned or unmanned.

The lunar-landing configuration (unmanned) entails the addition of landing legs and propulsion systems (two RL-10 engines or a J-2X engine) which are discussed in a subsequent section.

All of these configurations can be launched at Kennedy Space Center, using existing launch facilities and Saturn V launch operational procedures.

LASSO-LUNAR ORBIT MISSIONS AND SYSTEMS

The mission profile for the Baseline 1 LASSO shown in Figure 3a is very similar to the standard Saturn V LOR profile. The lunar transfer, however, is accomplished with a 110-hour trajectory instead of the 72-hour LOR trajectory. After translunar injection from an Earth orbit by the S-IVB, the CSM performs a transposition maneuver and docks with the S-IVB/IU/AM. The spent S-IVB/IU/AM has mass and dynamic characteristics similar to the loaded LM. The CSM makes all of the mid-course and lunar braking operations. After lunar orbit insertion, the S-IVB is passivated or neutralized for safety and occupied, as with the AS-211 orbital workshop.

The mission profile for the Baseline 2 and 3 LASSO vehicles shown in Figure 3b consists of a direct-ascent launch to injection into a 110-hour transfer trajectory. Injection via an Earth parking orbit is an option offering approximately 3, 600 lb less payload. The launch phase will be performed

LASSO MISSION PROFILE

S-IVB-3582

BASELINE 1 FIGURE 3a

BASELINE 2 & 3 FIGURE 3b

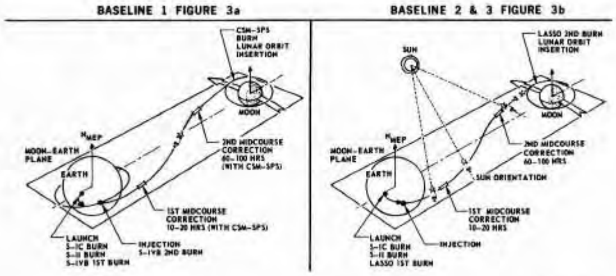


FIGURE 3

LASSO MODIFICATIONS
(BASELINES 2 AND 3)

S-IVB-3396

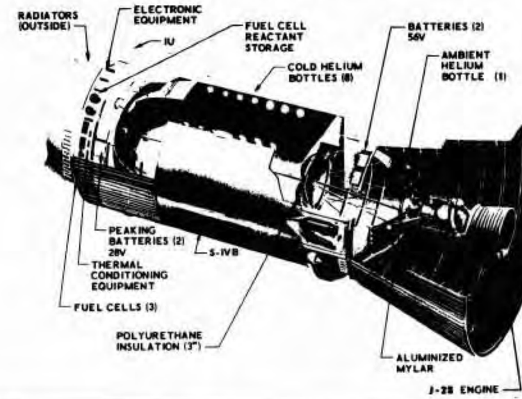


FIGURE 4

by use of standard S-IC and S-II stages as well as a first burn of the modified S-IVB. Throughout most of the 4-1/2-day coast, the vehicle will be maintained in solar alignment by the attitude control system. The vehicle will be aligned toward the sun (solar radiation impinging on the J-2S engine thrust structure) to reduce the amount of fuel boiloff and to prevent freezing of the liquid oxygen (LO_2). Mid-course corrections and ullages will be made with the J-2S engine in the appropriate thrust mode. A powered braking phase to the lunar orbit will be initiated by an Earth control signal. The J-2S burns for approximately 52 sec during braking.

Modifications to the S-IVB/IU

The LASSO modifications are defined as those changes required to convert an operational Saturn V/S-IVB/IU into a LASSO vehicle. The LASSO Baseline 1 configuration would be the same as a standard Saturn V/S-IVB/IU, except for addition of a passivation kit for neutralizing the stage after lunar orbit insertion and minor brackets for experiment support. There are no changes to the present subsystems.

The modifications to the S-IVB/IU required for Baseline 2 would be dependent upon the capability of certain subsystems of the CSM to accomplish the mission. The LASSO modifications for Baseline 3 are shown in Figure 4. The propulsion system is based on utilizing the J-2S engine, which has the low-thrust idle-mode and long-term coast characteristics. This engine is essentially interchangeable with the present J-2 and utilizes the same structural mounts, gimbal actuation, and propellant feed ducts. Eight additional cold helium bottles are needed for oxygen and hydrogen tank repressurization, via employment of the helium heater, for the lunar braking phase. The standard Saturn V/S-IVB presently has eight cold helium bottles. One ambient helium bottle is added to the thrust structure for stage and engine pneumatics. The J-2S is self-ullaging and can start on either gaseous or mixed-phase feed conditions. (The existing 72-lb thrust ullage engine in each of the two auxiliary propulsion system (APS) modules can be deleted.) Electrical heating blankets and thermal insulation must be added to the APS modules for temperature conditioning during the translunar coast.

Aluminized mylar insulation is added to the aft thrust structure area to reduce heat input to the oxygen tank during sun orientation. Three inches of polyurethane insulation is also added on the hydrogen tank side of the common bulkhead to reduct the heat transfer from the LO_2 tank during coast.

It is necessary to modify the existing electrical power system for the long coast. Weight optimization dictates the use of fuel cells for a nominal 2.4 kW power load. Two Apollo fuel cells, complete with controls and reactant storage, are needed to furnish the power. A third unit is included for reliability. Rechargeable batteries are used to supply the power increment required for the short-duration peak loads. The fuel cell systems can be located in the S-IVB forward skirt or the IU. Development of solar cell arrays for the workshop cluster would undoubtedly preclude the use of fuel cells. A closed-loop heat rejection system is also required to dissipate heat from the fuel cells and electronic equipment. The present ethylene glycol-water system must be modified to incorporate a space radiator. The radiator can be located in any one of several places in the S-IVB forward skirt, IU, or payload area. The specific location should be determined in a subsequent study.

Most of the required electronics to accomplish the mission would probably be located in the IU area and will consist of a high-gain, data-transmission antenna system, sun seeker, star and horizon trackers, and controls and sequencing equipment.

Weight and Performance

Baseline 1 with the SM used for lunar orbital braking has an S-IVB/IU-plus-payload weight capability at burnout in lunar orbit approximating the loaded LEM weight.

The nominal Baseline 2 and 3 mission weights and performance detailed in Figure 5 are for a direct ascent launch, a 110-hour coast, and an insertion into a 100-nmi lunar orbit. The key weights[4] are summarized as follows:

Gross weight injected	=	135,890 lb
Gross weight at lunar approach	=	122,140 lb
Gross weight in orbit (includes 2,000 lb of residuals)	=	101,400 lb
Dry vehicle (without payload or fairing)	=	30,200 lb
Payload	=	69,200 lb

LASSO WEIGHT & PERFORMANCE

S-IVB-3600

(BASELINE 2 & 3)

NOMINAL MISSION	WGTS (LBS)
WEIGHT INJECTED	135,890
PROPELLANT BURNED	203,250
PROPELLANT REMAINING	31,031
PROPELLANT EXPENDED IN COAST (RESERVES MIDCOURSE & VENTED)	10,550
PAYLOAD FAIRING JETTISONED	3,200
WEIGHT AT LUNAR APPROACH	122,140
PROPELLANT BURNED TO LUNAR ORBIT (100 NMI LUNAR PARKING ORBIT)	20,740
WEIGHT AT ENGINE CUTOFF	101,400
RESIDUALS AT BURNOUT	2,000
DRY ORBITAL WEIGHT	99,400
S-IVB STAGE (LESS BATTERIES)	23,250
INSTRUMENT UNIT	4,180
ECS (ADD RADIATOR SYS. & REMOVE SUBLIMATOR)	32
POWER SYSTEMS (FUEL CELLS & BATTERIES)	1,597
ELECTRONICS & STRUCT. MODS & INSULATION	421
ADDITIONAL REPRESSURATION REQTS	720
PAYLOAD FAIRING (JETTISONED)	(3,200)
DRY VEHICLE LESS PAYLOAD & FAIRING	30,200
PAYLOAD	69,200

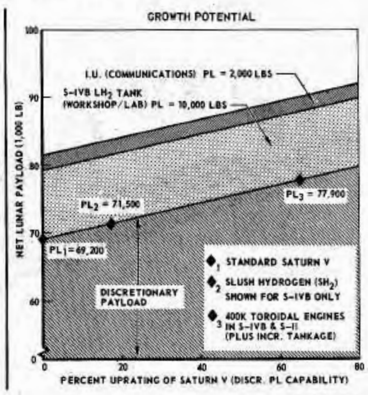


FIGURE 5

LASSO LUNAR LAUNCH WINDOW

LAUNCH AZIMUTH = 90°
TRANSFER TIME = 110 HOURS

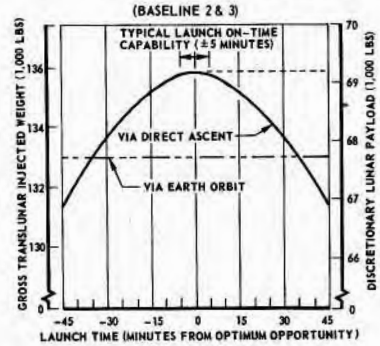


FIGURE 6

Growth potential appropriate for various uprating techniques (such as slush hydrogen in the S-IVB, high-performance engines, and/or strap-on motors) reflects a corresponding increase in discretionary payload available. Considering a portion of the S-IVB LH_2 tank to be useful payload as a workshop or laboratory, and similarly the IU as a communications and data handling system, the net lunar payload can be shown as a combination of both the useful and discretionary payload.

It should be noted that the 69,200-lb payload would have to include any micrometeoroid shielding or thermal insulation required for an S-IVB LH_2 tank with a shirtsleeve environment. The shielding and insulation is not required for an unmanned orbital operation. The Workshop Cluster has a meteoroid shield good for 30 days in Earth orbit with a probability of no penetration equal to 0.995.

Lunar Launch Window

The Baseline 2 and 3 LASSO lunar launch window performance characteristics, as a function of time from optimum launch opportunity, are presented in Figure 6 for both the direct and indirect launch modes. The windows are representative of a due east launch (90° azimuth), an optimum true anomaly at translunar attachment, and a 110-hour lunar transfer. The Baseline 1 lunar launch window payload performance is essentially constant at 17,850 lb via the indirect launch mode. The direct-ascent launch window (no Earth orbit) for Baselines 2 and 3 has the following characterisitcs:

1. Direct Ascent Launch Opportunities:

A. One launch opportunity (window) per day.

B. Eight consecutive opportunities (days with a window) per lunar month. (These occur during the moon's passage through its maximum negative declination.)

2. Direct Ascent Launch Performance:

A. The gross translunar weight injected at the window center is 135,890 lb.

B. The optimum discretionary payload obtained for launch at the window center is 69,200 lb into lunar orbit.

C. The payload loss is neglibible for a typical launch on-time capability of ±5 min.

D. The payload available over a 30-min window (±15 min) is 68,900 lb into lunar orbit.

The indirect-ascent launch window which employs a 100-nmi Earth orbit has the following characteristics:

1. Indirect Ascent Launch Opportunities:

A. Two launch windows per day, every day of the month.

B. Window size is typically 5 hours long.

2. Indirect Ascent Launch Performance:

A. The gross translunar weight throughout the launch window size shown is approximately 132,940 lb.

B. The discretionary payload deliverable is 67,700 lb into lunar orbit.

Mission No. 1 - Earliest Potential LASSO

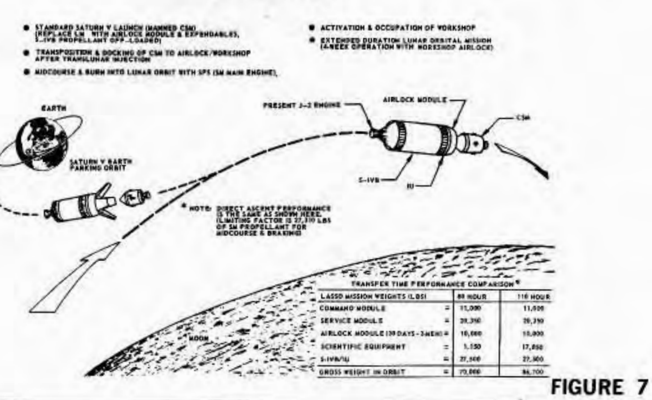
The earliest potential LASSO mission (Baseline Configuration 1) is portrayed in Figure 7. The significant feature of this 110-hour transfer mission is that it can be performed by the first available Saturn V/S-IVB stage with modifications similar (if not identical) to those of the S-IVB-orbital workshop stage and an AM. No new or modified engines are required and all the data and experience gained in the S-IVB workshop are directly applicable.

The S-IVB will inject the AM and CSM into the lunar transfer trajectory. After the docking of the CSM to the airlock/spent stage, the SPS is used for mid-course corrections and for braking the configuration into the desired orbit.

MISSION NO. 1
EARLIEST POTENTIAL LASSO

S-IVB-3583A

(BASELINE 1)



TRANSFER TIME PERFORMANCE COMPARISON*

LASSO MISSION WEIGHTS (LBS)	89 HOUR	110 HOUR
COMMAND MODULE =	11,000	11,000
SERVICE MODULE =	20,350	20,350
AIRLOCK MODULE (30 DAYS - 3 MEN) =	10,000	10,000
SCIENTIFIC EQUIPMENT =	1,150	17,850
S-IVB/IU =	27,500	27,500
GROSS WEIGHT IN ORBIT =	70,000	86,700

FIGURE 7

The primary requirements imposed on the pitch and yaw control system during SPS operation is thrust-vector pointing accuracy. The present SM main engine control system is designed to minimize thrust-vector pointing errors while maintaining adequate stability margins in the presence of propellant sloshing and body bending disturbances. A comparison was made of the important CSM/ S-IVB control system parameters, including body-bending frequencies and mode shapes and control moment coefficient with those of the loaded CSM/ LM. The comparison was simplified by the fact that the first-mode bending frequencies of the two vehicles are approximately the same. It may be concluded that a pointing accuracy equal to that of the CSM/LM could be achieved with the CSM/ LASSO during mid-course corrections, translunar coast, lunar braking, and lunar orbit.

The lunar mission could entail a 4-week manned orbital survey and operation as an orbital command post and way station. Provision for occupation by subsequent crews, and the capability of receiving logistics resupply modules, could be incorporated in the design. Discretionary payloads of approximately 18, 000 lb, in addition to the life support and airlock-docking structure, could be carried for the mission described.

Mission No. 2 - Single Launch LASSO

The LASSO missions described in Figure 8 provide for full utilization of the large payload capability (approximately 70, 000 lb) derived from braking the S-IVB vehicle configuration into lunar orbit with a J-2S engine. This mission is based on a single launch concept (Saturn V) wherein the S-IVB/IU LASSO vehicle is used to brake a manned CSM into lunar orbit, as well as other cargo (AM, expendables, and scientific equipment). The performance comparison between direct- and indirect-ascent launches is also presented.

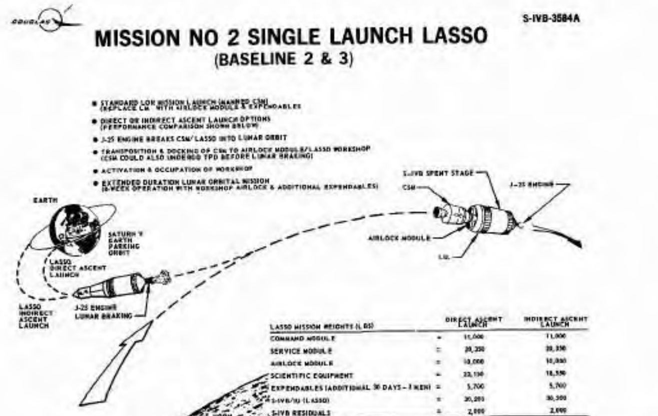


FIGURE 8

Long-duration lunar orbit missions are then available (with stay times to 8 weeks for 3 to 4 men) for a large variety of sophisticated experiments and operations requiring large payloads.

Mission No. 3 - LASSO Carrier

Another typical application is presented in Figure 9 as the Carrier mission during which several spacecraft systems are transported into a lunar orbit for later use. Typical examples are (1) two LM descent stages and fuel and expendables for resupply of the LM ascent stage (to allow three LM landings), and (2) several modified Surveyor stages for orbit-to-ground guided landings (to implant scientific stations).

FIGURE 9

The mission shown provides for long-term lunar surveillance and three successive LM landings at different points with only two Saturn V launches. The SCM/LM rendezvous with the LASSO and the crew activates and occupies the workshop (an advanced-type AM is shown which includes long-term life support capability). At the appropriate time the manned LM descends to perform the first landing and surface investigation. The LM ascent stage subsequently returns the crew to the LASSO Carrier for rest and rehabilitation. The ascent stage is refueled and mated to another descent stage and this process is repeated twice with crew rotation to provide for three landings. (Conversely, the LM/LASSO could be left behind in orbit to provide a rescue vehicle and orbital way station for later LOR missions.)

Mission No. 4 - LASSO Survey

Another typical concept for a large payload application is shown in Figure 10. The payload for this mission is devoted primarily to orbiting selenographical survey-equipment. Color photography, low-frequency radar, microwave radiometers, IR and UV detectors, and laser or radar profilometers are used to evaluate the mineral composition, selenographical formation, and gas and/or permafrost water profiles of the crust. These sensors will also determine surface contour, subsurface contour, and subsurface activity. It may be desirable to conduct this type of mission from lower orbital altitudes to reduce antenna and power requirements. An additional power supply would probably be used to operate some of the experiment equipment. Because of the probable time period of such a mission (1975), the power system would probably consist of solar panels with rechargeable peaking batteries.

LASS--LUNAR LANDING MISSION AND SYSTEMS

The mission profile shown in Figure 11 for the unmanned LASS lunar logistics/shelter vehicle consists of a direct-ascent launch to injection into a 110-hour lunar transfer. The launch is

MISSION NO 4 LASSO SURVEY
(BASELINE 3)

S-IVB-3586A

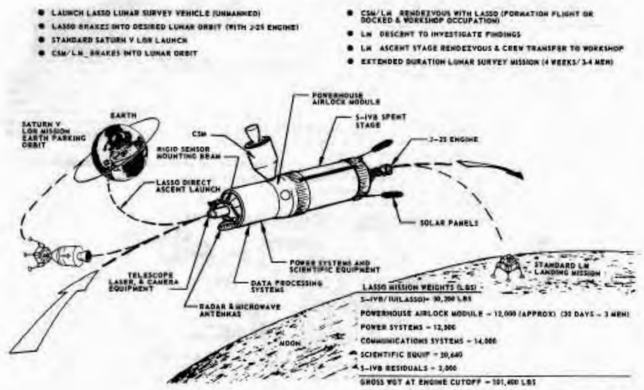


FIGURE 10

LANDING MISSION PROFILE

S-IVB-3381

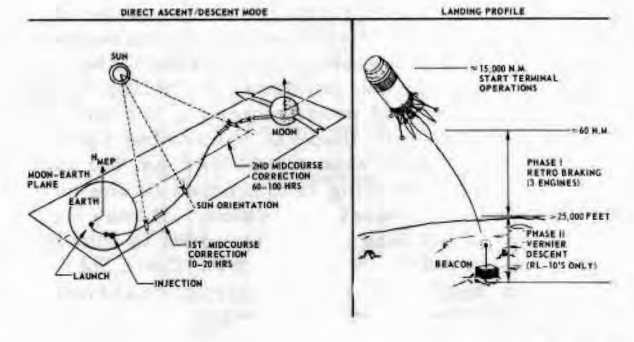


FIGURE 11

accomplished using standard S-IC and S-II stages as well as the first burn of the modified S-IVB. Throughout most of the 4-1/2-day coast, 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) will cancel the impact velocity and steer to the beacon. Phase II (throttling operation) will provide the terminal cutoff conditions. The powered phases of landing will begin at approximately 60 nmi and end at an altitude of approximately 10 ft with a velocity at touchdown of approximately 10 fps.

Preliminary calculations, based on constant values for mid-course and performance reserves, indicate that the 72-hour mission could be performed by the S-IVB with very nearly the same net lunar payload because of the translunar boiloff compensation. The accompanying increase in mid-course requirement and launch performance reserves for the shorter mission, however, would degrade the net payload. The baseline 110-hour mission, while not necessarily the optimum payload transfer, still maintains excellent tracking opportunities and lower velocity error margins. (5)

Lunar Landing Vehicles

The operation and performance of the four specific LASS configurations shown in Figure 12 (designated I through IV) were investigated early in the study to determine the best vehicle for detailed definition and examination. Specific design configurations were studied rather than making a parametric comparative analysis. The major differences between the various configurations is in the propulsion subsystem considered to meet the mission requirements. The other supporting control and power subsystems would also be modified as required to accommodate the respective propulsion systems. Five independent factors were considered, evaluated, rated, and presented in matrix form to compare each configuration. These factors include performance, relative cost, manufacturing complexity, design considerations, and shelter applicability. The ratings were summarized to indicate the relative rating of each vehicle configuration. Configuration I was determined to be the best overall by a significant margin. The relative rating ratios were: Configuration I, 43; Configuration II, 33; Configuration III, 29; and Configuration IV, 25.

EVOLUTION OF LUNAR LANDING VEHICLES

S-IVB-3379

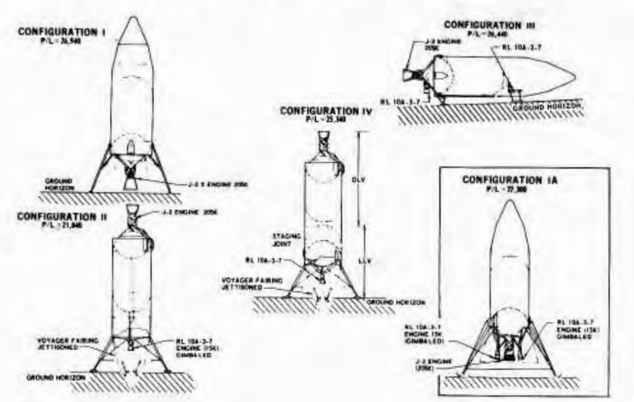


FIGURE 12

Configuration I is a vertical lander which uses a J-2X type engine (modified J-2) that has an idle mode capability and a throttling ability in the range of 20 or 25 to 1. This configuration offers a "do-all single engine" feature which minimizes stage modifications. The J-2X concept is an engine design currently under investigation and development by Rocketdyne to improve the flexibility and reliability of the J-2 engine. This program has tested an engine with the features summarized below. The J-2X as presently conceived, is expected to be capable of being throttled to 17% of rated thrust. A future capability goal is to achieve throttling down to 5%. This engine would provide the necessary braking and throttling capability for the LASS lunar descent. The estimated nominal specific impulse at full thrust of the J-2X is about the same as the J-2. The J-2X will achieve an idle mode thrust of about 6, 000 lb for mid-course corrections. The J-2X fires in this mode on tank head pressures and without special propellant conditioning. Propellant flow during idle mode operation chills down the engine and propellant feed system. This means that the current S-IVB J-2 recirculation system can be deleted. The J-2X can also be operated in the idle mode prior to first burn to settle propellants and thereby eliminate four 35, 000-lb thrust, solid ullage rockets. Propellant settling required prior to cyclic venting during the translunar coast can be accomplished by firing the J-2X in the auxiliary spark ignition (ASI) mode at about 50-lb thrust. Lunar descent, braking and landing control can conceivably utilize the idlemode operation. The J-2X turbine spinup is accomplished by using a solid-propellant gas generator to replace the high-pressure gaseous hydrogen start tank. This eliminates the potential problems associated with a restart after the 110-hour coast that existed with the standard GH_2 start sphere. The J-2X also has improvements which simplify the overall stage and acceptance testing. It requires no on-the-ground thrust chamber conditioning, it has eliminated various seal purges and drain requirements, and its new thrust chamber does not need to be supported for side loads during ground testing. The J-2X is completely interchangeable with the standard J-2 from a stage installation standpoint. This propulsion system fulfills the requirements of the 110-hour LASS mission with a minimum of stage modifications. The major drawback presently is the engine's state of development and resulting availability. Configuration I is the preferred vehicle approach if an engine of this type becomes available.

Configuration II was designed to utilize a single RL10 for the mid-course and landing maneuvers but proved to have undesirable propellant-feed conditions, limited cargo space, and poorer performance resulting largely from the lower thrust-to-weight ratio (compared to Configuration I) during lunar landing. The goal was to use a more readily available engine. This configuration uses a standard J-2 engine on the aft section of the S-IVB and a Pratt & Whitney RL10A-3-7 engine in the forward section. This engine is a standard Centaur configuration with an idle mode and throttling capability added.

This propulsion scheme presents a problem from a propellant supply consideration. The oxygen feed duct is exceptionally long and runs approximately 50 ft through the hydrogen tank. Running the duct outside of the hydrogen tank was also considered. However, this duct configuration would have a reverse pitch which could prevent free propellant flow because of gas entrapment. The shortest oxidizer duct length can be accomplished by running the duct through the hydrogen tank. This requires major structural tank modifications and insulation considerations to prevent oxidizer freezing. This configuration, which has an engine on each end of the tank, necessitates the addition of many dual systems in the tanks to permit operation. Two vent systems, two pressurization systems, and two propellant utilization systems are required. In addition, new antivortex screens are required for RL10 operation. Prior to J-2 first burn, the normal chilldown recirculation system must condition the propellants. The solid ullage rockets are required for propellant settling prior to first burn.

Sun orientation, mid-course corrections, and the lunar descent operations would be performed by the RL10A-3-7 engine. The RL10A-3-7 has a gimballing capability which allows it to be used for pitch and yaw control. To eliminate excess weight before landing, the J-2 engine could theoretically be staged sometime after the lunar injection firing. It should be noted, however, that the staging operation is complex and would require considerable development, and could result in a reliability degradation.

Configuration III, using a standard J-2 engine and two RL10A-3-7 engines, was designed to be landed horizontally for more suitable shelter applications and for unloading heavy cargo. The use of two RL10's resulted in a higher performance than Configuration II but could have very bad propellant-feed conditions and dynamic landing characteristics. From a liquid level and slosh standpoint, the RL10 engine locations create poor inlet liquid control conditions. Feed ducting would be exceptionally long, adding weight, increased pressure drop, and mounting difficulties. Dual vent and relief systems would have to be provided in both tanks to permit the different fluid operation positions. Engines locations are such that thrust lines of action create turning moments which must be counteracted by the APS. If a horizontal shelter is desired, it appears easier to land vertically (as in Configuration I) and then tip the stage over after landing.

Configuration IV consists of two independent stages and is based on staging that portion of the system (OLV) required for translunar injection and thus landing with a smaller stage (LLV). Although optimized staging generally results in higher payloads, it was not true in this case for two reasons:

1. The study ground rules required using full-size S-IVB oxygen tanks for each stage with the hydrogen tank walls merely shortened in length. This resulted in an inefficient propellant fraction but a high utilization of existing hardware.
2. A lower thrust-to-weight ratio results for the RL10's than for a J-2X type engine. This version does not present the propellant feed supply problem associated with Configurations II and III. The LLV contains the RL10A-3-7 engine. This concept from a propulsion viewpoint can utilize S-IVB program qualified hardware for the LLV except for new feed ducting. The standard J-2 engine is used on the OLV for translunar injection. LLV stage separation is accomplished after translunar injection. The LLV is a self-sufficient vehicle capable of lunar landing, although it does represent the development of basically a new stage.

Configuration IA evolved from the study of the previous four configurations. Configuration IA is basically the same as the preferred Configuration I but utilizes two RL10A-3-7 engines (15, 000 lb thrust each) in addition to a standard J-2. The RL10's provide the idle mode feature required for mid-course corrections, ullaging, and throttling for lunar landing. These engine features have been demonstrated by Pratt & Whitney on development engines, but they would have to be incorporated into the existing Centaur engine. Since the development of the RL10 has progressed further than the J-2X at this point in time, the engine development costs are lower than the J-2X engine. However, the RL10 installation has a greater effect on the stage than the J-2X, and a detailed study of costs and engine development schedules is required to make a final comparison. All subsequent discussions in this paper are limited to Configuration IA for purposes of indicating feasibility of a landing vehicle. Future studies can reflect the use of either engine.

Altitude control for these configurations can be provided with the existing Saturn V/S-IVB APS modules except for the indirect ascent launch applications (via on Earth parking orbit) of Configurations II, II, and IV. For this application, an extra APS propellant tank would need to be added to each of the two APS modules.

Modifications to the S-IVB/IU

The LASS modifications portrayed in Figure 13 are described as those changes required to convert an operational Saturn V/S-IVB/IU into the Configuration IA lunar landing vehicle previously described.

The propulsion system modifications include the addition of two RL10A-3-7 engines complete with structural mounts, gimbal actuators, and feed ducts. Six additional cold helium bottles are added for oxygen and hydrogen tank repressurization for the lunar descent engine burn. Two ambient helium bottles are added to the engine thrust cone. One is for pressurization of the hydrogen tank (1 psia NPSH) during the first mid-course correction which utilizes the RL10's in a 10% throttling mode. The second ambient bottle is used to supply pneumatic gas for stage and engine valve operation during the longer (110-hour) coast. Since the RL10's are self-ullaging and can start on either gaseous or mixed-phase feed conditions, the two existing 72-lb-thrust ullage engines in the APS modules can be deleted.

Electrical heating blankets and thermal insulation must be added to the APS modules for temperature conditioning during the translunar coast.

The insulation added to the stage of the proven system and the heat rejection systems are the same as previously described for the LASSO.

An S-IVB/S-II separation clearance problem between the RL-10's and interstage existed with one retro out. This required the use of 12 ordnance thrusters in lieu of the present four retrorockets.

Most of the electronics required to accomplish the mission are located in the IU area and consist of a long- and a short-range landing radar, a high-gain data transmission antenna system, a sun seeker, star and lunar horizon trackers, a lunar beacon tracker, controls, and sequencing equipment.

Landing the S-IVB on the lunar surface is recognized as the most critical phase of the LASS mission. The lunar surface environment, landing criteria, and the dynamic loads imposed were considered in establishing design criteria for the landing legs. The loads developed on landing had a significant effect on landing leg system design. The landing leg system's weight has a direct influence on payload capacity. The design of the landing leg system shown in Figure 14 allows the footpads and legs to slide and telescope, respectively, until all four legs are in contact with the lunar surface before any large dynamic loads can be applied to the S-IVB. Once these positions of contact have been assumed, the landing leg system is locked and the deflections of the crushable foot pads and leg pistons absorb the kinetic energy of the vehicle.

The landing leg design is based on lunar surface environment at the landing site which was assumed to be represented by a hard surface of 12° slope with surface faults running perpendicular to the lateral approach of the LASS. The assumed maximum vertical descent velocity was 10 fps and the assumed horizontal drift velocity was 3 fps down the slope of the lunar surface. From the time-histories developed, it was determined that the LASS configuration was basically stable under the assumed landing conditions. Detailed analysis of many other landing situations would be required in making the final design.

Therefore a four-leg landing system complete with cables, deployment mechanisms, a lurrain-compensating hydraulic-system and structural support must be added for the landing operations. The basic S-IVB structure must be "beefed-up" in the aft skirt area to accommodate the landing legs. Additional supports for the helium bottles, fuel cells, electronic systems, batteries, and propulsion system are also required. Several other landing leg concepts for the S-IVB land recovery on Earth have recently been presented. [6, 7]

Weight and Performance

The nominal mission weights and performance given in Figure 15 are for a direct-ascent launch,

S-IVB-3396

LASS MODIFICATIONS

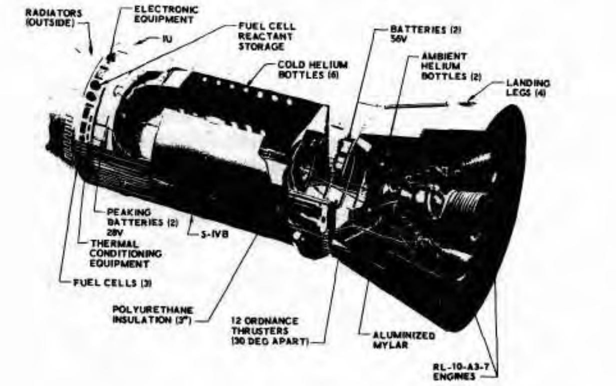


FIGURE 13

S-IVB-3405

LANDING LEG SYSTEM

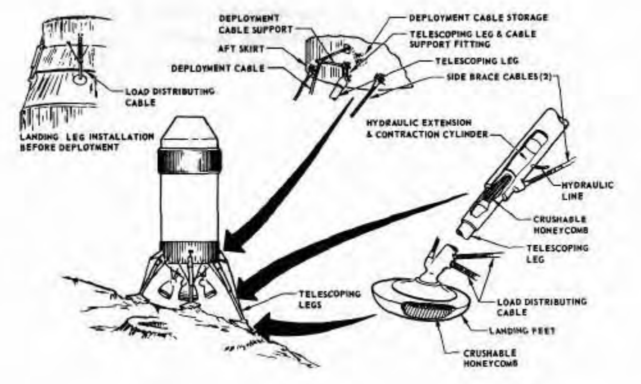


FIGURE 14

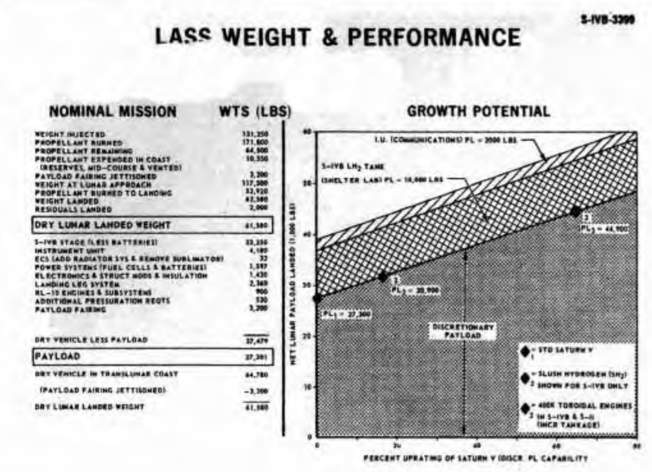


FIGURE 15

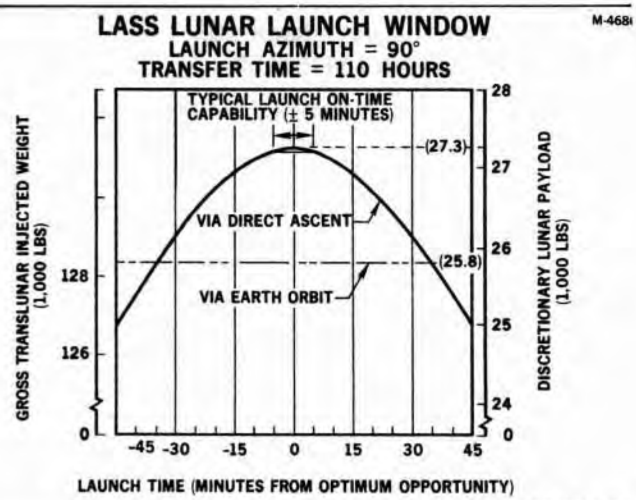


FIGURE 16

a 110-hour coast, and a direct-descent landing. The key weights are summarized briefly below:

Gross weight injected	=	131, 250 lb
Gross weight at lunar approach	=	117, 500 lb
Gross weight landed (includes 2, 000 lb of residuals)	=	63, 580 lb
Dry vehicle (without payload or fairing)	=	34, 279 lb
Payload		27, 301 lb

Growth potential appropriate for various uprating techniques (such as slush hydrogen, high-performance engines, and/or strap-on motors) reflects the increase in discretionary payload available. Considering a portion of the S-IVB LH_2 tank to be useful payload as a shelter or laboratory, and similarly considering the IU as a communications and data handling system, the net lunar payload can be a combination of both the useful and discretionary payloads.

The quoted 27, 301-lb payload does not include an allowance for micrometeoroid shielding and thermal insulation of the S-IVB LH_2 tank. This weight allowance is not required for the landing operation but is probably needed for any mission in which the tank will be converted to a shelter.

Lunar Launch Window

The LASS lunar launch window performance characteristics (payload degradation), as a function of time from optimum launch opportunity, are presented in Figure 16 for both the direct and indirect launch modes. The windows are representative of a due east launch (90° azimuth), an optimum true anomaly at translunar attachment, and a 110-hour lunar transfer. The direct-ascent (no Earth orbit) launch window has the following characteristics:

1. Direct Ascent Launch Opportunities:
   A. One launch opportunity (window) per day.
   B. Eight consecutive opportunities (days with a window) per lunar month. (These occur during the moon's passage through its maximum negative declination.)
2. Direct Ascent Launch Performance
   A. The gross translunar weight injected at the window center is 131, 250 lb.
   B. The optimum discretionary payload (obtained for launch at the window center) is 27, 300 lb to the lunar surface.
   C. The payload loss is negligible for a typical launch on-time capability of ±5 min.
   D. The payload available over a 30-min window (±15 min.) is 27, 000 lb to the lunar surface.

The indirect ascent launch window which employs a 100-nmi Earth orbit has the following characteristics:

1. Indirect Ascent Launch Opportunities:
   A. Two launch opportunities (windows) per day, every day of the month.
   B. Window size is typically 5 hours long.
2. Indirect Ascent Launch Performance:
   A. The gross translunar weight injection throughout the launch window size shown is 128, 300 lb.
   B. The discretionary payload deliverable is 25, 800 lb to the lunar surface.

It is concluded that, for unmanned missions, a direct ascent will be acceptable.

Performance Comparison for Lunar Landing Vehicles

The lunar landing performance for various vehicles is presented in Figure 17 to show a gross ability. It should be noted that each vehicle shown has been studied or designed under different ground rules. The vehicles are, however, representative of candidate lunar payload delivery systems. Two classes of payload capability presented are (1) approximately 10, 000 lb and (2) 25, 000 to 30,000 lb. Discretionary payload represents removable cargo on the part of the LLV_1/LLV_2[8] or stage for the Apollo/LOR mission, and total weight of the LM shelter for the extended Apollo mission. The LLV_1/ LLV_2 are the fourth and fifth stages of a Lunar Logistics Vehicle studied by MSFC[8] in 1963.

The vehicles compared vary in terms of their basic missions and the number of stages required. All of these vehicles rely on a basic Saturn V launch vehicle through injection, using the S-IC, S-II, and S-IVB stages. However, the LASS vehicle burns a portion of its propellant into injection and the remainder for lunar landing.

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PERFORMANCE COMPARISON FOR LUNAR LANDING VEHICLES

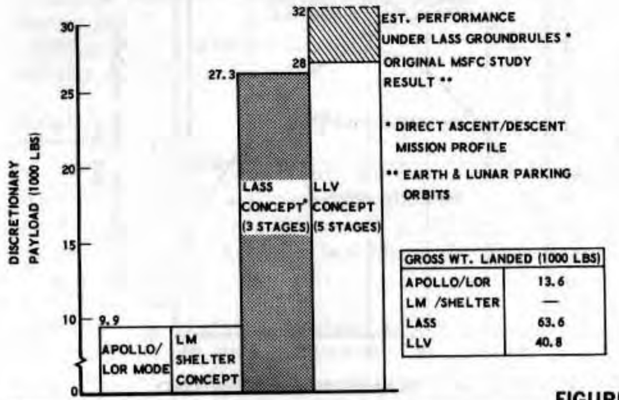

FIGURE 17

The following are the lunar operations for these vehicles:

1. Apollo/LOR (manned LM landing)--Brake CSM/LM into orbit with SM, staging of CSM/LM, and deorbit to landing with LM.
2. LLV_1/LLV_2 (unmanned)--Brake LLV_1/LLV_2 into orbit with LLV_1, (fourth Stage), staging of LLV_1 from LLV_2, deorbit to landing with LLV_2 (fifth Stage).
3. LASS (unmanned)--Brake LASS (S-IVB, IU, and Payload) to a direct-descent landing with S-IVB engines.
4. LM Shelter (unmanned)--Same as Apollo/LOR in Item 1, except for possible utilization of lunar polar orbit (for 14-day extended missions).

Payloads in the 10, 000-lb category can be achieved with relative ease by using available systems. Large payloads require new vehicles or modification of the S-IVB, as indicated. If the large payloads can be divided into two or three smaller payloads, perhaps the modified LM could handle them with multiple Saturn V launches. However, the relative economy of a single-launch configuration may very well dictate the selection.

LASS/LASSO Operations

Lunar Operations required to support specific lunar missions may require various LASS payload configurations. A possible application of a LASS payload could consist of (1) a two-man shelter; (2) a lunar rover, LSSM or equivalent; (3) scientific equipment; (4) cargo--equipment mounted above the IU or within the LH_2 tank; (5) expendables; and (6) cargo-handling equipment.

In the vertical configuration shown in Figure 18, the unmanned LASS would land with the aid of a lunar beacon. The mode of operation following the landing includes a manned LM landing in the vicinity of the LASS. The crewmen would deactivate the LM and prepare it for lunar hibernation so that the ascent stage could be used later to return to lunar orbit. Following this activity, the crewmen would activate the two-man shelter atop the LASS vehicle. The LSSM would be removed and prepared for lunar exploration sorties. The cargo would be brought into the LH_2 tank through an airlock mounted on the LH_2 tank dome access door and used to construct a laboratory/shelter in the tank. This laboratory/shelter could be pressurized or unpressurized, using an AM or equivalent, depending upon the type of experiments to be performed in the tank and the duration of those experiments.

S-IVB-3376

LASS OPERATIONS

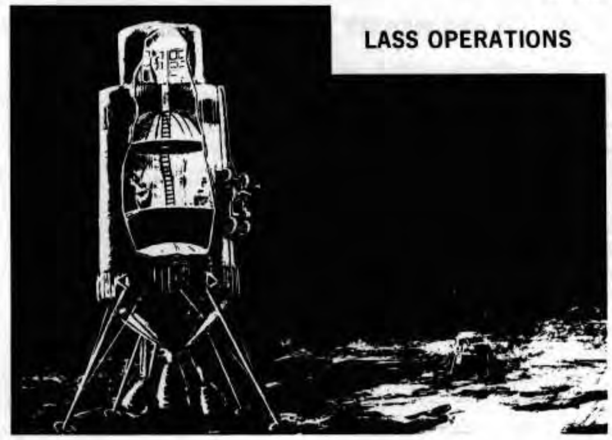

FIGURE 18

The duration of the lunar stay time is directly a function of the expendables required for the two-man shelter and/or the laboratory/shelter and the LSSM. The payload capability of the LASS (27, 300 lb) allows more than enough expendables for the above payload configuration to operate on the lunar surface more than 14 days.

Another payload configuration is the horizontal version presented in Figure 19. In this case, the payload contains more cargo in place of the two-man shelter. The mode of operation for this configuration is essentially the same as the vertical operation, except that the LASS has been tipped on its side to simplify deployment of the LSSM or Rover. Since this configuration would probably not include a separate shelter, the LM must be used until the LASS LH_2 tank can be converted into a habitable shelter. The cargo located in the payload area would be used for this purpose. This payload area could also be used as a maintenance shelter for the LSSM.

LASS OPERATIONS

S-IVB-3377

FIGURE 19

To provide a habitable environment within the LH_2 tank, an environmental control system such as in the S-IIIB workshop AM or equivalent, is required, the expendables provided for in this configuration allow a minimum of 21 days of operation on the lunar surface with 2 men.

LASS Modular Lunar Base. When lunar exploration has reached the point at which a permanent lunar base is required, LASS vehicles could be used as building blocks to construct such a base (Figure 20). The LASS vehicles used for earlier exploration missions could be brought together to form a modular base. The LH_2 and LO_2 tanks of the vehicles could be converted into living quarters, laboratories, maintenance shelters, and so forth. Pressurized interconnecting passageways from one LASS to another would allow free movement from one part of the base to another without pressure suits. The electrical power for the base would probably be supplied from a nuclear source. Resupply could be performed by additional LASS vehicles or modified LM descent stages

The base could be above ground or partially buried to aid in maintaining the desired temperature and to minimize radiation and micrometeoroid hazards.

The LASS therefore could be used for early lunar exploration missions and could be extended into a large permanent base of operations. Overall studies for optimum exploration are still required to determine the merits of a few large bases as compared to many smaller bases.

Combined Orbiting and Landing Mission. A mission can be visualized for the future which might utilize the present CSM/LM, LASSO, and LASS vehicles to provide a tremendously large lunar exploration capability.

Application of LASSO as an orbiting command post, data processing laboratory or extended duration orbital workshop is pictured in Figure 21 in conjunction with a LASS lunar lander mission. The mission concept pictured here required three Saturn V launches in the following sequence:

1. Saturn V launches the S-IVB/IU LASSO vehicle which brakes itself into a 100-nmi lunar orbit (payload = 69, 200 lb, nominal).

S-IVB-3378

LASS MODULAR LUNAR BASE

FIGURE 20

S-IVB-3587A

COMBINED ORBITING & LANDING MISSION

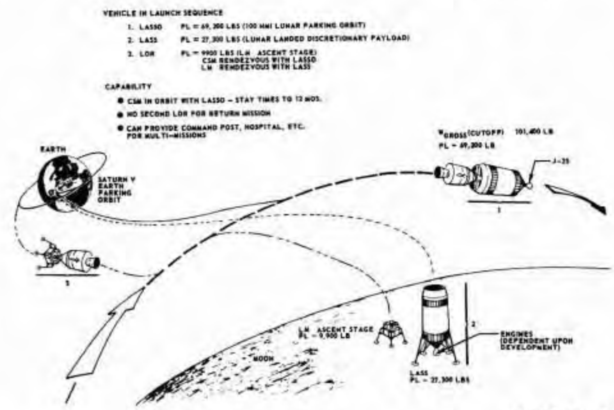

FIGURE 21

2. Saturn V launches the S-IVB/IU LASS vehicle for a soft lunar landing (payload = 27, 300 lb).
3. Saturn V launches the CSM/LM for rendezvous with LASSO followed by LM descent to the LASS.

The striking feature of this and other subsequent LOR or LOR/LASS missions is that the crew in the CSM/LASSO can stay in orbit for extended periods and wait for the lunar landing crew to rendezvous (that is, 2-to-10 weeks utilizing an AM and expendables as well as MOLAB size vehicles landed by the LASS). This satisifes the problem of requiring a subsequent Saturn V launch to pick up and return the lunar base crew.

Payload Variation with Lunar Mission Velocity Requirements. The payload variations for 72-hour and 110-hour lunar transfers are shown in Figure 22 over a broad spectrum of mission velocity requirements. These curves can be used to estimate payload performance at other LASSO altitudes than the 100-nmi baseline or with such different LASS landing velocity requirements as hover or larger performance margins.

Lunar Experiment Support. The lunar experiment programs studied to date have two primary goals:

1. To utilize the moon as a base for observation and operations.

LASS PAYLOAD VARIATION WITH LUNAR MISSION VELOCITY REQUIREMENTS

M-46863

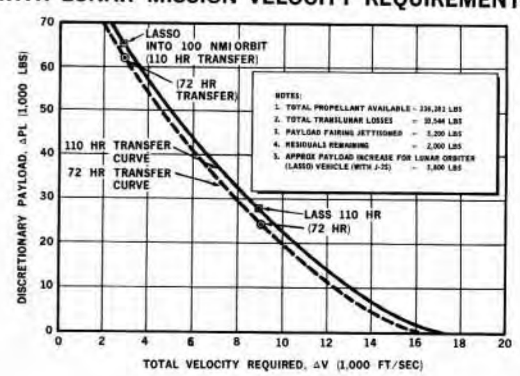

FIGURE 22

2. To explore and examine the composition and topography of the moon in order to determine its origin and evolution.

Many supporting functions can be performed by utilizing the existing subsystems, structure, and payload capability of LASS or LASSO to help achieve these goals.

Much of the communication (Figure 23), recording, command, telemetry, and data processing capability of the existing system can be applied to support this program. Use of the IU system, which services all three Saturn stages during Apollo flights, emphasizes again the economy inherent in using an existing system for a wholly new system application.

Immediately after the attainment of a lunar orbit or a landing, the LVDA, LVDC, and switch selector may be used to sequence valve operations for venting, purging, and pressurizing the S-IVB hydrogen tank prior to habitation. Monitoring and telemetering of temperature and pressure would allow Earth-based supervision and control override of this operation. Other lunar support capabilities of the IU include the following:

1. Digital Computer--Sequence experiments and operational functions; identify incipient spacecraft malfunctions and hazards.
2. Command System--Receive ground supplied data for control of subsystems, experiment apparatus, and roving or orbiting vehicles.
3. Communication System--Provide voice and TV links with the ground, roving, and orbiting vehicles.

GUIDANCE AND NAVIGATION ELECTRONICS S-IVB-3393

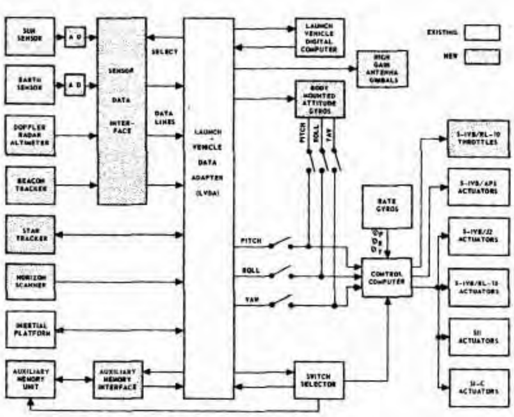

FIGURE 23

CONCLUSIONS

The feasibility of the LASS and LASSO concepts for lunar orbit and landing missions has been established. These concepts should be considered as part of the nation's vehicle inventory for future lunar exploration missions. Specific vehicle definition studies should now be accomplished under NASA direction and ground rules. These concepts are based on maximum utilization of existing Apollo-developed hardware and are a logical outgrowth of the Earth-orbital S-IVB workshop. The Baseline 1 lunar workshop approach for long-term orbital operations of the moon can be accomplished essentially with workshop hardware and the Saturn V launch vehicle.

The design, development, and qualification schedule of the LASS and LASSO vehicles would require approximately 3 years from a hardware go-ahead. The LASS configurations could be available as early as the 1972 to 1973 time period and can be accomplished largely with existing components and subsystem.

All of the missions could be achieved by utilizing S-IC and S-II stages and launch facilities with no change. Modifications are limited to the S-IVB/IU and supporting AGE.

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Landing Leg Design	- R. B. Carsley
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Thermal Analysis	- R. D. Mongan
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