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SHUTTLE PERFORMANCE AUGMENTATION WITH THE TITAN LIQUID BOOST MODULE

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ABSTRACT

The projected 24,000 pound payload lift capability for the baseline Space Shuttle, with anticipated orbiter and external tank weight savings programs implemented, will not meet the 32,000 pound payload requirements for the DOD Mission 4 from Vandenberg Air Force Base. NASA has selected the Titan Liquid Boost Module (LBM) to provide thrust augmentation during the boost phase sufficient to meet and provide margin for the defined Mission 4 requirements. The LBM will use Titan 34D Stage I engines and a cluster of four Titan derived 10 foot diameter tanks. The module will be attached to the aft end of the ET. This paper will provide a description of the LBM and discuss some of its advantages and capabilities.

INTRODUCTION

The Space Transportation System (STS) must have a payload lift capability of 32,000 pounds to meet the requirements of DOD Reference Mission 4 from Vandenberg Air Force Base. The projected Mission 4 capability of the baseline STS is only 24,000 pounds considering a weight savings program of 5,100 pounds for the Orbiter and 6,000 pounds for the External Tank (ET) and 109% of Rated Power Level for the Space Shuttle Main Engine (SSME).

Recognizing that additional weight savings programs and state-of-the-art performance improvements on the baseline STS would not make up the performance deficit, NASA, in 1978, initiated analyses of performance augmentation concepts. Early studies were centered on combinations of solid motors strapped onto the Solid Rocket Boosters and clusters of solid rocket motors attached beneath the ET. In early 1979 Martin Marietta Corporation and Aerojet Liquid Rocket Company presented a thrust augmentation concept which utilized Titan technology, hardware and propellants. Subsequent to further comparative analysis by the space agency during the summer and fall of 1979, the decision was made to adopt the Titan Liquid Boost Module (LBM) as the baseline Thrust Augmentation System. The LBM consists of the Aerojet Liquid Rocket Company's current Titan 34D Stage I engine with Titan type tanks, feed lines and a support truss which will be manufactured by Martin Marietta Corporation. The module will be attached to the aft end of the external tank and will occupy the space between the Solid Rocket Boosters.

COMPARATIVE ANALYSIS

The decision to adopt the Titan LBM System was based on technical, cost and programmatic reasons. Included were consideration of payload capability, man-rating, development risk, cost per payload pound, system loads and operational flexibility. Utilization of the existing Aerojet/Martin Titan team "know-how" and facilities is another plus for the LBM system as well as being a benefit to the Air Force in maintaining Titan III technology and capability.

Because the Titan LBM is based upon proven hardware, minimal development risks are incurred. The system will use the existing Stage I Titan 34D engine, developed to its present state by testing and flights conducted during the past 20 years. Martin Marietta will build the 10-ft diameter tanks (same as Titan) utilizing technology, materials, facilities and techniques developed for the Titan systems.

Initial studies by NASA with the solids options indicated that it would have been difficult to keep below the maximum STS allowable dynamic pressure of 650 pounds per square foot. The Titan LBM system, with its lower thrust being applied over a longer flight time will not violate the maximum pressure constraint. Accordingly, the LBM will provide a softer ride to shuttle payloads and less severe load-
ing during launch for the STS vehicle as a whole.

The LBM, as currently conceived, will provide an increase in the anticipated Mission 4 payload capability of more than 17,000 pounds. This would bring the capability of the Thrust Augmented STS to over 41,000 pounds.

NASA estimates indicate development costs would have been comparable for both the solid strap-on and the LBM options. While the cost per flight estimate is higher for LBM augmented flights, costs per pound of payload delivered is more favorable. NASA estimates these costs at approximately $1,700 per pound for the strap-on solid version compared to $1,500 per pound for the LBM.

Because the LBM augmented STS shows such a generous performance margin over the Mission 4 requirements, considerable mission planning flexibility will be available. For instance, the SSME's could be programmed for less operating time at 109% of rated power level during a mission, thereby enhancing the life expectancy of the engine.

**LIQUID BOOST MODULE CONFIGURATION**

The baseline configuration of the Titan Liquid Boost Module consists of four Titan-type ten foot diameter tanks (two fuel and two oxidizer), a Titan 34D Stage I engine, a truss that ties the tanks and engine together and a skirt assembly to attach the module to the aft end of the external tank. The skirt assembly includes an ordnance separation joint to allow the module to be jettisoned from the ET after the propellants have been expended. As on Titan vehicles, an engine heat shield assembly will be provided to protect the engine components from the launch environments. The heat shield will also protect components of an auxiliary helium pressurization system for the oxidizer tanks. The major components are shown in Figure 2.

The four propellant tanks will be arranged symmetrically with their centers on a 21.3 foot circle under the ET. The LBM assembly will extend 24.2 feet below the liquid hydrogen tank dome on the external tank. The module has an overall length of 34.6 feet from the attachment to the liquid hydrogen tank at the barrel to dome ring frame to the exit plane of the LBM engines.

The LBM engines will be ignited five seconds after SRB ignition and will burn for 200 seconds. This LBM engine start sequence is designed to minimize launch facility impacts. During operation, the engine will burn 350,000 pounds of hypergolic propellants (nitrogen tetroxide oxidizer and Aerozine 50 fuel). Engine shutdown will be initiated by propellant depletion which is a standard mode for Titan III Stage I engines. After shutdown the module will be jettisoned.

The Titan Liquid Boost Module offers great flexibility in operation. Although the tanks are being sized to carry propellants for 200 seconds burn time, missions that require less thrust augmentation can be accommodated by off loading the LBM tanks to provide a burn time compatible with mission requirements. Payload growth can be achieved by simply filling the baseline tanks to a minimum ullage level, providing additional auxiliary pressurization and extending the engine burn duration to 225 seconds. Other growth options are available by adding additional tank capability or adding additional engine subassemblies.

**TITAN-LBM ENGINE**

The current Stage I, Titan III engine for the Titan 34D (T34D) is a pump fed, hypergolic propellant engine. It consists of two identical subassemblies, each producing 264,500 pounds of thrust at altitude. The engine is qualified to twelve 200 second burns. The Titan-LBM design flight duration is 200 seconds. Major engine performance values are provided in Figure 3.

Each subassembly is started by a solid propellant start cartridge fired into the two stage turbine system which is gearbox connected to the fuel and oxidizer pumps. Rising fuel pressure opens the thrust chamber valves allowing oxidizer to flow directly through the injector, into the thrust chamber plenum cavity. Fuel flows through the regeneratively cooled 6:1 thrust chamber, into and through the injector causing the hypergolic ignition. A honeycomb constructed, fiberglass/phenolic resin ablative skirt expands the combustion gases to the final 15:1 area ratio.

Small amounts of each propellant are bootstrapped off the thrust chamber inlet lines to feed a gas generator which drives the turbine during steady state operation. Some gas generator hot gas is subsequently cooled and provides autogenous pressurization to the fuel tank. Similarly, oxidizer is tapped off the main discharge line, vaporized in a superheater and supplies autogenous pressurization to the oxidizer tank.

The entire engine system is supported by a tubular constructed, steel engine frame. Mechanical and electrical interfaces are nearly identical to Titan 34D excepting only the autogenous plumbing interface locations.

The T34D launch vehicle first stage consists of one each oxidizer and fuel tank. Space constraints under the STS External Tank resulted in the packaging of four propellant
tanks, a pair supplying each engine sub-assembly for the LBM. The packaging results in the addition of an identical fuel autogenous gas cooler and some fuel and oxidizer autogenous plumbing rerouting. The entire engine system including the autogenous components will be operated at existing Titan 34D performance levels.

Introduction of separate subassembly tankage allows the independent operation of each sub-assembly, enabling system verification testing to be done using one engine subassembly and two propellant tanks.

The engine is not required to gimbal for the STS application and accordingly the gimbal actuators will be replaced with stiff links and the gimbal hydraulic system removed.

Because there are no significant component or operational level changes, the Titan engine retains the "off-the-shelf" characteristics of a fully flight proven system. The benefits are obvious. The T34D engine is the culmination of design refinements from the Titan II weapon system engine developed in the early sixties. A man-rated version successfully powered the twelve Gemini flights during the mid-sixties. The more powerful existing version was developed for the Manned Orbital Laboratory (MOL) program and has since performed flawlessly for over 80 Titan III B/C/D/E flights for AF/SD and NASA. The total number of Titan powered flights including Titan II, Gemini and early Titan III exceeds 200.

During the "concept validation" phase of the NASA LBM studies, environmental impacts on the engine system were investigated. These studies were based on predicted environments in the area aft of the ET between the extensions of the two Solid Rocket Booster (SRB) motors. Predicted thermal, transient overpressure/underpressure and vibro-acoustical environments were compared with the Titan design, qualification and flight requirements and test experience. In all areas, the engine is qualified to meet or exceed the predicted environments.

SUPPORT TRUSS

The cluster of four propellant tanks will be tied together with a support truss which also will provide mounting points for the engine assembly and join the assembly to the ET separable aft skirt. The truss will be built in sections to facilitate assembly of the complete Liquid Boost Module. A center-core truss section, in the form of a cube, will provide points on the four sides to attach the four tanks and interfaces on the aft surface for mounting the engine assembly.

PROPELLANT TANKS

The four propellant tanks will be developed using technology, materials, facilities, fabrication techniques and tooling used in Titan tanks. The tanks will be ten foot diameter, the same as Titan, in order to minimize tooling modifications. Tank construction will be integral stringer skin panels stabilized with internal ring frames. Elliptical domes will be welded to each end. The domes will be built to the same \( \sqrt{2} \) elliptical contour as the Titan tank domes which will permit usage of the Titan dome tooling. The fuel and oxidizer tanks will have the same basic design; however, the fuel tank at 19.2 feet overall length will be 3.2 feet shorter than the oxidizer tank. The length difference will be accomplished by using different length barrel panels.

Each tank will be outfitted with a 10 foot diameter forward skirt to facilitate attachment to the support truss. The skirt will be fabricated of skin, stringers and ring frames with rivet and bolt construction.

Propellants will be withdrawn from each tank by means of an internal suction feed line. The feed line will consist of an inverted "morning glory" inlet located near the bottom of the tank dome. The feed line will penetrate the side of the tank at an elevation above the engine inlet interfaces. Each tank feed line will be routed to its own subassembly inlet interface. One oxidizer tank and one fuel tank will provide propellants to each of the engine subassemblies, making them totally independent.

EXTERNAL TANK SKIRT ASSEMBLY

The Liquid Boost Module will be attached to the STS by means of a skirt assembly which is the same diameter as the ET and 5.4 feet long. The skirt assembly consists of a forward skirt, an aft skirt and a staging separation joint. The forward skirt will bolt onto the ET at the barrel to aft dome frame of the liquid hydrogen tank. The skirts will be skin-stringer-ring frame construction using rivet and bolt fasteners. The LBM tank and engine support truss will bolt to mounting points on the aft skirt.

The separation joint located between the forward and aft skirt sections will be severed by means of a non-contaminating pyrotechnic system. The system consists of two mild detonating cords housed in a flattened steel tube which is in turn mounted between two frangible (notched) plates. When either or both mild detonating cords are ignited, the gas expansion causes the flattened steel tube to become cylindrical, thereby causing the notched plates to fracture and affect the separation.
TANK PRESSURIZATION

The LBM propellant tanks will be pressurized to flight pressure while still on the ground. In flight, tank pressures will be maintained by the autogenous gases from the engine, each subassembly providing pressurant to its oxidizer and fuel tank. Because the STS flight acceleration profile is different than Titan, an auxiliary helium pressurization system is used to supplement the engine autogenous system for the oxidizer tanks. Two high pressure spheres, identical to those used for Titan IIIC Transtage, will be used for helium storage. An ordnance actuated quad redundant valve assembly will release helium from each sphere through an orifice, into the oxidizer tanks. The first sphere will be released into the oxidizer tanks at approximately 45 seconds into the flight, the second sphere at about 90 seconds.

DESTRUCT ORDNANCE SYSTEM

The ordnance destruct system provided for LBM to satisfy range safety requirements will be designed utilizing many off-the-shelf components. Safe and arm devices, confined detonating fuse, linear shape charge and junction blocks have been qualified for use on the external tank and will be incorporated into the ordnance design for LBM. Range safety destruct commands will be provided from the existing system on the external tank.

AVIONICS

Minimal avionics will be required on the LBM because steering capability is not required in its propulsion system. Sequence commands for the LBM will be generated and issued by the orbiter. Commands will be required for engine start and shutdown, auxiliary pressurization functions and ordnance functions. Instrumentation measurements required to verify proper LBM operation will be provided to the orbiter for processing and return to earth.

DEVELOPMENT TESTING

Because the Liquid Boost Module maximizes the use of existing hardware, facilities and tooling, the scope of its development test program is minimized. The propellant tanks, truss and skirt will undergo structural testing. Hydraulic resistances will be developed for the tank/feedline/engine system and operation parameters will be verified.

The currently defined program includes a subassembly Propulsion System Verification Test (PSVT) battleship-type program and at least one Full Scale Demonstration Test (FSDT) with flight hardware. Both test series will be conducted on ALRC's Test Stand E-5, which will be dedicated solely to LBM testing (Figure 4). Details of the PSVT and FSDT programs will be defined during studies that are currently in progress.

LAUNCH FACILITY/OPERATIONS

The operational concept for VAFB will have the external tank delivered to Space Launch Complex 6 (SLC-6) with the LBM skirt assembly already attached. The tanks, truss and engine will be delivered for assembly and checkout to Space Launch Complex 4 (SLC-4) the Titan launch complex. A new building will be constructed around the Live End Item Storage Area bridge crane for use in assembling and checking out the LBM. Existing Titan skills and checkout equipment will be used on a shared basis to assemble and checkout the LBM. When needed at SLC-6, the 200 ton SRB segment transporter will carry the LBM from SLC-4 to SLC-6. The LBM will be mated to the External Tank during the erection operation (Figure 5).

Modifications to SLC-6 to accommodate LBM include addition of propellant and pressurization facilities and equipment and two access platform levels on the mobile service tower. The hypergolic storable propellants used on LBM will allow the tanks to be loaded several days before launch to minimize impact to the STS Timelines. Delaying ignition of the LBM engines until 5 seconds after liftoff eliminates the necessity of an exhaust duct and minimizes impacts to the launch complex.

Although there is currently no defined requirement for thrust augmentation at the Kennedy Space Center (KSC), the Titan LBM concept is compatible with the KSC facilities and could be added at a later date. The tanks, truss and engine could be assembled and checked out in the Air Force Vertical Integration Building in the Titan III complex. The LBM would then be delivered to the Vertical Assembly Building (VAB) to be mated to the external tank during erection and installation of the ET on the mobile launch platform. Launch Complex 39 modifications would be similar to those required at SLC-6 for propellant servicing and access.

SYSTEM BENEFITS (Figure 6)

The Aerojet/Martin Titan LBM system exceeds the current payload requirements and makes growth versions easily obtainable. A first growth option simply maximizes the baseline LBM tank designs (minimum ullage). A second growth option would extend the LBM tank length, move the engine location aft and further extend the burn duration. While the engine is qualified for 200 seconds, the only identified time sensitive component is the ablative skirt. Individual skirts have been tested to 300 (2 skirts) and 341 seconds without structural
failure.

Due to the evolutionary nature of the Titan systems during the past 20 years, the experience and data base is enormous. Thousands of component and engine tests and hundreds of flights result in a high degree of confidence in defining Liquid Boost Module development risks and costs. System reliability is assured.

Coupling the two Titan contractors, Aerojet and Martin, results in a continuation of existing teamwork which has successfully proven itself. Manufacturing, testing, handling and launch operations are defined and the same people will be used to implement these operations. The LBM also benefits the AF/SD Titan III backup program and can result in cost savings to the government.

As previously noted, the STS benefits from the Titan-LBM "softer" ascent loads and lower Max Q. STS system impacts are therefore minimized.

With the generous payload capability available with the Titan LBM thrust augmentation system, NASA will get built-in insurance relative to the STS performance goals such as the ET and orbiter weight reductions. The requirement for SSME operation at 109% of rated power level can also be minimized.

Though the need has not been defined, the packaging of the Titan-LBM has been done such that it could be used at the Kennedy Space Center (KSC) as well as Vandenberg Air Force Base. The Mobil Launch Platform (MLP) at KSC will accommodate the presently defined Baseline LBM.

CONCLUSION

The Aerojet/Martin Titan-LBM provides a common sense solution to Thrust Augmentation needs. More than adequate performance, an off-the-shelf engine and a proven contractor team are obvious benefits. Payload growth potential is inherent and simple. The Liquid Boost Module presents a marriage of proven hardware, known reliability and effective teamwork to solve currently defined and probable future requirements.
Figure 2. MAJOR LBM COMPONENTS
Altitude Thrust (Lb) 529,000
Altitude (ISP (SEC)) 301.0
Mixture Ratio 1.905
Chamber Pressure (PSIA) 827
Turbine Speed (RPM) 24,400

Figure 3. LBM ENGINE PERFORMANCE
Figure 4. LBM TEST STAND AT ALRC-SACRAMENTO
Figure 5. LBM FACTORY TO LAUNCH SEQUENCE AT VAFB
Titan Liquid Boost Module
- Excess Payload Capability
- Off-The-Shelf Engine
- Existing ALRC/MMC Contractor Team
- Use Existing Manufacturing Facilities And Procedures
- Mission Flexibility
- Growth Options Available
- Useable At KSC

Figure 6. LBM SYSTEM BENEFITS
Flight Concept

Ignition At L/O + 5 Seconds
200 Second Burn Time
Jettison LBM At Propellant Depletion

Expected Mission IV Performance

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Figure 1.  LIQUID BOOST MODULE CONCEPT