TM-71-1013-1

TECHNICAL MEMORANDUM

SPACE TRANSPORTATION SYSTEMS ANALYSIS

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ABSTRACT

A preliminary comparative analysis of the suitability of various possible vehicle concepts to form the basis for a new space transportation system is reported herein. The configuration alternatives are both one and two stage reusable launch vehicles; some with reusable non-propulsive orbiters. Both ballistic and lifting body stage configurations are considered.

Four types of missions were used as the transportation system design missions - a NASA space station logistics mission, a NASA cargo mission, a USAF hi-energy mission and a USAF reconnaissance mission. The general objectives are to either minimize the gross weight of the system or to minimize the number of expendable stages in the system. Within these objectives the concepts are compared on the basis of size, performance sensitivity, number of developments, number of expendable stages, operational modes, suitability for phased development, and growth potential.

The number of possible shuttle concepts was reduced by eliminating those that required expendable elements or more than two new developments. The remaining concepts include the two stage lifting concept, a single-stage-to-orbit ballistic booster with a separate non-propulsive lifting body crew vehicle, a two stage ballistic booster with a separate non-propulsive lifting body orbiter, and a two stage integral ballistic vehicle.

The rationale behind the concept selections and the ground rules and assumptions, essential in arriving at these results, are discussed herein. The details of all the supporting work are included in a series of appendices.

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subject: Space Transportation System Analysis
Case 105-4

TECHNICAL MEMORANDUM

1.0 INTRODUCTION

The NASA Space Shuttle Summary Report, Reference 1, states the driving issue for development of a shuttle: "To support future space operations there is a critical need to reduce greatly the annual cost of routine round-trip space transportation operations, while greatly increasing the number of space flights." A transportation system is clearly needed to support the complete spectrum of missions associated with future space programs.

This study considers various configuration concepts for the shuttle including the use of reusable ballistic stages as well as lifting bodies and evaluates reasonable candidate configurations as a base for a transportation system. These concepts are then fitted into transportation systems which minimize either gross weight or the number of expendable stages. Within these objectives the concepts are compared on the basis of size, performance sensitivity, number of developments, number of expendable stages, operational modes, suitability for phased development, and growth potential.

1.1 Background

The initial configuration selection and screening process is described in detail in Reference 2. Starting with a set of configuration variables based on future transportation requirements, a matrix of alternative concepts was derived.

There were three basic configuration issues: 1) the number of stages, 2) the shape of individual stages, and 3) the propulsive capability of the orbiter. The number of stages was considered to range from 1 to 3. This range includes single-stage-to-orbit (SSTO) concepts and rejects systems of more than 3 stages on the grounds that they would be expensive to develop and operate. The limit of three stages seemed reasonable and is subjective.

The shape of the individual stages fell into two generic categories - lifting bodies and ballistic bodies. The main differences between these categories were in their aerodynamic characteristics, propellant mass fractions and landing modes. These differences will be discussed in more detail later. For screening purposes it was assumed that lifting bodies were good flying machines capable of delivering large amounts of crossrange or fly-back range either through hypersonic glide or subsonic powered cruise. Because of their shapes and lifting surfaces, however, the propellant mass fractions would be low, making them inefficient propulsive machines.

Ballistic vehicles were assumed to be just the opposite; efficient propulsive vehicles but poor flying machines. As a consequence ballistic vehicles must use propulsion to achieve crossrange where it is required.

The final principle issue was the distinction between a separate or an integrated orbiter. An integrated orbiter participates in the boost propulsion, and as a result must be carefully integrated with the booster. A separate orbiter provides only on-orbit and deorbit propulsion. It appears, to the booster, simply as payload, and is therefore relatively independent of the booster.

These alternatives, or configuration variables, led to a matrix of 60 configuration concepts. Not all of the concepts were reasonable, however. Some were technologically unfeasible - such as a single-stage-to-orbit lifting body. Others seemed economically unattractive, such as an expendable SSTO system. After a preliminary screening to some qualitative feasibility criteria, 37 concepts remained. These are shown in Figure 1.1.

As an example, the Phase B configuration concepts for the shuttle fall under the concept marked "1". The Single-Stage to Earth Orbit Reusable Vehicle (SERV), corresponds to the concept marked "2". The early Star Clipper concept corresponds to the concept "3", and the Manned Upper Reusable Payload (MURP), with expendable launch vehicles matches concept "4".

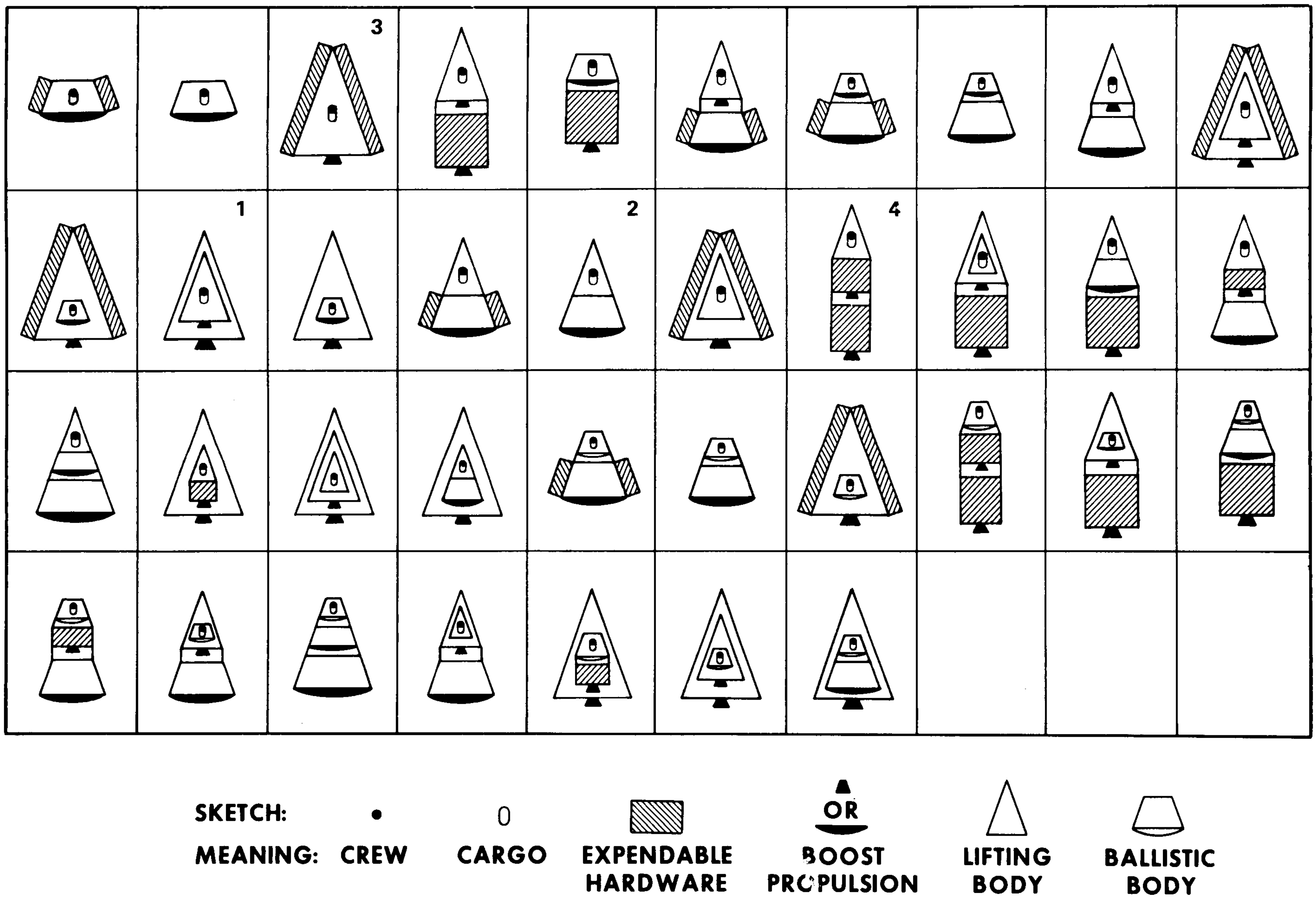


FIGURE 1.1 - CREW VEHICLE CONCEPTS

Two things must be kept in mind while looking at these concepts:

1. They are not configurations, but rather concepts that represent a class of configurations.

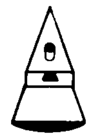
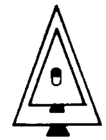
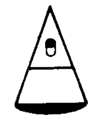
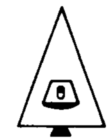
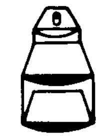
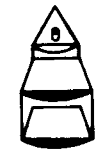
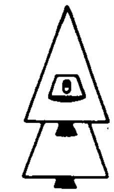
2. They represent only part of a transportation system. In most cases several different transportation systems are compatible with each particular concept for the logistics missions. The derivation of the transportation systems from these logistics concepts will be discussed later.

A second screening step was necessary to get an initial group of shuttle configurations small enough for further analysis. This was done by applying some present shuttle program requirements. Only those logistics concepts with no expendable elements and no more than two new developments were considered. This reduced the number of candidates meeting the shuttle program requirements for the crew/logistics mission to eleven. Admittedly the screening process was subjective; however care was taken to select screening criteria that would not significantly bias the analytical results. In addition, the subsequent derivation of transportation systems saw many concepts, rejected in this second screening, reappearing as other elements of the transportation system.

1.2 Candidate Configurations Review

The eleven surviving candidate shuttle concepts are shown in Figure 1.2. Briefly, they consist of fully recoverable systems with one and two stage launch vehicles. Both separate and integral crew systems are evaluated. The current shuttle concept, configuration 4, is a two stage lifting body launch vehicle with integrated crew and cargo systems. If the lifting body booster (first stage) is replaced by a ballistic booster, configuration 2 results. If the lifting body orbiter (second stage) is replaced by a ballistic orbiter, the result is configuration 7. Concept 3 is the case where both stages are ballistic.

If separate crew vehicles are used, and multiple staging is retained, configurations 8 through 11 result. Abiding by the ground rule of only two new developments, the two launch vehicle stages were assumed nearly identical, and can be approximately considered as only one new development. Hence, concepts 8 and 9 are two equal ballistic booster stages with separate ballistic and lifting body crew vehicles, respectively. If the ballistic booster stages are replaced by lifting body stages, concepts 10 and 11 result.

	1	2	3	4	5	6	7	8	9	10	11
											
NUMBER OF BOOSTER STAGES	1	2	2	2	1	1	2	2	2	2	2
ORBITER	—	L.B.	BAL.	L.B.	—	—	BAL.	BAL.	BAL.	L.B.	L.B.
BOOSTER	BAL.	BAL.	BAL.	L.B.	BAL.	BAL.	L.B.*	BAL.	BAL.	L.B.	L.B.
CREW VEHICLE	INT.	INT.	INT.	INT.	L.B.	BAL.	INT.	BAL.	L.B.	L.B.	BAL.
NUMBER OF DEVELOPMENTS	1	2	2	2	2	2	2	2†	2†	2†	2†
LANDING MODE											
ORBITER	—	HOR.	VERT.	HOR.	—	—	VERT.	VERT.	VERT.	HOR.	HOR.
BOOSTER	VERT.	VERT.	VERT.	HOR.	VERT.	VERT.	HOR.	VERT.	VERT.	HOR.	HOR.
CREW VEHICLE	—	—	—	—	HOR.	VERT.	—	VERT.	HOR.	HOR.	VERT.

* DUE TO CONFIGURATION PROBLEMS, THE BOOST STAGE CONSISTS OF CLUSTERS OF SMALL LIFTING BODY STAGES STRAPPED-ON TO A BALLISTIC ORBITER

† THE TWO BOOST STAGES ARE MADE AS IDENTICAL AS POSSIBLE AND THEREFORE CONSIDERED ONE DEVELOPMENT

BAL. – BALLISTIC
L.B. – LIFTING BODY
INT. – INTEGRATED

FIGURE 1.2 CANDIDATE SHUTTLE CONCEPTS

The remaining concepts are ballistic single-stage-to-orbit vehicles. Concept 1 has the payload and crew systems integrated into the stage, while concept 5 has a separate lifting body crew vehicle and concept 6 a separate ballistic crew vehicle.

2.0 GROUND RULES AND ASSUMPTIONS

There are a number of desirable characteristics of the space shuttle, and they are delineated in Reference 1. Low operating costs are certainly one critical characteristic. Explicit consideration of operating costs for the various shuttle concepts is beyond the scope of this report.

This report addresses other critical characteristics for a space transportation system. The system development - more specifically that of phased development program approach - is a desired characteristic of a space shuttle. Those systems which did not permit phased development were not considered prime shuttle candidates. Some single-stage-to-orbit (SSTO) vehicles which were not amenable to phased development were still included due to the inherent simplicity of the concept.

Operational performance and versatility are a necessity in a space transportation system. The system must meet all the operational requirements in terms of payload flexibility, flight system and ground support, and turn-around operations. It must be able to fly alternate missions with multi-agency space applications. Both NASA and Air Force missions are therefore considered in this study.

2.1 Missions

The design missions the transportation systems must support are shown in Figure 2.1. This study was conducted considering NASA only and subsequently NASA and USAF missions.

2.1.1 NASA Missions

When considering NASA missions only, the various shuttle configurations are designed to perform the crew/logistics mission and a cargo mission. The round trip logistics payload is 25,000 pounds to a 270 nautical mile 55° inclination orbit. This mission class is representative of logistic support of a space station, or sortie mode operation for scientific and applications payloads.

FIGURE 2.1 - TRANSPORTATION SYSTEMS MISSIONS SUMMARY

	NASA		USAF	
	LOGISTICS	CARGO	RECONNAISSANCE	HI-ENERGY
ORBIT	270 NM x 55°	100 NM x 28½°	100 NM x 90° (ALL AZIMUTH)	100 NM x 28½°
PAYLOAD	2 MEN + 25 K 12 MEN ROUND TRIP	150 K - UP 0 - DOWN	2 MEN + 10 K ROUND TRIP	2 MEN + 85 K - UP 2 MEN + 10 K - DOWN
CROSS RANGE	200 NM	200 NM	1500 NM	200 NM
VELOCITIES (ΔV) TOTAL TO ORBIT ON-ORBIT	 30647 fps 350 fps	 29960 fps 350 fps	 31427 fps 200 fps	 29400 fps 200 fps

The cargo mission necessitates 150,000 pounds of up only payload. This is placed in a 270 n.mi. orbit but at a 28.5° inclination for maximum payload delivery from ETR.

The crew/logistics class of missions is typically used in support of science and applications which require relatively small high cost payloads. The desire for these missions is the smallest possible cost per flight. Thus, when developing transportation systems, no expendable hardware was considered for that mission. The NASA cargo mission, however, delivers large bulk payloads to orbit usually in easterly type launches in which populated areas are not overflown. The cost per pound of payload is very important in this instance. Therefore, expendable hardware was used when desirable for this mission.

2.1.2 Air Force Missions

Two USAF missions were also considered, with both to a 100 n.mi. orbit, one being polar and the other a due east launch from KSC. The polar orbit mission, primarily for the purpose of reconnaissance, requires about 10,000 pounds of round trip payload and up to 1,500 n.mi. crossrange from the de-orbiting spacecraft. The due east launch will deliver an orbit-to-orbit shuttle (OOS) and its payload to low earth orbit, and return the expended OOS propulsion stage to Earth after it is used. Thus, around 85,000 pounds of up payload is desired, with about 10,000 pounds of down payload.

Polar orbit is assumed for USAF reconnaissance mission. The mission is somewhat ill defined and all azimuth launch capability could be required. This alone precludes the use of expendable hardware on this mission due to the possible impact of expendables on inhabited areas. The USAF high energy mission is required to place small satellites into synchronous orbits. The payload for the shuttle would be the satellite and an orbit-to-orbit shuttle or injection stage. The OOS would then be returned to earth within the shuttle. The launch will probably be due east from ETR, and therefore expendable hardware could be used for this mission. Thus, when transportation systems are developed for NASA/USAF missions, the basic shuttle size will be determined by either the NASA crew/logistics mission or the USAF crossrange mission. The remaining missions might get the necessary performance increase using expendable hardware.

2.2 Ascent Velocity Requirements

The ascent ΔV's indicated for each mission on Figure 2.1 were determined by computer trajectory simulation using a lift-off thrust to weight of 1.25. The boost drag characteristics were estimated for a SSTO vehicle with a relatively good aerodynamic shape for ascent. The total ascent ΔV was 29,960 fps including drag losses of 900 fps. The on-orbit and de-orbit ΔV's were derived from prior and current NASA and USAF shuttle studies.

Properly the ascent velocity requirement must be a function of each class of vehicle. For example, a two stage lifting body vehicle is constrained by the need to return the first stage to the launch site via unpowered flight. These requirements will naturally lead to an ascent velocity that is different from that shown. Piggy-back mounting of stages will increase the ascent drag. Similarly a two stage ballistic vehicle trajectory will be constrined by the lob retro maneuver used to return the first stage to the launch site, leading to a different velocity requirement than that shown. SSTO vehicles, such as SERV, exhibit rather high ascent losses due to the blunt, high drag shape which is necessary to minimize reentry heating because of the low lift coefficient. A non-propulsive lifting orbiter or a long external payload leads to a better fineness ratio, thus somewhat reducing the ascent drag.

Since this is a preliminary analysis the expedient course appeared to be one of assuming the same ascent velocities for all configurations and subsequently testing the sensitivity of the final recommendations to variations in ascent velocity. This final step is presented with the conclusions.

2.3 Configuration Ground Rules

Ballistic vehicles require hover time for vertical landing. About 20 seconds was considered sufficient, and therefore, 1,000 fps ΔV for removal of the terminal velocity and for hovering was assumed. This assumption is contingent on the use of a ground beacon at the landing site which provides a cooperative navigation and guidance system. Without such a beacon landing errors would probably be on the order of two nautical miles or less as experienced in Apollo landings. Also, if ballistic vehicles are required to provide 1,500 n.mi. crossrange from orbit, it must be accomplished propulsively. Analysis shows this maneuver to require about 10,360 fps ΔV, considering that ballistic vehicles can obtain about 100 n.mi. crossrange aerodynamically with an L/D of .2.

Payload packaging is a rather unique problem with the shuttle. When round trip payloads are required, they must be contained within the vehicle. Thus, significant weight penalties are incurred for providing a large internal volume as well as for structure necessary to protect, support and remove the payload from its compartment. An inert weight penalty equal to one-half of the recovered payload weight was added. For up only cargo missions where the payload can be mounted external to the launch vehicle, the weight of the shroud necessary to protect the payload during ascent is estimated at ten percent of the payload weight. The weight of the crew and crew systems including environmental control and life support is estimated at 5,000 pounds independent of vehicle size. This allowance was assumed adequate for a crew of 2. Support for additional men must come from the payload. A weight of 81,000 pounds (including payload) was assumed for a separate high L/D crew vehicle, and 58,000 pounds for a separate ballistic crew vehicle.

A number of other configurations contain deviations due to varying thrust requirements or interstage structure. Again the course elected was to ignore this complexity until the final step, and to then test the sensitivity of the recommendations to variations in mass fraction.

2.4 Transportation System Constraints

There are a number of constraints imposed on the space transportation systems in an effort to put a reasonable bound on the sizing problem and to put reality into the analysis. One such constraint is to limit the total gross liftoff weight of any of the transportation systems to that of the Saturn V. Prior studies of the shuttle have indicated that sizes on the order of one half the Saturn V can be expected using two lifting body stages. Since cost will be the primary driver of future programs, total weight may not be the key parameter, but the Saturn V weight was felt to be a reasonable upper limit.

Another constraint is to limit the number of booster stages to two. With the use of advanced HiP_c engines in the booster and high stage mass fractions, the addition of a third stage will not give large performance gains. Also, since all the stages are to be recovered and refurbished for reuse, as few stages as possible are desired. In designing an evolutionary system, however, more than two stages was acceptable in the interim until the shuttle is fully operational.

2.5 Stage Mass Fractions

In analyzing the various shuttle configurations, it was impractical to layout detailed designs and actually "weigh" all the systems considered. Numerous contractor studies have done this for various size stages. The available data were used to define curves of stage weight versus mass fraction. These curves are shown in Figures 2.2 and 2.3 with the various data points that were used. The lifting body data are based on numerous NASA and USAF funded studies while the ballistic data are derived from a few SSTO vehicle studies. A detailed discussion of the mass fraction curve generation and use is contained in Reference 3. This reference also discusses the computer program written to perform the calculations for this study. The form of the equations relating mass fraction to gross weight, $\lambda = S - \frac{T}{W_g^{1/3}} - \frac{U}{W_g}$, was derived on the assumption that the inert weight of a vehicle could be described by an equation of the form $W_I = U + S_o W_g + T W_g^{2/3}$.

U represents those weights that are fixed and independent of vehicle size, such as avionics and crew support systems. S and S_o represent those systems that are directly dependent on gross weight such as engines and tankage. T represents those systems that are dependent on vehicle surface area, such as insulation and interstage structure. Many systems obviously don't fit any of these categories, however, it was felt that these three groupings would accommodate the majority of the heavy systems.

The mass fraction curves are adequate for system comparisons, which is the main intent of this study. These data indicate substantially higher mass fractions for ballistic stages as compared with lifting body stages, an advantage which is the key to the results which follow. One can readily see from the plots that there is substantially less preliminary design data to support the ballistic vehicle correlation of λ vs. gross weight than there is for the lifting body. The sensitivity of the recommendations will be tested against variations in mass fraction from the correlation used.

The effect of crossrange of lifting body designs has been somewhat delineated in the preliminary results of the current Phase B studies. These results indicate about a .02 penalty in mass fraction (S is reduced by 0.02) for high crossrange orbiters. The weight penalty is mainly in the thermal protection system and some of these effects are shown in Figure 2.4, taken from Reference 4.

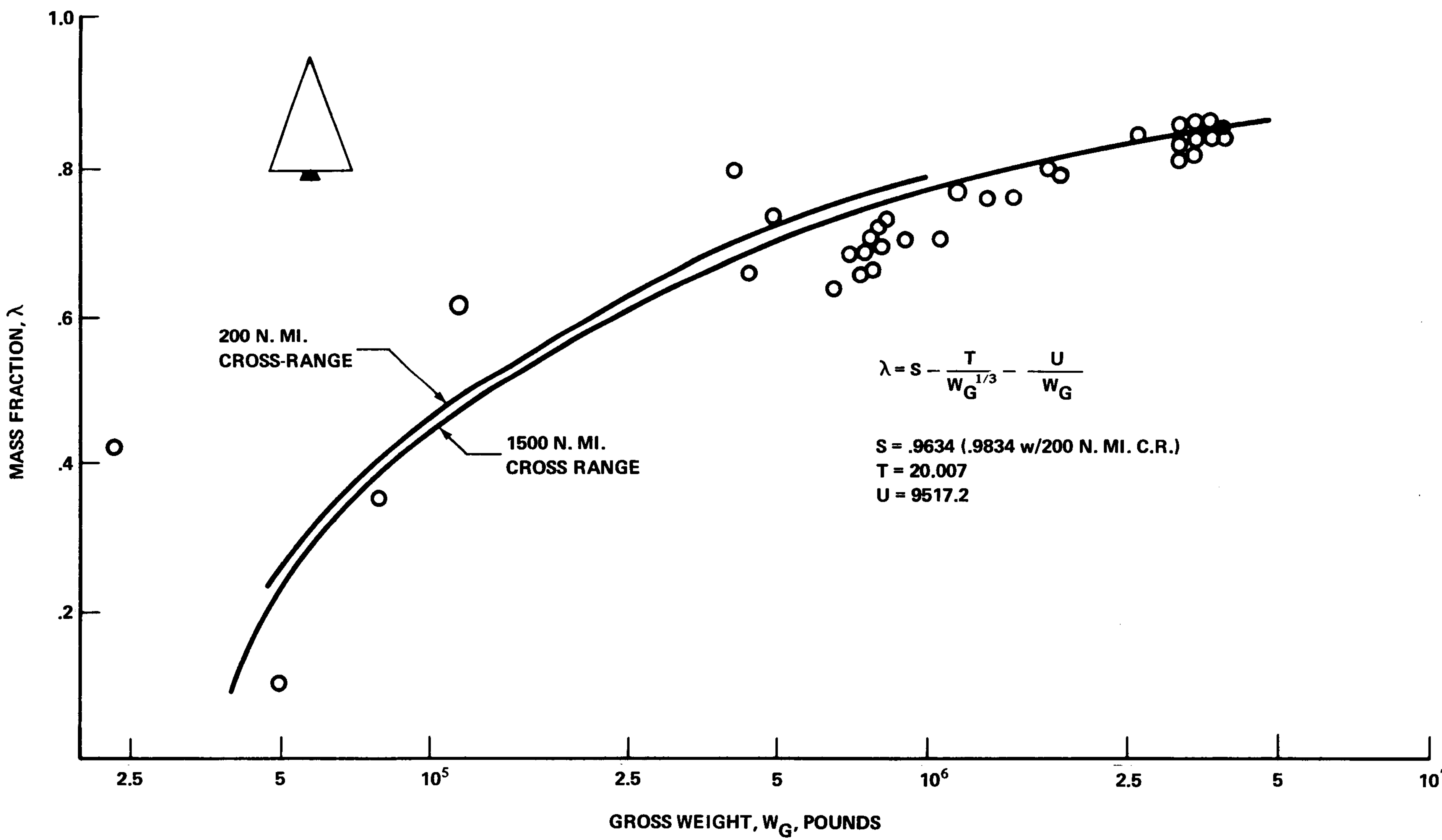


FIGURE 2.2 - MASS FRACTION VS. GROSS WEIGHT (NO PAYLOAD) FOR LIFTING BODIES

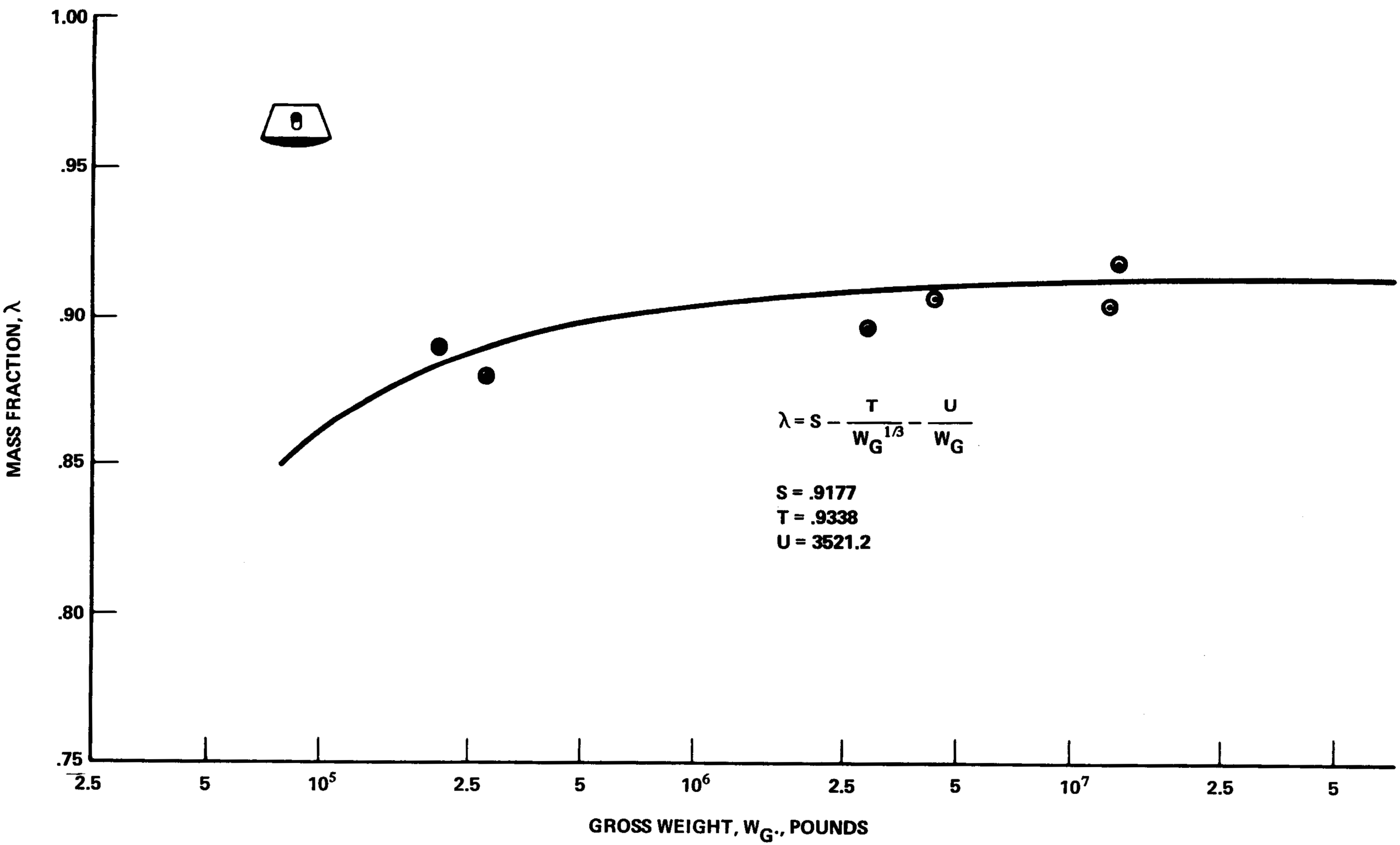


FIGURE 2.3 - MASS FRACTION VS GROSS WEIGHT (NO PAYLOAD) – BALLISTIC BODIES

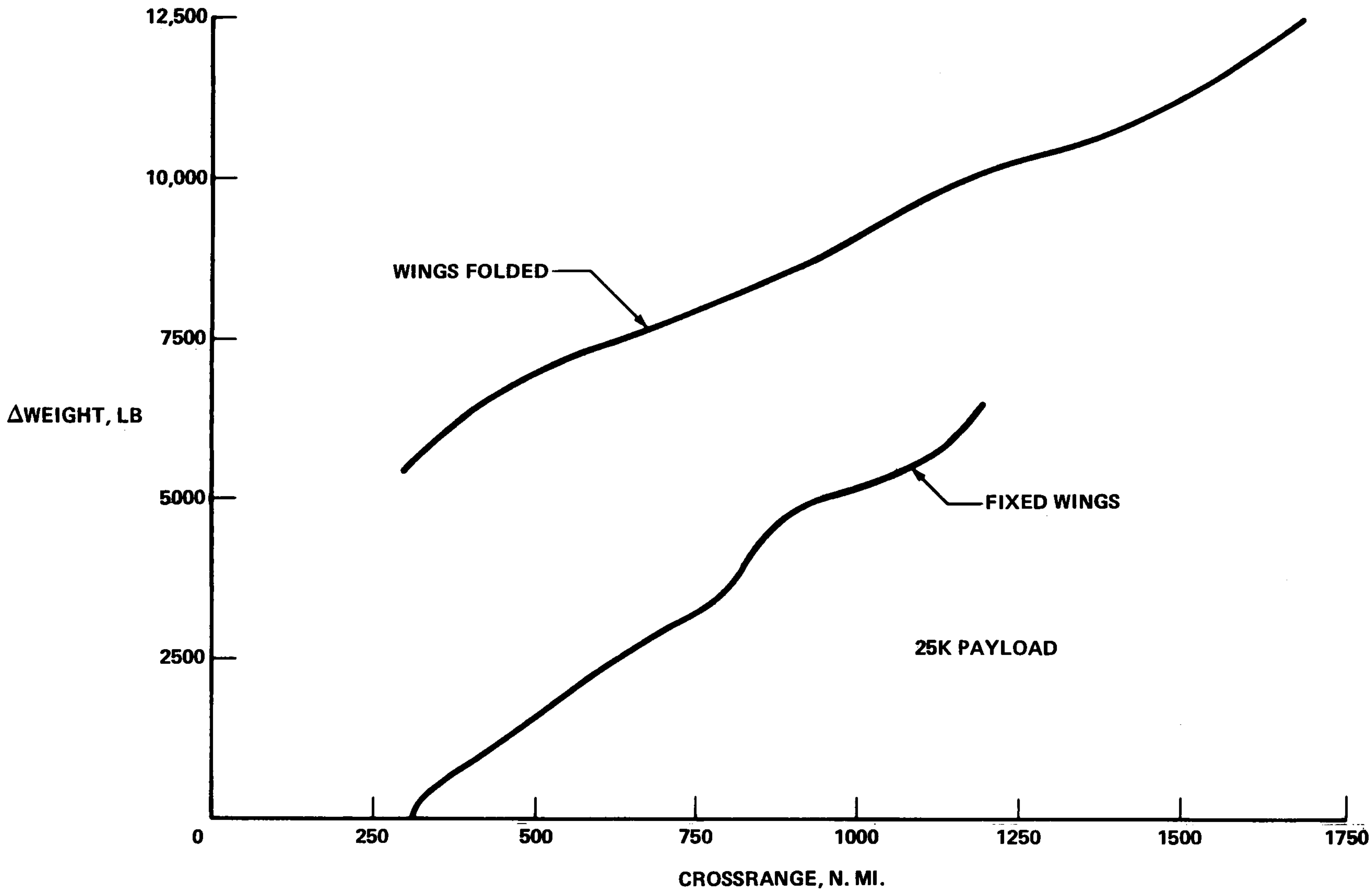


FIGURE 2.4 - WEIGHT PENALTY FOR CROSSRANGE

2.6 Propulsion

New, high performance rocket engines will be used on the shuttle. The performance assumed for these engines in this study was the specification called for in the Phase B shuttle engine statement of work, Reference 5. This assumes a sea level I_s of 383 seconds and a vacuum I_s of 459 seconds. A curve of I_s versus impulsive ΔV was approximated for use in the computer program. The actual and approximate curves from a trajectory simulation are shown in Figure 2.5.

HiP_c engines can also be used with reusable ballistic vehicles. For protection during reentry, some type of doors must be provided, either external or in the heat shield, to protect the bell nozzles. The aerospike engine, which was ruled out of competition for the lifting body vehicles, offers such attractive configuration advantages for ballistic vehicles that it should again be considered. For purposes of comparison in this study HiP_c engine performance was used in all cases.

2.7 Lob-Retro Maneuver

When analyzing two stage vehicles in which the first stage is ballistic, a unique problem exists in the recovery of that stage. In essence, three principle options are available for that first stage. The first possibility is to execute an impulsive maneuver immediately after staging that would put the booster on a high lofted trajectory ending back at the launch site. This is called impulsive return to the launch site, or more commonly, lob-retro.

A second method of booster recovery is to fly the booster, after stage separation, on to orbit. This would be done when the ΔV required to go to orbit would be less than that required for the lob-retro maneuver.

A third set of possibilities involves landing the booster down range. From there it could; 1) be refueled and flown ballistically back to the launch site on the main propulsion engines, 2) use lift fan-jet engines to fly back to the launch site, or 3) be carried back to the launch site via surface transportation. These methods are not considered attractive since it would involve the use of many recovery and launch facilities in numerous locations, would necessitate fairly long turn-around times, and would be expensive.

For this analysis, either the lob-retro maneuver or the flight to orbit of the empty booster was assumed to be used, depending on which resulted in the lower ΔV requirement. This maneuver is described and analyzed in Reference 6.

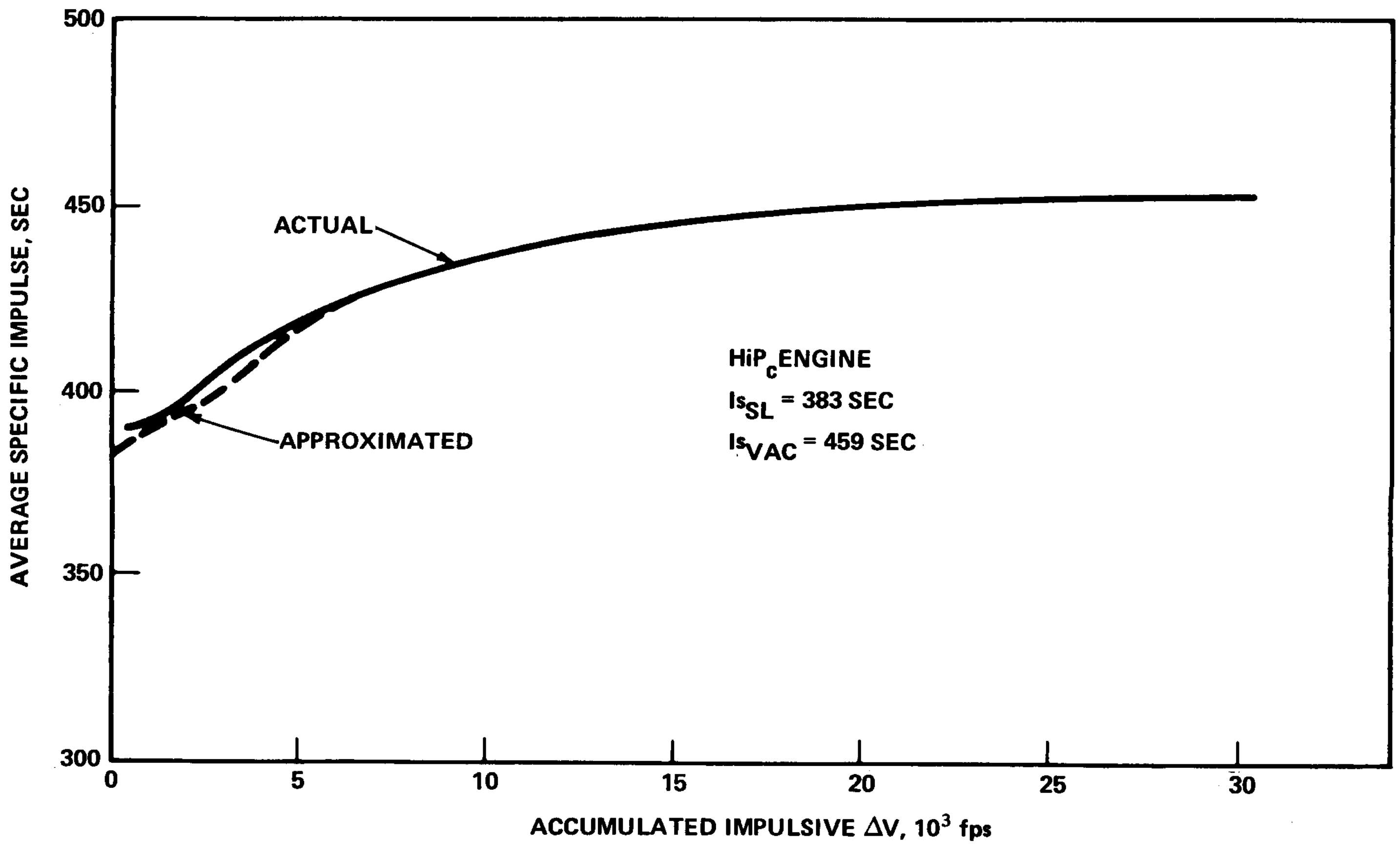


FIGURE 2.5 - AVERAGE SPECIFIC IMPULSE VS. ACCUMULATED ΔV

3.0 ANALYTICAL APPROACH

3.1 Systems Synthesis

The procedure followed in developing transportation systems to satisfy a variety of missions was to start by sizing a concept for one of the missions. When this vehicle is oversized for other missions, it was assumed that it would be either off-loaded to get the desired performance, or the increased performance capability would be utilized. If the vehicle is undersized for other missions, the use of expendable stages or tip tanks was examined. The process is repeated using each of the four missions as the design mission. An effort was made to maximize the commonality of hardware among the missions.

The development of the basic core vehicle for each concept is important, and evolutionary or phased development is desired to reduce high annual spending and high development risk. Thus, new low cost expendables or existing stages are used in the interim to enable stepwise development of the space transportation system baseline vehicle.

3.2 Sizing Analysis

A computer program was written to analyze the various candidate space transportation systems. The program uses the mission velocities and payloads to compute the required vehicle size. Features of the program are the ability to estimate the mass fraction of the various stages by means of a curve fit of gross weight vs. λ based on available data for each type of vehicle. It will size the stages either for minimum gross weight or equal size stages. It considers the variation in specific impulse with altitude by using an approximation for average I_s versus impulsive ΔV. In addition, the program will evaluate and select either the lob-retro or the on-to-orbit mission mode for ballistic boosters.

The sensitivity of the various configurations to design and mission variables can be computed by this program, as well as the performance of fixed stages with varying mission characteristics inputs. This program is described in detail in Reference 3.

Transportation systems are constructed using the various candidate shuttle configurations as a baseline. The shuttle is first sized to accomplish the mission requiring the largest vehicle. The vehicle is then used, either off-loaded or with excess payload, for the remainder of the design missions. The crew systems are then fitted into an evolutionary program where early use is accomplished utilizing low cost expendable boosters when possible. This then comprises one transportation system.

The shuttle is then designed for the next most energetic mission. Expendables are added to allow completion of the mission requiring increased performance. Once again, off-loading or utilization of the additional payload capability is applied for the remaining missions.

This sizing procedure is continued until the shuttle is sized for either the logistics or reconnaissance mission such that both can be accomplished without expendables. Various types of expendables are then added for the other missions, and the crew systems are fitted into an early use evolutionary program. This same procedure is followed in deriving the various transportation systems within each shuttle concept.

4.0 RESULTS

The results of this study are presented in two sections. The first is the space transportation systems considering NASA missions only while the second is the transportation systems when USAF missions are also considered. This will allow the determination of the effect of USAF missions when added to NASA requirements, and give an indication of the growth potential of the various configuration alternatives.

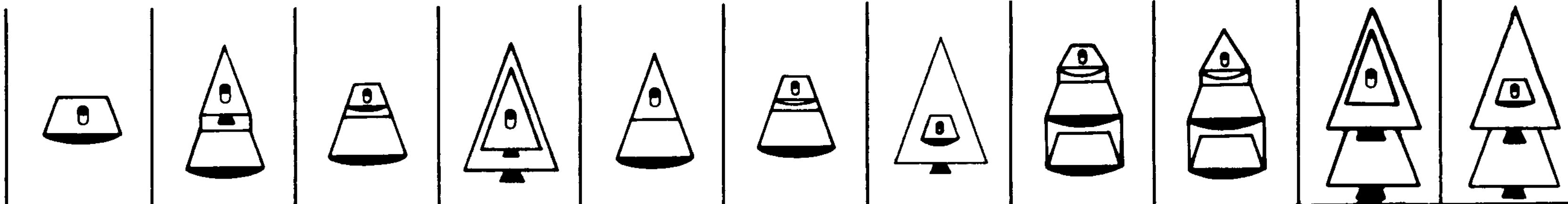
Space transportation systems have been developed for all concepts to perform all the design missions. These systems were compared, and only the results of the most promising concepts presented here. The minimum possible vehicle size for all the concepts is presented.

4.1 NASA Missions

The first step in a comparative study will involve sizing a transportation system for NASA missions only. The effects and penalties for designing an all-service shuttle can then be determined by adding the USAF missions to the requirements and re-sizing all the concepts. A summary of all the concepts sized for the NASA crew/logistics mission is shown in Figure 4.1. Four of these concepts were less attractive than the others and were dropped from further study at this point. They are shaded in Figure 4.1 and are concepts 2, 7, 10 and 11.

Concept 1, a SSTO vehicle with crew and cargo included is heavy, has a high sensitivity to design changes, and must be developed in an all up program. It was still considered due to its extremely simple operational characteristics. For crew/logistics missions, only one piece of hardware is used and recovered. Tip tanks or an expendable stage is required for the cargo mission.

FIGURE 4.1
VEHICLE SIZING SUMMARY
NASA MISSIONS ONLY
MINIMUM VEHICLE SIZE



	1	2	3	4	5	6	7	8	9	10	11
CREW VEHICLE					.055	.033		.033	.055	.055	.033
ORBITER		.983	.385	.547			.500	.514	.677	3.074	2.842
BOOSTER	3.539	2.204	.602	2.474	3.367	2.598	(2) .443	.514	.677		2.842
GROSS LIFTOFF	3.564	3.212	1.012	3.046	3.447	2.656	1.411	1.086	1.433	6.228	5.742

ALL VEHICLES SIZED FOR CREW/LOGISTICS MISSION

PL = 25000 LBS TO 270 N. MI., 55° INCLINATION ORBIT

CROSS-RANGE = 200 N. MI.*

* FOR BALLISTIC ORBITERS, 100 N. MI. CROSS-RANGE IS ATTAINED AERODYNAMICALLY, 100 N. MI. ATTAINED PROPULSIVELY

Concept 2, a ballistic first stage and a lifting second stage, offers no obvious performance or operational advantages over concept 4. It is also somewhat heavier and would necessitate the development of two different types of stages. Thus, a learning process from a phased development program would be somewhat limited. This concept was therefore set aside for the present, with more detailed analysis not warranted at this time.

Another concept deferred from further study at this time is concept 7. This concept has an integrated ballistic orbiter with a lifting body booster. Initial sizing analyses indicated that the relative sizes of the two stages would not physically permit this arrangement since the ballistic orbiter diameter was too large. A better conceptual approach is to consider that the booster is really two or more smaller lifting bodies, mounted around the periphery of the orbiter. Since these booster stages burn in parallel, the effect is of a single booster stage with a mass fraction corresponding to the λ for the individual booster elements. When a booster stage small enough to permit physical compatibility is considered, the system loses any promised weight advantage. In addition the multiplicity of vehicles that must be integrated and processed for each flight is a significant economic disadvantage. Finally the concept appears to offer no advantages over concept 3, which has a ballistic stage in place of the lifting body booster stages.

The last two concepts deemed not competitive are concepts 10 and 11 which consist of two equal size lifting body stages with separate crew vehicles. These stages are very heavy, have extremely high sensitivities to changes in design requirements or performance capability, and in general offer no attractive features relative to the other concepts. These configurations will no longer be studied. The system balances and sensitivities of those concepts eliminated are shown in Appendix C, Figures C.5 through C.9.

A summary of the major system characteristics of the surviving concepts considering NASA missions only is shown in Figure 4.2. The numbers shown are for the baseline vehicles designed for either minimum gross weight or minimum expendables. When designed for minimum gross weight, the vehicle attains the necessary performance for the more energetic missions with the use of low cost expendable hardware. When designing for minimum expendables, the penalty is paid in the form of a larger baseline vehicle in which most or all missions are performed without the use of expendables. The number of new developments includes any expendables such as drop tanks or expendable stages that may be required.

FIGURE 4.2
TRANSPORTATION SYSTEMS EVALUATION
NASA MISSIONS

CONCEPT	1	3		4	5	6	8		9	
DESIGNED FOR MINIMUM . .	WT.	WT.	EXP.	WT.	WT.	WT.	WT.	EXP.	WT.	EXP.
GROSS LIFTOFF WEIGHT, 10^6 LBS	3.564	1.012	2.866	3.046	3.447	2.656	1.086	2.664	1.434	2.664
DESIGN SENSITIVITY INERT WT., LBS PL/% * I_s, LBS PL/SEC **	−3146 1979	− 489 472	−1468 1634	−2191 1164	−3434 2265	−2676 1746	− 670 643	−1533 1627	− 860 849	−1533 1627
NEW DEVELOPMENTS	2	3	2	3	3	3	3	2	3	2
RECOVERABLE ITEMS	1	2	2	2	2	2	3	3	3	3
EXPENDABLE ITEMS	1	1	0	1	1	1	1	0	1	0
PHASED DEVELOPMENT	NO	NO		NO	YES	YES	YES		YES	

* DISCRETIONARY PAYLOAD CHANGE FOR A 1% GROWTH IN INERT WEIGHT

** DISCRETIONARY PAYLOAD CHANGE FOR A 1 SECOND GROWTH IN ENGINE I_s

Factors such as the number of new developments and the phased development of the hardware help in the understanding of relative RDT&E costs of the various concepts. A system amenable to phased development is one in which the crew vehicle could be developed and flown well before the total concept IOC. Items such as the number of recoverable and expendable pieces of hardware give an indication of the relative operating cost of the various shuttle concepts.

In general, the major effect of excluding USAF missions was lower gross weight and design sensitivities of the candidate configurations. This is particularly true of those concepts having the crew and payload in ballistic vehicles. In general, it can be said that the two stage ballistic vehicles are quite light and have low sensitivities. They also adapt well to phased development programs. Another advantage is that these concepts could be designed such that no expendable hardware is needed for either mission. The single-stage-to-orbit vehicles do not appear competitive from any standpoint other than operational simplicity. This factor, however, could be very important and should keep this class of vehicles under consideration.

Concept 4, is lighter and less sensitive than the SSTO vehicles but heavier and more sensitive than the multi-stage ballistic vehicles. While it requires the use of expendable hardware for cargo missions it does not require development of both ballistic and lifting recoverable vehicles and generally requires equal or fewer stages in operation than the multi-stage ballistic systems.

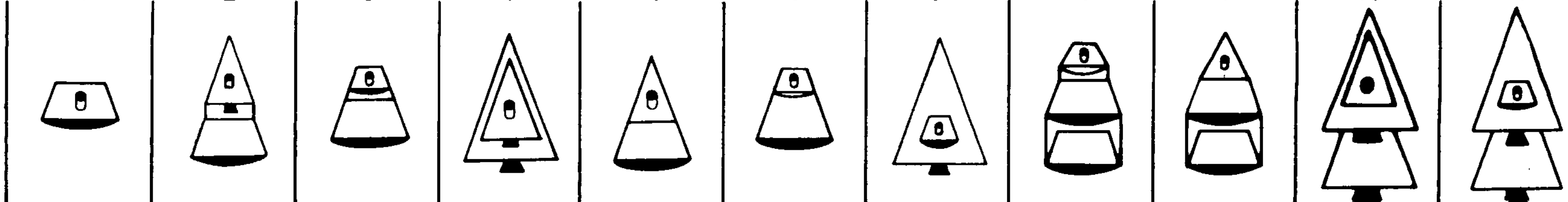
Appendix B contains the system balances, sensitivities, candidate transportation systems, and sizing curves for the attractive concepts considering only NASA missions. Discussion of the significant characteristics of each concept is also included.

4.2 NASA/USAF Missions

A summary of the minimum vehicle size for the eleven candidate concepts designed for both NASA/USAF missions is shown in Figure 4.3. The minimum vehicle size was determined by the USAF crossrange mission for all concepts except 4 and 9; these were sized by the NASA crew/logistics mission.

As before, the concepts not considered competitive for NASA only missions were dropped here for the same reasons. In addition the single-stage-to-orbit vehicle with integral

FIGURE 4.3
VEHICLE SIZING SUMMARY
NASA/USAF MISSIONS
MINIMUM VEHICLE SIZE



	1	2	3	4	5	6	7	8	9	10	11
CREW VEHICLE					.054	.076		.076	.055	.054	.076
ORBITER	NOT	1.018	.879	.532			.556	.812	.677	3.338	3.600
BOOSTER	POSSIBLE	2.747	2.582	2.770	3.758	4.853	(2) 1.337	.812	.677	3.338	3.600
GROSS LIFT-OFF		3.775	3.471	3.327	3.822	4.939	3.240	1.710	1.434	6.740	7.286

ALL VEHICLES SIZED FOR CROSS-RANGE MISSION (EXCEPT CONCEPTS 4 AND 9)

CONCEPTS 4 AND 9 DESIGNED FOR CREW/LOGISTICS MISSION

PL = 10,000 LBS TO 100 N. MI. POLAR INCLINATION ORBIT

CROSS-RANGE = 1500 N. MI.*

* FOR BALLISTIC ORBITERS, 100 N. MI. CROSS-RANGE IS ATTAINED AERODYNAMICALLY. 1400 N. MI. ATTAINED PROPULSIVELY

crew/payload, concept 1, could not perform the USAF crossrange mission without expendable hardware. It necessitates all-up development with no phased development being possible and is extremely sensitive to inert weight and specific impulse changes. For these reasons, it was no longer considered for NASA/USAF missions.

The design system balance and sensitivities of the eliminated concepts are shown for completeness in Appendix C.

The major effect of adding USAF missions was to greatly increase the size of those vehicles in which the crossrange is obtained with a ballistically shaped vehicle. This necessitates a large increase in the propulsion capability of the stages. As a result, concept 3 more than tripled in size. The other concepts showing the most significant effect were 6 and 8 which both have separate ballistic crew vehicles. A summary of the pertinent information on the candidate space transportation system concepts is shown in Figure 4.4.

From both a weight and sensitivity standpoint, the data indicate that two stage ballistic vehicles with separate crew vehicles are very attractive. These concepts are the lightest and have a low sensitivity to parametric variations.

Concept 4 is approximately the same as 3, 5 and 6 although less sensitive. It is heavier and more sensitive than 8 and 9 but is operationally similar. It retains the virtue of not requiring development of both lifting and ballistic vehicles and is in this regard quite like concept 9. Concept 4 is not well suited to phased development whereas 5, 6, 8 and 9 are.

Since the USAF crossrange mission is somewhat ill-defined, the effect of payload for this mission on vehicle gross weight was determined for some concepts and shown on Figure 4.5. It can be seen that concepts 4 and 9 are relatively insensitive to payload size, while concept 3 is quite sensitive to changes in payload for this mission. In general, it can be said that systems having crew and payload in a ballistic vehicle have a high sensitivity to payload changes for the crossrange mission since the crossrange is acquired propulsively. Thus, concepts 3, 6 and 8 would show the greatest gross weight changes if the payload for this mission were to change.

The system balances, sensitivities, candidate transportation systems, and sizing curves are presented in Appendix B for all the candidate concepts. Discussion of the significant characteristics of each concept is also included.

FIGURE 4.4
TRANSPORTATION SYSTEMS EVALUATION
NASA/USAF MISSIONS

CONCEPT	3	4		5	6	8		9	
DESIGNED FOR MINIMUM . . .	WT.	WT.	EXP.	WT.	WT.	WT.	EXP.	WT.	EXP.
GROSS LIFTOFF WEIGHT, 10^6 LBS.	3.471	3.327	3.929	3.822	4.939	1.710	2.664	1.434	2.664
DESIGN SENSITIVITY INERT WT., LBS PL/% * I_s, LBS PL/SEC **	 –2858 1784	 –2381 1236	 –2987 1760	 –3863 2459	 –4884 3138	 –1009 977	 –1533 1621	 – 860 851	 –1533 1621
NEW DEVELOPMENTS	2	4	3	3	3	3	2	3	2
RECOVERABLE ITEMS	2	2	2	2	2	3	3	3	3
EXPENDABLE ITEMS	0	2	1	1	1	1	0	1	0
PHASED DEVELOPMENT	NO	NO		YES	YES	YES		YES	

* DISCRETIONARY PAYLOAD CHANGE FOR A 1% GROWTH IN INERT WEIGHT

** DISCRETIONARY PAYLOAD CHANGE FOR A 1 SECOND GROWTH IN ENGINE SPECIFIC IMPULSE

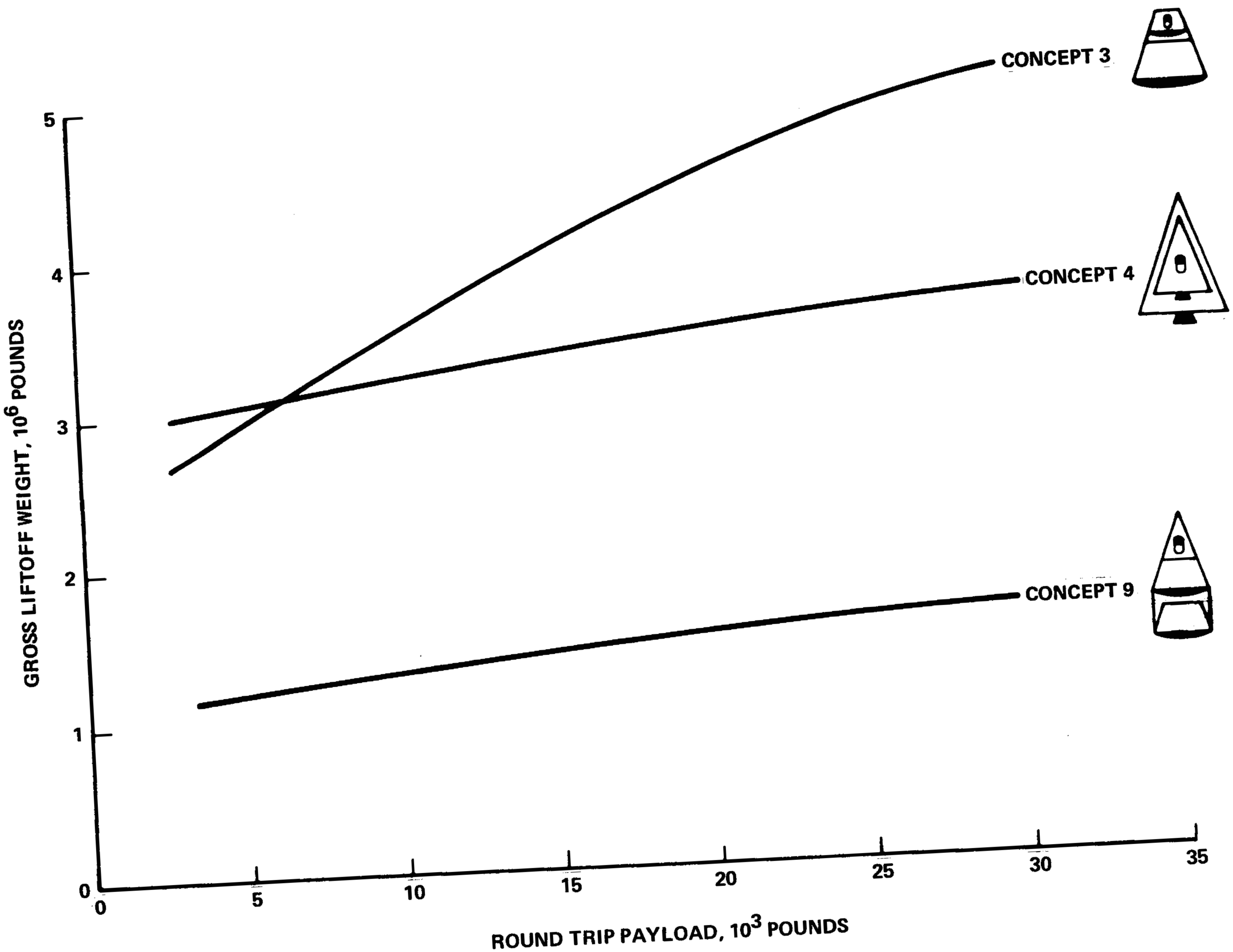


FIGURE 4.5 - PAYLOAD EFFECT ON GROSS LIFTOFF WEIGHT 1500 N. MI. CROSS-RANGE

5.0 SUMMARY

5.1 Configuration Considerations

1) The addition of the USAF missions, more specifically that of requiring the deorbiting spacecraft to have a 1500 n.mi. crossrange capability, has a number of important consequences. Most significant is the conclusion that the deorbiting spacecraft should not be ballistic if large crossrange is desired. This is the case because a ballistic vehicle must attain the crossrange propulsively and this results in a large increase in the stage weight over a low crossrange design and a high sensitivity to payload weight changes. Applying this conclusion to the configurations studied, concepts 6 and 8 are no longer considered as attractive. The difference between concepts 5 and 6 is simply the character of the crew vehicle and the same can be said of concepts 8 and 9. In addition, concept 3 becomes extremely sensitive to changes in inert weight, I_{sp}, etc. and is only marginally competitive. The configurations with lifting body crew vehicles do not show significant differences when comparing for NASA only and NASA/USAF mission and are thus favored because of the inherent mission flexibility.

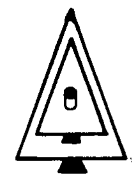
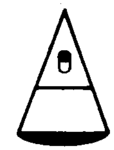
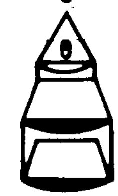
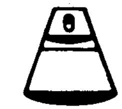
2) In the absence of a large crossrange requirement, or if a separate high L/D crew vehicle is used, the two stage ballistic vehicle concepts appear to be light and to have low sensitivities to small parametric changes, assuming close to nominal values for mass fractions, ascent ΔV's, etc.

3) Single stage-to-orbit concepts are only marginally competitive with the other concepts on a size and sensitivity basis. It's principal advantage seems to be its inherent operational simplicity.

4) Based on the assumptions, four of the concepts studied warrant further investigation. These concepts, along with a summary of their relative characteristics, are shown in Figure 5.1. They consist of the two stage lifting concept, two stage ballistic vehicles with both separate and integrated crew and cargo systems, and a single-stage-to-orbit booster with a separate lifting body orbiter.

It can be seen from the figure that the two stage ballistic vehicle with a separate crew vehicle has a weight advantage over the other concepts. It also displays an almost equal sensitivity advantage. The ballistic vehicles can all be designed with no expendable hardware required.

FIGURE 5.1 - RECOMMENDED TRANSPORTATION SYSTEMS

CONCEPT	4 		5 		9 	3 
QUANTITATIVE COMPARISONS	MINIMUM WEIGHT	MINIMUM EXPENDABLES	MINIMUM WEIGHT	MINIMUM EXPENDABLES	MINIMUM EXPENDABLES	MINIMUM WEIGHT
● RELATIVE WEIGHT	1.0	1.3	1.0	1.8	0.5	1.0
● RELATIVE SENSITIVITY	1.0	1.3	1.8	1.8	0.5	1.0
● EXPENDABLE ELEMENTS	2	1	1	0	0	0
● NEW DEVELOPMENTS	4	3	3	2	2	2
● RECOVERY MODE	HORIZONTAL		MIXED		MIXED	VERTICAL
QUALITATIVE COMPARISONS						
● PHASED DEVELOPMENT MERIT	LOW		HIGH		HIGH	LOW
● PERFORMANCE AUGMENTATION	COMPLEX		SIMPLE		MODERATE	MODERATE
● MISSION SIMPLICITY	MEDIUM HIGH		HIGH		LOW	MED. LOW

Phased development allows the early use of the crew and cargo system before full development of the booster. Thus, concepts with separate crew vehicles will be more amenable to phased development (i.e., #5 and #9).

The ability to augment the performance of a stage, once built, is important if the design goals are not met. This augmentation is considered easier with relatively symmetric ballistic boosters, and especially with the SSTO vehicle since there is no change in the staging characteristics.

5.2 General Analytical Considerations

1) The need clearly exists for more ballistic vehicle design data. The results of this study are based on only limited analytical studies of large SSTO ballistic vehicles. In depth study is needed to determine stage mass fractions, the effect of internal payload volume on stage weights, the weight of a separate orbiter, interstage weights, and ascent and landing ΔV's. More detailed investigation is needed into vertical landing and lob-retro maneuvers for ballistic stages, particularly in the area of reentry navigation and guidance to achieve a high degree of accuracy.

2) A clearer definition of the design reference missions should be made. A single design mission can't be found but all missions should be used.

3) The choice of propulsion systems for ballistic vehicles is a significant technical question. The feasibility and use of annular nozzles must be explored in full since its use results in an attractive configuration. The base heat shield which must protect the engines during reentry could also be a problem.

4) The advantages of the two stage ballistic vehicle under the assumptions made have been presented. Previous concern has been expressed in the areas of ascent velocity, design state-of-the-art as represented by the quite attractive mass fractions for the ballistic recoverable vehicles, and weight penalties due to interstage structure and differing thrust requirements.

Should the reader desire a full explanation, Appendix D contains a record of the analysis and an explanation of the numerical estimates associated with the following presentation. Table 5.1 displays the gross liftoff weight of concept 9 when sized to meet both NASA and USAF missions with no expendable hardware. The dimensions of the matrix of Table 5.1 are the relative values of the structural fractions of the first and second stages of the boost vehicle to those one would derive from Figure 2.2*. Note that the vehicle was originally sized with f - 1.05 to approximate penalties arising from the commonality requirement.

If we now adjust the first stage engine weight penalty and add an interstage weight penalty, the anticipated gross weight becomes $\underline{2.689 \times 10^6}$ lbs. ($f_1 = 1.35$, $f_2 = 1.0$) (as opposed to 2.664×10^6 lbs.).

If we further assume the design state of the art as represented by Figure 2.2 is optimistic by 20%, (f = 1.2) then $f_1 = 1.6$, $f_2 = 1.2$ and the liftoff weight becomes $\underline{3.293 \times 10^6}$ lbs. Similarly one can assume that Figure 2.2 is pessimistic by 20% (f = 0.8) then $f_1 = 1.1$ and $f_2 = 0.8$ and the liftoff weight is $\underline{2.252 \times 10^6}$ lbs.

Table 5.1

GROSS LIFTOFF WEIGHT VERSUS
STAGE STRUCTURAL WEIGHT FACTOR
(NASA Cargo Mission, Two Equal Ballistic Stages)

FIRST STAGE, f_1

	(10^6 lb.)	1.05	1.1	1.35	1.6
SECOND STAGE, f_2	0.8		2.252	2.325	
	1.0		2.588	2.689	2.782
	1.05	2.664			
	1.2			3.159	3.293

---

*$f = \frac{\sigma'}{\sigma}$, where $\sigma = 1-\lambda$ as taken from Figure 2.2. Propellant weights are held constant when adjusting σ and thus the stage gross weight must also change.

The same data is repeated on Table 5.2 for an ascent velocity that is 500 fps higher and on Table 5.3 for an ascent velocity 500 fps lower than that used in this analysis. It can be seen that in these cases, the gross liftoff weight of the vehicle is less than the predicted weight for the current shuttle candidate vehicle.

Table 5.2

GROSS LIFTOFF WEIGHT VERSUS

STAGE STRUCTURAL FRACTION

(NASA Cargo Mission, Two Equal Ballistic Stages
Ascent ΔV = 29,960 + 500, fps)

FIRST STAGE, f_1

(10^6 lb.)	1.05	1.1	1.35	1.6
0.8		2.379	2.460	
1.0		2.758	2.869	2.976
1.05	2.844			
1.2			3.410	3.567

Table 5.3

GROSS LIFTOFF WEIGHT VERSUS
STAGE STRUCTURAL FRACTION

(NASA Cargo Mission, Two Equal Ballistic Stages
Ascent ΔV = 29,960 - 500, fps)

FIRST STAGE, f_1

(10^6 lb.)	1.05	1.1	1.35	1.6
0.8		2.135	2.203	
1.0		2.438	2.526	2.616
1.05	2.506			
1.2			2.942	3.062

5.3 Conclusions

Based on the quantitative assumptions relative to mass fractions, ascent losses, engine performance, mission requirements, etc., and subjective judgments used in screening of candidate shuttle configurations, four concepts as described above warrant further study. Of these, all are under current study except the two stage ballistic vehicles. The general considerations listed above indicate the areas in which further investigation is needed.

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APPENDIX A

A.1. Stage Descriptions

The current shuttle design in Phase B is a two stage fully reusable lifting body configuration. The stages have winged surfaces, either fixed or swing-type, and are configured for horizontal land landing. Many designs have been proposed and the majority of these are discussed in detail in References 7 to 14.

A significant characteristic of a lifting body stage is its generally low mass fraction, due mainly to its geometry. The configuration is not well suited to the packaging of propellants and a large surface to volume ratio exists. Also, large winged surfaces which must withstand ascent and reentry loads make the structure quite heavy.

Numerous small lifting body crew vehicles have been designed, built, and undergone successful but limited testing. From an operational standpoint, these configurations have demonstrated their feasibility. Significant technology problems exist with the larger stages now considered, and these are mainly in the areas of thermal protection, flight stability, and operations.

A.2. Recoverable Ballistic Systems

Recoverable ballistic systems have been studied to a fair degree in the past, but were usually limited to large payload single-stage-to-orbit systems, References 15 to 18. A ballistic stage has a characteristic blunt aft end, and an overall conical shape. The stages lift-off vertically and land vertically. Reentry is accomplished in a fashion similar to the Apollo spacecraft, with the heat shield designed to enhance reusability, protect the engines, and minimize refurbishment.

Limited cross range can be achieved from a reentering ballistic stage due to an L/D around .2. Any additional cross range that is desired would have to be achieved propulsively. Vertical landing is accomplished similar to the LM or Surveyor by firing the main engines to remove the terminal velocity and to allow some hover and translation time. A booster which burns out down-range will have to use propulsion to return to the launch site. This can be accomplished by firing the main engines at the apogee of the trajectory to "lob-retro" back to the launch site. This maneuver is described in more detail in Reference 6. Airbreathing engines could in principle be used for subsonic cruise back to the launch site rather than using a "lob-retro", but fuel consumption would be prohibitive.

The shape of the ballistic vehicles enables relatively high mass fractions to be attained. The geometry presents a good configuration for propellant packaging, and there are no heavy winged surfaces. A single-stage-to-orbit ballistic booster then becomes feasible, since the high mass fractions can be obtained. A number of studies have been conducted in the past on these type stages and they appear attractive. An estimation of stage diameter vs. gross weight using judgment and simple geometric considerations is made.

APPENDIX B

SYSTEMS SUMMARY

B.1. NASA/USAF Transportation Systems Summary

B.1.1 Concept 3

This concept, a two stage ballistic vehicle with integrated crew and payload, has a minimum on-pad weight of about 3.5 million pounds. The vehicle is sized for the USAF cross range mission and has more than sufficient capability to perform all the other NASA/USAF missions with excess payload capability. It can carry more than 85,000 pounds up while returning 10,000 pounds for the USAF OOS mission. In addition, as an external cargo carrier, it can place 185,000 pounds of discretionary payload into an orbit desired by NASA.

The most attractive transportation system built around this concept is to design the vehicle for the USAF cross range mission and fly exactly the same vehicle for all other missions. This is a very desirable attribute of this concept.

The sensitivity of this design to parametric changes gives an indication of the risk involved in the development of this vehicle. The important sensitivities are that of payload change for inert weight growth and for specific impulse changes from nominal design. It is not unusual for stages under development to experience at least a 10 percent growth in inert weight. If this were to be the case for this vehicle, approximately 40 percent of the payload would be lost for a crew/logistics mission. The entire payload for the cross-range mission would be lost with only a 3 1/2 percent inert weight growth. A one percent decrease in delivered specific impulse will reduce the payload by 35 percent for the cross-range mission.

Figure B.1. summarizes the concept system design and sensitivities, while Figure B.2 shows the transportation system based on this concept. Sizing curves showing the stage and gross liftoff weights vs. orbiter and booster velocity split are presented in Figure B.3.

B.1.2 Concept 4

The current NASA Phase B design concept is depicted as concept 4 in this analysis. It consists of two lifting body stages with payload and crew integrated into the orbiter.

FIGURE B.1

CONFIGURATION 3

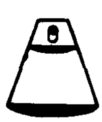
NASA/USAF MISSIONS

SYSTEM BALANCE – RECONNAISSANCE

BOOSTER – BALLISTIC

ORBITER – BALLISTIC (WITH INTEGRATED CREW/PAYLOAD)

PAYLOAD (UP – DOWN) 10000 – 10000



	BOOSTER		ORBITER
ASCENT DELTA V'S	12913		18514
FRACTION OF BOOST VELOCITY	.4109		.5891
SPECIFIC IMPULSE	440.7		459.0
STAGE MASS FRACTION	.9094		.9038
STAGE GROSS WEIGHT	2.582×10^6		$.879 \times 10^6$
LIFT-OFF GROSS WEIGHT		3.471×10^6	

VEHICLE SENSITIVITIES

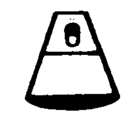
	BOOSTER		ORBITER
PROPELLANT WEIGHT (LBS PL/%)	558.9		791.4
STRUCTURAL WEIGHT (LBS PL/%)	– 243.9		– 828.5
SEA LEVEL I_S (LBS PL/SEC)	53.4		25.6
VACUUM I_S (LBS PL/SEC)	170.5		533.8
ON-ORBIT DELTA V (LBS PL/FPS)			– 8.4
CROSS-RANGE DELTA V (LBS PL/FPS)			– 8.2
HOVER DELTA V (LBS PL/FPS)	– 2.4		– 9.9
LOB-RETRO DELTA V (LBS PL/FPS)	– 2.0		
TOTAL IMPULSIVE DELTA V (LBS PL/FPS)		– 8.2	
DE-ORBIT DELTA V (LBS PL/FPS)		– 8.4	
TOTAL VEHICLE STRUCTURAL WEIGHT (LBS PL/%)		–1072.6	

FIGURE B.2

TRANSPORTATION SYSTEMS

CONCEPT 3

NASA/USAF MISSIONS

	EVOLUTIONARY	NASA MISSION A CREW/LOGISTICS	NASA MISSION B CARGO	USAF MISSION C HI ENERGY	USAF MISSION D RECONNAISSANCE
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS LIFT-OFF		USE RECON. DESIGN EXCESS P. L. CAPABILITY	USE RECON. DESIGN PL = 185,000 LBS	USE RECON. DESIGN EXCESS P. L. CAPABILITY	 .010 .879 2.582 3.471

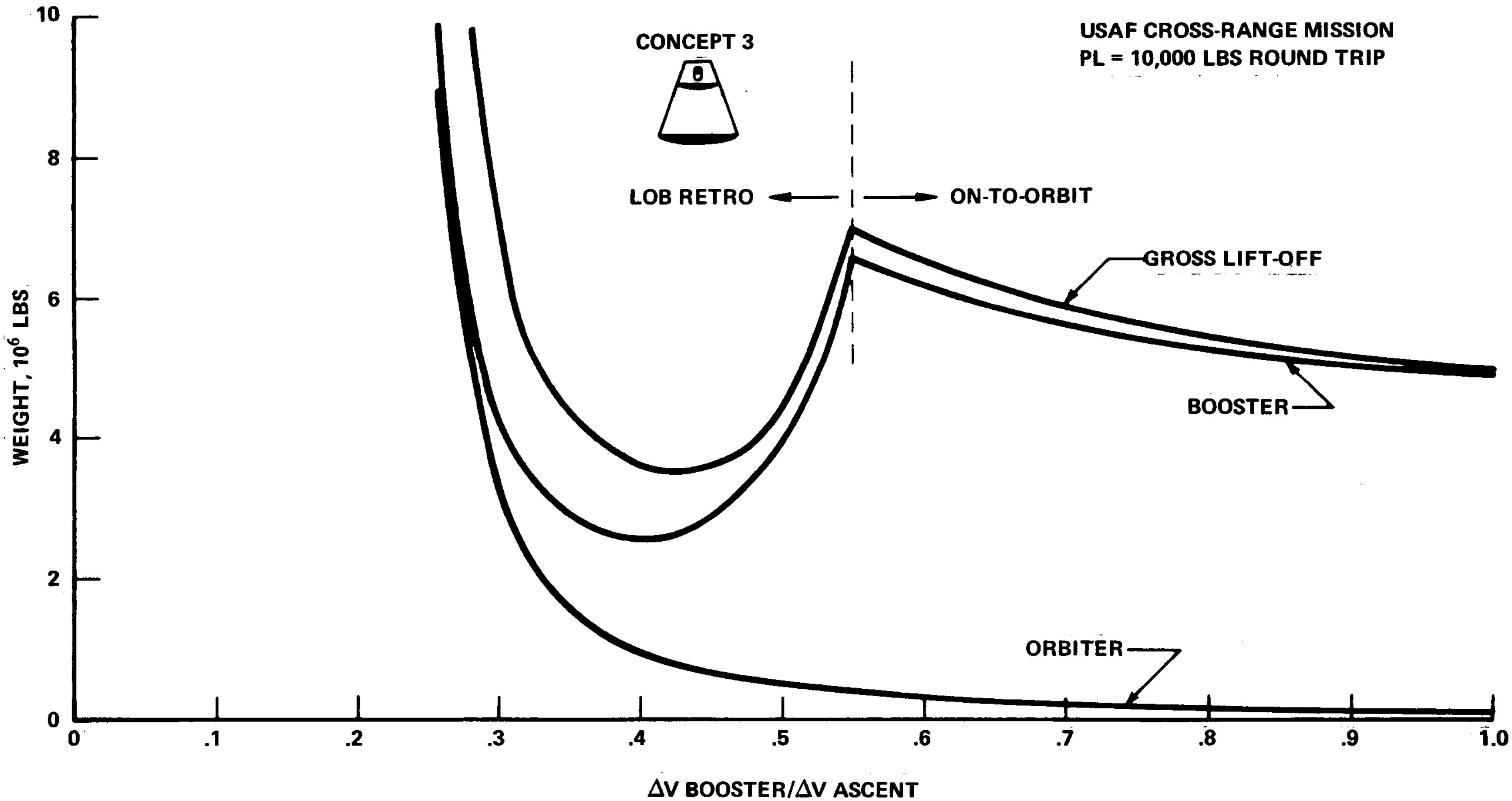


FIGURE B.3 - VEHICLE SIZING CURVE

The smallest gross weight at liftoff, under the ground rules for the transportation systems, results when the stage is designed for the crew/logistics mission with the orbiter design reflecting the 1500 nm cross range requirement of the USAF. Liftoff gross weight is then 3.3 million pounds with the orbiter weighing about 0.5 million pounds and the booster around 2.8 million. A system balance for this configuration is shown in Figure B.4.

A number of transportation system alternatives exist with this concept. The basic vehicle could be designed for the crew/logistics mission and have excess payload capability for the USAF cross range mission. Some expendable tankage would then have to be added to the vehicle to obtain the necessary increase in performance for the USAF OOS mission. For the NASA cargo mission, the upper stage is removed, and the necessary performance is obtained by either adding an expendable upper stage or tip tanks to the booster stage.

Other reasonable transportation system alternatives that exist are based on a vehicle designed for the OOS mission. The resulting gross liftoff weight is around 4.0 million pounds, but the vehicle now has the capability to fly the crew/logistics and cross range missions as well as the OOS mission with no design changes. The NASA cargo mission, however, would still require the removal of the upper stage for replacement with an expendable stage, or for the addition of expendable tip tanks to the booster.

It was impractical to design for the cargo mission since this necessitated a stage gross weight of almost 6.0 million pounds and would be grossly oversized for the remaining missions.

This concept can be developed in an evolutionary program with the orbiter being launched by a new low cost expendable stage. With J-2 type performance, this stage will weigh about 2.0 million pounds. The various transportation systems and their respective characteristics are shown in Figure B.5.

The sensitivity of this configuration to parametric change is relatively high. The payload for the crew/logistics mission would decrease over 60 percent with a 10 percent inert weight growth. Also, a one percent change in specific impulse would change the payload by over 20 percent. A significant design risk would therefore be incurred if development of this concept is undertaken.

FIGURE B.4

CONFIGURATION 4

NASA/USAF MISSIONS

SYSTEM BALANCE – CREW/LOGISTICS MISSION

BOOSTER – LIFTING BODY

ORBITER – LIFTING BODY (WITH INTEGRATED CREW/PAYLOAD)

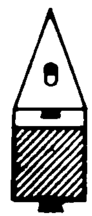
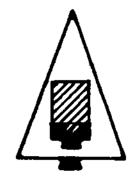
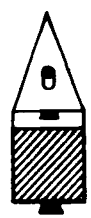
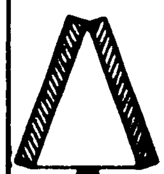
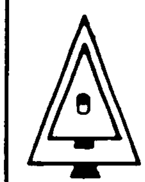
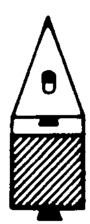
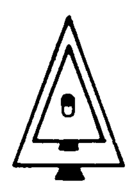
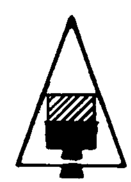
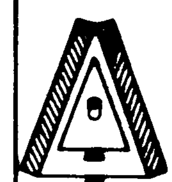
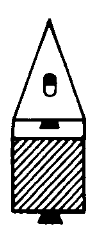
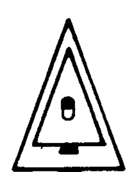
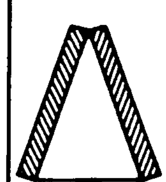
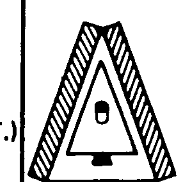
PAYLOAD (UP – DOWN) 25000 – 25000

	BOOSTER		ORBITER
ASCENT DELTA V'S	16332		14315
FRACTION OF BOOST VELOCITY	.5329		.4671
SPECIFIC IMPULSE	444.4		459.0
STAGE MASS FRACTION	.8174		.6953
STAGE GROSS WEIGHT	2.770×10^6		$.514 \times 10^6$
LIFT-OFF GROSS WEIGHT		3.327×10^6	

VEHICLE SENSITIVITIES

	BOOSTER		ORBITER
PROPELLANT WEIGHT (LBS PL/%)	1721.2		1092.4
STRUCTURAL WEIGHT (LBS PL/%)	– 814.2		–1566.8
SEA LEVEL I_S (LBS PL/SEC)	143.5		0
VACUUM I_S (LBS PL/SEC)	509.4		583.0
ON-ORBIT DELTA V (LBS PL/FPS)			– 17.6
CROSS-RANGE DELTA V (LBS PL/FPS)			
HOVER DELTA V (LBS PL/FPS)			
LOB-RETRO DELTA V (LBS PL/FPS)			
TOTAL IMPULSIVE DELTA V (LBS PL/FPS)		– 17.4	
DE-ORBIT DELTA V (LBS PL/FPS)		– 17.8	
TOTAL VEHICLE STRUCTURAL WEIGHT (LBS PL/%)		–2381.0	

FIGURE B.5
TRANSPORTATION SYSTEMS
CONCEPT 4
NASA/USAF MISSIONS

	EVOLUTIONARY	NASA MISSION A CREW/LOGISTICS	NASA MISSION B CARGO	USAF MISSION C HI ENERGY	USAF MISSION D RECONNAISSANCE
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS LIFTOFF	 .025 — .673 1.550 2.248	USE HI ENERGY DESIGN EXCESS PAYLOAD CAPABILITY	 .150 — .320 3.171 3.641	 .085 — .673 3.171 3.929	USE HI ENERGY DESIGN EXCESS PAYLOAD CAPABILITY
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS LIFTOFF	 .025 — .734 2.026 2.785	USE HI ENERGY DESIGN EXCESS PAYLOAD CAPABILITY	 .150 — 3.233 (3.140T.T) 6.523	 .085 — .734 3.233 4.052	USE HI ENERGY DESIGN EXCESS PAYLOAD CAPABILITY
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS LIFTOFF	 .025 — .532 1.930 2.487	 .025 — .532 2.770 3.327	 .150 — .429 2.770 3.349	 .085 — .532 2.770 (2.750T.T.) 6.157	USE C/L DESIGN EXCESS PAYLOAD CAPABILITY
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS LIFTOFF	 .025 — .532 1.930 2.487	 .025 — .532 2.890 3.447	 .150 — 2.890 (3.106T.T.) 6.146	 .085 — .532 2.890 (2.940T.T.) 6.447	USE C/L DESIGN EXCESS PAYLOAD CAPABILITY

A sizing curve for this concept is shown in Figure B.6.

B.1.3. Concept 5

A single-stage-to-orbit vehicle with a separate lifting body crew vehicle comprises concept 5. The payload is integrated into the crew vehicle and all the ascent propulsion is provided by the booster. When designed for the USAF cross-range mission, the booster weighs about 3.75 million pounds and the crew vehicle about 55000 pounds. A system balance for this design is shown on Figure B.7.

Three transportation systems based on this concept appear attractive. They consist of designing the single-stage-to-orbit booster for either the OOS mission, the polar orbit reconnaissance mission, or the NASA cargo mission. The stage cannot be designed for the crew/logistics mission because it would then have insufficient performance for the polar orbit mission without the use of some expendables. This violates the ground rule of all-azimuth launch for that mission.

When designing for the OOS mission, the booster weighs almost 4.0 million pounds and has excess payload capability for the crew/logistics and reconnaissance missions. For the NASA cargo mission, the crew vehicle is removed and about 300,000 pounds of tip tanks are added to obtain the desired payload. The stage, when designed for the reconnaissance mission, has excess performance capability for the crew/logistics mission. Only about 70,000 pounds of tip tanks are needed to increase the stage performance enough to allow the OOS mission to be accomplished. For the cargo mission, the crew vehicle is once again removed and about 0.5 million pounds of tip tanks are needed.

The evolutionary development program possible for this concept is to launch the crew vehicle with existing or new expendable stages. If new expendable stages are used, two identical O_2/H_2 stages of about 700,000 pounds each are required. These three transportation system alternatives for this concept are depicted in Figure B.8.

The sensitivity of the booster to parametric change is shown on Figure B.7. The single-stage-to-orbit booster is extremely sensitive to design changes, and either a 10 percent increase in inert weight or a one percent decrease in design specific impulse would completely eliminate the payload. The inert weight increase would also prevent the booster from attaining orbit. This type vehicle also has a high sensitivity to ideal velocity changes.

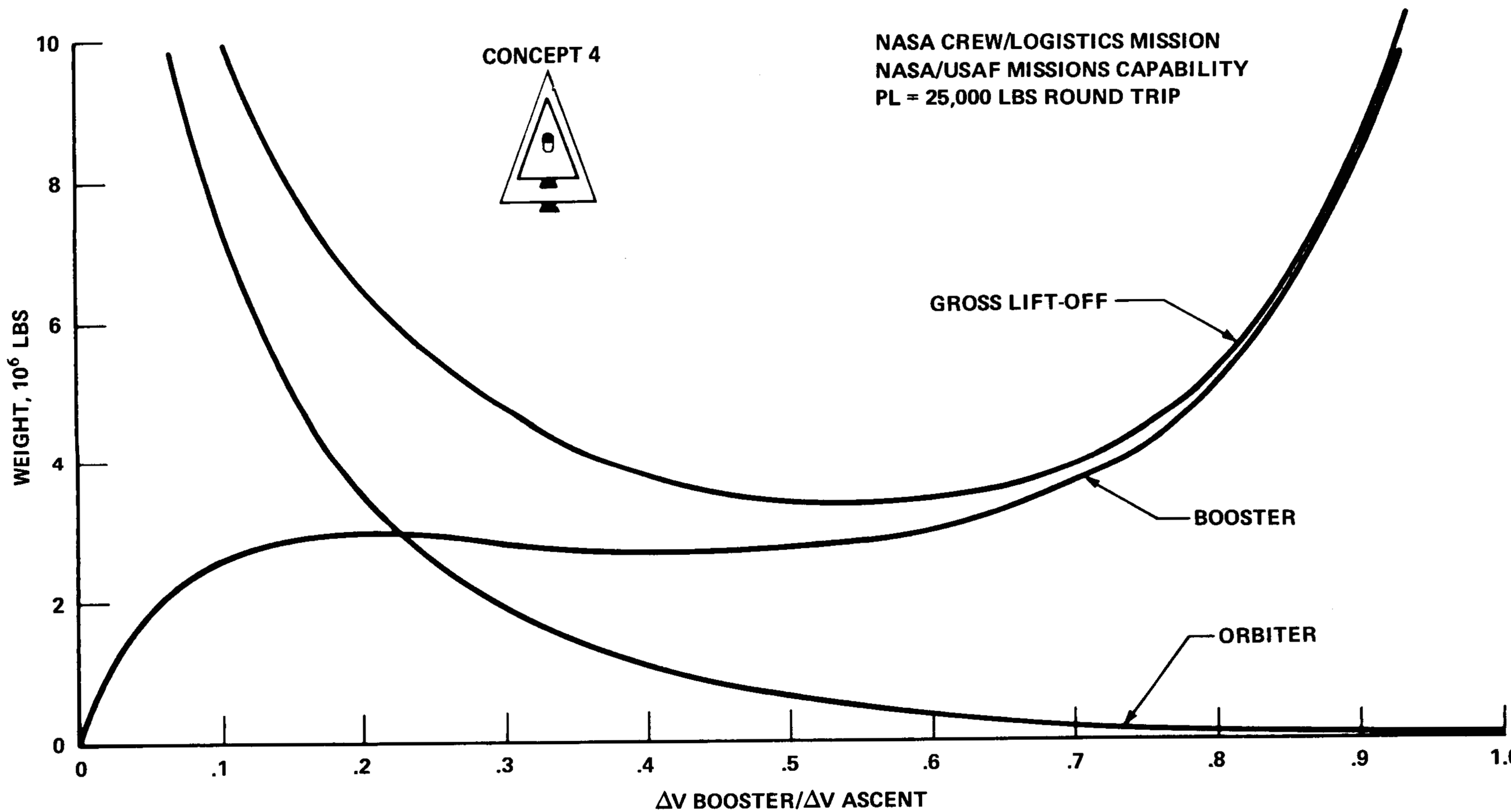


FIGURE B.6 - VEHICLE SIZING CURVE

FIGURE B.7

CONFIGURATION 5

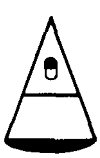
NASA/USAF MISSIONS

SYSTEM BALANCE – RECONNAISSANCE

BOOSTER – SINGLE-STAGE-TO-ORBIT BALLISTIC

ORBITER – (WITH SEPARATE LIFTING BODY CREW VEHICLE)

PAYLOAD (UP – DOWN) 10000 – 10000

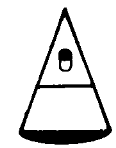
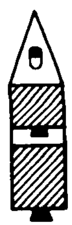
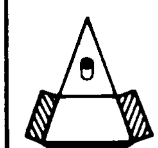
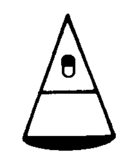


	BOOSTER	CREW VEHICLE
ASCENT DELTA V'S	31427	
FRACTION OF BOOST VELOCITY	1.0000	0
SPECIFIC IMPULSE	451.3	459.0
STAGE MASS FRACTION	.9107	.0830
STAGE GROSS WEIGHT	3.758×10^6	$.055 \times 10^6$
LIFT-OFF GROSS WEIGHT	3.823×10^6	

VEHICLE SENSITIVITIES

	BOOSTER
PROPELLANT WEIGHT (LBS PL/%)	4502.9
STRUCTURAL WEIGHT (LBS PL/%)	–3863.0
SEA LEVEL I_S (LBS PL/SEC)	90.2
VACUUM I_S (LBS PL/SEC)	2368.4
ON-ORBIT DELTA V (LBS PL/FPS)	
CROSS-RANGE DELTA V (LBS PL/FPS)	
HOVER DELTA V (LBS PL/FPS)	– 34.9
LOB-RETRO DELTA V (LBS PL/FPS)	
TOTAL IMPULSIVE DELTA V (LBS PL/FPS)	– 34.1
DE-ORBIT DELTA V (LBS PL/FPS)	– 29.4
TOTAL VEHICLE STRUCTURAL WEIGHT (LBS PL/%)	–3863.0

FIGURE B.8
TRANSPORTATION SYSTEMS
CONCEPT 5
NASA/USAF MISSIONS

	EVOLUTIONARY	NASA MISSION A CREW/LOGISTICS	NASA MISSION B CARGO	USAF MISSION C HI ENERGY	USAF MISSION D RECONNAISSANCE
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS LIFT-OFF	 .025 .055 .690 .690 1.460	USE HI ENERGY DESIGN EXCESS PAYLOAD CAPABILITY	 .150 — 3.818 (.319T.T.) 4.287	 .085 .055 — 3.818 3.958	USE HI ENERGY DESIGN EXCESS PAYLOAD CAPABILITY
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS-LIFTOFF	 .025 .055 .690 .690 1.460	USE CARGO DESIGN EXCESS PAYLOAD CAPABILITY	 .150 — — 5.144 5.294	USE CARGO DESIGN EXCESS PAYLOAD CAPABILITY	USE CARGO DESIGN EXCESS PAYLOAD CAPABILITY
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS-LIFT-OFF	 .025 .055 .690 .690 1.460	USE RECON. DESIGN EXCESS PAYLOAD CAPABILITY	 .150 — 3.758 (.506T.T.) 4.414	 .085 .055 3.758 (.073T.T.) 3.471	 .010 .055 — 3.758 3.823

B.1.4 Concept 6

This shuttle alternative is basically the same as concept 5 with a separate ballistic crew vehicle replacing the lifting body crew vehicle. The stage, designed for the cross range mission, weighs just under 5.0 million pounds. The ballistic crew vehicle, which must attain the 1500 nm cross range propulsively, weighs about 76000 pounds. The system balance of this concept is shown in Figure B.9.

Only two transportation system alternatives appear reasonable under this concept. The single-stage-to-orbit booster can be designed for the reconnaissance mission or for the cargo mission. It cannot be designed for crew/logistics or the OOS mission because expendables or some type of stage addition would then be necessary for the reconnaissance mission. This has already been ground ruled as unacceptable.

When designed for the reconnaissance mission, the vehicle can be used as is for both the crew/logistics and OOS missions with excess performance capability. About 200,000 pounds of tip tanks must be added, after removal of the crew vehicle, to attain the desired payload for the cargo mission. The booster, when designed for the cargo mission, will weigh over 5.1 million pounds. It then has the lifting capacity to perform all the other missions.

The only evolutionary development program possible with this concept is as with concept 5 - to use an expendable booster to lift the crew vehicle. Two identical new O_2/H_2 stages would weigh just under 1.0 million pounds each. The ballistic booster must be developed in an all-up program. The transportation systems based on this concept are shown in Figure B.10.

The sensitivity of the booster to parametric change is very high. As was the case with concept 5, a 10 percent inert weight increase or one percent decrease in specific impulse would completely eliminate the payload and prevent the booster from even reaching orbit. Thus, single-stage-to-orbit boosters present very simplified operations and handling, but are significant design risks. The stage sensitivities are shown in Figure B.9.

B.1.5 Concept 8

This shuttle alternative employs a two stage ballistic booster with a separate ballistic crew vehicle. To minimize the number of new developments, the two booster stages are made

FIGURE B.9

CONFIGURATION 6

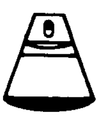
NASA/USAF MISSIONS

SYSTEM BALANCE – RECONNAISSANCE

BOOSTER – SINGLE-STAGE-TO-ORBIT BALLISTIC

ORBITER – (WITH SEPARATE BALLISTIC CREW VEHICLE)

PAYLOAD (UP – DOWN) 10000 – 10000

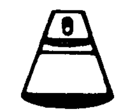


	BOOSTER	CREW VEHICLE
ASCENT DELTA V'S	31427	
FRACTION OF BOOST VELOCITY	1.0000	0
SPECIFIC IMPULSE	451.3	459.0
STAGE MASS FRACTION	.9115	.8335
STAGE GROSS WEIGHT	4.852×10^6	$.076 \times 10^6$
LIFT-OFF GROSS WEIGHT	4.939×10^6	

VEHICLE SENSITIVITIES

	BOOSTER
PROPELLANT WEIGHT (LBS PL/%)	5749.1
STRUCTURAL WEIGHT (LBS PL/%)	–4884.1
SEA LEVEL I_S (LBS PL/SEC)	114.0
VACUUM I_S (LBS PL/SEC)	3023.7
ON-ORBIT DELTA V (LBS PL/FPS)	
CROSS-RANGE DELTA V (LBS PL/FPS)	
HOVER DELTA V (LBS PL/FPS)	– 44.1
LOB-RETRO DELTA V (LBS PL/FPS)	
TOTAL IMPULSIVE DELTA V (LBS PL/FPS)	– 43.6
DE-ORBIT DELTA V (LBS PL/FPS)	– 37.2
TOTAL VEHICLE STRUCTURAL WEIGHT (LBS PL/%)	–4884.1

FIGURE B.10
TRANSPORTATION SYSTEMS
CONCEPT 6
NASA/USAF MISSION

	EVOLUTIONARY	NASA MISSION A CREW/LOGISTICS	NASA MISSION B CARGO	USAF MISSION C HI ENERGY	USAF MISSION D RECONNAISSANCE
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS LIFTOFF	 .025 .076 .935 .935 1.971	USE RECON. DESIGN EXCESS PAYLOAD CAPABILITY	 .150 — 4.852 (.200T.T.) 5.202	USE RECON. DESIGN EXCESS PAYLOAD CAPABILITY	 .010 .076 — 4.852 4.938
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS LIFTOFF	 .025 .076 .935 .935 1.971	USE CARGO DESIGN EXCESS PAYLOAD CAPABILITY	 .150 — — 5.144 5.294	USE CARGO DESIGN EXCESS PAYLOAD CAPABILITY	USE CARGO DESIGN EXCESS PAYLOAD CAPABILITY

equal in size and are thus considered as one new development. There will, of course, be differences in the stages but these will be of a second order effect. A system balance for this concept, designed for the cross range mission, is shown in Figure B.11. The two booster stages weigh slightly over 800,000 pounds each, with the crew vehicle weighing 76000 pounds. The gross liftoff weight is about 1.7 million pounds. A sizing curve for this concept is presented in Figure B.12 showing that almost no gross liftoff weight penalty is paid in designing for equal size stages rather than for minimum gross weight. This is a significant factor in making this concept attractive.

Two transportation systems appear reasonable under this concept. The two stage booster can be designed to lift the crew-vehicle and payload for the polar orbit reconnaissance mission, or it can be designed to lift the necessary payload for the cargo mission. If designed for polar orbit, it can perform the crew/logistics and OOS missions without any configuration changes and with excess payload. About 600,000 pound tip tanks are then added to the booster for the cargo mission. If the stage is designed for the cargo mission, it has excess lifting capacity for all the other required missions and forms a very simple transportation system. Each stage would weigh about 1.25 million pounds.

As with concept 6, the only attractive evolutionary program which includes the crew/logistics system would be to launch the crew vehicle on existing or new low cost expendable stages. The stages used would be similar to those described under concept 6. Figure B.13 shows the transportation systems for this concept.

This concept has a lower sensitivity to parametric change than the other concepts discussed, however, it still presents a significant design risk. A 10 percent inert weight growth will eliminate the payload but the vehicle could still reach orbit for the cross range mission. A one percent reduction in specific impulse will result in a 45 percent reduction in payload. All the significant vehicle sensitivities are shown in Figure B.11.

B.1.6 Concept 9

This shuttle concept is identical to the previous one with the replacement of the ballistic crew vehicle by a lifting body crew vehicle. This concept, however, cannot be designed for the reconnaissance mission because it would not have the necessary performance for the crew/logistics mission. This would necessitate the addition of expendables and is not acceptable. The vehicle is therefore designed for the crew/logistics mission and represents the minimum gross weight it

FIGURE B.11

CONFIGURATION 8

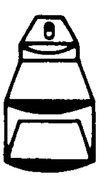
NASA/USAF MISSIONS

SYSTEM BALANCE – RECONNAISSANCE

BOOSTER – BALLISTIC

ORBITER – BALLISTIC (WITH SEPARATE BALLISTIC CREW VEHICLE)

PAYLOAD (UP – DOWN) 86500 – 0



	BOOSTER		ORBITER
ASCENT DELTA V'S	7215		24212
FRACTION OF BOOST VELOCITY	.2296		.7704
SPECIFIC IMPULSE	427.3		459.0
STAGE MASS FRACTION	.9034		.9034
STAGE GROSS WEIGHT	$.811 \times 10^6$		$.811 \times 10^6$
LIFT-OFF GROSS WEIGHT		1.709×10^6	

VEHICLE SENSITIVITIES

	BOOSTER		ORBITER
PROPELLANT WEIGHT (LBS PL/%)	736.2		1137.0
STRUCTURAL WEIGHT (LBS PL/%)	– 114.1		– 895.0
SEA LEVEL I_S (LBS PL/SEC)	101.7		21.3
VACUUM I_S (LBS PL/SEC)	126.2		728.1
ON-ORBIT DELTA V (LBS PL/FPS)			
CROSS-RANGE DELTA V (LBS PL/FPS)			
HOVER DELTA V (LBS PL/FPS)	– 1.6		– 8.3
LOB-RETRO DELTA V (LBS PL/FPS)	– 1.3		
TOTAL IMPULSIVE DELTA V (LBS PL/FPS)		– 13.5	
DE-ORBIT DELTA V (LBS PL/FPS)		– 7.0	
TOTAL VEHICLE STRUCTURAL WEIGHT (LBS PL/%)		–1009.3	

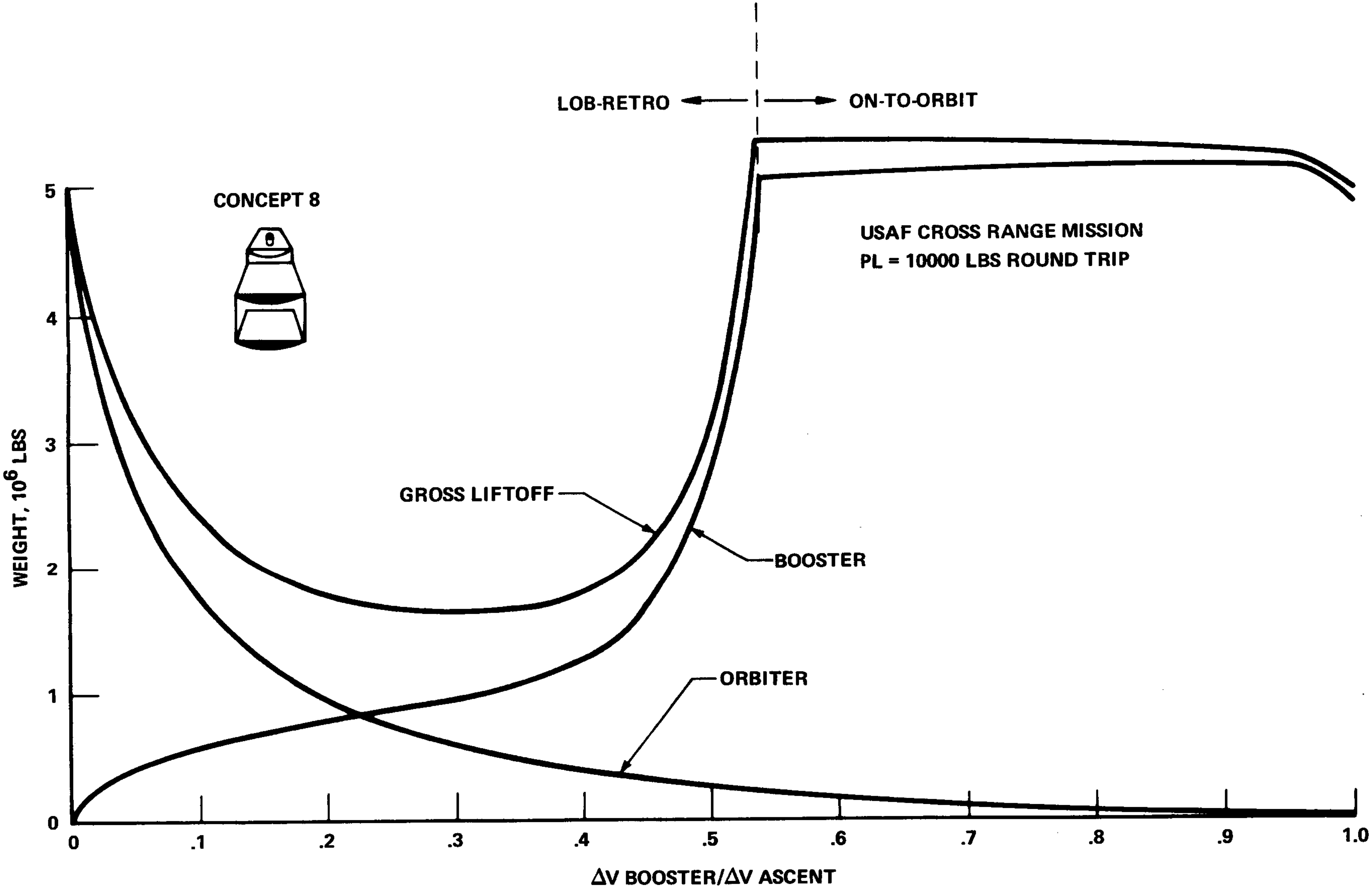
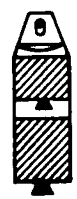
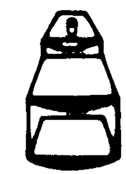


FIGURE B.12 - VEHICLE SIZING CURVE

FIGURE B.13
TRANSPORTATION SYSTEMS
CONCEPT 8
NASA/USAF MISSIONS

	EVOLUTIONARY	NASA MISSION A CREW/LOGISTICS	NASA MISSION B CARGO	USAF MISSION C HI ENERGY	USAF MISSION D RECONNAISSANCE
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS LIFTOFF	 .025 .076 .935 .935 1.971	USE RECON. DESIGN EXCESS PAYLOAD CAPABILITY	 .150 — .812 .812 (.612T.T.) 2.186	USE RECON. DESIGN EXCESS PAYLOAD CAPABILITY	 .010 .076 .812 .812 1.710
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS LIFTOFF	 .025 .076 .935 .935 1.971	USE CARGO DESIGN EXCESS PAYLOAD CAPABILITY	 .150 — 1.257 1.257 2.664	USE CARGO DESIGN EXCESS PAYLOAD CAPABILITY	USE CARGO DESIGN EXCESS PAYLOAD CAPABILITY

can achieve. A system balance for this design is shown in Figure B.14. It can be seen that each stage would weigh just under 700,000 pounds. The sizing curve for this concept is shown in Figure B.15 and indicates the small penalty paid, in terms of gross liftoff weight, to make these stages equal size.

Three transportation system alternatives appear reasonable for this concept. They consist of designing the booster for either the crew/logistics, OOS, or cargo mission. The simplest system would be to design for cargo. The stages would then be the same as in concept 8 and could perform all the other missions. If it is designed for the OOS mission, the cargo mission is the only one it could not perform. Therefore, about 325,000 pound tip tanks must be added. If designed for crew/logistics, tip tanks are added for both the OOS and cargo missions. The tip tanks would weigh about 450,000 pounds for the OOS mission and about 800,000 pounds for the cargo mission.

An evolutionary development program would be as with concept 5; the crew vehicle would be launched with existing or new expendable stages. The booster stages could be tested by launching a dummy payload prior to orbiter testing. These transportation systems are shown in Figure B.16.

The sensitivity of the stage to parametric design changes is the lowest of the concepts considered. About 35 percent of the crew/logistics payload is lost when the inert weight grows 10 percent. Only about 15 percent of the payload is lost if the specific impulse is one percent less than design. The various sensitivities are shown in Figure B.14.

FIGURE B.14

CONFIGURATION 9

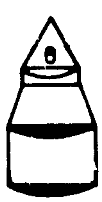
NASA/USAF MISSIONS

SYSTEM BALANCE – CREW/LOGISTICS MISSION

BOOSTER – BALLISTIC

ORBITER – BALLISTIC (WITH SEPARATE LIFTING BODY CREW VEHICLE)

PAYLOAD (UP – DOWN) 80000 – 0



	BOOSTER		ORBITER
ASCENT DELTA V'S	7144		23503
FRACTION OF BOOST VELOCITY	.2331		.7669
SPECIFIC IMPULSE	427.0		459.0
STAGE MASS FRACTION	.9019		.9019
STAGE GROSS WEIGHT	$.678 \times 10^6$		$.678 \times 10^6$
LIFT-OFF GROSS WEIGHT		1.436×10^6	

VEHICLE SENSITIVITIES

	BOOSTER		ORBITER
PROPELLANT WEIGHT (LBS PL/%)	652.9		1006.6
STRUCTURAL WEIGHT (LBS PL/%)	– 100.9		– 759.8
SEA LEVEL I_S (LBS PL/SEC)	90.8		18.1
VACUUM I_S (LBS PL/SEC)	110.8		630.9
ON-ORBIT DELTA V (LBS PL/FPS)			
CROSS-RANGE DELTA V (LBS PL/FPS)			
HOVER DELTA V (LBS PL/FPS)	– 1.4		– 7.0
LOB-RETRO DELTA V (LBS PL/FPS)	– 1.2		
TOTAL IMPULSIVE DELTA V (LBS PL/FPS)		– 12.0	
DE-ORBIT DELTA V (LBS PL/FPS)		– 5.9	
TOTAL VEHICLE STRUCTURAL WEIGHT (LBS PL/%)		– 860.3	

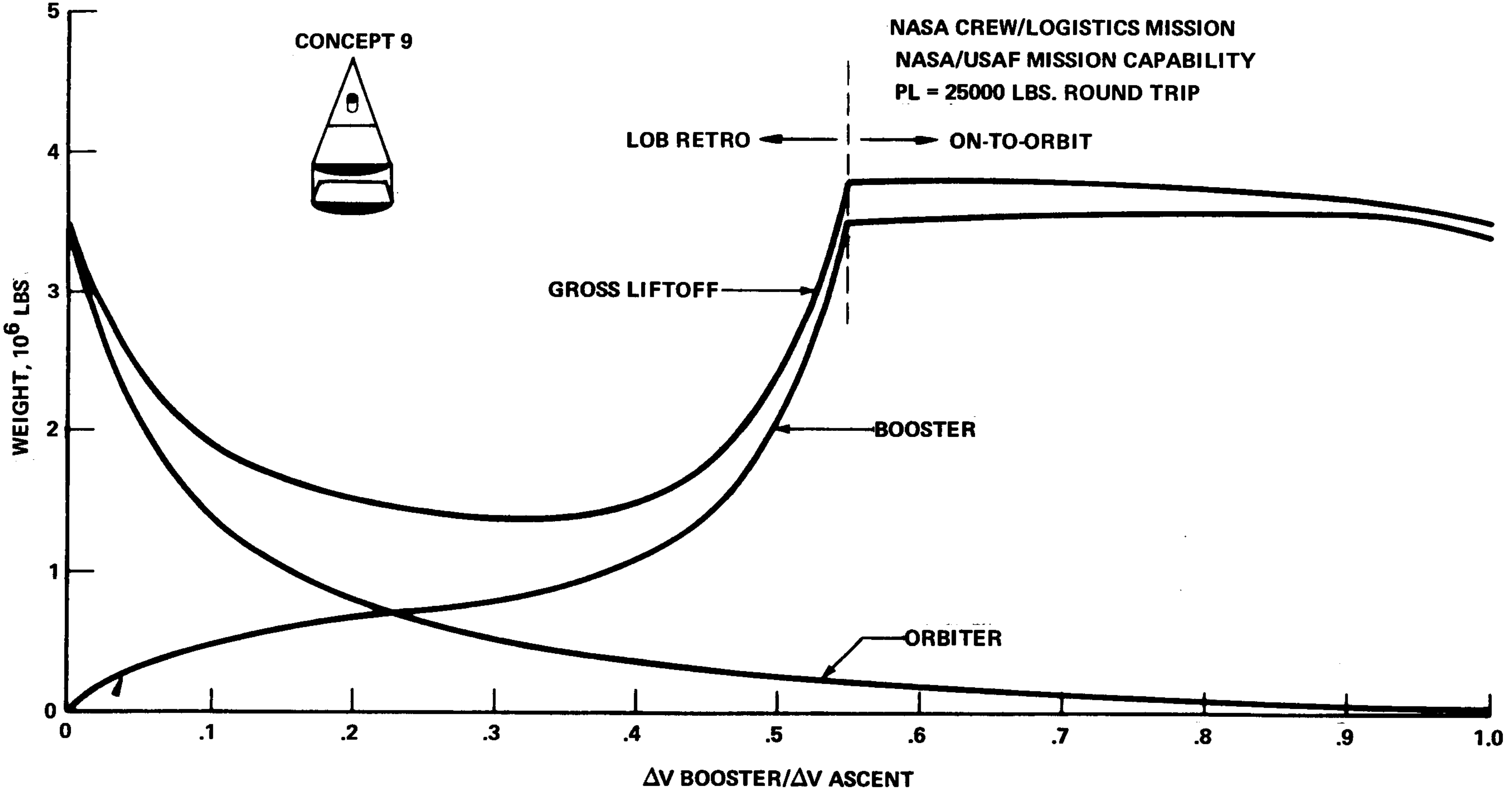
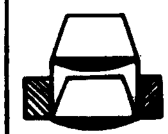
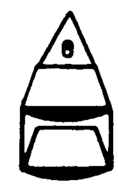
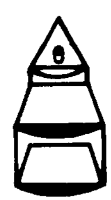
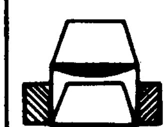
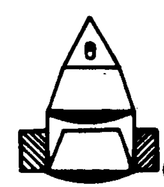


FIGURE B.15 - VEHICLE SIZING CURVE

FIGURE B.16
TRANSPORTATION SYSTEMS
CONCEPT 9
NASA/USAF MISSIONS

	EVOLUTIONARY	NASA MISSION A CREW/LOGISTICS	NASA MISSION B CARGO	USAF MISSION C HI ENERGY	USAF MISSION D RECONNAISSANCE
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS LIFTOFF	 .025 .055 .750 .750 1.580	USE HI ENERGY DESIGN EXCESS PAYLOAD CAPABILITY	 .150 — .961 .961 (.325T.T.) 2.397	 .085 .055 .961 .961 2.062	USE HI ENERGY DESIGN EXCESS PAYLOAD CAPABILITY
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS LIFTOFF	 .025 .055 .750 .750 1.580	USE CARGO DESIGN EXCESS PAYLOAD CAPABILITY	 .150 — 1.257 1.257 2.664	USE CARGO DESIGN EXCESS PAYLOAD CAPABILITY	USE CARGO DESIGN EXCESS PAYLOAD CAPABILITY
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS LIFTOFF	 .025 .055 .750 .750 1.580	 .025 .055 .677 .677 1.434	 .150 — .677 .677 (.788T.T.) 2.292	 .085 .055 .677 .677 (.447T.T.) 1.941	USE C/L DESIGN EXCESS PAYLOAD CAPABILITY

B.2 NASA Only Transportation Systems Summary

B.2.1 Concept 1

This single-stage-to-orbit vehicle has the crew and payload integrated into it. The vehicle has a gross weight of about 3.5 million pounds when designed for crew logistics. For the cargo mission, about 750,000 pound tip tanks are added to achieve the necessary performance. The stage could not be designed for the cargo mission because the stage gross weight exceeded that of the Saturn V and was therefore too heavy. This concept does not lend itself to an evolutionary program, but is still considered due to its operational simplicity.

This stage is extremely sensitive to inert weight growth, such that a 10 percent change will eliminate the payload and prevent the vehicle from attaining orbit. In addition, a one percent change in delivered specific impulse will result in a 35 percent change in payload. The vehicle system balance and sensitivities are shown in Figure B.17, while the transportation system is shown in Figure B.18.

B.2.2 Concept 3

The consideration of NASA missions only for this concept reduced its size by a factor of over 3. This is due primarily to the fact that the orbiter need only attain 200 nm rather than 1500 nm cross range. With a ballistic vehicle, about 100 nm cross range can be attained aerodynamically, with the remainder requiring propulsion. The gross liftoff weight for this concept is about 1.0 million pounds with the booster weighing about 600,000 and the orbiter about 400,000 pounds. The velocity split resulting in the minimum gross liftoff weight dropped from about 41 percent for the booster to about 31 percent. The system balance is shown in Figure B.19 and the sizing curve in Figure B.20.

Three transportation systems appear reasonable with this concept. One is to design for the cargo mission. The vehicle then has excess payload capability for the crew/logistics mission. The gross liftoff weight for this vehicle is under 3.0 million pounds. With the vehicle designed for crew/logistics, the cargo mission is achieved by using either an expendable booster with the orbiter, or using tip tanks with the booster only. In all cases, the evolutionary development program would have the orbiter launched with a new low cost O_2/H_2 expendable booster. These transportation systems are shown in Figure B.21.

FIGURE B.17

CONFIGURATION 1

NASA MISSIONS

SYSTEM BALANCE – CREW/LOGISTICS MISSION

BOOSTER – SINGLE-STAGE-TO-ORBIT BALLISTIC

ORBITER – (WITH INTEGRATED CREW/PAYLOAD)

PAYLOAD (UP – DOWN) 25000 – 25000

	BOOSTER
ASCENT DELTA V'S	30647
FRACTION OF BOOST VELOCITY	1.0000
SPECIFIC IMPULSE	451.1
STAGE MASS FRACTION	.9106
STAGE GROSS WEIGHT	3.539×10^6
LIFT-OFF GROSS WEIGHT	3.564×10^6

VEHICLE SENSITIVITIES

	BOOSTER
PROPELLANT WEIGHT (LBS PL/%)	3576.4
STRUCTURAL WEIGHT (LBS PL/%)	–3146.4
SEA LEVEL I_S (LBS PL/SEC)	83.4
VACUUM I_S (LBS PL/SEC)	1895.9
ON-ORBIT DELTA V (LBS PL/FPS)	– 26.9
CROSS-RANGE DELTA V (LBS PL/FPS)	– 26.9
HOVER DELTA V (LBS PL/FPS)	– 32.2
LOB-RETRO DELTA V (LBS PL/FPS)	
TOTAL IMPULSIVE DELTA V (LBS PL/FPS)	– 27.0
DE-ORBIT DELTA V (LBS PL/FPS)	– 27.2
TOTAL VEHICLE STRUCTURAL WEIGHT (LBS PL/%)	–3146.4

FIGURE B.18
TRANSPORTATION SYSTEMS
CONCEPT 1
NASA MISSIONS

	EVOLUTIONARY	NASA MISSION A CREW/LOGISTICS		NASA MISSION B CARGO	
PAYLOAD	NONE		.025		.650
CREW VEHICLE			—		—
ORBITER			—		3.539
BOOSTER			3.539		(.754T.T.)
GROSS LIFTOFF			3.564		4.443

FIGURE B.19

CONFIGURATION 3

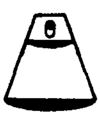
NASA MISSIONS

SYSTEM BALANCE – CREW/LOGISTICS MISSION

BOOSTER – BALLISTIC

ORBITER – BALLISTIC (WITH INTEGRATED CREW/PAYLOAD)

PAYLOAD (UP – DOWN) 25000 – 25000



	BOOSTER		ORBITER
ASCENT DELTA V'S	9559		21088
FRACTION OF BOOST VELOCITY	.3119		.6881
SPECIFIC IMPULSE	434.6		459.0
STAGE MASS FRACTION	.9007		.8951
STAGE GROSS WEIGHT	$.602 \times 10^6$		$.386 \times 10^6$
LIFT-OFF GROSS WEIGHT		1.013×10^6	

VEHICLE SENSITIVITIES

	BOOSTER		ORBITER
PROPELLANT WEIGHT (LBS PL/%)	401.2		516.5
STRUCTURAL WEIGHT (LBS PL/%)	–103.1		–385.9
SEA LEVEL I_S (LBS PL/SEC)	45.8		19.9
VACUUM I_S (LBS PL/SEC)	90.0		316.0
ON-ORBIT DELTA V (LBS PL/FPS)			– 6.5
CROSS-RANGE DELTA V (LBS PL/FPS)			– 6.4
HOVER DELTA V (LBS PL/FPS)	– 1.2		– 7.6
LOB-RETRO DELTA V (LBS PL/FPS)	– 1.0		
TOTAL IMPULSIVE DELTA V (LBS PL/FPS)		– 6.3	
DE-ORBIT DELTA V (LBS PL/FPS)		– 6.4	
TOTAL VEHICLE STRUCTURAL WEIGHT (LBS PL/%)		–488.9	

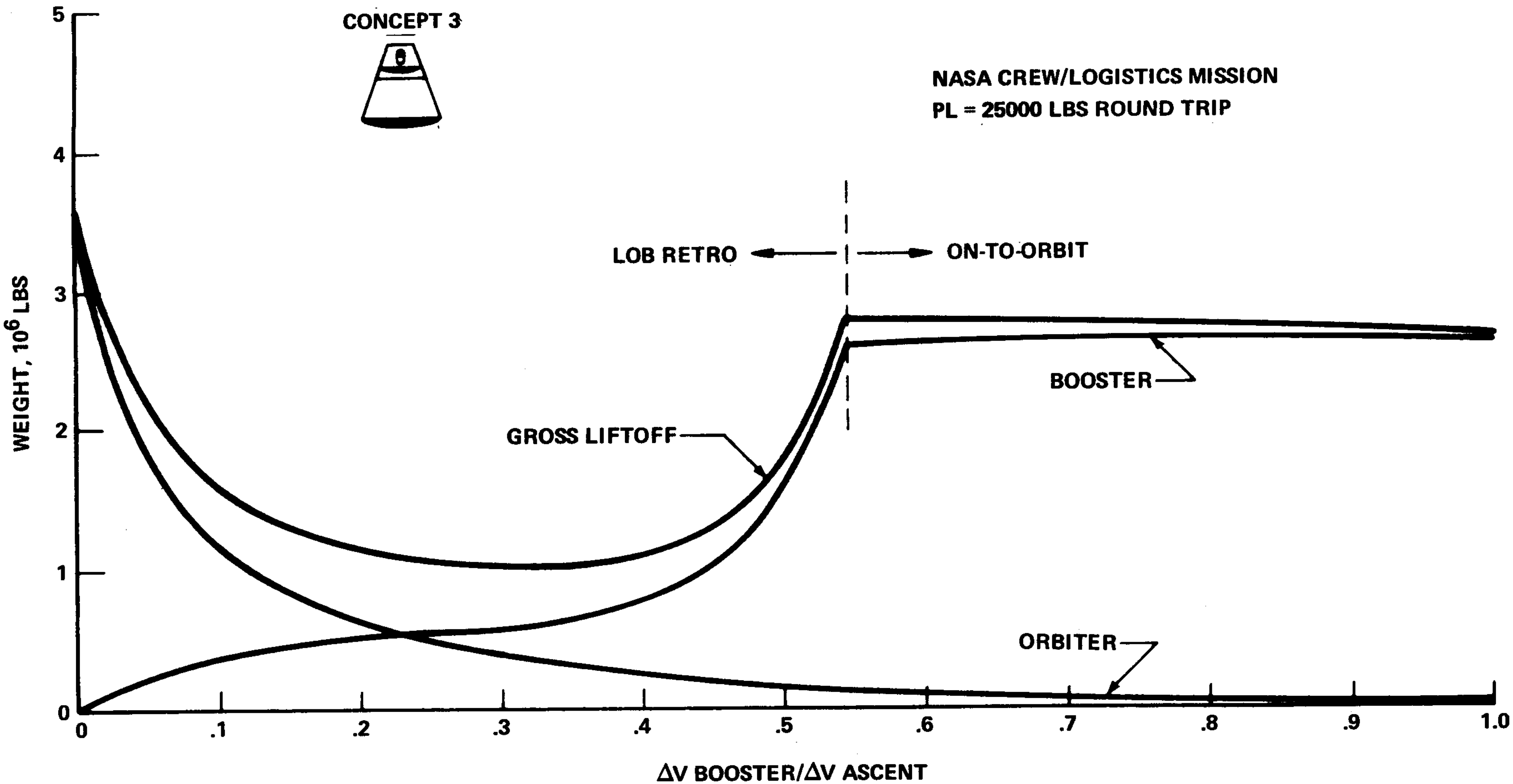
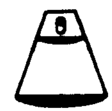


FIGURE B.20 - VEHICLE SIZING CURVE

FIGURE B.21
TRANSPORTATION SYSTEMS
CONCEPT 3
NASA MISSIONS

	EVOLUTIONARY		NASA MISSION A CREW/LOGISTICS		NASA MISSION B CARGO	
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS LIFTOFF		.025 — .385 .558 .968		.025 — .385 .602 1.012		.150 — .385 2.175 2.710
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS LIFTOFF		.025 — 1.052 .390 1.467	USE CARGO DESIGN EXCESS PAYLOAD CAPABILITY			.150 — 1.052 1.664 2.866
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS LIFTOFF		.025 — .385 .558 .968		.025 — .385 .615 1.025		.150 — .385 (1.812T.T.) 2.347

This concept is relatively insensitive to parametric changes. A 10 percent inert weight growth will reduce the payload by less than 25 percent. Additionally, a one percent change in delivered specific impulse will change the payload by less than 9 percent. Of all the concepts analyzed, this is one of the least sensitive to parametric changes. The sensitivities of this vehicle are shown in Figure B.19.

B.2.3 Concept 4

The major difference in this concept design when USAF missions are excluded is that a higher mass fraction can be obtained for the orbiter. Lifting bodies attain their cross-range aerodynamically, and the reduction of this requirement to 200 nm significantly reduces the thermal protection system (TPS) requirements. This results in a lighter stage and hence a higher mass fraction. The net effect is a gross liftoff weight reduction of about 10 percent to just over 3.0 million pounds.

The transportation systems that appear attractive have the basic vehicle designed for crew/logistics. The cargo mission is then attained in one of three ways - adding tip tanks to the booster stage, using an expendable first stage with the orbiter, or using an expendable orbiter with the booster. The most reasonable method appears to be the expendable orbiter with the shuttle booster. In all cases, the orbiter is developed first in an evolutionary program by launching it on top of a low cost expendable booster.

This design is fairly sensitive to parametric changes. The payload will be reduced over 85 percent by an inert weight growth of 10 percent. The payload will be reduced over 20 percent if the design specific impulse is one percent low. The system balance and sensitivities are shown in Figure B.22, a sizing curve in Figure B.23, and the transportation systems in Figure B.24.

B.2.4 Concept 5

This concept was reduced in weight by about 13 percent when considering only NASA missions. The lifting body crew vehicle had almost no weight change, but the crew/logistics design mission was less energetic than the USAF polar orbit mission resulting in the smaller weight. The system balance for this vehicle is shown in Figure B.25.

FIGURE B.22

CONFIGURATION 4

NASA MISSIONS

SYSTEM BALANCE – CREW/LOGISTICS MISSION

BOOSTER – LIFTING BODY

ORBITER – LIFTING BODY (WITH INTEGRATED CREW/PAYLOAD)

PAYLOAD (UP – DOWN) 25000 – 25000

	BOOSTER		ORBITER
ASCENT DELTA V'S	15379		15268
FRACTION OF BOOST VELOCITY	.5018		.4982
SPECIFIC IMPULSE	443.6		459.0
STAGE MASS FRACTION	.8117		.7180
STAGE GROSS WEIGHT	2.474×10^6		$.547 \times 10^6$
LIFT-OFF GROSS WEIGHT		3.046×10^6	

VEHICLE SENSITIVITIES

	BOOSTER		ORBITER
PROPELLANT WEIGHT (LBS PL/%)	1566.6		1055.8
STRUCTURAL WEIGHT (LBS PL/%)	– 699.9		–1491.3
SEA LEVEL I_S (LBS PL/SEC)	134.8		0
VACUUM I_S (LBS PL/SEC)	445.0		583.5
ON-ORBIT DELTA V (LBS PL/FPS)			– 16.6
CROSS-RANGE DELTA V (LBS PL/FPS)			
HOVER DELTA V (LBS PL/FPS)			
LOB-RETRO DELTA V (LBS PL/FPS)			
TOTAL IMPULSIVE DELTA V (LBS PL/FPS)		– 16.4	
DE-ORBIT DELTA V (LBS PL/FPS)		– 16.7	
TOTAL VEHICLE STRUCTURAL WEIGHT (LBS PL/%)		–2190.7	

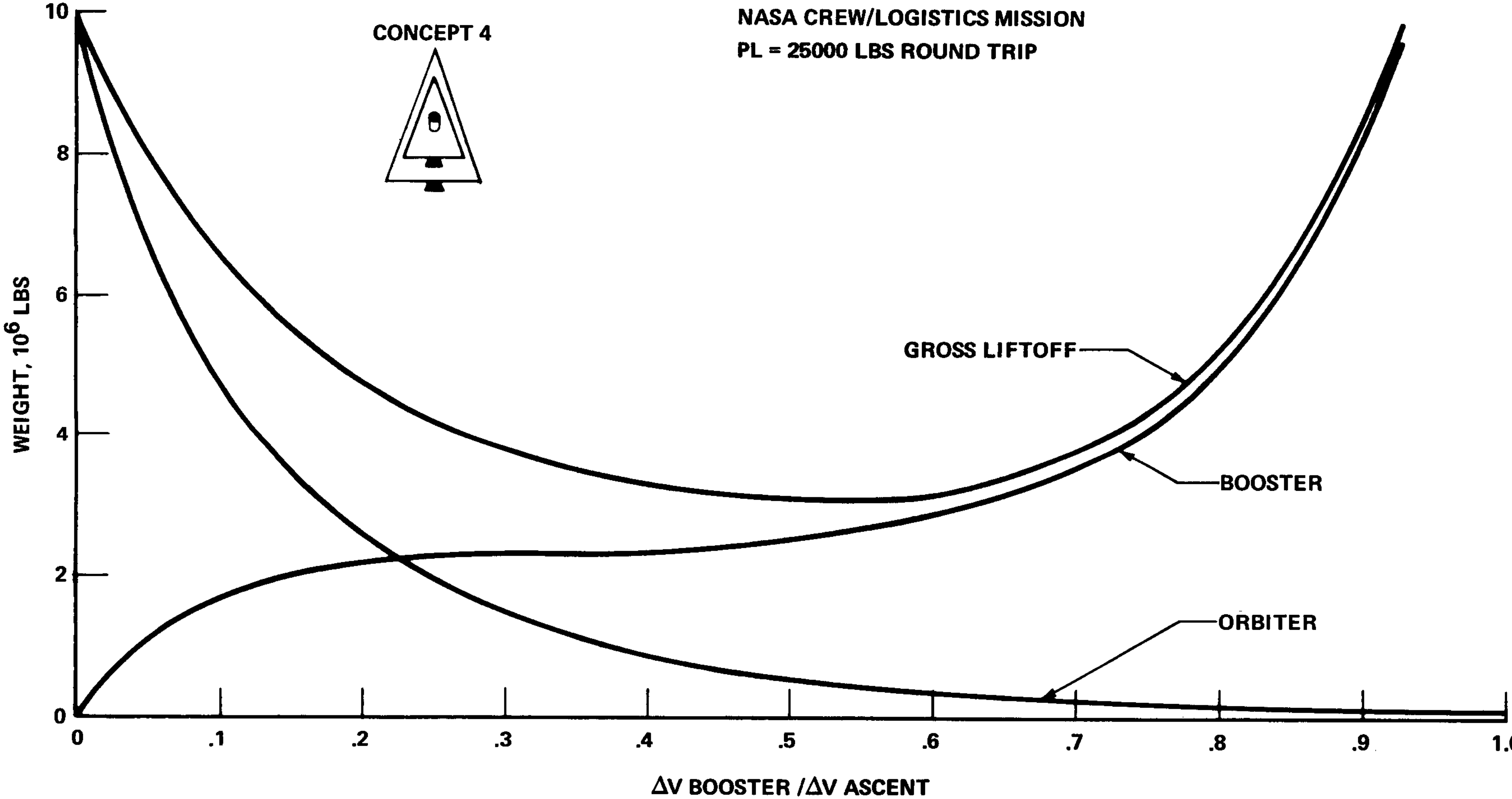


FIGURE B.23 - VEHICLE SIZING CURVE

FIGURE B.24
TRANSPORTATION SYSTEMS
CONCEPT 4
NASA MISSIONS

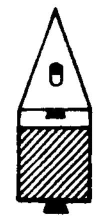
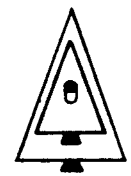
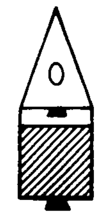
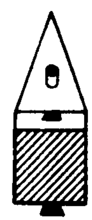
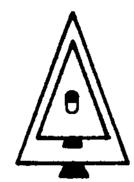
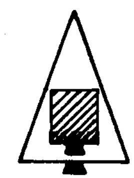
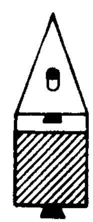
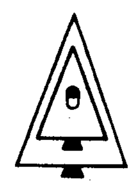
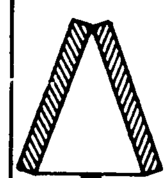
	EVOLUTIONARY	NASA MISSION A CREW/LOGISTICS	NASA MISSION B CARGO
			
PAYLOAD	.025	.025	.150
CREW VEHICLE	—	—	—
ORBITER	.547	.547	.547
BOOSTER	1.745	2.474	3.610
GROSS LIFTOFF	2.317	3.046	4.307
			
PAYLOAD	.025	.025	.150
CREW VEHICLE	—	—	—
ORBITER	.547	.547	.530
BOOSTER	1.745	2.474	2.474
GROSS LIFTOFF	2.317	3.046	3.154
			
PAYLOAD	.025	.025	.150
CREW VEHICLE	—	—	—
ORBITER	.576	.576	2.545
BOOSTER	1.751	2.545	(2.830T.T.)
GROSS LIFTOFF	2.352	3.146	5.525

FIGURE B.25

CONFIGURATION 5

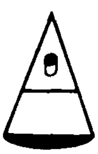
NASA MISSIONS

SYSTEM BALANCE – CREW/LOGISTICS MISSION

BOOSTER – SINGLE-STAGE-TO-ORBIT BALLISTIC

ORBITER – (WITH SEPARATE LIFTING BODY CREW VEHICLE)

PAYLOAD (UP – DOWN) 25000 – 25000



	BOOSTER	CREW VEHICLE
ASCENT DELTA V'S	30647	
FRACTION OF BOOST VELOCITY	1.0000	0
SPECIFIC IMPULSE	451.1	459.0
STAGE MASS FRACTION	.9104	.1214
STAGE GROSS WEIGHT	3.367×10^6	$.055 \times 10^6$
LIFT-OFF GROSS WEIGHT	3.447×10^6	

VEHICLE SENSITIVITIES

	BOOSTER
PROPELLANT WEIGHT (LBS PL/%)	4230.5
STRUCTURAL WEIGHT (LBS PL/%)	–3434.0
SEA LEVEL I_S (LBS PL/SEC)	80.7
VACUUM I_S (LBS PL/SEC)	2183.9
ON-ORBIT DELTA V (LBS PL/FPS)	
CROSS-RANGE DELTA V (LBS PL/FPS)	
HOVER DELTA V (LBS PL/FPS)	– 31.2
LOB-RETRO DELTA V (LBS PL/FPS)	
TOTAL IMPULSIVE DELTA V (LBS PL/FPS)	– 32.3
DE-ORBIT DELTA V (LBS PL/FPS)	– 26.3
TOTAL VEHICLE STRUCTURAL WEIGHT (LBS PL/%)	–3434.0

Two transportation systems seem most reasonable with this concept. In both cases, the stage is designed for the crew/logistics mission and the cargo mission is accomplished by either using tip tanks or an expendable upper stage. The stage designed for the cargo mission seemed impractical when considering just NASA missions. The stage would be greatly over-designed for the crew/logistics mission. The crew vehicle could be developed in an evolutionary program using two identical O_2/H_2 expendable stages as the launch vehicle. One of these stages could be used as the upper stage for cargo and a payload of about 200,000 pounds would result. These transportation systems are shown in Figure B.26.

This vehicle is still very sensitive to parametric changes with the vehicle unable to reach orbit if a 10 percent inert weight growth occurs. The payload would also be reduced by over 40 percent if the design specific impulse is low by one percent. The vehicle sensitivities are shown in Figure B.25.

B.2.5 Concept 6

The single-stage-to-orbit booster of this concept has about a 50 percent reduction in gross weight when eliminating USAF missions. This is primarily due to the large weight reduction of the ballistic crew vehicle and the less energetic design orbit. The gross liftoff weight is slightly over 2.5 million pounds. The ballistic crew vehicle size is reduced to 33,000 pounds. The system balance is shown in Figure B.27.

Two transportation systems appear attractive with this concept. The vehicle is designed for the crew logistics mission, and the cargo mission is accomplished by either adding tip tanks or an expendable upper stage. This expendable upper stage can be one of the two used in a precursor program to develop the crew vehicle. The resulting payload for the cargo mission would be about 160,000 pounds. These transportation systems are depicted in Figure B.28.

As with concept 5, the sensitivity of this vehicle to parametric change is high. The vehicle cannot attain orbit if it incurs a 10 percent inert weight growth. Additionally, the payload would be reduced over 30 percent by a one percent specific impulse reduction. These sensitivities are shown in Figure B.27.

FIGURE B.26
TRANSPORTATION SYSTEMS
CONCEPT 5
NASA MISSIONS

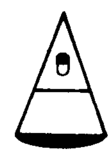
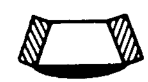
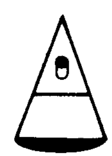
	EVOLUTIONARY		NASA MISSION A CREW/LOGISTICS		NASA MISSION B CARGO	
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS LIFTOFF		.025 .055 .690 .690 1.460		.025 .055 — 3.367 3.447		.150 — 3.367 (.362T.T.) 3.879
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS LIFTOFF		.025 .055 .690 .690 1.460		.025 .055 — 4.121 4.201		USE EXPENDABLE STAGE FROM EVOLUTIONARY PROGRAM PL = 200,000 LBS

FIGURE B.27

CONFIGURATION 6

NASA MISSIONS

SYSTEM BALANCE – CREW/LOGISTICS MISSION

BOOSTER – SINGLE-STAGE-TO-ORBIT BALLISTIC

ORBITER – (SEPARATE BALLISTIC CREW VEHICLE)

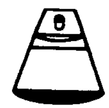
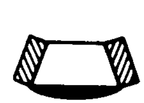
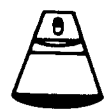
PAYLOAD (UP – DOWN) 25000 – 25000

	BOOSTER	CREW VEHICLE
ASCENT DELTA V'S	30647	
FRACTION OF BOOST VELOCITY	1.000	0
SPECIFIC IMPULSE	451.1	459.0
STAGE MASS FRACTION	.9095	.6524
STAGE GROSS WEIGHT	2.598×10^6	$.033 \times 10^6$
LIFT-OFF GROSS WEIGHT	2.657×10^6	

VEHICLE SENSITIVITIES

	BOOSTER
PROPELLANT WEIGHT (LBS PL/%)	3260.9
STRUCTURAL WEIGHT (LBS PL/%)	–2676.3
SEA LEVEL I_S (LBS PL/SEC)	62.9
VACUUM I_S (LBS PL/SEC)	1683.4
ON-ORBIT DELTA V (LBS PL/FPS)	
CROSS-RANGE DELTA V (LBS PL/FPS)	
HOVER DELTA V (LBS PL/FPS)	– 24.3
LOB-RETRO DELTA V (LBS PL/FPS)	
TOTAL IMPULSIVE DELTA V (LBS PL/FPS)	– 24.9
DE-ORBIT DELTA V (LBS PL/FPS)	– 20.5
TOTAL VEHICLE STRUCTURAL WEIGHT (LBS PL/%)	–2676.3

FIGURE B.28
TRANSPORTATION SYSTEMS
CONCEPT 6
NASA MISSIONS

	EVOLUTIONARY		NASA MISSION A CREW/LOGISTICS		NASA MISSION B CARGO	
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS LIFTOFF		.025 .033 .569 .569 1.196		.025 .033 — 2.598 2.656		.150 — 2.598 (.611T.T.) 3.359
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS LIFTOFF		.025 .033 .569 .569 1.196		.025 .033 — 3.207 3.265		USE EXPENDABLE STAGE FROM EVOLUTIONARY PROGRAM PL = 160,000 LBS

B.2.6 Concept 8

This concept has a 35 percent weight reduction upon elimination of the USAF missions. Again, this was primarily due to the reduction in size of the ballistic crew vehicle and the lower energy design mission. The gross liftoff weight for this concept is just over 1.0 million pounds, with each stage weighing 514,000 pounds. The system balance for this concept is shown in Figure B.29. The sizing curve, Figure B.30, shows the small weight penalty that must be paid to design equal size stages rather than for minimum gross weight.

The transportation system that appears most reasonable with this concept has the vehicle designed for the cargo mission. It then is capable of performing the crew/logistics mission with excess payload capability. If designed for crew/logistics, the cargo mission is attained by adding tip tanks or a new expendable booster to the configuration. About one million pound tip tanks are required or a new stage weighing almost 1.7 million pounds. The precursor development program for the crew vehicle is as described in concept 6. The various transportation systems are shown in Figure B.31.

This concept has the lowest sensitivity, of those compared, to parametric change. A 10 percent inert weight increase will result in about a 15 percent payload reduction, while a one percent reduction in specific impulse will cause about a 12 percent reduction in payload. These vehicle sensitivities are shown in Figure B.29.

B.2.7 Concept 9

This concept showed almost no change after elimination of the USAF missions. The separate lifting body crew vehicle had only a small decrease in size due to the better mass fraction for the low cross range vehicle. The small propulsion requirement for the crew vehicle, and the same design mission are the reasons for the almost identical size of the stages both with and without USAF mission requirements. The system balance for this concept and the vehicle sensitivities are shown on Figure B.32 and can be seen to be almost identical to those shown on Figure B.14. A sizing curve is shown in Figure B.33.

Three transportation system alternatives for this concept are shown in Figure B.34. Two consist of designing the vehicle for crew/logistics and then adding either tip tanks or an expendable lower stage for the cargo mission. The other system is to design for cargo and have excess payload capability for crew/logistics. The evolutionary development program is the same as described for concept 5.

FIGURE B.29

CONFIGURATION 8

NASA MISSIONS

SYSTEM BALANCE – CREW/LOGISTICS MISSION

BOOSTER – BALLISTIC

ORBITER – BALLISTIC (WITH SEPARATE BALLISTIC CREW VEHICLE)

PAYLOAD (UP – DOWN) 58500 – 0

	BOOSTER		ORBITER
ASCENT DELTA V'S	7119		23528
FRACTION OF BOOST VELOCITY	.2324		.7676
SPECIFIC IMPULSE	426.9		459.0
STAGE MASS FRACTION	.8993		.8993
STAGE GROSS WEIGHT	$.514 \times 10^6$		$.514 \times 10^6$
LIFT-OFF GROSS WEIGHT		1.087×10^6	

VEHICLE SENSITIVITIES

	BOOSTER		ORBITER
PROPELLANT WEIGHT (LBS PL/%)	490.7		763.2
STRUCTURAL WEIGHT (LBS PL/%)	– 77.9		–592.1
SEA LEVEL I_S (LBS PL/SEC)	68.4		14.3
VACUUM I_S (LBS PL/SEC)	83.3		476.7
ON-ORBIT DELTA V (LBS PL/FPS)			
CROSS-RANGE DELTA V (LBS PL/FPS)			
HOVER DELTA V (LBS PL/FPS)	– 1.0		– 5.5
LOB-RETRO DELTA V (LBS PL/FPS)	– .9		
TOTAL IMPULSIVE DELTA V (LBS PL/FPS)		– 9.1	
DE-ORBIT DELTA V (LBS PL/FPS)		– 4.6	
TOTAL VEHICLE STRUCTURAL WEIGHT (LBS PL/%)		–669.9	

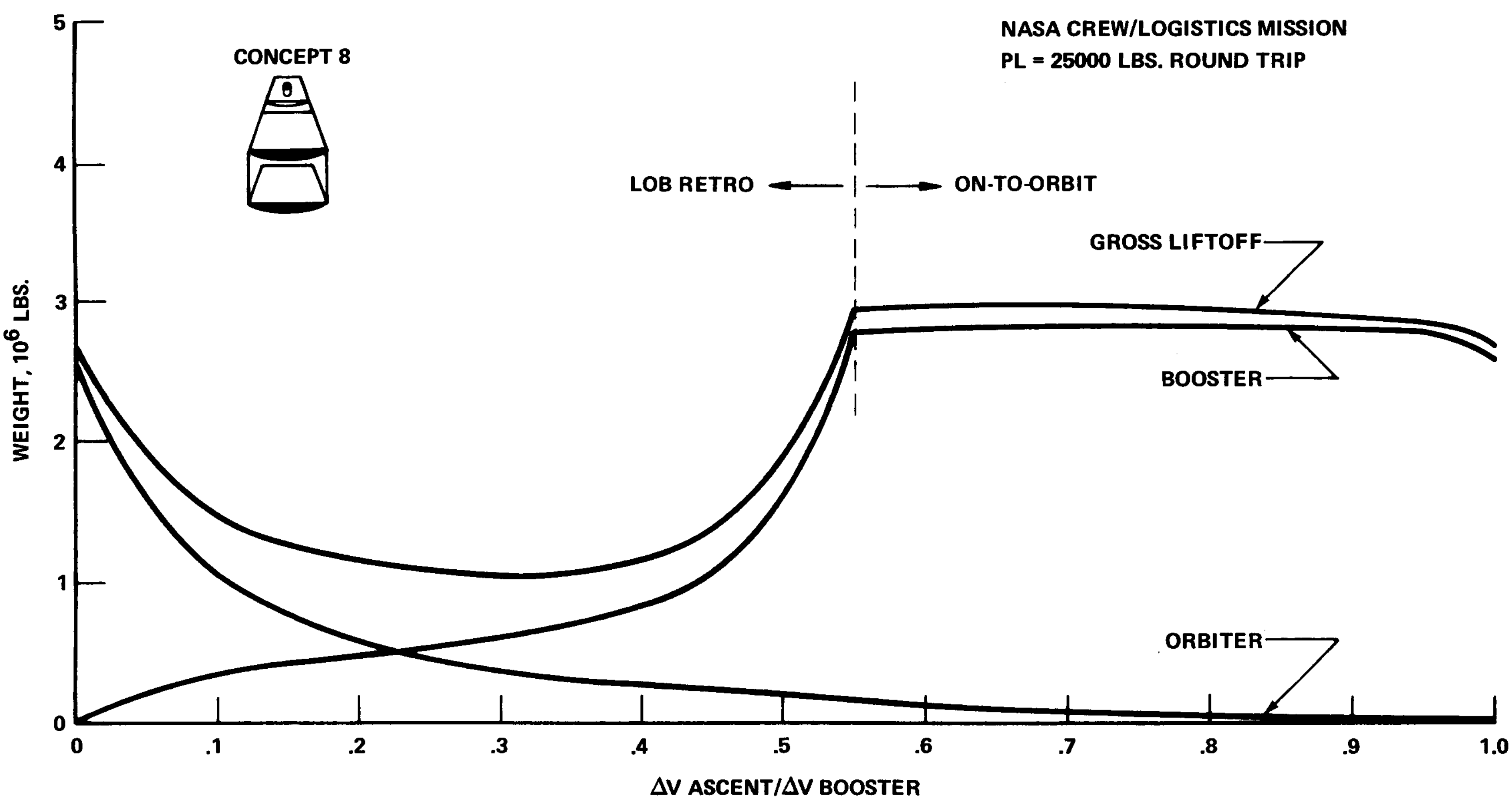


FIGURE B.30 - VEHICLE SIZING CURVE

FIGURE B.31
TRANSPORTATION SYSTEMS
CONCEPT 8
NASA MISSIONS

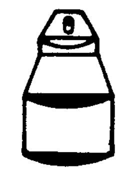
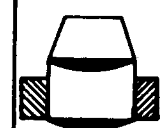
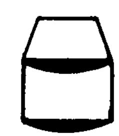
	EVOLUTIONARY		NASA MISSION A CREW/LOGISTICS		NASA MISSION B CARGO	
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS LIFTOFF		.025 .033 .569 .569 1.196		.025 .033 .514 .514 1.086		.150 — .514 1.682 2.346
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS LIFTOFF		.025 .033 .569 .569 1.196		.025 .033 .514 .514 1.086		.150 — .514 .514 (1.050T.T.) 2.228
PAYLOAD CREW VEHICLE ORBITER BOOSTER GROSS LIFTOFF		.025 .033 .569 .569 1.196	USE CARGO DESIGN EXCESS PAYLOAD CAPABILITY			.150 — 1.257 1.257 2.664

FIGURE B.32

CONFIGURATION 9

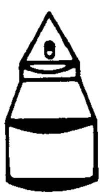
NASA MISSIONS

SYSTEM BALANCE – CREW/LOGISTICS MISSION

BOOSTER – BALLISTIC

ORBITER – BALLISTIC (WITH SEPARATE LIFTING BODY CREW VEHICLE)

PAYLOAD (UP – DOWN) 80,000 – 0



	BOOSTER		ORBITER
ASCENT DELTA V'S	7144		23503
FRACTION OF BOOST VELOCITY	.2331		.7669
SPECIFIC IMPULSE	427.0		459.0
STAGE MASS FRACTION	.9019		.9019
STAGE GROSS WEIGHT	$.677 \times 10^6$		$.677 \times 10^6$
LIFT-OFF GROSS WEIGHT		1.433×10^6	

VEHICLE SENSITIVITIES

	BOOSTER		ORBITER
PROPELLANT WEIGHT (LBS PL/%)	651.4		1004.3
STRUCTURAL WEIGHT (LBS PL/%)	–100.7		– 759.7
SEA LEVEL I_S (LBS PL/SEC)	90.6		18.1
VACUUM I_S (LBS PL/SEC)	110.5		629.5
ON-ORBIT DELTA V (LBS PL/FPS)			
CROSS-RANGE DELTA V (LBS PL/FPS)			
HOVER DELTA V (LBS PL/FPS)	– 1.4		– 7.0
LOB-RETRO DELTA V (LBS PL/FPS)	– 1.2		
TOTAL IMPULSIVE DELTA V (LBS PL/FPS)		– 12.0	
DE-ORBIT DELTA V (LBS PL/FPS)		– 5.9	
TOTAL VEHICLE STRUCTURAL WEIGHT (LBS PL/%)		–850.0	

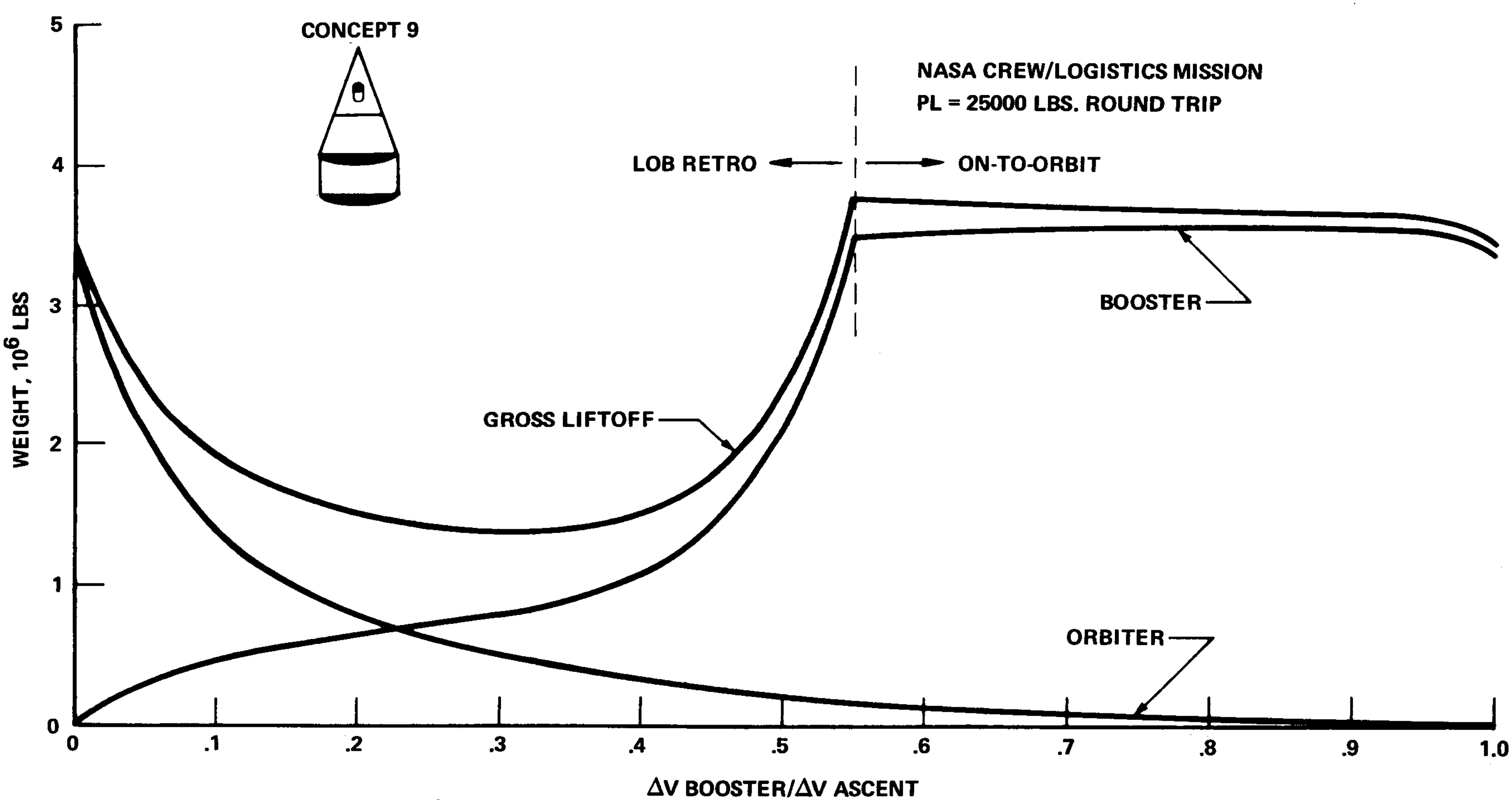
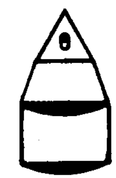
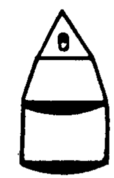
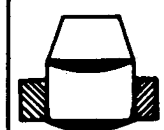


FIGURE B.33 - VEHICLE SIZING CURVE

FIGURE B.34
TRANSPORTATION SYSTEMS
CONCEPT 9
NASA MISSIONS

	EVOLUTIONARY		NASA MISSION A CREW/LOGISTICS		NASA MISSION B CARGO	
PAYLOAD		.025		.025		.150
CREW VEHICLE		.055		.055		—
ORBITER		.690		.677		.677
BOOSTER		.690		.677		1.550
GROSS LIFTOFF		1.460		1.434		2.377
PAYLOAD		.025		.025		.150
CREW VEHICLE		.055		.055		—
ORBITER		.690		.686		.686
BOOSTER		.690		.686		.686 (.797T.T.)
GROSS LIFTOFF		1.460		1.452		2.319
PAYLOAD		.025	USE CARGO DESIGN EXCESS PAYLOAD CAPABILITY			.150
CREW VEHICLE		.055				—
ORBITER		.690				1.257
BOOSTER		.690				1.257
GROSS LIFTOFF		1.460				2.664

APPENDIX C

SYSTEM SUMMARY - ELIMINATED CONCEPTS

C.1 NASA/USAF Missions

C.2 NASA Only Missions

FIGURE C.1

CONFIGURATION 2

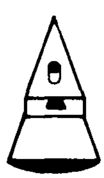
NASA/USAF MISSIONS

SYSTEM BALANCE – CREW/LOGISTICS MISSION

BOOSTER – BALLISTIC

ORBITER – LIFTING BODY (WITH INTEGRATED CREW/PAYLOAD)

PAYLOAD (UP – DOWN) 10000 – 10000



	BOOSTER		ORBITER
ASCENT DELTA V'S	12596		18831
FRACTION OF BOOST VELOCITY	.4008		.5492
SPECIFIC IMPULSE	440.3		459.0
STAGE MASS FRACTION	.9098		.7538
STAGE GROSS WEIGHT	2.747×10^6		1.068×10^6
LIFT-OFF GROSS WEIGHT		3.775×10^6	

VEHICLE SENSITIVITIES

	BOOSTER		ORBITER
PROPELLANT WEIGHT (LBS PL/%)	1562.4		1816.0
STRUCTURAL WEIGHT (LBS PL/%)	– 640.8		–2461.2
SEA LEVEL I_S (LBS PL/SEC)	150.9		0
VACUUM I_S (LBS PL/SEC)	461.8		980.3
ON-ORBIT DELTA V (LBS PL/FPS)			– 23.1
CROSS-RANGE DELTA V (LBS PL/FPS)			
HOVER DELTA V (LBS PL/FPS)	– 6.5		
LOB-RETRO DELTA V (LBS PL/FPS)	– 5.4		
TOTAL IMPULSIVE DELTA V (LBS PL/FPS)		– 22.7	
DE-ORBIT DELTA V (LBS PL/FPS)		– 23.3	
TOTAL VEHICLE STRUCTURAL WEIGHT (LBS PL/%)		–3102.2	

FIGURE C.2

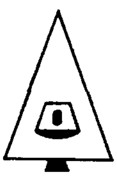
CONFIGURATION 7

NASA/USAF MISSIONS

SYSTEM BALANCE – CREW/LOGISTICS MISSION

BOOSTER – LIFTING BODY (TWO STRAP-ON STAGES
STAGES)
ORBITER – BALLISTIC (WITH INTEGRATED CREW/PAYLOAD)

PAYLOAD (UP – DOWN) 10000 – 10000



		BOOSTER		ORBITER
ASCENT DELTA V'S		14541		16886
FRACTION OF BOOST VELOCITY		.4627		.5373
SPECIFIC IMPULSE		442.7		459.0
STAGE MASS FRACTION		.7747		.8996
STAGE GROSS WEIGHT	(2)	1.337×10^6		$.555 \times 10^6$
LIFT-OFF GROSS WEIGHT			3.240×10^6	

VEHICLE SENSITIVITIES

	BOOSTER		ORBITER
PROPELLANT WEIGHT (LBS PL/%)	562.6		546.2
STRUCTURAL WEIGHT (LBS PL/%)	–288.6		–540.2
SEA LEVEL I_S (LBS PL/SEC)	49.9		9.6
VACUUM I_S (LBS PL/SEC)	154.0		376.6
ON-ORBIT DELTA V (LBS PL/FPS)			– 6.1
CROSS-RANGE DELTA V (LBS PL/FPS)			– 6.1
HOVER DELTA V (LBS PL/FPS)			– 7.4
LOB-RETRO DELTA V (LBS PL/FPS)			
TOTAL IMPULSIVE DELTA V (LBS PL/FPS)		– 6.1	
DE-ORBIT DELTA V (LBS PL/FPS)		– 6.2	
TOTAL VEHICLE STRUCTURAL WEIGHT (LBS PL/%)		–829.1	

FIGURE C.3

CONFIGURATION 10

NASA/USAF MISSIONS

SYSTEM BALANCE – CREW/LOGISTICS MISSION

BOOSTER – LIFTING BODY

ORBITER – LIFTING BODY (WITH SEPARATE LIFTING BODY CREW VEHICLE)

PAYLOAD (UP – DOWN) 64000 – 0

	BOOSTER	ORBITER
ASCENT DELTA V'S	7247	24180
FRACTION OF BOOST VELOCITY	.2306	.7694
SPECIFIC IMPULSE	427.4	459.0
STAGE MASS FRACTION	.8267	.8267
STAGE GROSS WEIGHT	3.338×10^6	3.338×10^6
LIFT-OFF GROSS WEIGHT	6.740×10^6	

VEHICLE SENSITIVITIES

	BOOSTER	ORBITER
PROPELLANT WEIGHT (LBS PL/%)	2907.5	4167.8
STRUCTURAL WEIGHT (LBS PL/%)	– 422.0	–6016.4
SEA LEVEL I_S (LBS PL/SEC)	404.1	0
VACUUM I_S (LBS PL/SEC)	474.7	2772.6
ON-ORBIT DELTA V (LBS PL/FPS)		
CROSS-RANGE DELTA V (LBS PL/FPS)		
HOVER DELTA V (LBS PL/FPS)		
LOB-RETRO DELTA V (LBS PL/FPS)		
TOTAL IMPULSIVE DELTA V (LBS PL/FPS)	– 50.9	
DE-ORBIT DELTA V (LBS PL/FPS)	– 47.0	
TOTAL VEHICLE STRUCTURAL WEIGHT (LBS PL/%)	–6437.8	

FIGURE C.4

CONFIGURATION 11

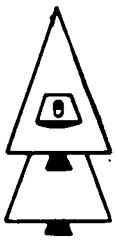
NASA/USAF MISSIONS

SYSTEM BALANCE – CREW/LOGISTICS MISSION

BOOSTER – LIFTING BODY

ORBITER – LIFTING BODY (WITH SEPARATE BALLISTIC CREW VEHICLE)

PAYLOAD (UP – DOWN) 86500 – 0



	BOOSTER	ORBITER
ASCENT DELTA V'S	7267	24160
FRACTION OF BOOST VELOCITY	.2312	.7688
SPECIFIC IMPULSE	427.5	459.0
STAGE MASS FRACTION	.8302	.8302
STAGE GROSS WEIGHT	3.600×10^6	3.600×10^6
LIFT-OFF GROSS WEIGHT	7.287×10^6	

VEHICLE SENSITIVITIES

	BOOSTER	ORBITER
PROPELLANT WEIGHT (LBS PL/%)	3160.5	4506.6
STRUCTURAL WEIGHT (LBS PL/%)	– 448.7	–6357.0
SEA LEVEL I_S (LBS PL/SEC)	438.5	0
VACUUM I_S (LBS PL/SEC)	517.3	3004.5
ON-ORBIT DELTA V (LBS PL/FPS)		
CROSS-RANGE DELTA V (LBS PL/FPS)		
HOVER DELTA V (LBS PL/FPS)		
LOB-RETRO DELTA V (LBS PL/FPS)		
TOTAL IMPULSIVE DELTA V (LBS PL/FPS)	– 55.2	
DE-ORBIT DELTA V (LBS PL/FPS)	– 49.7	
TOTAL VEHICLE STRUCTURAL WEIGHT (LBS PL/%)	–6805.9	

FIGURE C.5

CONFIGURATION 2

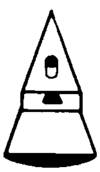
NASA MISSIONS

SYSTEM BALANCE – CREW/LOGISTICS MISSION

BOOSTER – BALLISTIC

ORBITER – LIFTING BODY (WITH INTEGRATED CREW/PAYLOAD)

PAYLOAD (UP – DOWN) 25000 – 25000



	BOOSTER		ORBITER
ASCENT DELTA V'S	11692		18955
FRACTION OF BOOST VELOCITY	.3815		.6185
SPECIFIC IMPULSE	438.9		459.0
STAGE MASS FRACTION	.9090		.7710
STAGE GROSS WEIGHT	2.204×10^6		$.983 \times 10^6$
LIFT-OFF GROSS WEIGHT		3.212×10^6	

VEHICLE SENSITIVITIES

	BOOSTER		ORBITER
PROPELLANT WEIGHT (LBS PL/%)	1477.1		1678.3
STRUCTURAL WEIGHT (LBS PL/%)	– 517.8		–2211.0
SEA LEVEL I_S (LBS PL/SEC)	148.7		0
VACUUM I_S (LBS PL/SEC)	401.7		945.7
ON-ORBIT DELTA V (LBS PL/FPS)			– 22.0
CROSS-RANGE DELTA V (LBS PL/FPS)			
HOVER DELTA V (LBS PL/FPS)	– 5.4		
LOB-RETRO DELTA V (LBS PL/FPS)	– 4.5		
TOTAL IMPULSIVE DELTA V (LBS PL/FPS)		– 21.6	
DE-ORBIT DELTA V (LBS PL/FPS)		– 22.2	
TOTAL VEHICLE STRUCTURAL WEIGHT (LBS PL/%)		–2728.9	

FIGURE C.6

CONFIGURATION 7

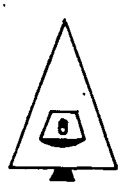
NASA MISSIONS

SYSTEM BALANCE – CREW/LOGISTICS MISSION

BOOSTER – LIFTING BODY (2 STRAP-ON STAGES)

ORBITER – BALLISTIC (WITH INTEGRATED CREW/PAYLOAD)

PAYLOAD (UP – DOWN) 25000 – 25000



	BOOSTER		ORBITER
ASCENT DELTA V'S	7686		22961
FRACTION OF BOOST VELOCITY	.2508		.7492
SPECIFIC IMPULSE	429.1		459.0
STAGE MASS FRACTION	.6796		.8985
STAGE GROSS WEIGHT	(2) $.443 \times 10^6$		$.500 \times 10^6$
LIFT-OFF GROSS WEIGHT		1.412×10^6	

VEHICLE SENSITIVITIES

	BOOSTER		ORBITER
PROPELLANT WEIGHT (LBS PL/%)	421.8		645.5
STRUCTURAL WEIGHT (LBS PL/%)	–147.7		–490.0
SEA LEVEL I_S (LBS PL/SEC)	56.1		22.1
VACUUM I_S (LBS PL/SEC)	72.5		383.1
ON-ORBIT DELTA V (LBS PL/FPS)			– 7.1
CROSS-RANGE DELTA V (LBS PL/FPS)			– 7.1
HOVER DELTA V (LBS PL/FPS)			– 8.6
LOB-RETRO DELTA V (LBS PL/FPS)			
TOTAL IMPULSIVE DELTA V (LBS PL/FPS)		– 7.1	
DE-ORBIT DELTA V (LBS PL/FPS)		– 7.2	
TOTAL VEHICLE STRUCTURAL WEIGHT (LBS PL/%)		–637.5	

FIGURE C.7

CONFIGURATION 10

NASA MISSIONS

SYSTEM BALANCE – CREW/LOGISTICS MISSION

BOOSTER – LIFTING BODY

ORBITER – LIFTING BODY (WITH SEPARATE LIFTING BODY CREW VEHICLE)

PAYLOAD (UP – DOWN) 80000 – 0

	BOOSTER	ORBITER
ASCENT DELTA V'S	7164	23483
FRACTION OF BOOST VELOCITY	.2338	.7662
SPECIFIC IMPULSE	427.1	459.0
STAGE MASS FRACTION	.8227	.8227
STAGE GROSS WEIGHT	3.074×10^6	3.074×10^6
LIFT-OFF GROSS WEIGHT	6.228×10^6	

VEHICLE SENSITIVITIES

	BOOSTER	ORBITER
PROPELLANT WEIGHT (LBS PL/%)	2824.0	4058.9
STRUCTURAL WEIGHT (LBS PL/%)	– 415.2	–5670.0
SEA LEVEL I_S (LBS PL/SEC)	395.7	0
VACUUM I_S (LBS PL/SEC)	456.4	2638.2
ON-ORBIT DELTA V (LBS PL/FPS)		
CROSS-RANGE DELTA V (LBS PL/FPS)		
HOVER DELTA V (LBS PL/FPS)		
LOB-RETRO DELTA V (LBS PL/FPS)		
TOTAL IMPULSIVE DELTA V (LBS PL/FPS)	– 49.9	
DE-ORBIT DELTA V (LBS PL/FPS)	– 44.8	
TOTAL VEHICLE STRUCTURAL WEIGHT (LBS PL/%)	–6085.9	

FIGURE C.8

CONFIGURATION 11

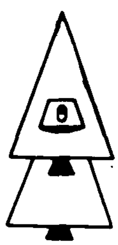
NASA MISSIONS

SYSTEM BALANCE – CREW/LOGISTICS MISSION

BOOSTER – LIFTING BODY

ORBITER – LIFTING BODY (WITH SEPARATE BALLISTIC CREW VEHICLE)

PAYLOAD (UP – DOWN) 58500 – 0



	BOOSTER		ORBITER
ASCENT DELTA V'S	7143		23504
FRACTION OF BOOST VELOCITY	.2331		.7669
SPECIFIC IMPULSE	427.0		459.0
STAGE MASS FRACTION	.8188		.8188
STAGE GROSS WEIGHT	2.841×10^6		2.841×10^6
LIFT-OFF GROSS WEIGHT		5.742×10^6	

VEHICLE SENSITIVITIES

	BOOSTER		ORBITER
PROPELLANT WEIGHT (LBS PL/%)	2587.4		3740.7
STRUCTURAL WEIGHT (LBS PL/%)	– 389.4		–5356.4
SEA LEVEL I_S (LBS PL/SEC)	363.3		0
VACUUM I_S (LBS PL/SEC)	417.1		2426.2
ON-ORBIT DELTA V (LBS PL/FPS)			
CROSS-RANGE DELTA V (LBS PL/FPS)			
HOVER DELTA V (LBS PL/FPS)			
LOB-RETRO DELTA V (LBS PL/FPS)			
TOTAL IMPULSIVE DELTA V (LBS PL/FPS)		– 45.8	
DE-ORBIT DELTA V (LBS PL/FPS)		– 42.2	
TOTAL VEHICLE STRUCTURAL WEIGHT (LBS PL/%)		–5746.4	

APPENDIX D

INTRODUCTION

The following addresses three issues associated with ballistic recoverable vehicles in general, but in this instance only the two equal stage configurations will be analysed. The issues are;

1. Non-equality of stages
2. Design state of the art
3. Ascent velocity requirement

The purpose here is to assess the sensitivity of the results pertaining to this configuration option presented elsewhere in this report, to errors or variance in the three issue areas. Of course the combined effects are derived.

NON-EQUALITY OF STAGES

In the body of the report the two stages are treated as being identical for purposes of analysis. That is, the correlation shown on Figure 2.2 (mass fraction versus stage gross weight) was used for both the first and second stages. Because of this a penalty of 5% was assessed against the stages to allow for penalties due to commonality. Such penalties are imposed as follows:

1. Using the equation shown on Figure 2.2, for a given gross weight, establish the mass fraction

$$\lambda = g(GW) .$$

2. Establish the structural weight and the propellant weight

$$SW = (1-\lambda)(GW)$$

$$PW = \lambda(GW) .$$

3. Maintain the propellant weight constant and adjust the structural weight by the factor f to obtain a modified structural weight

$$SW' = f(1-\lambda)(GW) \ .$$

4. Compute the new gross weight,

$$\begin{aligned} GW' &= SW' + PW \\ &= f(1-\lambda)(GW) + \lambda(GW) \\ &= (GW)(f-f\lambda+\lambda) \ . \end{aligned}$$

5. Compute the new mass fraction,

$$\lambda' = \frac{PW}{GW'} = \frac{\lambda}{f-f\lambda+\lambda}$$

The sizing computer program uses this method to establish a new correlation of mass fraction vs. gross weight and then resizes the vehicle to meet the payload and velocity requirement.

In the following analysis independent values of f will be estimated for the first stage and for the second stage, thus recognizing the distinctions between them. The λ correlation given on Figure 2.2 represents the family of recoverable single stage-to-orbit vehicles and implies no interstage weight, an initial thrust to weight ratio of about 1.25 and an orbital reentry and soft vertical landing. Such conditions apply properly to the second stage rather than the first; although a thrust to weight ratio of 1.25 might be a bit high, it is close enough for our purposes here. Consequently an f of 1.0 will be used for the second stage. The first stage has somewhat different requirements, so compensation is required.

<u>Interstage</u>

Vehicles of this class are approximately represented by a sphere of LH_2 contained within a truncated cone. A sphere of 44' diameter contained within a cone of 63' base diameter and 31' top diameter corresponds to a stage gross weight of about 1.25×10^6 lb. The cone side angle is constrained by the need to meet entry angle of attack requirements.

If two such vehicles are stacked, then a reasonable interstage structure might consist of eight compression members, running from the second stage thrust structure to the first stage thrust structure. If one sizes these members in accord with both Euler column buckling criteria and local instability criteria the total weight penalty is less than 20,000 lb (using aluminum).

Propulsion

Again, with reference to the 1.25×10^6 stage gross weight vehicle, Figure 2.2 represents a thrust of 1.56×10^6 lb whereas an ignition liftoff thrust of 3.33×10^6 is required for the liftoff weight of 2.664×10^6 lb. Using a propulsion system thrust to weight ratio of 75 yields a weight penalty of 23,600 lb.

Heat Shield

One would expect the heat shield weight of the first stage to be substantially less than that required for entry from orbit since the entry velocity is but 5000 fps. However, the entry angle is substantially higher and the total energy load is not significantly different from that of orbital entry. Because of this no weight reduction is made for this approximate analysis.

Summary

The estimated weight penalty against the first stage is 43,600 lb. The structural weight derived from Figure 2.2 is 117,500 lb. Thus, the value of f is about 1.35. A similar set of computations for a stage gross weight of 2×10^6 lb yields the same value of f. The second stage appears to be fairly represented by f = 1.0, so no further consideration is required.

The result of these variations is shown on Table D-1.

Table D-1.

GROSS LIFTOFF WEIGHT VERSUS STAGE
STRUCTURAL WEIGHT FACTOR
($f_1 = f_2 = 1.0$ Corresponds To Figure 2.2)

FIRST STAGE, f_1

	10^6 lbs.	1.05	1.35
SECOND STAGE, f_2	1.0		2.689
	1.05	2.664	

DESIGN STATE OF THE ART

The correlation of λ and gross weight used in these analyses is based on very few data points and consequently could be in error. There is no straight forward way to bound such errors. Because of this the effect of an $\sim \pm 20\%$ variation in structural weight about the nominal value ($f_1 = 1.35$, $f_2 = 1.0$) established above is shown in Table D-2.

Table D-2.

GROSS LIFTOFF WEIGHT VERSUS STAGE
STRUCTURAL WEIGHT FACTOR
($f_1 = f_2 = 1.0$ Corresponds To Figure 2.2)

FIRST STAGE, f_1

	10^6 lbs.	1.05	1.1	1.35	1.6
SECOND STAGE, f_2	0.8		2.252	2.325	
	1.0		2.588	2.689	2.782
	1.05	2.664			
	1.2			3.159	3.293

Ascent Velocity Requirement

The ascent velocity, 29,960 fps, was established by trajectory simulation of a single stage to orbit vehicle using an initial thrust to weight ratio of 1.25 and flying a 3g maximum trajectory. The vehicle base diameter is 66 ft., and the drag coefficient curve is characterized by $C_{D,max} = 0.8$, $C_{D,\infty} \simeq 0.3$. The injection point is a 50 x 100 n.mi. ellipse at an inclination of 28.5°. The aero drag losses are 880 fps and the gravity losses are 3870 fps.

The two stage vehicle could fly on this trajectory, and if the aero drag characteristics were compatible injection would be achieved. This is not the optimum trajectory, because of the lob-retro maneuver. The optimum trajectory will be lofted so that the return range for the first stage is decreased. Of course aero drag will decrease also while gravity losses will increase. Since specific trajectory optimizations have not been carried out it is not possible to estimate the reduction in velocity requirement due to optimization.

The vehicle used to establish the trajectory has a biconic forebody (25°, 13°) while the vehicle in question here is a single cone (23°). This implies a possible increase in drag losses of about 440 fps. Using SERV trajectory data and adjusting the aero drag terms for the reduction in diameter and changes in weight and drag coefficient suggests a possible increase of 500 fps.

Compensating for this possible increase in velocity requirement is the improvement in I_{sp} that is expected to yield a better than 1% increase in delivered specific impulse over the values used in this report. That would yield an effective ascent velocity requirement decrease of 300 fps.

The possible range of error seems to be about $\pm$ 500 fps. The impact of these changes on the system gross liftoff weight is shown on Tables D-3 and D-4.

Table D-3.

GROSS LIFTOFF WEIGHT VERSUS STAGE
STRUCTURAL WEIGHT FRACTION
($f_1 = f_2 = 1.0$ Corresponds To Figure 2.2
Ascent Velocity = 29,960 + 500 fps)

FIRST STAGE, f_1

SECOND STAGE, f_2	10^6 lbs.	1.05	1.1	1.35	1.6
	0.8		2.379	2.460	
	1.0		2.758	2.869	2.976
	1.05	2.844			
	1.2			3.410	3.567

Table D-4.

GROSS LIFTOFF WEIGHT VERSUS STAGE
STRUCTURAL WEIGHT FRACTION
($f_1 = f_2 = 1.0$ Corresponds To Figure 2.2
Ascent Velocity = 29,960 - 500 fps)

FIRST STATE, f_1

	10^6 lbs.	1.05	1.1	1.35	1.6
SECOND STAGE, f_2	0.8		2.135	2.203	
	1.0		2.438	2.526	2.616
	1.05	2.506			
	1.2			2.942	3.062

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