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Paper Session I-A - Liquid Rocket Boosters for Shuttle

James E. Hughes
Manager, LRB Studies, Marshall Space Flight Center, NASA

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LIQUID ROCKET BOOSTERS
FOR SHUTTLE

James E. Hughes, Manager
LRB Studies
Marshall Space Flight Center, NASA

ABSTRACT
The Liquid Rocket Booster study was initiated by NASA to define an alternative to the Solid Rocket Boosters used on the STS. These studies have involved MSFC, JSC and KSC and their contractors. The prime study contractors, Martin Marietta Corporation and General Dynamics Space Systems, have identified Liquid Booster configurations which would replace the SRB's in the Shuttle stack.

The Liquid Rocket Booster increases Shuttle performance to 70K LBS, provides improved reliability, hold down and verification prior to vehicle release, engine out and improved abort capability, and is phased into the STS launch operations without adversely affecting flight rate.

INTRODUCTION
The Challenger accident caused NASA to reconsider all possible options for STS boost propulsion, including the possibility of replacing the Solid Rocket Booster (SRB) with a Liquid Rocket Booster (LRB). Accordingly, studies were initiated in October 1987 to identify two Liquid Rocket Booster concepts for the Shuttle. These concepts were to include a conventional liquid system using pump fed engines similar to those used on the Saturn vehicles, and a pressure fed system, once referred to as the "Big Dumb Booster". The prime study contractors, Martin Marietta Corporation and General Dynamics Space Systems, were assisted considerably by the efforts of Lockheed Space Operations Co. (LSOC) at the Kennedy Space Center and Lockheed Engineering and Sciences Co. (LESC) at Johnson Space Center, as well as wind tunnel testing at MSFC, and other support.

The Liquid Rocket Booster was required by NASA Headquarters to provide the STS with a payload capability of 70,500 pounds to a 160 NM, 28 1/2 degree orbit with SSME power level @ 104 % (Rated Power Level). An alternate case of 62,500 pounds to a 160 NM orbit, 28 1/2 degree orbit with SSME power level @ 104 % was also required (The larger 70K case covered both needs with only a minor difference in Booster length for the diameters of interest). All STS requirements and specifications were to be met, and impacts to the launch vehicle and facilities minimized. The most important requirement was to provide engine out capability, to improve the abort capability of the entire Shuttle system, and enhance the probability of safe
Orbiter and crew return in the event of major malfunction anywhere in the system. An additional ground rule was adopted which said the LRB would be able to be integrated into the KSC ground processing flow without interrupting the planned STS launch rate.

**BOOSTER SIZING**

Initial concerns in sizing the Liquid Booster centered around the fact that for all liquid propellants considered, the LRB diameter exceeded the current SRB diameter of 12 feet, since all liquid propellants are less dense than the solid propellant used in the SRB.

The Booster diameter is of critical significance to the Orbiter wing loads based on the results of initial wind tunnel tests at MSFC. These tests were conducted with models scaled to represent diameters in the 12-20 foot range, and lengths in the 150-200 foot range based on initial sizing performed by both contractors for a variety of propellant combinations. Early results showed that booster diameters of 14-16 feet were probably maximum to avoid unacceptable Orbiter wing loads. Also to be considered were physical issues such as forward and aft External Tank attach point locations, engine nozzle exit plane location, keeping engine plumes within the flame trench limitations at pad 39 and VAB door clearance.

**PROPULSION CONSIDERATIONS**

The only liquid propellant options which appeared to offer the total impulse required, and stay close to the dimensions of the SRB were storable propellants and metallized gels. The storable propellant combination (N2O4/MMH) was baselined by Martin Marietta initially in order to minimize diameter, but later rejected due to the severe environmental and safety problems with these propellants in the large quantities required by the STS. The metallized gels were also investigated, but were rejected due to their limited experience and the open technology issues. The propellant combination that seemed to best fit the criteria at this point in the study activity was LOX/RP-1, since a diameter of approximately 15 feet could be accommodated, the attach points to the External Tank would be in non-pressurized structure, and the propellant combination is one with which NASA and industry has a firm technology base and considerable engine experience.

Propellant combinations using LOX and Hydrogen and LOX/Methane were thought initially to require diameters in excess of what the early wind tunnel test data showed as limits. Additional wind tunnel tests were performed, in which the SRB protuberance effects caused by the aft ET attach ring and the IEA (Integrated Electronics Assembly) boxes were evaluated. These results showed that protuberances had a much larger effect than was earlier believed; and, if the LRB could be made without protuberances adjacent to the Orbiter wing, that diameters of up to 18 feet were possible without violating wing load constraints. Due to the operational complications of another propellant at the launch pad (RP-1), the KSC personnel supported the LOX/Hydrogen selection, since these propellants are already used for the SSME’S.

As shown in Figure 1 “Range of LRB Concepts”, the propulsion options considered both new and existing engines for the pump fed concepts as well as a variety of propellant
Combinations for both pump and pressure fed designs. Four engines per booster were baselined to provide "engine out" capability. Existing engines were rejected for various reasons - the SSME due to cost and producibility limitations, the AJ-23 due to the propellant decision to avoid the highly toxic N2O4/MMH, and the F-1 due to its 1.5 M lb thrust level where only two engines would be required and would not allow for engine out capability. Propane was also considered as a fuel, but the severe coking of injectors experienced in recently conducted technology tests resulted in that fuel being dropped. Methane presented an attractive option for a fuel, and was investigated fully using the split expander cycle engine being considered in the concurrent ALS propulsion studies by MSFC. Methane was not selected since it offered no significant benefits over hydrogen in sizing, and it's use as a rocket engine fuel is relatively new and unproven.

The selected fuel, by both contractors, for the pressure fed booster was RP-1, and for the pump fed, MMC selected RP-1 and General Dynamics, LH2.

Primary reasons for the selection of RP-1 are the density and the well known characteristics in rocket engine use. The selection of LH2 was primarily influenced by alternate applications, and the ease of integration at the launch pad. Either of these options could be integrated into the STS stack and provide major advantages over the SRB currently used.

**RECOVER OR EXPEND?**

An analysis of life cycle costs to develop and operate the recoverable and the expendable Liquid Rocket Booster showed a cost advantage for the recoverable case; however, the answer is highly dependent on the assumptions used and the cost sensitivity to such parameters as water impact damage (refurbishment % of new), flight rate, engine cost, salt water compatibility, mission model size, etc. [Note: only ballistic boosters similar to the SRB are covered in this study - flyback options are not considered.] The pressure fed system would have very rugged tanks (rated at 600-1000 psi) and would more nearly represent the SRB recovery, i.e. the entire stage recovered by parachute. The pump fed system would have lower pressure tanks which could not survive the water impact loads; therefore, recovery schemes for pump fed systems involved only the main engine portion of the Booster, i.e. a Booster Recovery Module.

Due to the relatively low engine unit cost forecast by the ALS engine contractors (approximately $4M ea), the design impacts of incorporating recovery, and the additional front end funding required by the recoverable concept, the expendable mode was selected. The penalty of error in the initial assumptions for the recoverable case was also a factor in
establishing the expendable as the conservative choice. Figure 2 illustrates the sensitivity of various parameters used in the analysis to life cycle cost. These conclusions were made for both the pump fed and pressure fed configurations, however, should future information provide some confidence that, for example engines can be recovered and refurbished for less than 30% of new cost, recovery could be incorporated into the LRB design.

CONFIGURATION SELECTION

PRESSURE FED:
Pressure fed configurations selected by both study contractors are LOX / RP-1 systems with the LOX tank located forward. Both designs use four thrust chambers due to the requirement for "engine out" capability. Some significant differences exist between the two design approaches. The MMC design uses Aluminum / Lithium tanks of higher structural strength than conventional materials, and has optimum weight at a tank pressure of approximately 1000 psi. This results in a thrust chamber pressure of approximately 700 psi. The GDSS design uses the more conventional 2219 T-6 aluminum, and has it's optimum weight at a lower ullage pressure. This design has an ullage pressure of only approximately 500 psi and a thrust chamber pressure of 334 psi. Both systems are large and require thrust levels of 750K - 850 K per thrust chamber @ sea level to provide the Shuttle with necessary thrust / weight.

The attempt to define what was once thought of as the "Big Dumb Booster" was severely complicated in two major areas. First, the pressurization system becomes the most critical system on the vehicle, since loss of pressurization would cause total loss of thrust on one booster, and possibly loss of the vehicle. The size, weight and complexity of this system is beyond what was once thought of as a "simple system". Although specific design ap-
proaches differ, both use helium for pressurization of both Lox and RP-1 tanks. The liquid helium is stored in large insulated tanks, heated and pressure regulated before being fed to the propellant tanks. These systems would weigh approximately 25 - 30,000 lbs per booster, and would require considerable development before being selected for a flight application.

The second area of complexity found in defining the pressure fed booster configuration, was the propellant tank fabrication. These tanks are very large and heavy, with welds from 1" to 2" in thickness, depending on the tank material. Welding, and verification of quality of these welds would represent a major challenge, since welds of this thickness in Aluminum are not common practice.

**PUMP FED:**

The pump fed booster designs defined by the prime contractors are driven primarily by the propellant selected.

The Lox / RP-1 system selected by MMC uses four engines providing 685 K maximum sea level thrust @ a chamber pressure of 1300 psia. The engines are gas generator cycle, with nozzle expansion ratio of 21/1, providing 6 degrees of gimbal capability, and a throttle range of 65-100%.

These boosters utilize approximately 970,000 lbs of propellant during the 130 sec burn. The booster diameter is 15.3 feet, and length 151 feet (only two feet longer than the current SRB). This allows the forward ET attach point to be located in the LRB forward skirt, thus avoiding the heavy internal ring frames that
would be necessary with this attach point in the tank area.
The MMC design uses the Aluminum - Lithium alloy "Weldalite". The LOX tank is located forward and the RP-1 tank aft. This was preferred by MMC to avoid the structural load problem that would be introduced in the aft booster / external tank strut with a cryogenic aft, i.e. both ends contract during propellant loading.
The Lox/LH2 system selected by GDSS uses four engines providing 515 K Lbs. maximum sea level thrust @ a chamber pressure of 2250 psia. The engines are gas generator cycle, with nozzle expansion ratio of 20/1, providing 6 degrees of gimbal capability, and a step throttle range between 75-100% Rated Power level.
These boosters utilize approximately 692,000 lbs of propellant during the 153 sec burn. The booster diameter is 18 feet, and length 178 feet. External Tank attach points are located such that internal ring frames are required in the booster tanks where these struts are located. The lower thrust levels of the LH2 system compared to the RP-1 system is due to the much lower gross liftoff weight of the vehicle. Smaller propellant loads are required due to the much higher performance of the LH2 system. Figure 3 illustrates the various configurations discussed.

ABORT CONSIDERATIONS
The most important contribution to the STS provided by the Liquid Rocket Booster is its ability to provide abort capability during flight times when none exists with the SRB, and during other times, vastly improved abort options. The Liquid Rocket Boosters flown on a given mission are first verified by static firing at the acceptance test facility, then when integrated into the stack and on the launch pad, verified again during the "hold down" period before launch commit. Neither of these tests are available when using the SRB. During booster operation, should a major failure occur in any system, the liquid boosters can be shut down, and an early RTLS (Return To Launch Site) initiated, also not available with the SRB. Due primarily to the increased performance of the LRB, all abort windows are improved. The liquid booster designs all allow for booster engine out with abort to orbit capability. Since current STS maximum payload is limited by the orbiter landing weight, full mission capability with engine out is inherent with liquid boosters.

ALTERNATE APPLICATIONS
The LRB would provide an excellent booster for other applications in addition to the STS. The Advanced Launch System (ALS) being studied by the USAF and the NASA may use a liquid booster very similar to the type required for the STS. Since both of the prime LRB study contractors (MMC and GDSS) are also involved in the ALS programs, they have evaluated the LRB in the ALS application, and found a very close match in requirements. Development of a liquid booster that could be used on both an improved STS and future launch vehicles such as ALS would be mutually beneficial and cost effective. Also, Shuttle C would benefit in the same ways as the STS. The liquid booster using LH2 when used with Shuttle C would also make available a new, low cost engine as a possible replacement for the SSME.

"Stand Alone" launch vehicles using the STS liquid booster were also evaluated, and would
provide a payload capability greater than the current Atlas / Centaur or Titan IV launch vehicles.

PROGRAMMATIC CONSIDERATIONS
The DDT&E cost estimate for the liquid rocket booster is estimated to be $2.0 B, including the engine, with additional cost for modification of KSC facilities to accommodate the LRB and to provide for the transition from the SRB to the LRB, while maintaining flight rate. The development schedule is estimated at 6-7 years from go-ahead, based on past experience, and will be paced by the engine development time. Other changes to the STS such as Orbiter cockpit displays, ground and flight software, etc. would also be required. With an early start, the LRB could be available in the mid 1990's for incorporation into the STS.

SUMMARY
The Liquid Rocket Booster would provide major improvements to the Shuttle launch vehicle not obtainable in any other way. Primary among these is the increased reliability and flight safety through hold-down verification, engine out, and improved abort options in all flight regimes. Also the improved performance would allow payloads of up to 65 K to be delivered to the Space Station orbit - a significant improvement over present performance. The environmental products of either the RP-1 or the LH2 fueled version of the LRB are also significantly less contaminating than the products of the SRB, which may become a factor in future launch criteria.

The Liquid Rocket Booster that could provide boost propulsion for the Shuttle, would also have other applications, and could become a major national asset.