ARTICLE NO. 79-1302R

A 80-070

LEASAT Liquid Apogee Motor Subsystem Design

60009
10024

G.F. Pasley* and P.A. Donatelli†
Hughes Aircraft Company, Los Angeles, Calif.

This paper describes the bipropellant propulsion subsystem for the LEASAT spacecraft. LEASAT is a Shuttle-launched spacecraft which will provide satellite communications services to the United States Navy. Propulsion is provided by three separate subsystems: a solid perigee motor, a bipropellant subsystem, and a monopropellant reaction control subsystem. The solid perigee motor provides impulse to raise the apogee from the Shuttle parking orbit. The bipropellant subsystem, which utilizes monomethyl hydrazine and nitrogen tetroxide, is designed to provide the impulse required for apogee augmentation and injection into synchronous orbit at apogee. The monopropellant hydrazine reaction control subsystem provides the impulse required for spacecraft spinup, apogee augmentation, attitude and spin speed control, and other required on-orbit maneuvers. The subsystem presented herein is scheduled to be flown in 1982, and represents one of the first configurations designed for Shuttle-optimized spacecraft.

Introduction

THE LEASAT spacecraft (Fig. 1) is being developed to optimize the cost performance of the space transportation system (STS) for synchronous-altitude satellite launches. It is the first satellite system to be designed specifically for optimal use of the STS.

The central concept is to provide an optimized spacecraft design that utilizes the capability of the Shuttle in such a way that overall mission costs are minimized. The key characteristics of the spacecraft that must be controlled to accomplish this are length and weight.

The Space Shuttle offers enormous payload capacity. The STS payload bay is 15 ft in diameter, 60 ft in length, and can carry 65,000 lb into a 160 n. mi. orbit. Practical geostationary satellite designs do not require the full STS capacity; NASA, therefore, has offered a shared user cost formula. The cost of partial capacity is based on a 75% load factor times the ratio of the payload weight to 65,000 lb or the ratio of the payload length to 60 ft, whichever is greater. The optimum partial payload cost is acheived when the ratios of weight and length are equal, as they are on LEASAT.

Another key feature of the design is the manner in which the orbital injection propulsion is integrated as internal and self-contained elements of the spacecraft. The Space Shuttle carries its payload to 160 n. mi. only, whereas a geostationary satellite orbits at an altitude of 19,300 n. mi. Raising a geostationary communications satellite 100 times higher than the Shuttle's orbit dictates additional propulsion capabilities beyond those presently designed into spacecraft launched by expendable launch vehicles. These requirements are most efficiently achieved with separate impulses (Fig. 2), the first series being applied at perigee, placing the spacecraft into transfer orbits, and the second series at apogee, placing the spacecraft into circular synchronous orbit.

Consequently, an STS-launched geostationary satellite must include both perigee and apogee stages. The propulsion requirements are satisfied by a large solid perigee motor mounted in the center of the satellite (Fig. 3). To minimize development costs, the Minuteman III solid motor was chosen as the perigee motor. Its impulse, however, is too low to achieve the desired transfer orbit. Therefore, apogee augmentation burns are required on the liquid apogee motor (LAM) subsystem to produce the required velocity change. A propellant budget is shown in Table 1. The LAM tanks are mounted around the solid perigee motor. Integration of the solid and liquid motors within the spacecraft rather than a booster stage permits the propulsion requirements to be satisfied in a short dense package.

The spacecraft has a despun, Earth-oriented platform on which are mounted the communication components and antennas. The large diameter spinning section permitted by the STS launch provides a moment of inertia that is sufficient for the spacecraft to be a stable spinner throughout all mission phases. This configuration permits the use of simple spacecraft control techniques.

On-orbit attitude and spin speed control is provided by a monopropellant (hydrazine) reaction control system (RCS), since the LAM has completed its function when the spacecraft achieves synchronous orbit.

The spacecraft configuration also lends itself to safe and accurate separation from the STS Orbiter. The innovative engineering design for separating the spacecraft from the Orbiter uses a "frisbee" technique in which the cradle ejection mechanism imparts both a linear separation velocity of about 2 ft/s and a spin speed of 2-3 rpm (Fig. 4).

Liquid Apogee Motor Subsystem

The LAM, shown schematically in Fig. 5, is located in the spinning section of the spacecraft.

The propellants are settled to the outlet of each tank by the centrifugal force associated with the spinning spacecraft, assuring bubble-free propellant flow at each tank outlet and

Table 1 LAM propellant budget

Maneuver	Requirement	Propellant, lbm
Perigee velocity augmentation	2058 ft/s, three burns	1380.6
Apogee velocity change	5978 ft/s, two burns	2629.9
	Propellant residual	20.0
	Total loaded propellant	4030.5

Presented as Paper 79-1302 at the AIAA/SAE/ASME 15th Joint Propulsion Conference, Las Vegas, Nev., June 18-20, 1979; submitted Oct. 1, 1979; revision received March 7, 1980.

Index categories: Liquid Rocket Engines and Missile Systems; Spacecraft Propulsion System Integration.

*Senior Project Engineer, Propulsion Department.
†Associate Manager, Propulsion Department. Associate Fellow AIAA.

avoiding the requirement for mechanical expulsion devices. Helium pressurant gas is stored in two high-pressure spheres and is isolated from both the pressure regulators and propellant tanks by a normally closed squib valve assembly during launch. Three-way squib valves located in the pressurization manifolds prevent propellant migration during launch and any potential propellant vapor mixing prior to initial operation in space.

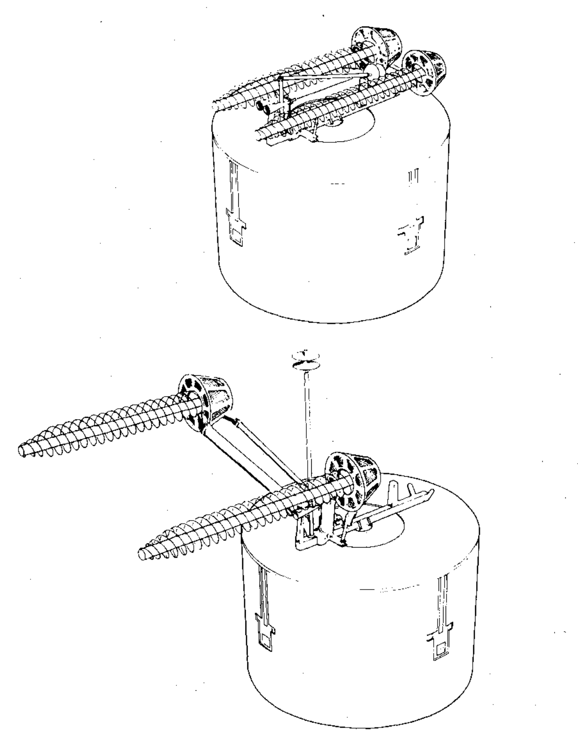

Fig. 1 LEASAT spacecraft: (top) launch configuration; (bottom) on-orbit configuration.

These valves are explosively actuated by dual NSI-1 initators, either one of which is capable of effecting reliable functioning of the valve. Since the squib driver circuits are independent, a double failure is required to prevent valve actuation. The pressure developed in the cavity above the ram by either initiator is more than 1.5 times the pressure required to shear the sealing cups. Actuation is not affected by line pressure because the ram is isolated before actuation.

Two dual poppet series redundant check valve assemblies are incorporated into the system to prevent fuel or oxidizer migration up into the helium supply system after the squib valve firing, one in the oxidizer low-pressure gas supply line and one in the fuel low-pressure gas supply line. Design crack

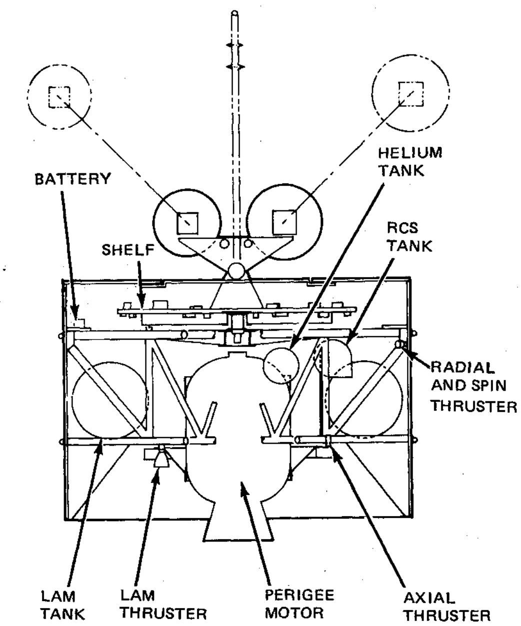

Fig. 3 Spacecraft arrangement.

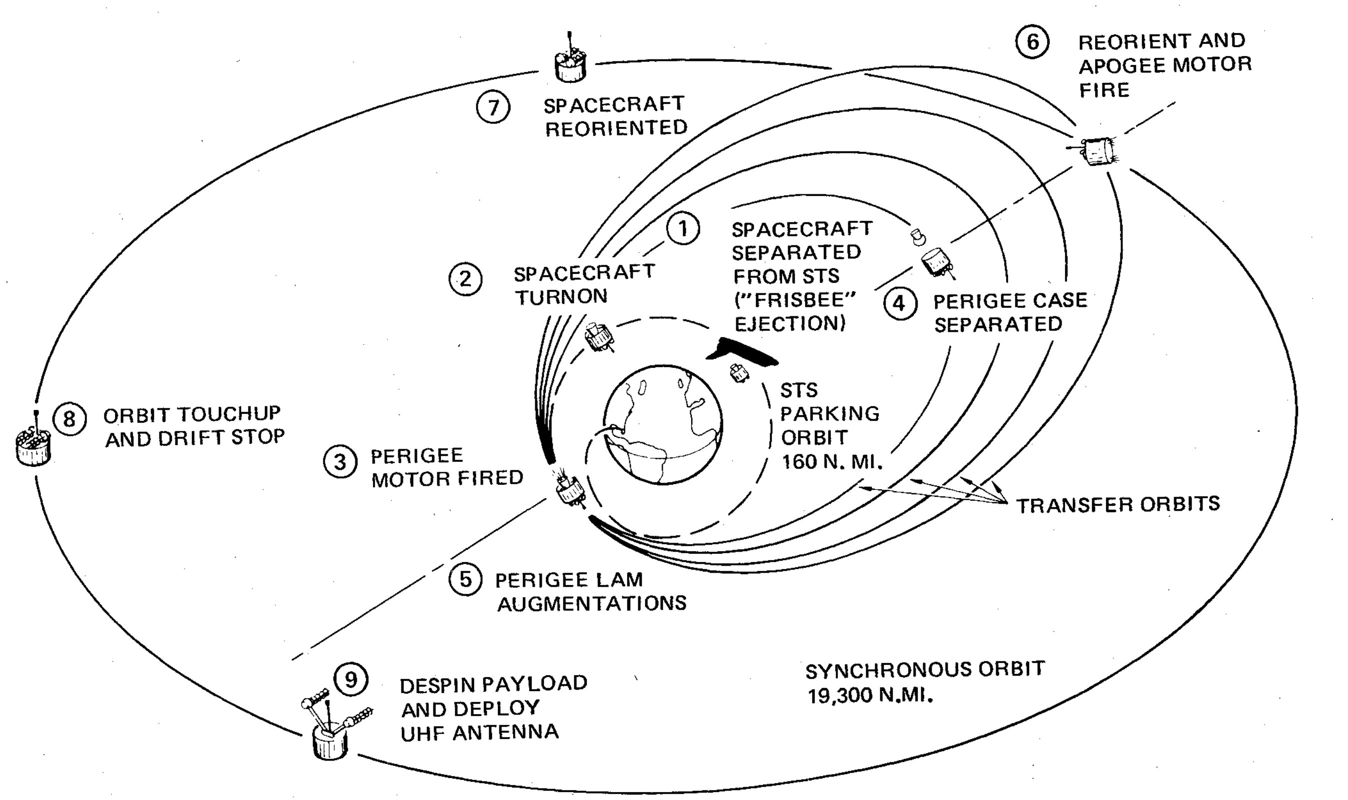

Fig. 2 LEASAT ascent operations.

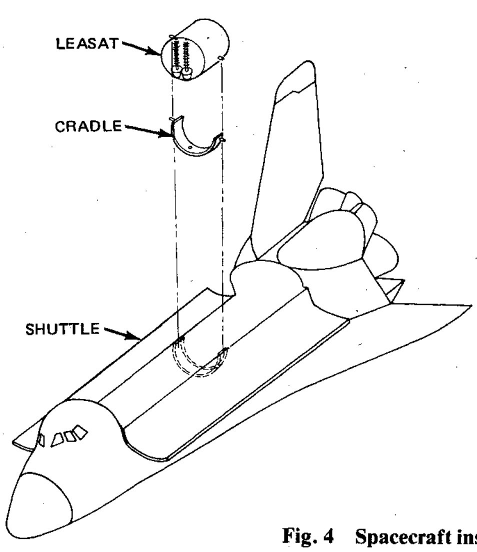

Fig. 4 Spacecraft installation in STS.

pressure is 7 psid, which is small compared to the driving pressure from the regulated pressure supply. Furthermore, the poppet travel is small and its length-to-diameter ratio is large, which precludes poppet misalignment with the housing. Hence, opening is virtually guaranteed. Pressure drop is measured prior to installation into the subsystem, allowing the propellant load to be adjusted to compensate for any valve-to-valve variations which could cause mixture ratio variations at the engines. Failure to close has a low probability of causing mission failure since four check valves would have to fail open to allow mixing of propellant vapors. In addition, any resulting formation of salts would not be significant in the short period (approximately two weeks) of subsystem operation.

When commanded, the propellant control valves of the two liquid bipropellant thrusters[1] are opened. The oxidizer, nitrogen tetroxide (N_2O_4), and the fuel, monomethyl-hydrazine (MMH), are pressure fed to the thrusters where the propellants ignite spontaneously to produce high-temperature gases that are exhausted through a nozzle to produce thrust.

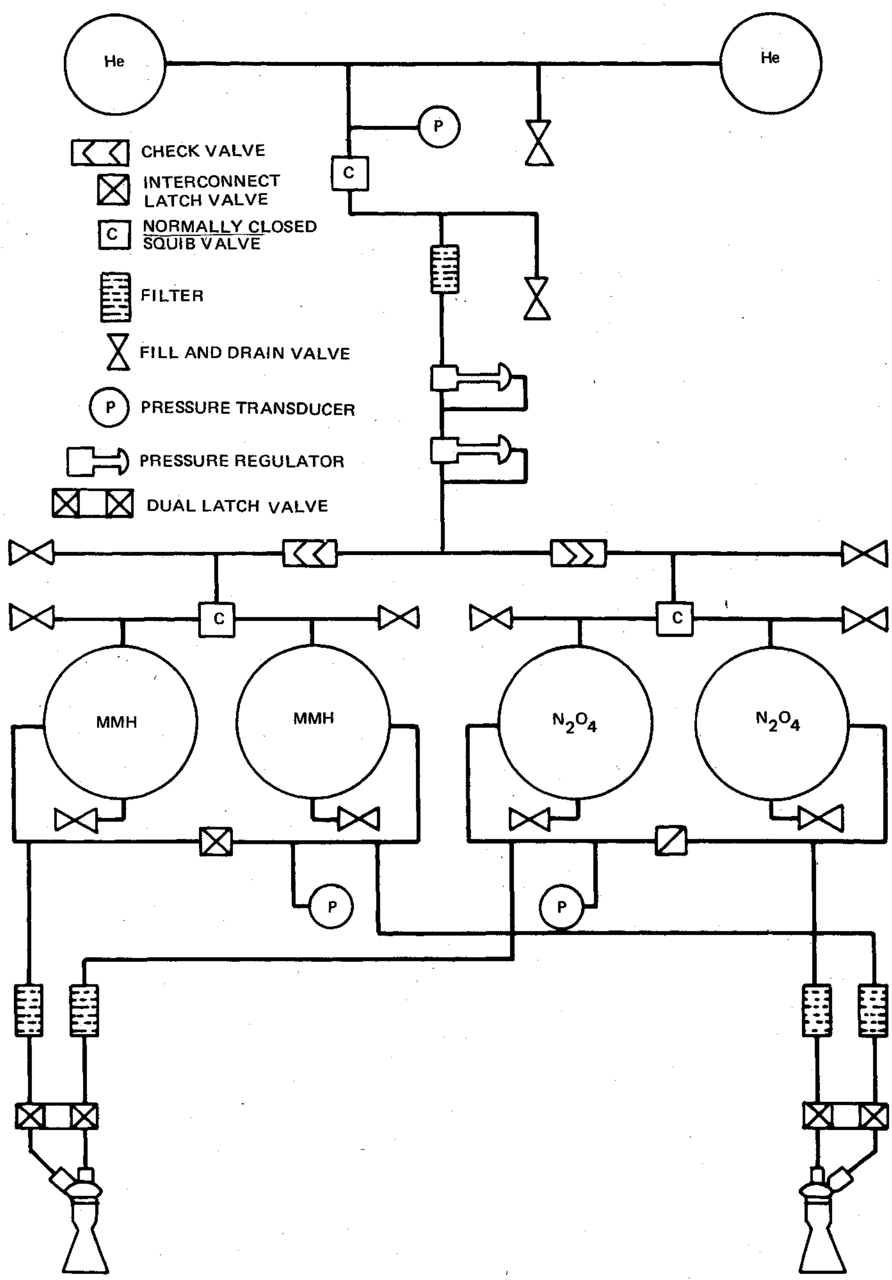

Fig. 5 LAM subsystem schematic.

LAM maneuvers may be performed by a single thruster in the unlikely event that a propellant flow control valve fails to open. Should the valve fail in a closed position, the subsystem liquid manifold design allows all of the propellant to be available to the redundant thruster. If a propellant valve fails in an open position, or if an excessive leakage condition is detected between LAM burns, the latching valves in the propellant feed lines to that thruster would be closed.

The STS launch vehicle has specific safety design requirements[2] for all spacecraft payloads. The premature firing of liquid propellant propulsion systems is deemed a catastropic hazard; hence, each system must contain three mechanically independent propellant flow control devices in series that remain closed during all ground and flight phases (except ground servicing) until the deployed payload has reached a safe distance from the Orbiter. For bipropellant systems, these devices must prevent mixing of or any contact between the fuel and oxidizer, as well as prevent expulsion of either or both propellants through the thrust chamber.

This requirement is satisfied in the LEASAT design by three mechanically independent valves—the engine oxidizer and fuel valves plus the dual latching valve.

As required, the design of the subsystem pressure vessels meets the requirements of MIL-STD-1522, including qualification testing to demonstrate no failure at the design burst pressure level and life cycle capability of at least twice the maximum predicted number of operating cycles.

Pressurized lines and fittings exceed the requirement of an ultimate factor of safety equal to or greater than four.

The requirement that hazardous fluid systems must contain the fluids after exposure to all STS environments including normal and emergency landing loads is satisfied by the LAM subsystem design. The design will also survive exposure to the high-temperature environment attendant to a worst-case abort sequence.

After assembly, each subsystem is flow tested with referee propellants to accurately determine pressure losses. This information, in addition to engine, regulator, and check valve flow data, is then input into a computer program which simulates subsystem operation. Input propellant loadings are varied until the minimum residual is predicted. Uncertainties in flow measurements indicate that a maximum residual of 20 lb of propellant will result.

The interconnect latching valves are closed during engine firings to preclude any cross-talk between the two engines through the connecting plumbing; however, between burns, the valves are opened to allow any propellant unbalance in the tanks caused by differences in engine flowrates to equalize.

Conclusions

The LAM subsystem, as optimized for the STS, will provide the impulse required to achieve the desired orbit while simultaneously meeting all STS requirements.

References

[1] Anon., "R-4D-10, Model Specification for the Marquardt 100 lb Thrust Bipropellant Rocket Engine," Marquardt Co., Van Nuys, Calif., Nov. 1977.

[2] Anon., "Safety Policy and Requirements for Payloads Using the Space Tansportation System (STS)," NASA NHB 1700.7, May 1979.