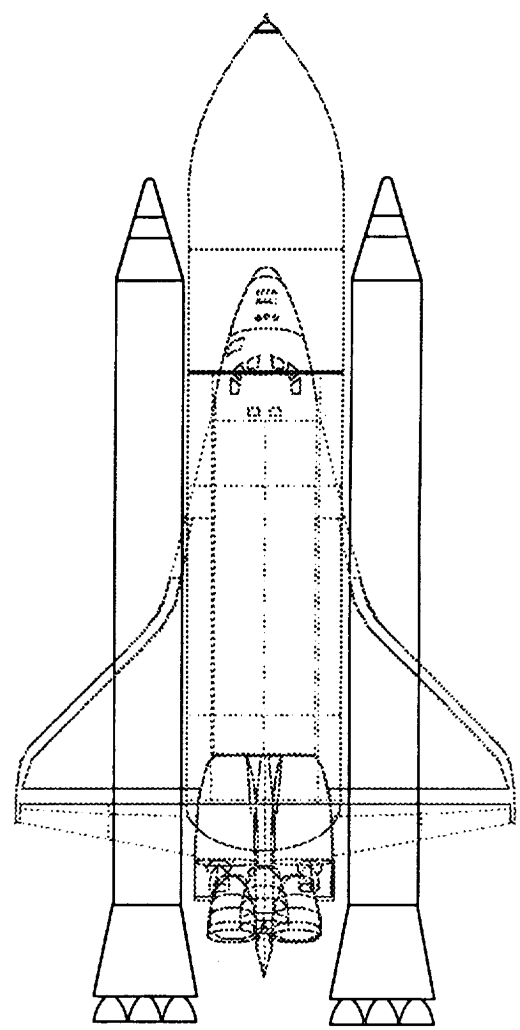
NAS8-37136

March 1989

Appendix F
Performance
and Trajectory
for ALS/LRB
Launch Vehicles

Liquid Rocket Booster (LRB) for the Space Transportation System (STS) Systems Study



(NASA-CR-183792-App-F) LIQUID ROCKET BOOSTER (LRB) FOR THE SPACE TRANSPORTATION SYSTEM (STS) SYSTEMS STUDY. APPENDIX F: PERFORMANCE AND TRAJECTORY FOR ALS/LRB LAUNCH VEHICLES (Martin Marietta Corp.) N90-28606

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Performance and Trajectory for ALS/LRB Launch Vehicles

Appendix F

PERFORMANCE SUMMARY

By simply combining two baseline pump-fed LOX/RP-1 LRB's with the Denver core (STBE/STME Quarterly Review - September 1988) a launch vehicle is obtained that can perform both the 28.5 deg ALS mission and the polar orbit ALS mission. This vehicle is shown in figure 15.3.1. It is referred to as the Option 1 ALS.

The Option 2 LRB was obtained by finding the optimum LOX/LH2 engine for the STS/LRB reference mission (70.5 K lb payload). Then this engine and booster were used to estimate ALS payload for the 28.5 deg. inclination ALS mission. Previous studies indicated that the optimum number of STS/LRB engines is four. When the engine/booster sizing was performed, each engine had 478K lb sea level thrust and the booster carried 625,000 lb of useable propellant. Two of these LRB's combined with the Denver core provided a launch vehicle that meets the payload requirements for both the ALS and STS reference missions.

The Option 3 LRB uses common engines for the core and boosters. The booster engines do not have the nozzle extension. These engines were sized as common ALS engines. An ALS launch vehicle that has six core engines and five engines per booster provides 109,100 lb payload for the 28.5 deg. mission. Each of these LOX/LH2 LRB's carries 714,100 lb of useable propellant. It is estimated that the STS/LRB reference mission payload would be 75,900 lb.

DENVER LIQUID/LIQUID EXPENDABLE ALS

This vehicle was sized to provide 160,000 lb payload for a polar orbit. It was referred to in the STBE/STME Quarterly Review - September 1988 as the mission 2B vehicle. This reference mission is for the expanded mission model. The launch vehicle had eight liquid rocket boosters with pressure-fed LOX/LH2 engines. To obtain the mission 2A (28.5 deg inclination) payload the following vehicle changes were made:

1. The number of liquid boosters was reduced from eight to four
2. The payload shroud became smaller

This was because of the reduced payload capability. The shroud weight estimate decreased from 79,000 to 19,000 lb . The payload obtained was within an acceptable range, so no more sizing was required.

Several approximations or allowances were made in the payload calculations. An item identified as " Engine Out Margin " was defined as follows:

Engine Out Margin = 0.15 Payload Capability

Payload Capability = MECO Weight - CORE (Dry + Residuals) -
Engine Out Margin

It should be understood that this Engine Out Margin is a simple calculation which is sufficient for this assessment, but this does not imply that detailed engine out analysis has been performed.

Flight Performance Reserve is stated as 2% Core ISP. This was simulated by reducing CORE engine ISP.

440.6 x 0.98 = 431.8

To accomplish this, the propellant flow was increased without changing the thrust. The results of this method are within 2000 lb of either:

a. Reducing thrust with propellant flow held constant or

b. Increasing VIDEAL by 2% using a core ISP of 440.6 sec.

The fact that these three methodologies produced the same results indicates that the method selected, increasing propellant flow, is reasonable. Simply increasing the propellant carried to MECO by 2 % of the core useable over states this requirement by a factor of 2 and can't be used as the Flight Performance Reserve.

Both the STBE/STME Quarterly Review 2A and 2B configurations were simulated using the POST computer program. Payload estimates differed by less than 1000 lb from the Denver results. Since no ALS aerodynamic estimates were available, the STS/LRB aerodynamics were used . Both zero angle of attack and zero lift profiles were flown. There was essentially no differences in payload capability. The STS/LRB aero may slightly over estimate the ALS drag. However the total drag losses for the due East mission was only 300 ft/sec. These results indicate that the assumed aerodynamics does not effect payload conclusions.

ALS PERFORMANCE GROUND RULES AND ASSUMPTIONS

In order to provide results which are directly comparable, the Denver payload calculation methodology and terminology were used. All missions were flown to direct injection MECO target. The flight path angle at MECO was = 0.0 and the inertial velocity target was 25,765.9 ft/sec. This provided a 80 x 150 NM equatorial orbit. The first stage was flown at zero angle of attack after the pitch-over phase. The Michoud pump-fed LOX/RP-1 booster followed the baseline criteria such as weight growth of 10% and residual propellant equal to 0.55% of the useable propellant.

Since the ALS is an expendable unmanned vehicle, several assumptions that differ from the STS/LRB ascent flight constraints were made . These include:

1. No maximum dynamic pressure limit
2. No first stage axial acceleration limit (second stage limited to 7.0 g's)

It is implied that most payloads will require upper stages that typically have axial acceleration limits of 10 g's.

ALS PERFORMANCE USING THE DENVER CORE

Option 1 ALS was obtained by replacing the four pressure-fed LOX/LH2 Denver boosters with 2 baseline pump-fed LOX/RP-1 LRB's. When these LRB's are flown with the engines at EPL a payload increase of 4,300 lb is obtained. Total vehicle GLOW is reduced by about 400,00 lb. Most axial accelerations and dynamic pressures increase, but remain within acceptable levels. The staging altitude is lower. By running the engines at a slightly reduced power level, payload would be reduced but the dynamic pressure would be lowered and the staging altitude would be higher. For example, it is estimated that running the LRB engines at 0.962 of EPL would provide 105,800 lb of payload. This would decrease QMAX from 1069 to 1023 psf and raise the staging altitude by 2,750 ft.

Trajectory characteristics using the Option 2 LRB for the ALS mission are very similiar to the Option 1 trajectory. Dynamic pressures, timelines, and booster separation conditions are very close. The slightly smaller payload can be attributed to the higher weight growth of 20% that this LOX/LH2 booster had.

The Option 3 ALS using the Denver core was obtained in the following manner:

1. Each booster had 5 LOX/LH2 engines
2. Useable booster propellant was determined to be 714,100 lb
3. Booster jettison weight was roughly estimated to be 150,116 lb
4. The core uses 6 LOX/LH2 common engines

Five of the option 3 booster engines which were downsized from the Option 2 core engine were used. Each engine had sea level thrust of 443,900 lb, total propellant flow rate of 1134.7 lb/sec, and exit area of 15.321 ft sq. Table15.3.1 provides a performance comparison of four vehicles using the Denver core. The four vehicles are the Denver 2A vehicle, Option 1 LRB 's (LOX/RP-1), Option 2 (common fuel LH2), and Option 3 (common fuel and common engine) .

STS/LRB PERFORMANCE

All of the STS/LRB performance analysis conformed to all of the STS ascent trajectory constraints. These include limiting maximum dynamic pressure and flying -3000 (psf deg). Q-alpha. The single LRB engine failure requirement was also imposed. Previous engine-out analysis results indicated that if the LRB engines are sized such that the normal thrust is equal to (n-1)/ n of full rated thrust, then throttling the remaining engines up to full rated thrust when there is a single LRB engine failure provides the same thrust as without this failure. The result is that a single LRB engine failure becomes transparent to mission completion. Because of the preliminary nature of this study, an existing STS/LRB aerodynamic data base was used for the LOX/LH2 booster configurations. The largest booster size for which aerodynamics are available has 16.2 ft. diameter and 163 ft length. It was felt this is slightly unconservative, but that the increase in drag losses for the actual size of the LOX/LH2 boosters would decrease payload by less than 1,000 lb. Since both LOX/LH2 boosters have more margin than this, no effect for correcting the aerodynamics is expected on the study conclusions.

A summary of the STS/LRB reference mission performance is provided in Table 15.3.2 Some interesting fixtures were noticed during the LOX/LH2 LRB sizing. Option 2 sizing was done to determine the optimum size STS/LRB booster and engine. The first engines were too big. This caused the payload and maximum dynamic pressure (QMAX) to be high. The payload could be decreased by reducing the useable propellant, but this would increase the already too high dynamic pressure. Throttling down the engines would lower QMAX. This QMAX throttling to the minimum throttle level of 65% of rated power was included in the Option 2 engine sizing. The resulting engine/booster compared to the Option 3 engine/booster in the following manner :

Option 2 has more thrust ,but smaller useable propellant.

Option 3 has significantly lower QMAX (612 psf)

This shows that using the maximum allowable QMAX throttling results in the smallest tank size but a higher thrust/weight at lift-off. With Option 3 there was a common downsized engine. If the booster engine size was varied, the commonality with the core engine would be lost. Therefore, the only variable was the number of engines . With this common engine, the core required six engines and each booster required five engines. The significant reduction in QMAX was not a sizing goal, but a coincidental result. This was accomplished without QMAX throttling.

ALS/LRB TRAJECTORY DATA

Numerous trajectories were simulated. As an example the ALS using the Denver core and two Michoud pump-fed LOX/RP-1 boosters is presented in Table 15.4.1 .