(NASA-CR-157444) EARTH-TO-ORBIT REUSABLE LAUNCH VEHICLES: A COMPARATIVE ASSESSMENT Final Report (General Research Corp., McLean, Va.) 202 p HC A10/MF A01 CSCL 22A
N79-27192
Unclas
G3/12 26921

709-02-CR

Earth-to-Orbit Reusable Launch Vehicles

— A Comparative Assessment —

By:

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Prepared for:

National Aeronautics and Space Administration
Langley Research Center
Under Contract NASW-2973 for the Office of Aeronautics and Space Technology

February 1978

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EARTH-TO-ORBIT REUSABLE LAUNCH VEHICLES

- A COMPARATIVE ASSESSMENT -

Final Report

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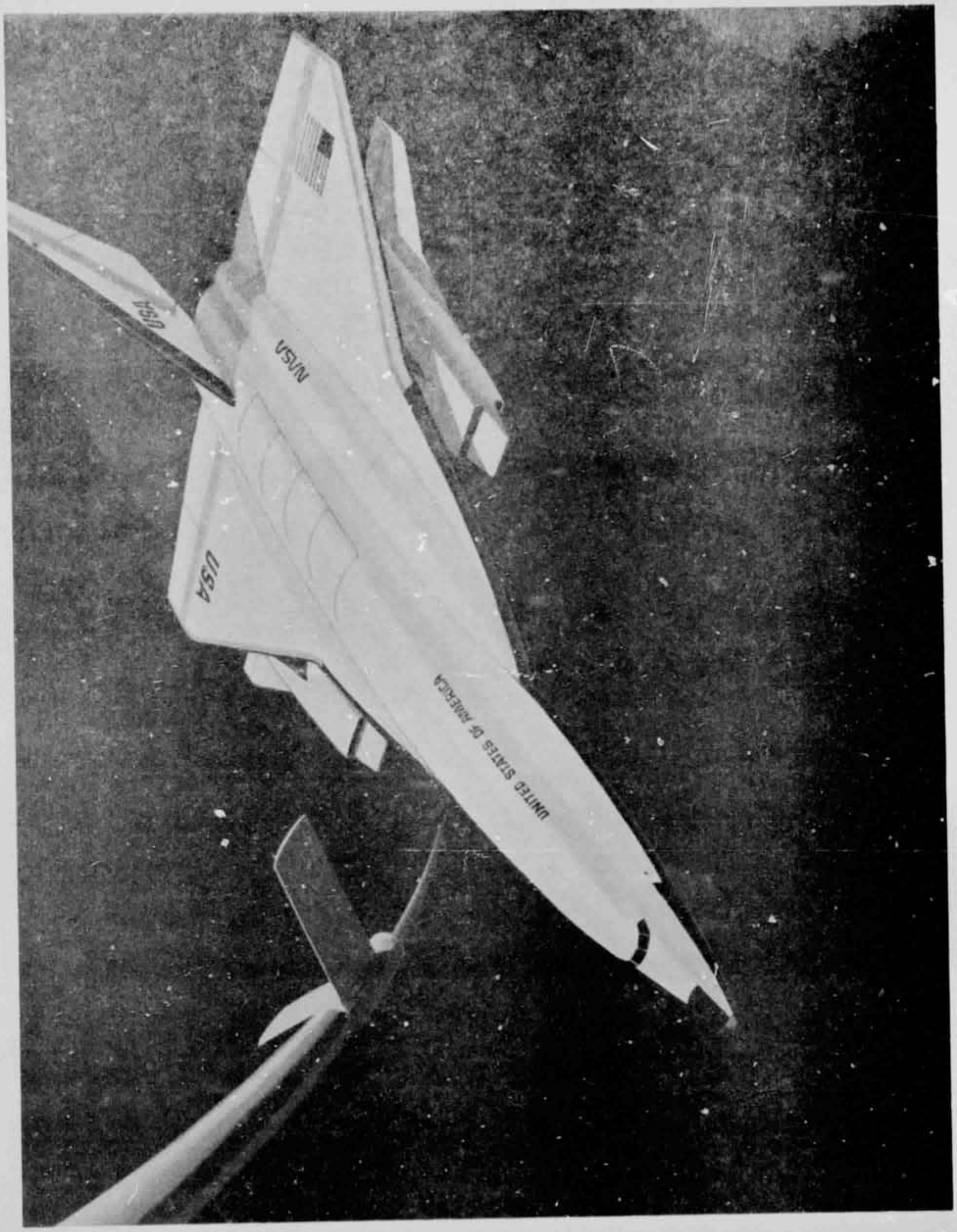
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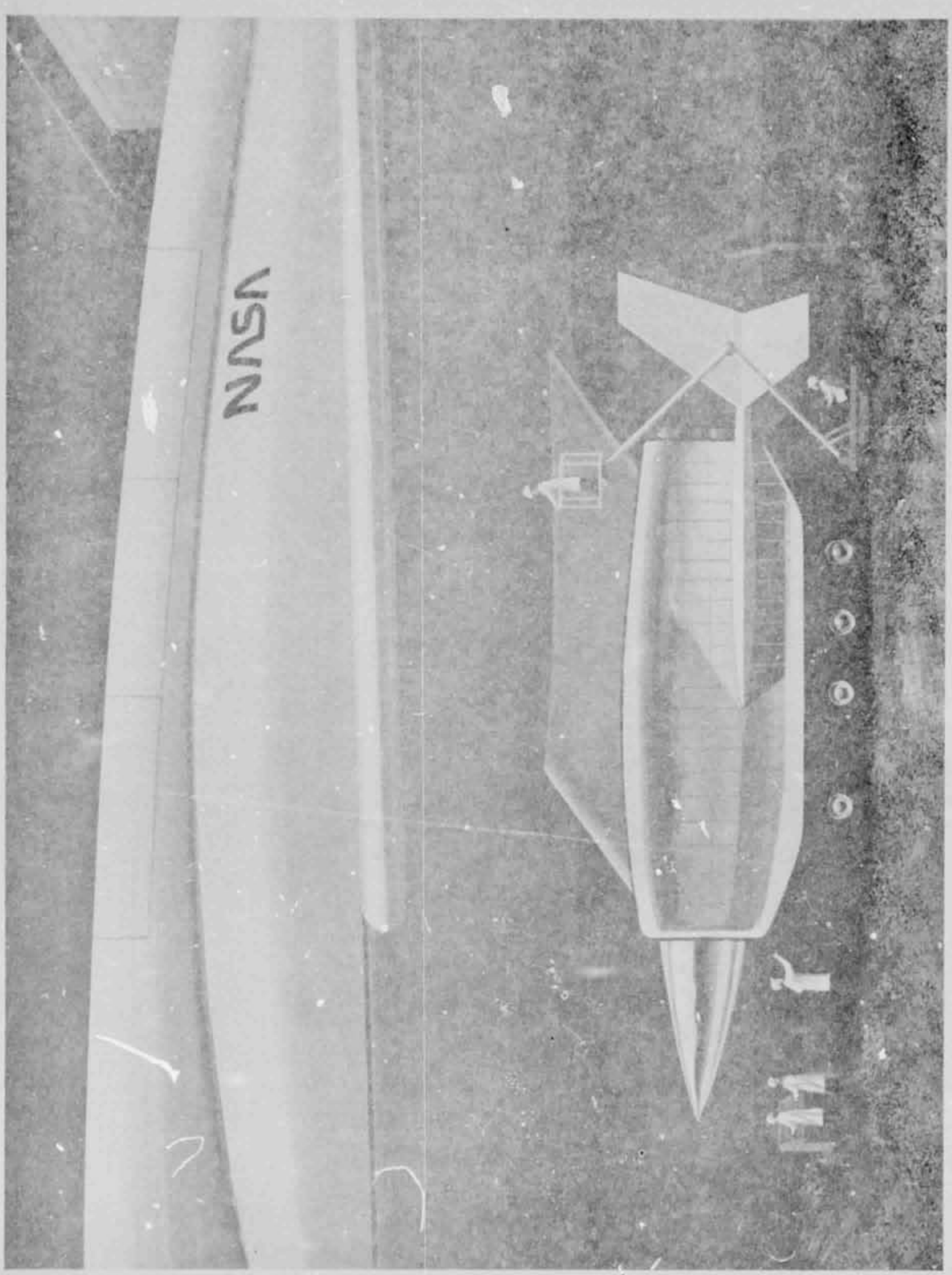
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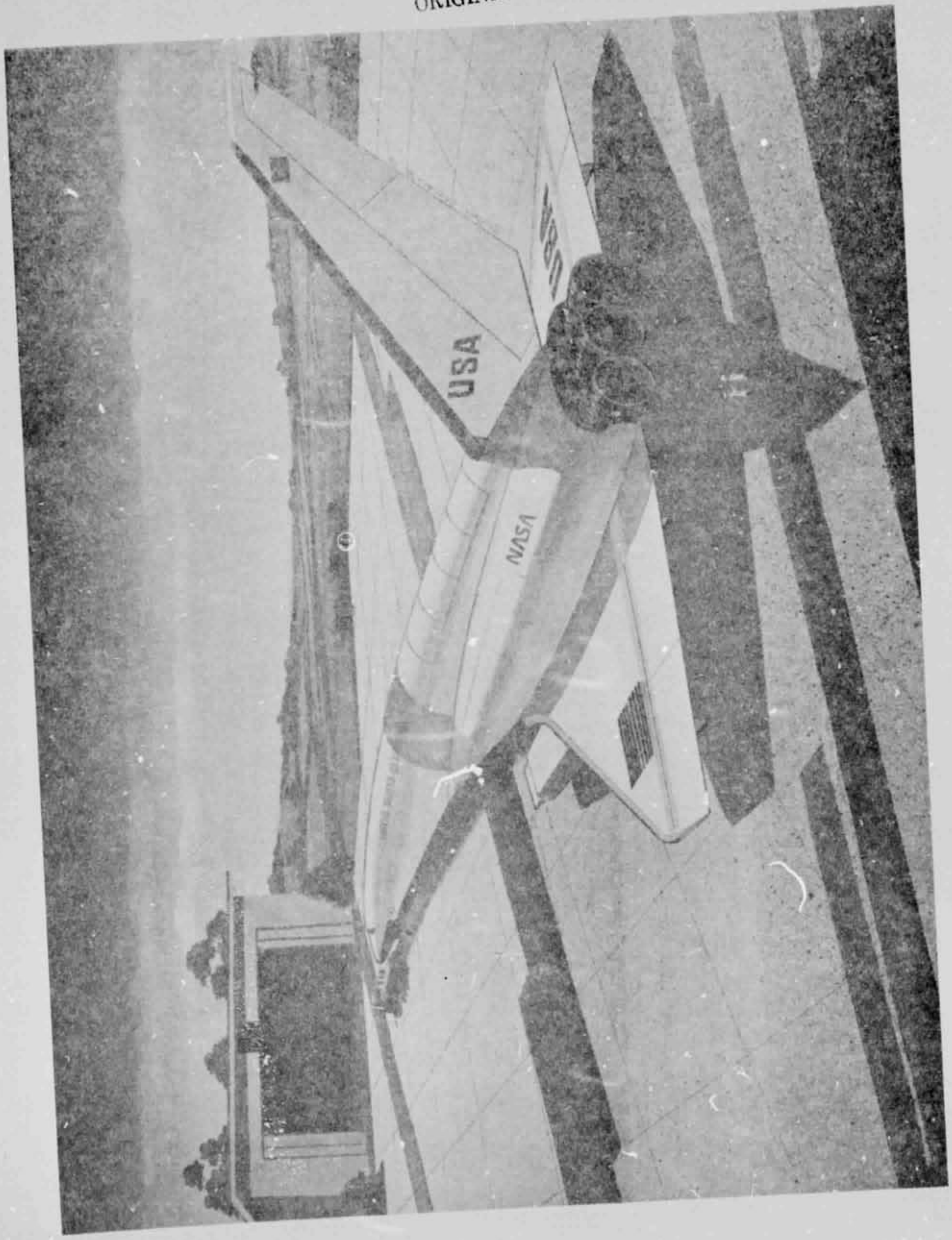
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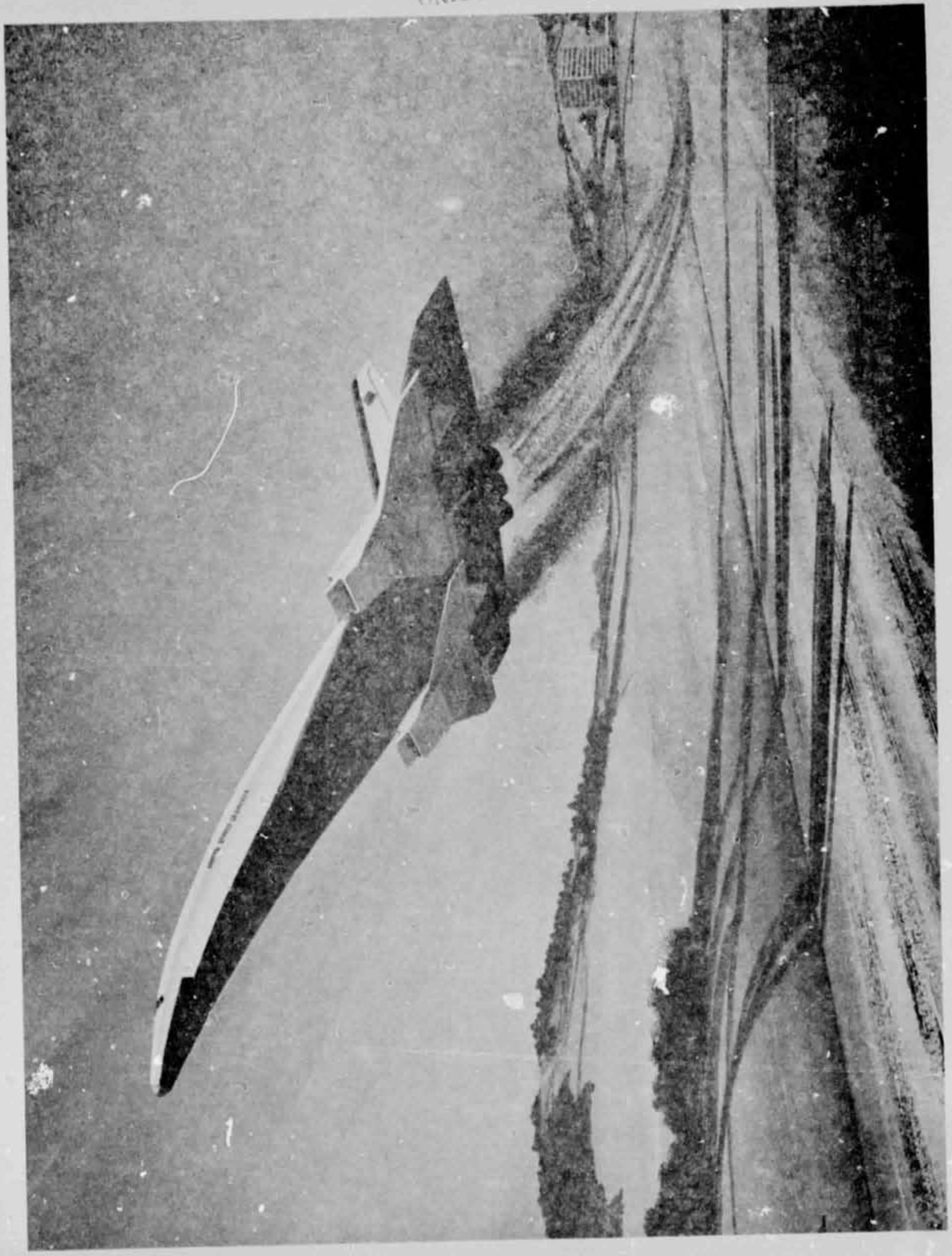

ACKNOWLEDGMENTS

GENERAL RESEARCH CORPORATION

R. L. Chase .... Study Leader, Mission and Technology Assessment

G. Gorman .... Performance

W. Flueckiger .... Costing Assessment

L. Cormier (Consultant) .... Vehicle Definition, Trajectory Analysis

W. Bos (Consultant) .... Propulsion Assessment

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J. A. Martin .... Performance and Costing

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ABSTRACT

Reusable Earth-to-orbit two-stage launch vehicles with air-breathing boosters were studied to determine their utility over a range of staging Mach numbers. Specifically, air-breathing propulsion was incorporated into the booster of a two-stage launch vehicle which used a "parallel-lift" design approach to achieve significant reduction in vehicle size and weight. The study consisted of three parts:

1 Establishing a representative set of space systems, functions, and missions for NASA and DoD from which launch vehicle requirements and characteristics were derived.

2 Establishing a set of representative air-breathing launch vehicles based on graduated technology capabilities corresponding to increasingly higher staging Mach numbers (subsonic, supersonic, and hypersonic).

3 Assessing the utility of the air-breathing launch vehicle candidates based on lift-off weight, performance, technology needs, risk, and costs compared to alternative concepts.

The results indicate that a fully reusable launch vehicle, whether two stage or one stage, could potentially reduce the cost per flight by 60-80% compared to that for a partially reusable vehicle such as the current Shuttle; but a fully reusable launch vehicle would require advances in thermal protection system technology. A two-stage-to-orbit, parallel-lift vehicle with an air-breathing booster would cost approximately the same as a single-stage-to-orbit vehicle, but the former would have greater flexibility and a significantly reduced developmental risk. The study also found that a twin-booster, subsonic-staged, parallel-lift vehicle represents the lowest system cost (by a small margin) including developmental risk. However, if a large supersonic turbojet engine in the 350,000-N thrust class were available, supersonic staging would be preferred, and the investment in development would be returned in reduced program cost.

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CONTENTS (Cont.)

FIGURES

FIGURES (Cont.)

FIGURES (Cont.)

1 INTRODUCTION, SUMMARY, AND CONCLUSIONS

1.1 STUDY OBJECTIVES

The Hypersonic Branch of the Langley Research Center (LaRC) tasked General Research Corporation (GRC) in June 1977 to assess the utility of fully reusable two-stage launch vehicles incorporating air-breathing propulsion.[1] The specific objectives of the study were:

1 To establish a set of launch vehicle requirements based on an assessment of future NASA and military mission opportunities.

2 To establish for comparison purposes a set of launch vehicle candidates which would be representative of different levels of technology.

3 To assess the utility of two-stage launch vehicles incorporating air-breathing propulsion in the booster stage by determining the performance, cost, technology needs, technology risk, and associated benefits of both these vehicles and competitive nonair-breathing vehicles. In evaluating the air-breathing candidates, the preferred staging Mach number was to be identified (i.e., subsonic, supersonic, or hypersonic).

A specific two-stage launch vehicle design comprised of an orbiter and twin air-breathing boosters capable of Mach 3.5 was suggested by LaRC. Each booster is powered by eight 350,000-380,000 N (80,000-85,000 lbf) supersonic turbojets.

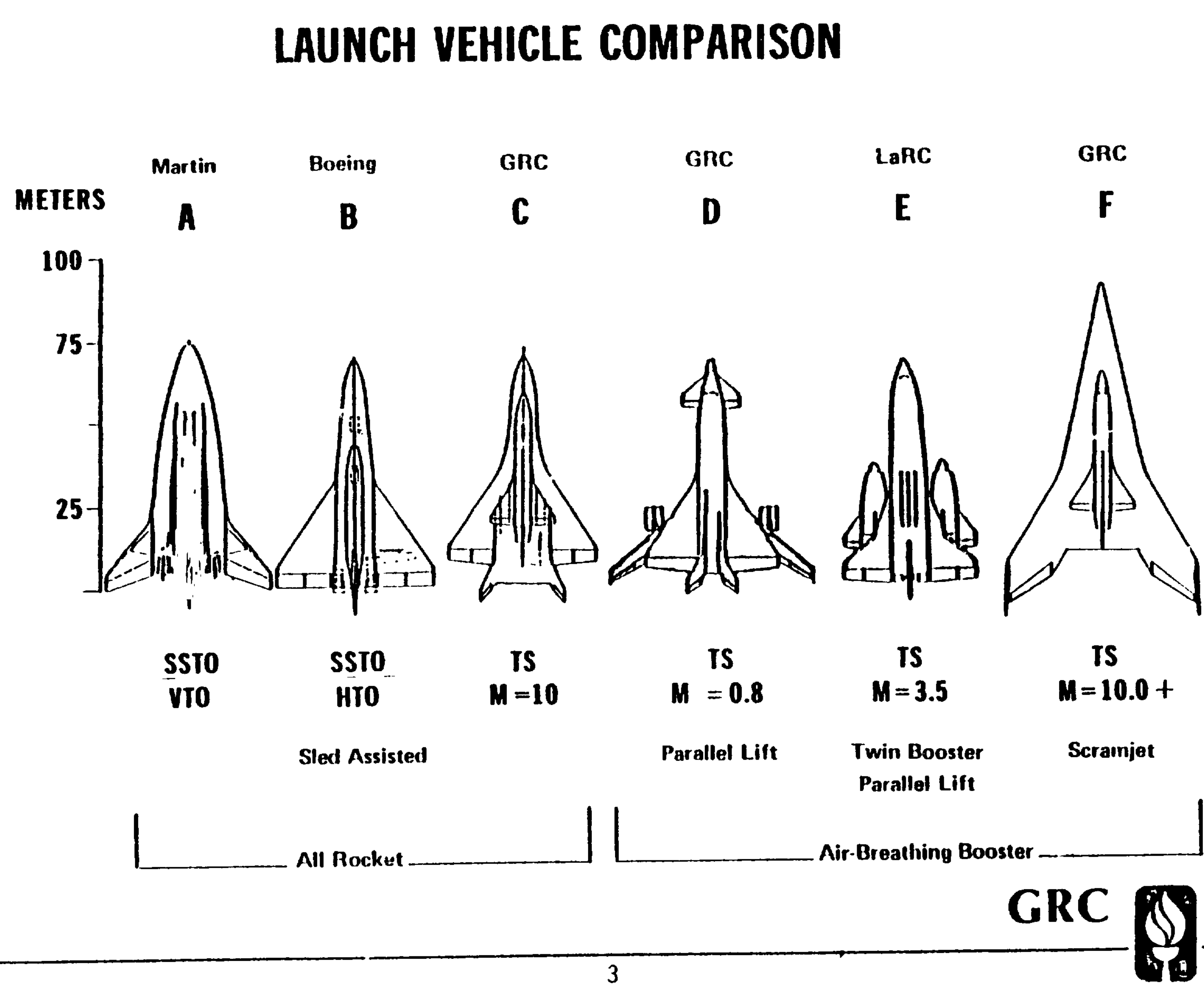
1.2 SUMMARY OF ANALYSIS

Seven different vehicles are compared, one of which receives less than full attention as it was considered only late in the study. Two designs of single-state-to-orbit (SSTO) concepts are included for comparison. The seven launch vehicle designs are described below and are depicted in Fig. 1-1. Details of each design are in Sec. 4 and in Appendix A.

- A Single-stage-to-orbit rocket vehicle, vertical takeoff, designed by Martin.
- B Single-stage-to-orbit rocket vehicle, horizontal takeoff with sled assist, designed by Boeing.
- C Two-stage vehicle, all rocket, staging at Mach 10, designed by GRC.
- D Two-stage parallel-lift (see below) vehicle, air-breathing booster, staging at Mach 0.8, designed by GRC.
- E Two-stage parallel-lift vehicle, twin air-breathing boosters, staging at Mach 3.5, designed by LaRC.
- F Two-stage vehicle, air-breathing scramjet booster, staging at Mach 10, designed by GRC.
- G Two-stage parallel-lift vehicle, twin air-breathing boosters, staging at Mach 0.8, designed by LaRC (considered only with respect to cost).

All stages of all vehicles land horizontally, and all vehicles except A take off horizontally. The term "parallel lift" is used to denote that both orbiter and booster wings provide lift during flight prior to staging. Hence all parallel-lift vehicles and all air-breathing designs are two-stage vehicles. Some vehicles are also frequently identified by staging velocity (subsonic, supersonic, and hypersonic); any vehicle so described has two stages.

Figure 1-1



LAUNCH VEHICLE COMPARISON
METERS
100
75
25
Martin
A
Boeing
B
GRC
C
GRC
D
LaRC
E
GRC
F
SSTO
VTO
SSTO
HTO
TS
M =10
TS
M = 0.8
TS
M=3.5
TS
M=10.0+
Sled Assisted
Parallel Lift
Twin Booster
Parallel Lift
Scramjet
All Rocket
Air-Breathing Booster
GRC

All orbiter vehicles are not identical, but they all deliver 30,000 kg* (65,000 lb) payload to lower earth orbit (LEO). The specific booster and orbiter characteristics minimize the gross weight at takeoff subject to the staging conditions. The orbiter is rocket powered; the air-breathing designation applies only to the boosters.

This study compared the performance of the various vehicles (Sec. 4.10), the maintenance requirements and operational flexibility (Sec. 2.3–2.4), and the costs (Sec. 6), including those associated with technological risk. Where assumptions of vehicle utilization were necessary, a launch rate of 420/year for a 5-vehicle fleet was used.

The mission assessment indicates a transition from Earth-based to space-based mission support. Initially the launch vehicle must be able to provide diversified support over a wide range of locations in space, including serving as habitat, fueling depot, construction base, and experiment platform. When space-based support facilities become a reality, the Earth-to-orbit launch vehicle shifts from being a multifunctional flexible vehicle to a more specialized cargo and passenger vehicle. It would deliver passengers and cargo to a limited set of destinations, but more frequently.

1.3 RESULTS AND CONCLUSIONS

Each launch vehicle candidate considered in the study is fully reusable. However, with the present uncertainty about the Shuttle's reusable surface insulation (RSI) thermal protection

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*The exact payload weight used in the calculations of vehicle weight and performance was 29,483 kg (65,000 lb), corresponding to the payload capability of the current Shuttle. Throughout this report, except in Appendix A, the 29,483-kg value is referred to as 30,000 kg.

system (TPS), the development of a fully reusable launch vehicle depends upon demonstrated advances in TPS technology, which may be provided by the Shuttle.

The results of the cost assessment indicate that a fully reusable launch vehicle may reduce the cost per flight by 60-80% compared to that of the Shuttle. The elimination of expendable and refurbished hardware requirements would provide a 50% reduction in cost. Increased efficiency, reduced operations and maintenance manpower, and elimination of facilities indicate a further reduction of 50% of the remaining costs. Total savings could run as high as $34B over 10 years, compared to the Shuttle, which is more than the proposed total program cost for the reusable launch vehicle.

The GRC assessment further indicates that a two-stage parallel-lift launch vehicle would require a slightly higher initial cost than an SSTO, but would have a lower cost per flight, resulting in a total program cost that is approximately the same. The parallel-lift vehicles would also have more operational flexibility, reflected in extended range for self-ferrying, and greater capability for offset orbit injection, loiter, and recall. In addition, the parallel-lift launch vehicles represent lower development risk because of the high utilization of existing technology, engines, and subsystems.

A twin-booster subsonic-staged parallel-lift vehicle represents the lowest cost and development risk. However, it would appear that the investment in the development of a new high-thrust turbojet engine for the supersonic parallel-lift vehicle would return the development cost in total program savings such that the supersonic parallel-lift vehicle would be the economic choice. It must be cautioned, however, that the cost difference between the most economic alternatives may not be significant because of the uncertainties in the cost estimates.

1.4 RECOMMENDATIONS

The cursory assessment of two-stage launch vehicles employing air-breathing boosters as presented in this study indicates that their utility is sufficient to justify additional studies. The concept of parallel lift has opened a fertile new area for generating launch vehicle options. The present study has considered only three parallel-lift vehicle concepts and a single payload size. A supersonic parallel-lift vehicle in the 5,000-10,000 kg payload class is an interesting option as a vehicle of that size could use existing supersonic engines. The preferred staging Mach number needs further study. The Mach 3.5 staging considered here for the supersonic vehicle was selected on the basis of an assessment of the J-58 turbojet engine, which uses 1960 technology. Utilization of a more advanced engine could significantly change the optimum staging Mach number.

To assist in determining the preferred staging Mach number for an air-breathing parallel-lift vehicle, it is recommended that a data base be obtained for turbojet engines which would assist in selecting the type of engine most suitable for a parallel-lift vehicle application. RDT&E cost estimates associated with the development of a supersonic turbojet engine specifically for a parallel-lift vehicle would be useful.

Several important needs for supporting technology have been identified. The thermal protection system for a fully reusable vehicle will, to a large extent, depend on the success of the Shuttle TPS. However, the military use of an Earth-to-orbit launch vehicle could impose environmental requirements that may only be satisfied by a more advanced TPS than that on the Shuttle. It would appear desirable to support development of metallic TPS or still more advanced RSI concepts.

Studies to date have indicated that the transonic drag of parallel-lift vehicles is a key factor in engine thrust-level selection. LaRC is presently planning limited wind tunnel testing to determine the magnitude of the transonic drag problem associated with a parallel-lift vehicle. It is recommended that experimental and analytical vehicle configuration studies be continued and expanded to consider questions related to the magnitude of vortex lift that can be induced during takeoff. Independent of whether a single or twin booster is preferred, additional experimental and analytical analysis is recommended to answer questions regarding the preferred engine inlet configuration for multiple engine pods.

In the area of advanced structures, it is recommended that the feasibility of cryogenic wet wings be studied in detail, with alternative wet-wing design approaches formulated and evaluated. It may even be desirable to conduct limited tests of alternative concepts to aid in selecting the most promising.

This study has proposed a new operational and maintenance concept based on scheduled maintenace patterned after airline operations rather than current space operations. It is recommended that the impact of scheduled maintenance be studied and incorporated into an operational and maintenance cost model to assist in studying the advantages in more detail. It would seem important to obtain inputs from people cognizant of airline maintenance operations.

2 REUSABLE LAUNCH VEHICLE CONCEPTS

2.1 PARALLEL LIFT

The launch vehicle initially proposed by LaRC represents a new concept, called "parallel lift" in this study. Parallel lift is illustrated by the two vehicles shown in Fig. 2-1. In the vehicle without parallel lift, the booster provides the entire lift during takeoff and climb and resembles a very large transport aircraft. In the parallel-lift vehicle, both the orbiter and booster wings provide lift during takeoff and climb. This permits the booster to be reduced by approximately one-third in size and weight. The orbiter wing is sized primarily to withstand reentry heating. The booster wing is sized for flyback and landing, but is modified to better match the orbiter wing for takeoff (to hold takeoff speed within the limits of state-of-the-art tires). Three parallel-lift vehicles were evaluated in this study (see Sec. 4).

2.2 COMPARISON OF AIR-BREATHING AND ROCKET BOOSTERS

Air-breathing propulsion for Earth-to-orbit launch vehicles has been studied several times since the early 1960s. The continual interest in air-breathing propulsion is due primarily to the high engine specific impulse (I_{sp}) obtainable--a factor of 10 better for hydrogen-fueled air-breathing propulsion systems compared to hydrogen-fueled rocket systems. However, when considered in the context of overall system performance, the well-known engine specific impulse advantages shown in Fig. 2-2 translate into less advantageous system performance effects.

Figure 2-1

PARALLEL LIFT

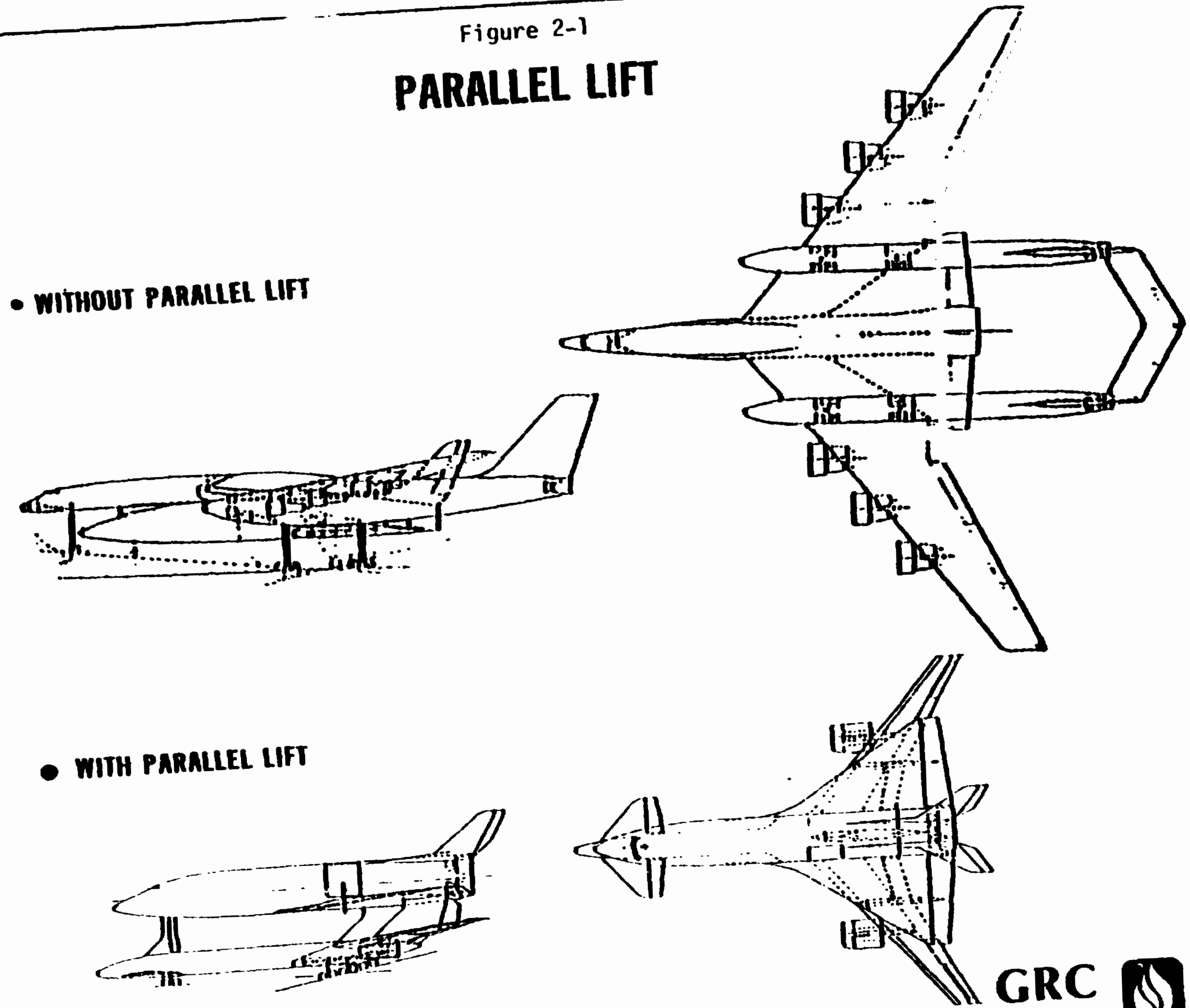

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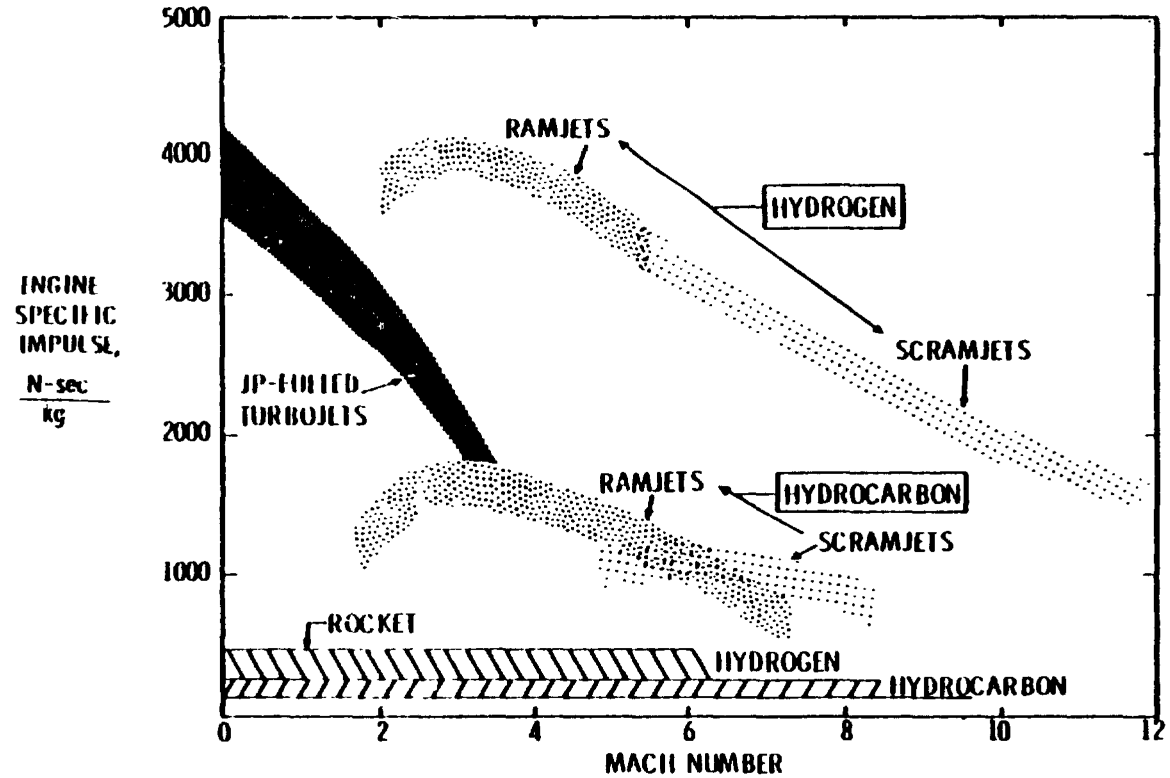
Figure 2-2

PROPULSION OPTIONS



In a two-stage system, both the booster and orbiter propulsion systems impact the average effective specific impulse.* Because air-breathing boosters have lower thrust-to-weight ratios than rocket systems, they are in the atmosphere for a longer time, resulting in higher drag losses. Thus the effective specific impulses of air-breathing systems are lower than the engine specific impulse values shown in Fig. 2-2, but are still higher than those of pure rockets. In practice, the higher engine specific impulse tends to more than compensate for the poorer system mass ratio and higher drag losses associated with air-breathing propulsion. Figure 2-3 compares effective specific impulse for several launch vehicles.

A major advantage of air-breathing propulsion lies in operational flexibility rather than large improvements in performance, relative to a pure rocket. But the air-breathing systems with high staging Mach numbers tend to cost more than rocket systems because of greater dry weight and higher complexity.

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*The average effective specific impulse is the integral over the flight of the instantaneous effective specific impulse, which is defined as

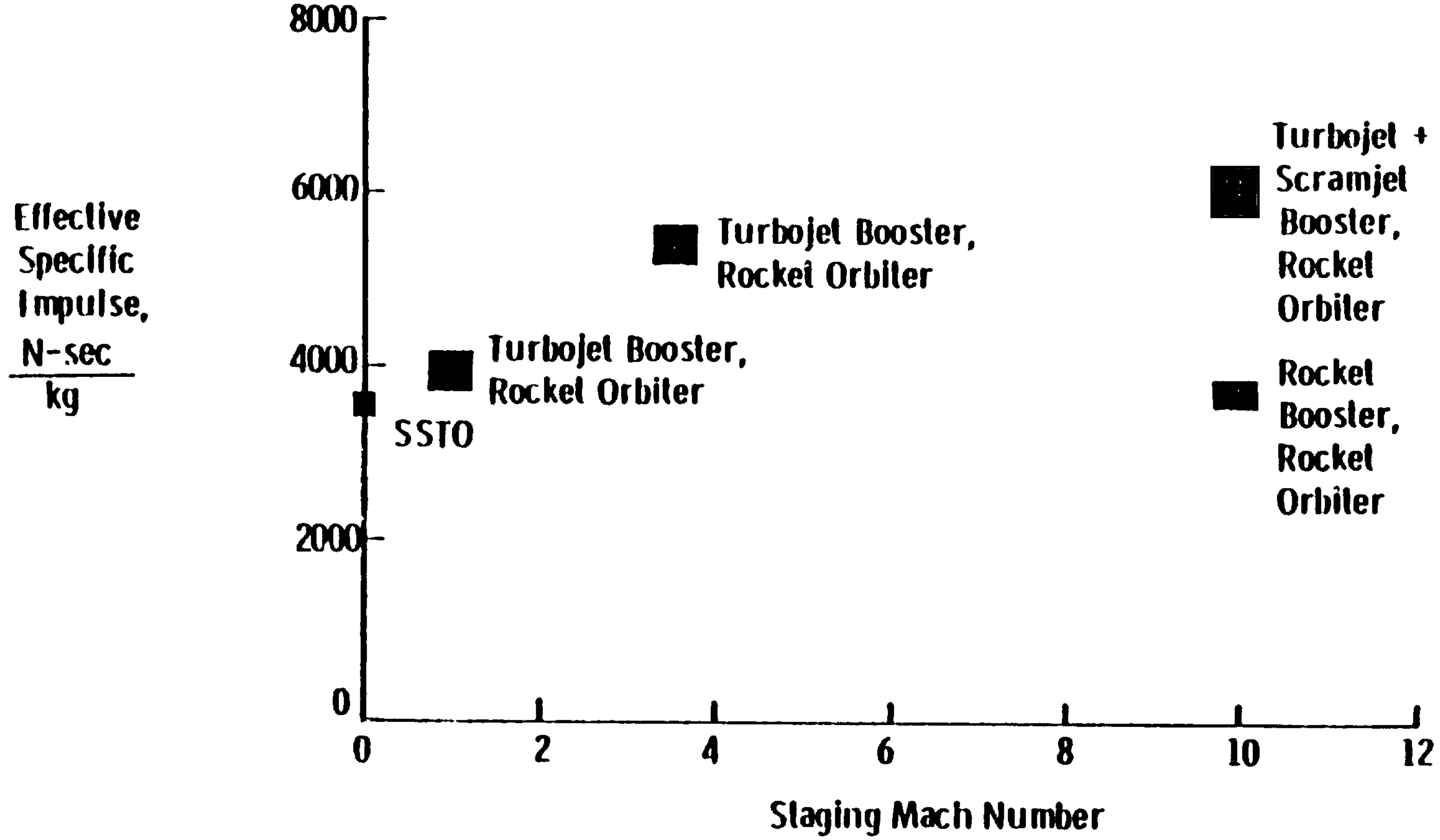
$$I_{eff} = I\left(1 - \frac{D/W + \sin\theta}{T/W}\right)$$

where I = engine specific impulse, D/W = drag-to-weight ratio, T/W = vehicle thrust-to-weight ratio, θ = flight path angle from horizontal. $(D/W + \sin\theta)$ represents the flight path losses. The average effective specific impulse can be considered as the value which gives the final vehicle velocity when used for specific impulse in the rocket equation without gravity and drag losses ($V \propto I \ln r$).

Figure 2-3

PERFORMANCE ASSESSMENT — PROPULSION

92.5 x 185 km, 28° ORBIT (93 x 185 km)



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2.3 OPERATIONAL CONCEPT

A typical mission profile (shown in Fig. 2-4) for a horizontal-takeoff two-stage launch vehicle consists of:

1 A horizontal takeoff and climb to staging altitude and Mach number using an air-breathing booster.

2 At staging, the orbiter main engine is started and the booster engines are throttled back to allow the orbiter to fly away from the booster(s).

3 The booster(s) then flies (fly) back to the launch site, either piloted or remotely guided for a horizontal landing.

4 The orbiter continues into orbit after staging, delivering its payload, and returning to either the launch site or an alternative landing site, and lands horizontally.

A ground operations profile for the parallel-lift two-stage launch vehicle is shown in Fig. 2-5. After landing, the orbiter is retrieved by a tow vehicle which supplies all ground power (electrical, pneumatic, transport). The orbiter is taken directly to a deservicing facility, where any returned payload is removed. In the deservicing facility, the hydrogen propellant lines and propellant tanks are purged to eliminate any residual hydrogen gases and liquids which could be a potential explosion hazard. Any other potentially hazardous material is also removed. After de-servicing, the orbiter is towed to the maintenance and assembly facility for routine checkout and servicing of noncritical, scheduled-maintenance items. All unscheduled maintenance is also completed, and the orbiter is prepared for booster mating. The boosters are serviced prior to the orbiter return and are available for the mating operation as soon as the orbiter is ready. In the case of the two-booster configuration, it is envisioned that the boosters would be sufficiently lowered

Figure 2-4

MISSION FLIGHT PROFILE

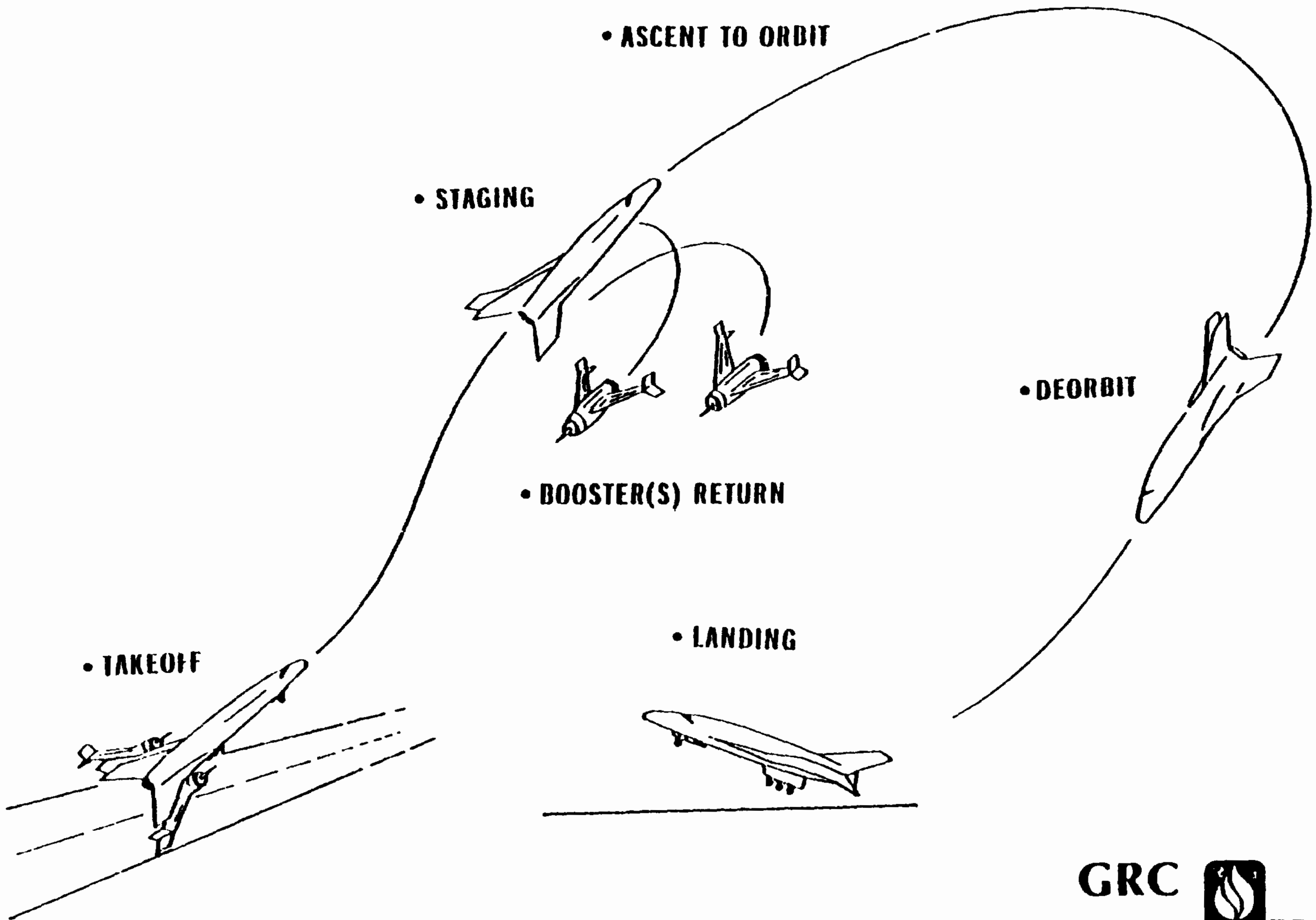

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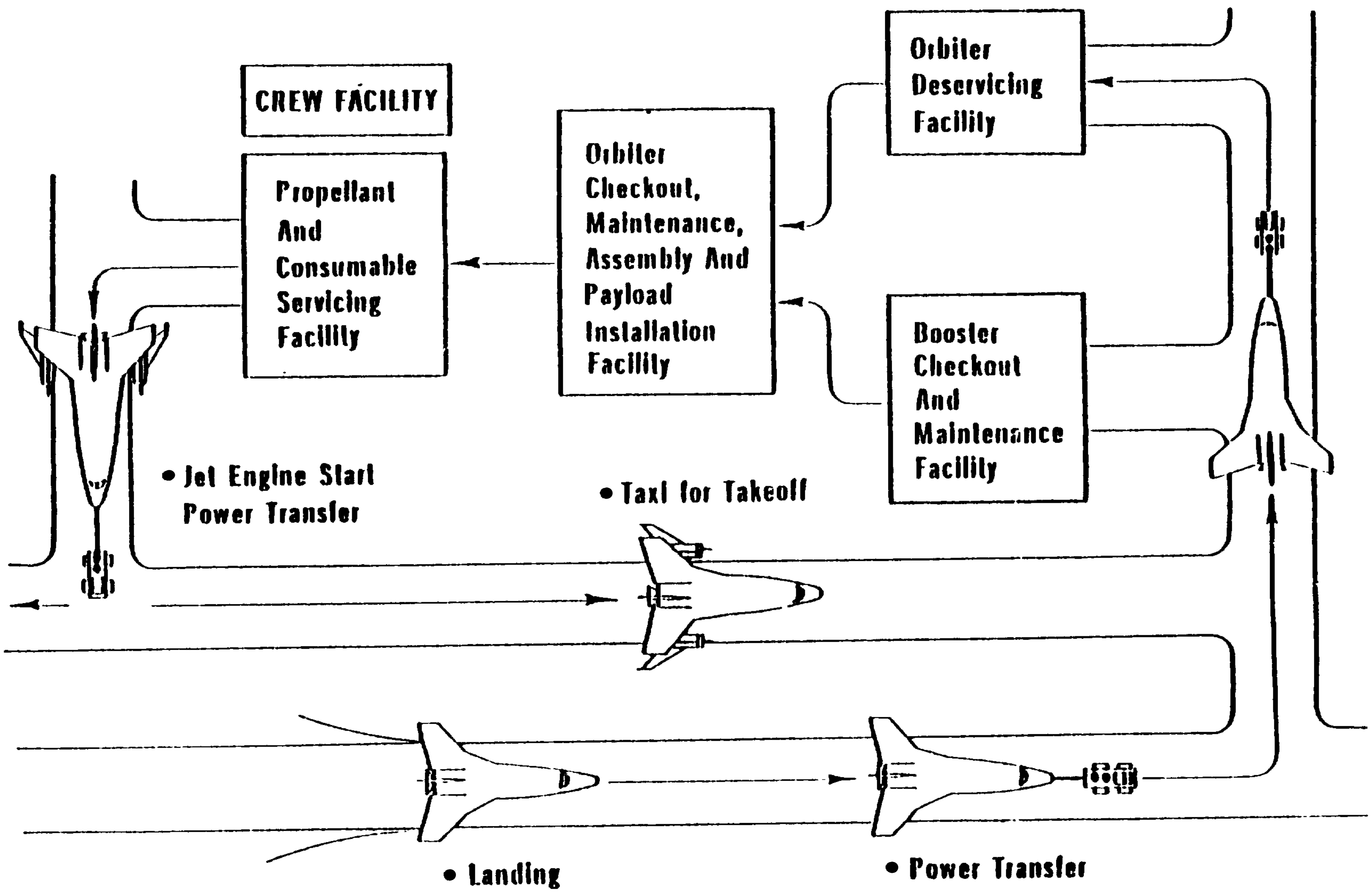
Figure 2-5

GROUND OPERATIONS PROFILE

(60 Hour Turnaround Time)



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by hydraulic-activated landing gear to allow them to be towed under the orbiter wings. The boosters would then be raised and mated to the orbiter. After the mating operation, the assembled vehicle undergoes an integrated operations verification. Next the payload is loaded and the vehicle towed to the propellant and consumable servicing facility, where final preparations for flight are completed.

The crew boards the vehicle during the final stages of propellant loading to conduct the final preflight checkout. Then the vehicle is towed onto the runway apron, where the jet engines are started, and power is transferred from ground to on-board systems. The vehicle is now ready for takeoff. Based on the timeline shown in Fig. 2-6, it is estimated that this turnaround could be accomplished in 60 hours over a 2.5-day period, assuming a three-shift operation.

2.4 ATTRIBUTES OF AIR-BREATHING TWO-STAGE VEHICLES

Figure 2-7 lists the attributes of air-breathing reusable vehicles. As already noted, all launch vehicles considered in the study are assumed to be fully reusable, not requiring recovery, refurnishment, or replacement operations such as those associated with the Shuttle solid rocket motors (SRM). Horizontal assembly, takeoff, and landing operations are compatible with this concept and would appear to result in appreciable savings of cost and time compared to vertical assembly and launch operations, since no launch pad or mobile launcher is required. It is assumed that air-breathing designs are compatible with existing runways (as long as the bearing pressure on the run-way is kept at current levels), thereby extending launch site opportunities to any site with adequate runway length and the availability of cryogenic servicing. Hence, reusable air-breathing boosters could provide extended range operations enabling remote launch site operations while retaining the advantages of centralized maintenance. In-flight refueling of the booster would enable the launch vehicle to be flown to or from any place desired. The increased efficiency of

Figure 2-6

TYPICAL GROUND OPERATIONS FLOW
(PARALLEL-LIFT VEHICLE)

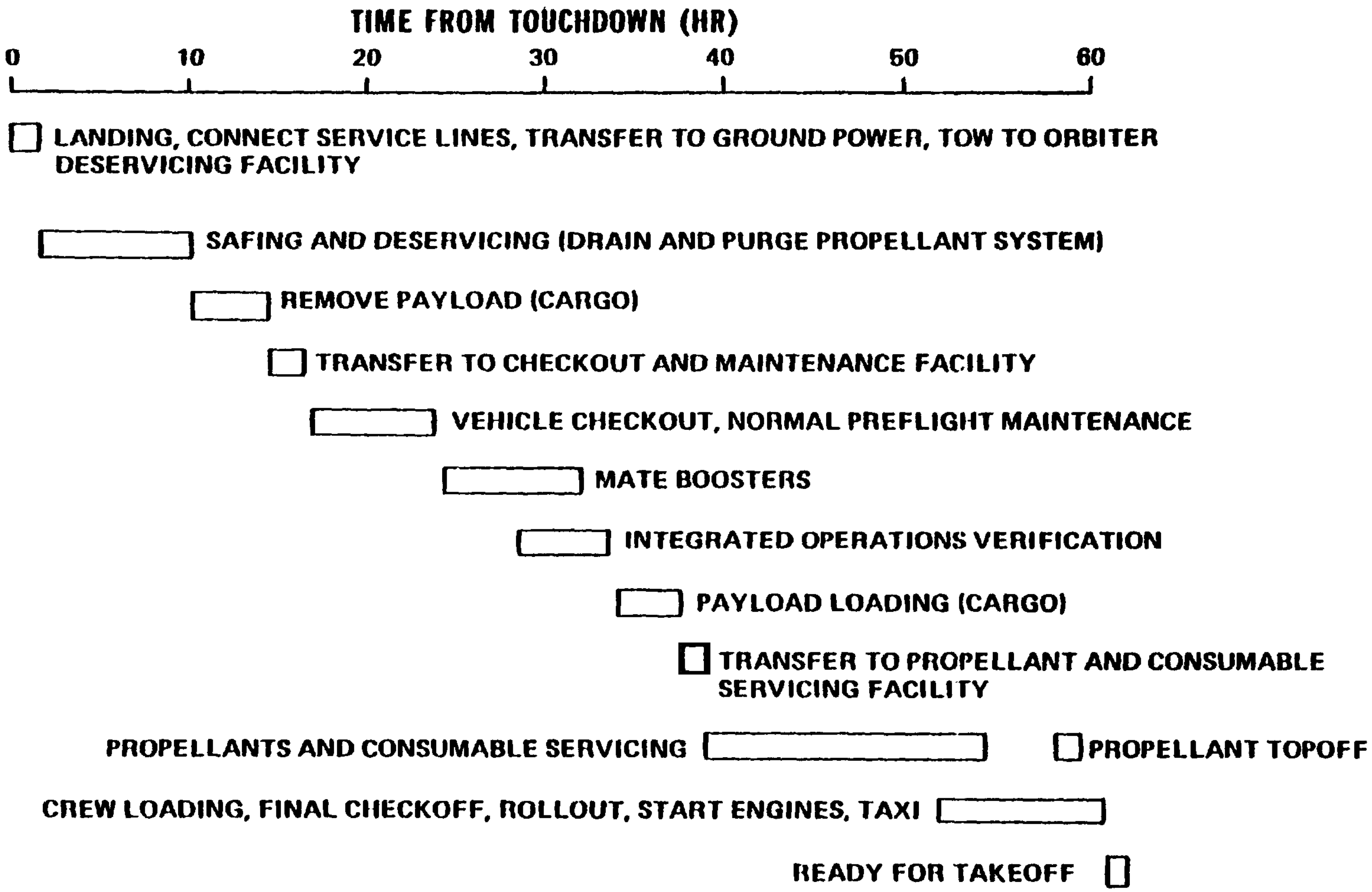

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Figure 2-7

AIR-BREATHING LAUNCH VEHICLE ATTRIBUTES

- FULLY REUSABLE LAUNCH VEHICLE
- HORIZONTAL ASSEMBLY
- HORIZONTAL TAKEOFF AND LANDING
- MULTIPLE LAUNCH, MULTIPLE LANDING SITES
- EXTENDED RANGE
- OFFSET ORBIT INJECTION
- PARALLEL BURN
- LOITER
- SCHEDULED MAINTENANCE

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air-breathing engines compared to rocket engines would enable a 200-km offset orbit injection capability to be included in the nominal fuel loading. The offset range could be used for loiter or recall to the launch site after takeoff.

Extended ferry operations offer the opportunity of using remote launch sites in equatorial regions or foreign countries. Foreign lease of a launch vehicle for a specific period of time, compatible with scheduled maintenance, could be desirable in terms of international relations.

A fully reusable launch vehicle would not have launch azimuth restrictions imposed by falling solid rocket boosters and external tanks. Hence launch operations could be conducted from various sites (some inland), or all launches could be conducted from a single site, eliminating the need for East Coast and West Coast launch sites (as with the Shuttle) to satisfy mission requirements. Savings in launch site costs could easily run into hundreds of millions of dollars.

For applications in which time-to-orbit is a key factor, a parallel-burn launch is possible: the orbiter rocket engines are started once the vehicle starts its ground roll, or as soon as the vehicle is airborne and a safe distance from the runway, to prevent damage due to rocket exhaust impingement. (Local noise ordinances are a consideration as well.) Another advantage of a parallel-burn capability is that it might permit the use of lower thrust turbojet engines, alleviating the need for a high-thrust engine development program.

The most important advantage of reusable vehicles identified in this study is scheduled maintenance operations. If the maintenance schedule proposed here can be achieved, an increase in launch vehicle utilization results, and this is reflected in significant reductions in operating costs.

(Indications are that a factor of at least 2 relative to the Shuttle may be achievable in launch vehicle utilization rates.) The ground operations timelines are based on a maintenance schedule that assumes for the launch vehicle a reusable TPS that requires refurbishment only after seven flights. Technological advances are required before the outlines operations schedule can be achieved.

3 MISSION ASSESSMENT AND LAUNCH VEHICLE REQUIREMENTS

Based on a survey of proposed advanced space systems (both NASA[2,3] and military[1]), mission opportunities were identified and categorized according to function, e.g., observation, communications, weapons, and services. In parallel with the mission classification, several space scenarios proposed by the Hudson Institute[4] and the Aerospace Corporation[5] were reviewed and condensed. The scenarios and the mission data were then combined to provide specific launch vehicle payloads and delivery orbits. The results can be used to define future Earth-to-orbit launch vehicle requirements. No attempt was made to establish a specific launch payload model such as that currently in use for Shuttle planning purposes.

3.1 SCENARIOS

The Hudson Institute and the Aerospace Corporation scenarios (Fig. 3-1) were condensed into: (1) business as usual with normal growth, and (2) the rapid expansion of space operations.

3.1.1 Scenario No. 1

It is anticipated that the Shuttle will eventually become a successful enterprise, and that commercial use of space will gradually increase as business ventures prove economically successful. A reusable orbital transfer vehicle (OTV) will be developed to conduct Earth orbital operations and provide low-Earth-to-geosynchronous-orbit transfer. (A vehicle that could reach geosynchronous orbit and return would also be able to operate throughout cis-lunar space as the need occurred.) The OTV will be Earth based and upon occasion refueled in low Earth orbit. The total demand for Shuttle flights is not expected to exceed 100 per year. It is not likely that a new Earth-to-orbit launch vehicle will be developed.

Figure 3-1

FUTURE SCENARIOS

SCENARIO	EXPECTED SPACE ACTIVITY
(1) BUSINESS AS USUAL WITH NORMAL GROWTH (100 SHUTTLE FLIGHTS PER YEAR)	• SHUTTLE IS SUCCESSFUL • SPACE BUSINESS APPLICATIONS ARE SUCCESSFUL • STEADY USE OF CIS-LUNAR SPACE AFTER 1980's
(2) BREAKTHROUGH WITH THE RAPID EXPANSION OF SPACE OPERATIONS (1000 LAUNCH VEHICLE FLIGHTS PER YEAR)	• A CHANGE OCCURS — IN TECHNOLOGY, PUBLIC OPINION, OR SPACE EXPLORATION/EXPLOITATION • RAPID REDUCTION IN SPACE TRANSPORTATION COSTS • IMPROVED RETURNS FROM SPACE INVESTMENTS • RAPID EXPANSION IN SPACE SERVICES AND ACTIVITIES • RETURNS FROM SPACE SERVICES AND ACTIVITIES STRONGLY AFFECT EVENTS ON EARTH

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3.1.2 Scenario No. 2

It is assumed that a breakthrough will dramatically change the demand for space utilization. The nature of the breakthrough could be a change in the public's perception of space, a technological event that makes space operations extremely desirable, or a discovery that changes the need for space operations. Extremely profitable space investments could initiate a strong competitive demand and, of course, a recognized military advantage could accelerate competition between nations. The achievement of very low transportation costs could also establish a strong demand for space utilization. Whatever the cause, it is postulated that a rapid increase in space operations can be expected. Orbital transfer vehicles will be space based. Several hundred launches per year are anticipated.

3.2 MISSION OPPORTUNITIES

More than 500 near- and far-term proposed advanced space systems were surveyed. The systems were categorized functionally as observation, communications, weapons, and support operations. Each category was further divided into classes of missions (Fig. 3-2). Corresponding to each of the two scenarios above, a set of typical missions was derived from within the mission classes (Fig. 3-3); they are representative of the spectrum of expected launch vehicle payload and space operations requirements. In the business-as-usual scenario (#1), the launch vehicle is required to carry a variety of individual spacecraft for near-earth and deep-space operations and to serve as (1) a spacecraft launch facility; (2) a spacecraft maintenance and repair facility; (3) a short-duration space laboratory and habitat; (4) an orbital-transfer-vehicle delivery, launch and retrieval system; and (5) an Earth orbital construction facility, including provisions for teleoperator services. The launch vehicle has a high degree of in-orbit flexibility in order to conduct short-term space support functions to compensate for the lack of space basing.

Figure 3-2

SUMMARY OF MISSION CLASSES

SPACE FUNCTION	NASA MISSIONS	MILITARY MISSIONS
(Categories)		
OBSERVATION	LAND OCEANS ATMOSPHERIC SOLAR SPACE: NEAR EARTH, DEEP SPACE	LAND OCEANS ATMOSPHERIC SOLAR" NEAR EARTH SPACE
COMMUNICATIONS	INTERGOVERNMENT INTRAGOVERNMENT GOVERNMENT PEOPLE PEOPLE PEOPLE	NATIONAL COMMAND & CONTROL INTRATHEATER INTERTHEATER STRATEGIC FORCES SPECIAL OPERATIONS
WEAPONS	—	SPACE-BASED OFFENSIVE & DEFENSIVE WEAPONS GROUND-BASED SPACE DEPLOYABLE OFFENSIVE & DEFENSIVE WEAPONS

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Figure 3-2 (Cont.)

SUMMARY OF MISSION CLASSES (Cont.)

SPACE FUNCTION	NASA MISSIONS	MILITARY MISSIONS
(Categories)	NAVIGATION	NAVIGATION
	TRANSPORTATION CONTROL	TRANSPORTATION CONTROL
	ENERGY PRODUCTION & TRANSFER	ENERGY PRODUCTION & TRANSFER
	ENVIRONMENT MODIFICATION	ENVIRONMENT MODIFICATION
	MANUFACTURING	RDT&E ACTIVITIES
SUPPORT	RDT&E ACTIVITIES	DISPOSAL & CONTROL OF WASTE MATERIAL
	DISPOSAL & CONTROL OF WASTE MATERIAL	SPACE TRANSPORTATION
	SPACE CONSTRUCTION	SPACE CONSTRUCTION
	SPACE DELIVERY & MAINTENANCE	SPACE DELIVERY & MAINTENANCE
	SPACE TRANSPORTATION	MANNED SPACE OCCUPANCY
	MANNED SPACE OCCUPANCY	

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Figure 3-3

TYPICAL MISSION OPPORTUNITIES

SCENARIO	MISSIONS
(1) BUSINESS AS USUAL WITH NORMAL GROWTH (100 SHUTTLE FLIGHTS PER YEAR)	• SATELLITE DELIVERY SYSTEM • SHORT-DURATION SPACE LABORATORY • PLANETARY SPACECRAFT DELIVERY AND LAUNCH • SATELLITE SERVICING • ORBITAL TRANSFER VEHICLE DELIVERY, LAUNCH & RETRIEVAL • EARTH ORBITAL ASSEMBLY OPERATIONS
(2) BREAKTHROUGH WITH THE RAPID EXPANSION OF SPACE OPERATIONS (1000+ FLIGHTS PER YEAR)	• GENERAL CARGO AND PASSENGER DELIVERY

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In the rapid expansion scenario (#2), a high level of space-based operations is provided by facilities other than the launch vehicle. The launch vehicle is a general cargo and passenger delivery system with very limited orbit stay-time capability and no space-support functions.

3.3 LAUNCH VEHICLE REQUIREMENTS

Since in the business-as-usual scenario, the launch vehicle is required to perform many space support functions (as well as deliver a variety of spacecraft), it is expected to be able to reach a highly diversified spectrum of orbital destinations. Individual payloads consist predominately of single or multiple spacecraft and erectable structures up to the payload weight of the vehicle. Limited in-orbit assembly operations requiring two or more payloads are required. In the rapid expansion scenario, a large number of scheduled flights to a very limited number of destinations are conducted by the launch vehicle. The payload consists largely of passengers to and from space, equipment for space bases, and general cargo of which a high percentage is resupply and construction materials. The launch vehicle requirements for the two scenarios are summarized in Fig. 3-4.

Figure 3-4

LAUNCH VEHICLE REQUIREMENTS SUMMARY

	(1) BUSINESS AS USUAL WITH NORMAL GROWTH	(2) BREAKTHROUGH WITH THE RAPID EXPANSION OF SPACE OPERATIONS
ORBITS	500 km 35-58 INCLINATIONS 900 km SUN SYNCHRONOUS 200-1100 km POLAR SYNCHRONOUS EQUATORIAL ELLIPTICAL SYNCHRONOUS	350-900 km, 35-50° INCLINATION 200-1100 km, POLAR (SPECIALIZED TRANSPORT VEHICLE FROM LOW EARTH ORBIT)
PAYLOADS	WEIGHT, 700-20,000 kg, SINGLE P/L 30,000 kg LABORATORY SIZE, 10-200 m	5-20,000 kg PASSENGERS/CARGO 5-50,000 kg GENERAL CARGO/ EQUIPMENT 5000-500,000 kg CONSTRUCTION MATERIAL 5,000,000-20,000,000 kg BASES 2-3 m 10-200 m 1000-10,000 m

GRC

4 LAUNCH VEHICLE DESCRIPTIONS

The alternative launch vehicles considered in this study are noted in Sec. 1.2 and depicted in Fig. 4-1. The seven vehicles, differentiated by propulsion type, number of stages, and staging conditions, are described in more detail in this section.

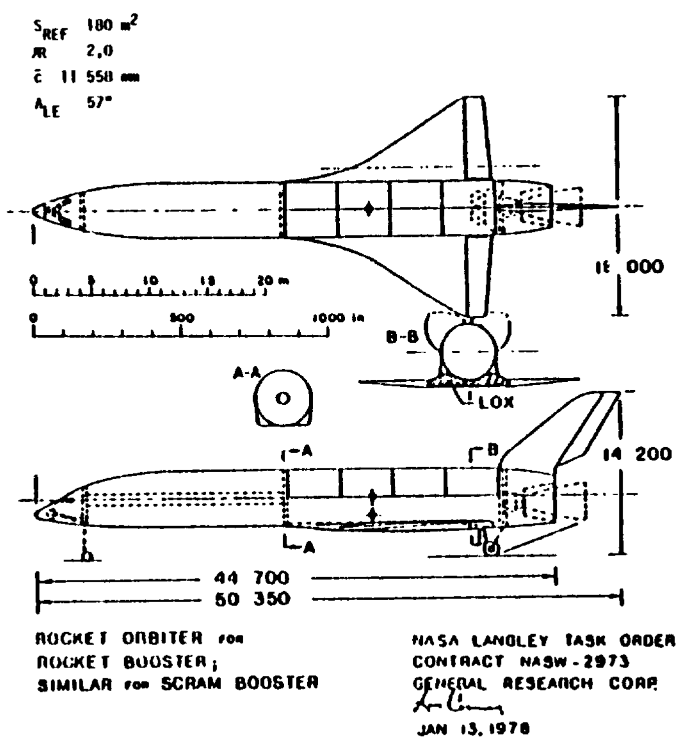
As noted in Sec. 2, all stages are fully reusable and land horizontally in either a manned or unmanned mode. All air-breathing boosters burn RP except the hydrogen-burning scramjet. All rocket engines use H_2/O_2 propellant. Each vehicle is designed for minimum liftoff weight with a 30,000-kg payload (in a Shuttle-sized bay) delivered to a 93 × 185 km, 28° orbit. All of the horizontal take-off boosters utilize a wet wing, which reduces structural weight.

The design of the supersonic-staged vehicle (Sec. 4.5) was provided by LaRC at the time that this study was tasked, and is perhaps the preferred, or reference design. Late in the study, LaRC provided an additional design, this one for a subsonic-staged vehicle using twin boosters (Sec. 4.8). Because of limited time, this design received only partial consideration and is hence not included in all figures comparing the alternatives. Both LaRC designs, as well as the GRC-designed single-booster subsonic-staged vehicle, use parallel lift, which is of prime interest in this study (see Sec. 2.1).

Alternative designs for performance and cost comparison were obtained from Martin[6,7,8] (Sec. 4.2) or Boeing[9,10] (Sec 4.3), or were generated as part of this study (Secs. 4.4, 4.6, and 4.7). Because of the finite effort available, none of these designs is necessarily optimized. The purpose of this study was to examine the relative merits of different types of vehicles, for which these designs are quite satisfactory. Within each design type, several options that are not pursued in this study are available.

Figure 4-1

ORBITER FOR HYPERSONIC BOOSTER SYSTEMS



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The various launch vehicles are discussed in Secs. 4.2-4.8, with emphasis on the booster. The orbiters are discussed in Sec. 4.1, the weights of all the vehicles are summarized in Sec. 4.9, and Sec. 4.10 presents flight parameter data. Since all vehicles deliver the same payload to the same orbit, the relative performance is best compared on the basis of gross vehicle weight.

4.1 ORBITER VEHICLES

The differences in the staging conditions among the several two-stage vehicles naturally lead to differences in the orbiters, although there was an attempt to use similar design features where possible. The orbiters of all two-stage vehicles use an aluminum structure, in contrast to the more advanced structural materials of the single-stage-to-orbit vehicles.

All orbiters except the SSTO-VTO use the same engines: modified Space Shuttle main engines (SSME) uprated to 23.8 MN/m^2 (3450 psia) chamber pressure and 2.65 MN (596,000 lbf) vacuum thrust, and two position nozzles with expansion ratios of 82 and 150. (Appendix A has more detail on SSME performance.) The two hypersonic-staged orbiters are identical vehicles (Fig. 4-1) using a single SSME. The other three orbiters and the SSTO-HTO vehicle have three SSMEs each, and the SSTO-VTO has six advanced engines.

Scramjet engines were also considered for the orbiter stage of the supersonic and subsonic parallel-lift vehicles. However, preliminary calculations indicated only a small performance advantage, which was offset by a relatively large increase in complexity and costs. Perhaps new technical data or new design concepts could lead to a different result at a later date.

The projected shift from Earth- to space-based operations suggests a high-density internal cargo bay and perhaps a capability for carrying very long structural members for assembly in space. The solar power mission, for example, would require many such structural members and possibly rolls of aluminized plastic reflecting material. The orbiter shown in Fig. 4-2 (for the single subsonic-staged vehicle) attempts to accommodate these requirements. The side-loading cargo doors free the back of the orbiter for strap-on cargo and fairings. This type of door should also be structurally more efficient than the 18-m (60-ft) Shuttle clamshell-type doors. Side-loading should also be operationally more efficient for horizontally oriented operations. The twin tails represent a further attempt to provide for very long, narrow cargo, and would also provide additional hypersonic directional stability at moderate angles of attack.

For the hypersonic-staged orbiters (Fig. 4-1), the Shuttle cargo-bay shape does not seem to impose much of a penalty. The cargo bay with the required 5-m (15-ft) inside diameter appears to blend with the lightly loaded thin wing and relatively narrow forward hydrogen tank, with little penalty. However, for the subsonic-staged orbiter, the Shuttle cargo-bay shape, as well as size, appears to preclude a structure of maximum efficiency. The supersonic-staged orbiter is somewhat less sensitive to structural efficiency.

4.2 SINGLE STAGE TO ORBIT WITH VERTICAL TAKEOFF (SSTO-VTO)

The Martin Company design of the SSTO-VTO (Fig. 4-3) has a gross weight of 1200 metric tons, based on (1) high-pressure H_2/O_2 propulsion, and (2) advanced structure technology. Performance of single-stage-to-orbit vehicles is extremely sensitive to structural weight. A 1-kg increase in structure means a 1-kg decrease in payload and consequently a 10% increase in structure (from the

Figure 4-2

ROCKET ORBITER FOR SUBSONIC PARALLEL-LIFT SINGLE BOOSTER

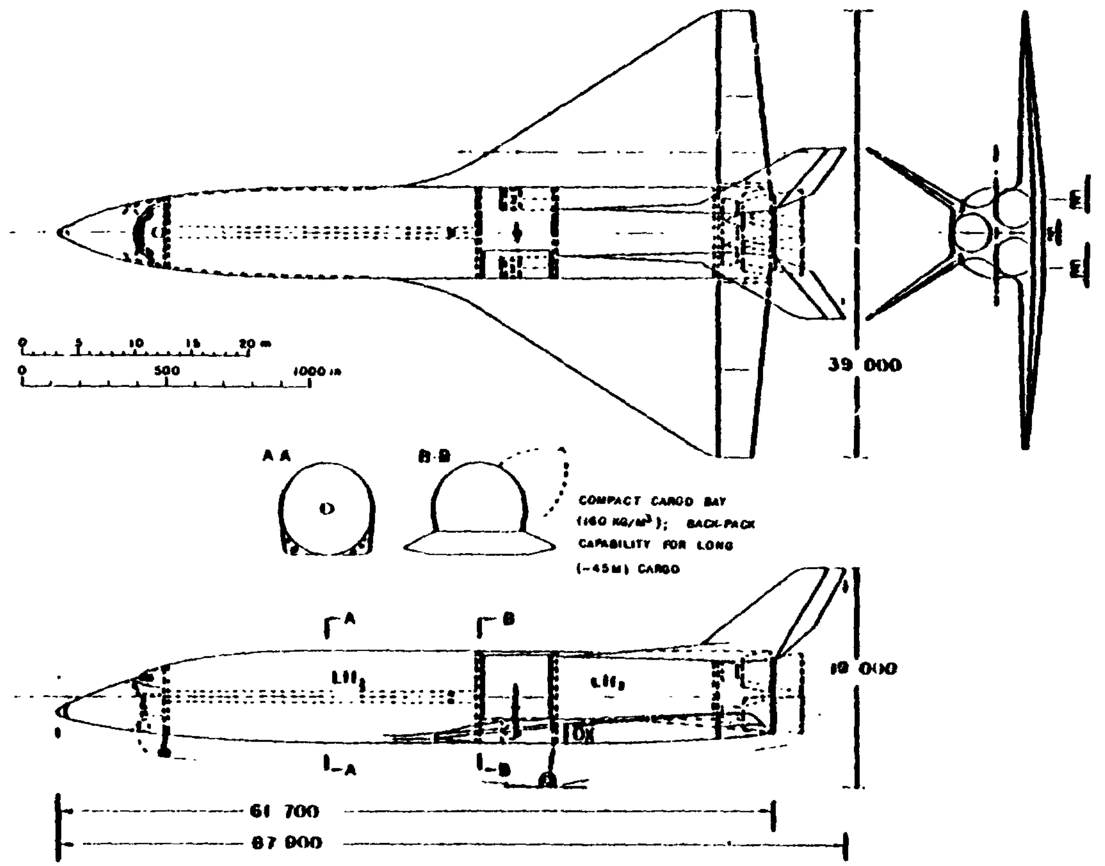

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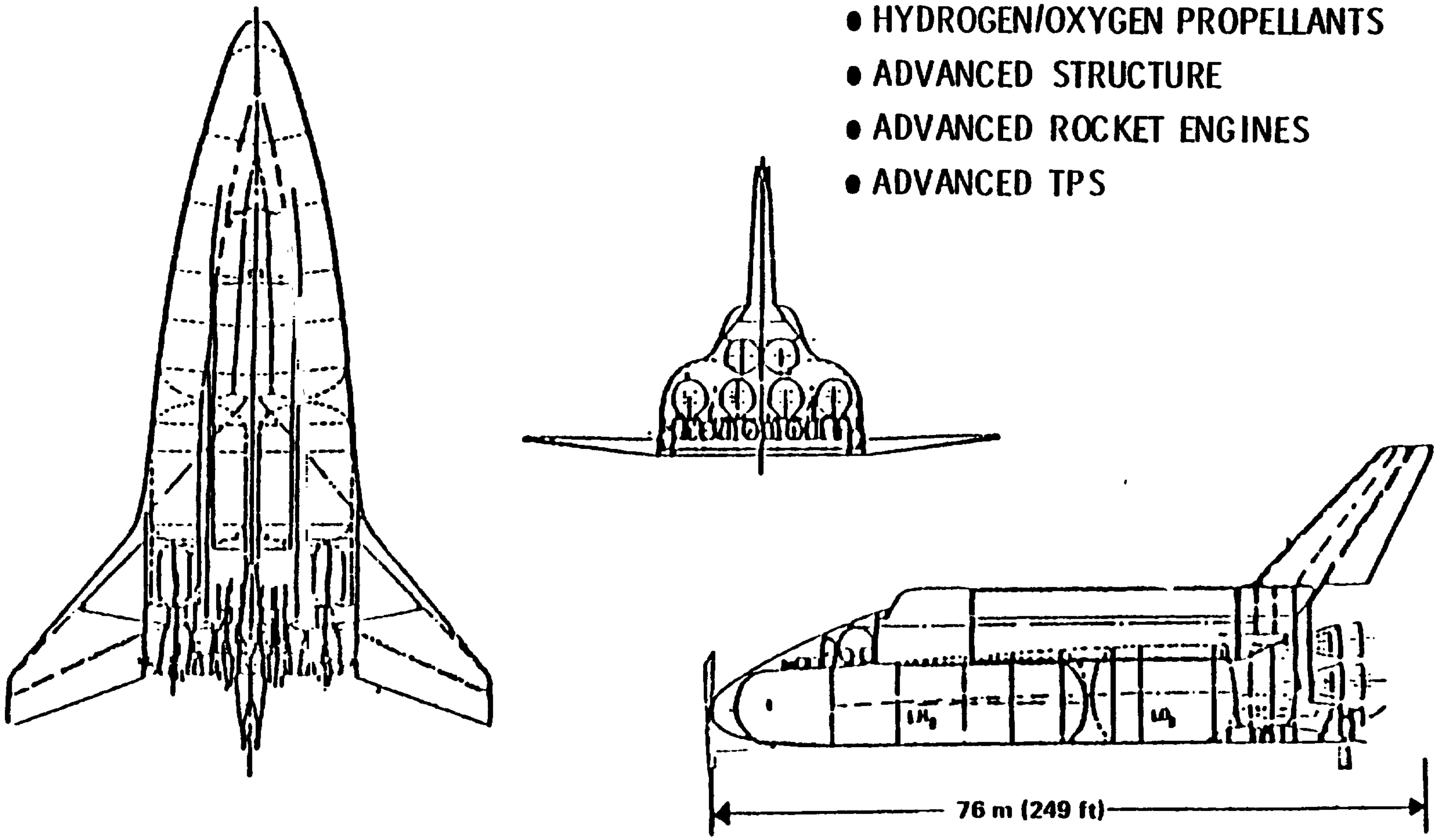
Figure 4-3

SINGLE-STAGE-TO-ORBIT LAUNCH VEHICLE

(VERTICAL TAKEOFF, HORIZONTAL LANDING)

- HYDROGEN/OXYGEN PROPELLANTS
- ADVANCED STRUCTURE
- ADVANCED ROCKET ENGINES
- ADVANCED TPS



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objective) would mean a payload reduction of almost 50%. The TPS consists of non-metallic reusable surface insulation supported by an advanced metallic substructure.

4.3 SINGLE STAGE TO ORBIT WITH HORIZONTAL TAKEOFF (SSTO-HTO)

The Boeing conceptual design[6] (Fig. 4-4) utilizes a rocket sled to permit horizontal takeoff. After the assisted takeoff, the vehicle is single stage to orbit. Landing weight is only about 14% of liftoff weight, so the sled permits a lighter landing gear, as well as providing initial velocity. The estimated liftoff weight is approximately 1250 metric tons (2,750,000 lb). The sled would weigh about 250 metric tons.

Horizontal takeoff permits a lower initial thrust-to-weight ratio than vertical takeoff. Optimum thrust-to-weight for sled-assisted horizontal takeoff is approximately 0.7 compared to 1.3 for vertical takeoff. This results in substantial engine weight reductions and consequent structural weight savings from less stringent vehicle balance requirements. The TPS is an integrated metallic heat shield and substructure of honeycomb construction, referred to as a "hot structure."

4.4 ALL-ROCKET TWO-STAGE VEHICLE

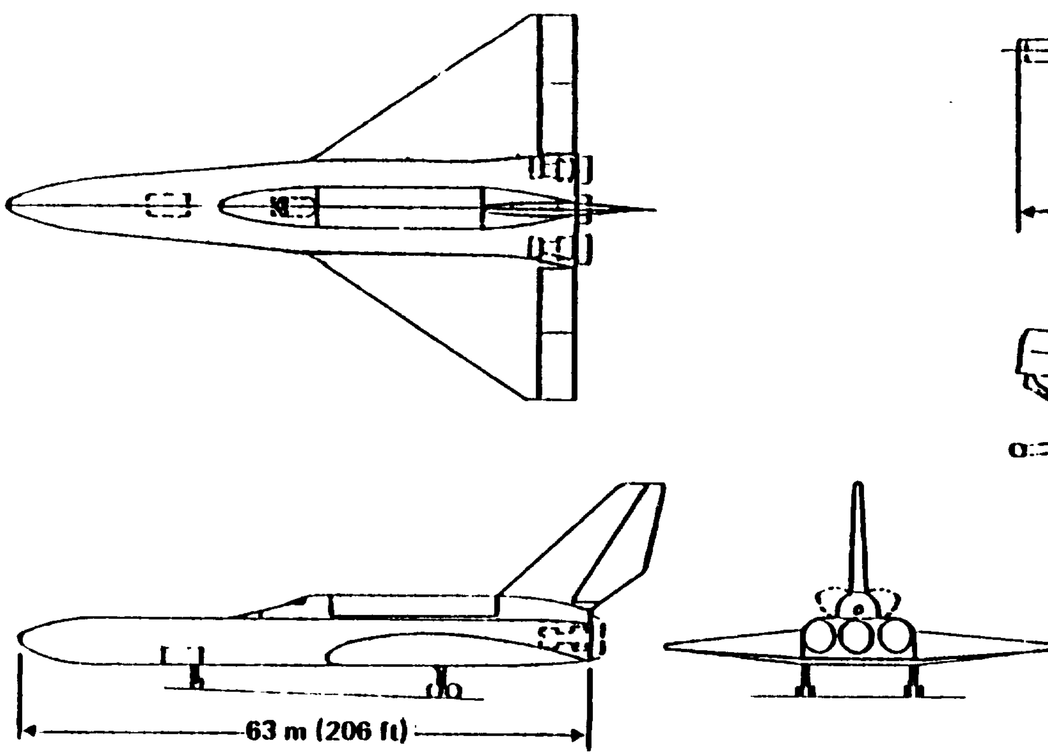
The conventional approach to a two-stage launch vehicle (all-rocket propulsion) is included for comparison with the air-breathing boosters. This rocket booster (Fig. 4-5) is powered by four SSMEs, the orbiter by one. The gross weight is 1050 metric tons (2,310,000 lb). The orbiter is identical to the one designed for the scramjet launch vehicle (Sec. 4.8), and the rocket booster is designed to provide the desired performance with that orbiter. Consequently the overall design is not optimum, possibly contributing to the somewhat difficult staging conditions (75 km altitude) that result in some uncertainty regarding the TPS and the technological risk associated with the design.

Figure 4-4

SINGLE-STAGE-TO-ORBIT LAUNCH VEHICLE

(HORIZONTAL TAKEOFF AND LANDING — SLED ASSIST)

- ORBITER
  - HYDROGEN/OXYGEN PROPELLANTS
  - NORMAL GROWTH STRUCTURE
  - MODIFIED SHUTTLE MAIN ENGINE
  - ADVANCED TPS



- SLED
  - EXISTING ROCKET ENGINE
  - EXISTING AVIONICS
  - ADVANCED TIRES

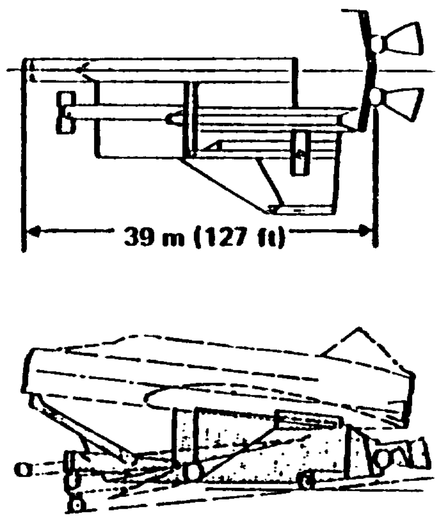


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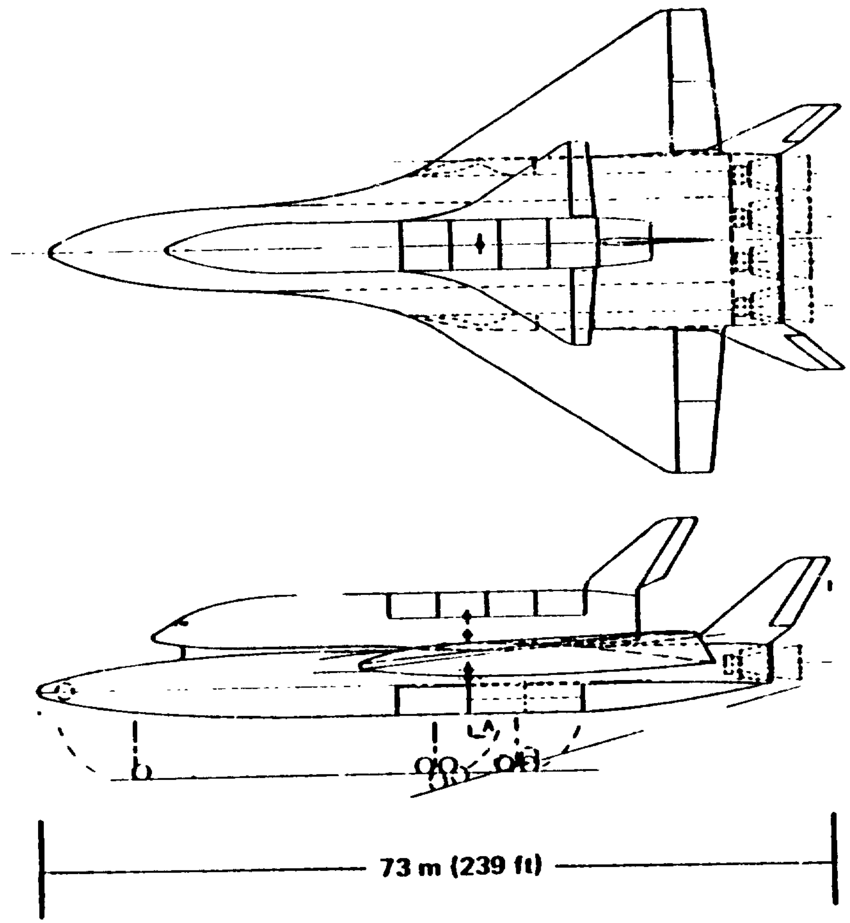
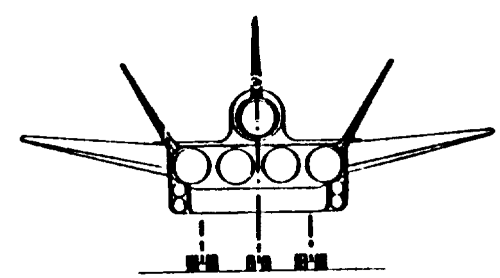
Figure 4-5

TWO-STAGE-ALL-ROCKET LAUNCH VEHICLE
(HORIZONTAL TAKEOFF AND LANDING)



- ROCKET BOOSTER
- (Mach 10+ Staging)
- HYDROGEN/OXYGEN PROPELLANTS
- NORMAL GROWTH STRUCTURE
- MODIFIED SHUTTLE MAIN ENGINE
- ADVANCED TPS



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4.5 SUBSONIC-STAGED SINGLE AIR-BREATHING BOOSTER PARALLEL-LIFT VEHICLE

To enable the use of currently produced jet engines, subsonic staging of the parallel-lift launch vehicle is considered. The engine selected is the F-100 currently used in the F-15 and F-16 fighter planes. To maximize the use of existing hardware, a single-booster configuration is selected, making maximum use of 747 wing structure. The orbiter in the subsonic configuration was initially sized for a high-density payload and side loading rather than top loading as is the case with the supersonic configuration (Sec. 4.6) and the Shuttle. For consistency in costing, an orbiter for the subsonic vehicle configured with the Shuttle payload bay is also considered.

Figure 4-6 shows the vehicle configuration (designed by GRC), which uses parallel-lift booster flight. Staging occurs at 6700 m altitude and 250 fps (Mach 0.8), only slightly greater velocity than the sled-assisted launch of the SSTO-HTO. The initial vehicle weight is 1371 metric tons, of which 1104 metric tons is the orbiter plus payload. This weight is heavier than the SSTO-HTO because of differences in the technology levels assumed.

4.6 SUPERSONIC-STAGED TWIN AIR-BREATHING BOOSTER PARALLEL-LIFT VEHICLE

The design for the supersonic vehicle (Fig. 4-7) was supplied by LaRC at the initiation of this study, to be compared with other conceptual designs. The vehicle incorporates RP propellants in unmanned twin boosters, and hydrogen/oxygen in the rocket orbiter using three modified Shuttle main engines. The booster is powered by eight 350,000-N (80,000-lbf) thrust supersonic turbojet engines, which would constitute a new development. Existing 220,000-N (50,000-lbf) thrust engines could provide the technological base. The initial gross weight is 1285 metric tons. The staging conditions are Mach 3.5 at an altitude of 18,000 m (57,000 ft).

Figure 4-6

SUBSONIC-STAGED PARALLEL-LIFT LAUNCH VEHICLE (Single Booster)

- TURBOJET BOOSTER
- (Mach 0.8 Staging)
- HYDROGEN/OXYGEN PROPELLANTS
- CURRENT STRUCTURE
- EXISTING TURBOFAN ENGINES
- MODIFIED SHUTTLE MAIN ENGINE
- ADVANCED TPS

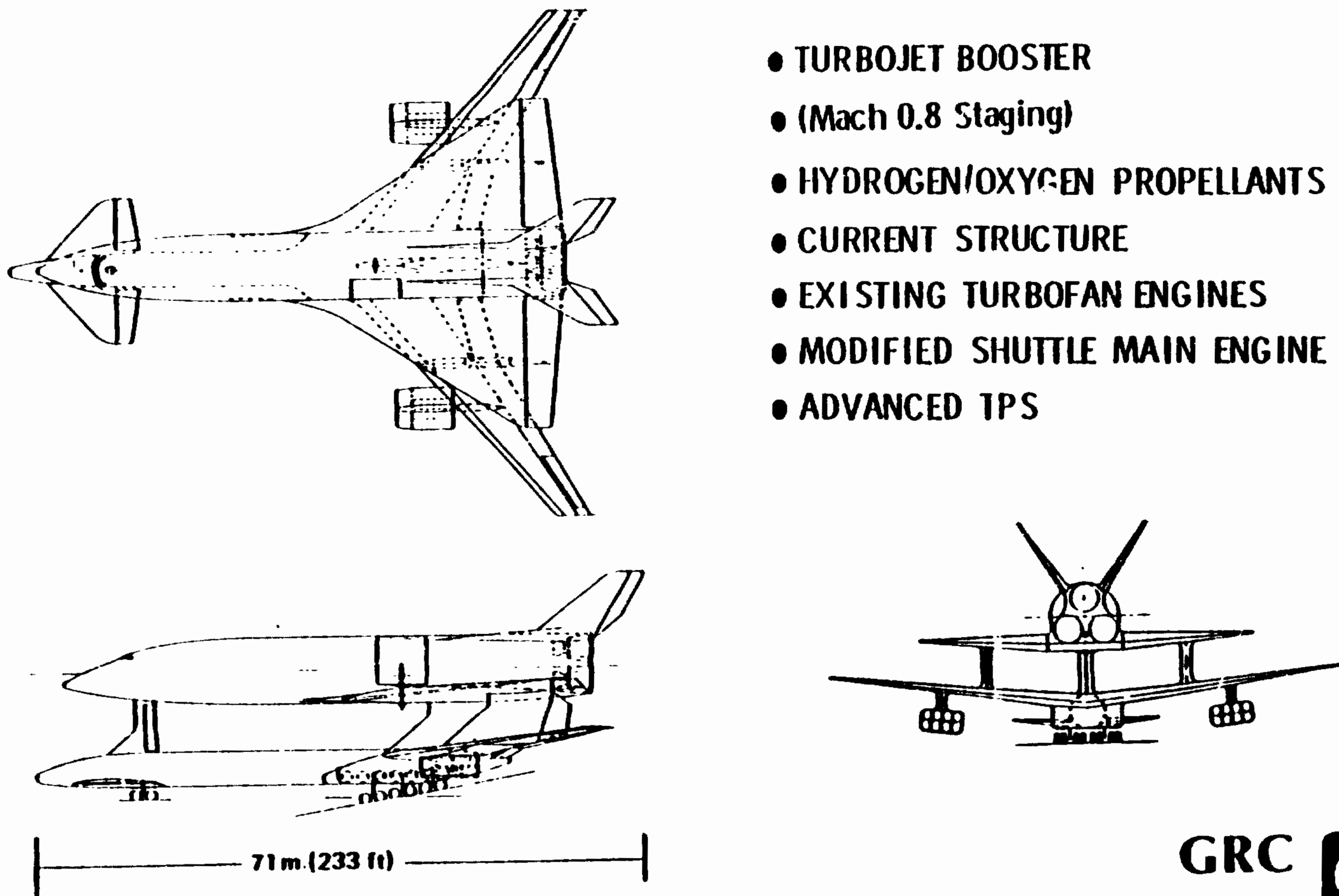

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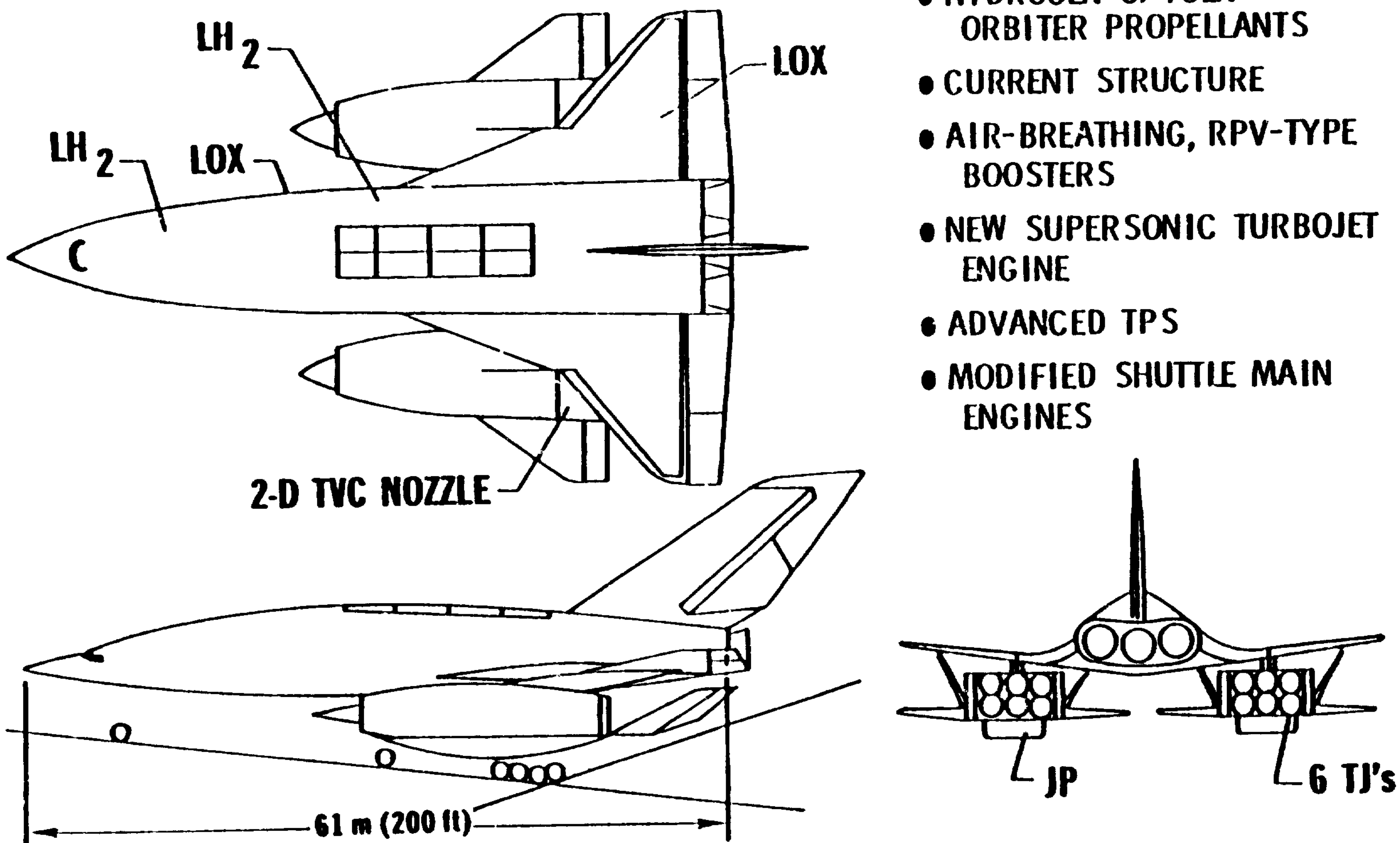
Figure 4-7

SUPERSONIC-STAGED PARALLEL-LIFT LAUNCH VEHICLE (Twin Booster)

- HYDROGEN-OXYGEN ORBITER PROPELLANTS
- CURRENT STRUCTURE
- AIR-BREATHING, RPV-TYPE BOOSTERS
- NEW SUPERSONIC TURBOJET ENGINE
- ADVANCED TPS
- MODIFIED SHUTTLE MAIN ENGINES



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4.7 AIR-BREATHING BOOSTER HYPERSONIC-STAGED VEHICLE

The scramjet-powered booster (Fig. 4-8) uses turbojet propulsion to taxi, take off, accelerate to scramjet takeover speed, and fly back. A dual-mode scramjet (subsonic and supersonic combustion) is assumed for primary propulsion. The sixteen 350,000-N class turbojet are similar to those used for the supersonic parallel-lift boosters. Gross weight is 1049 metric tons, of which the orbiter constitutes 216 metric tons.

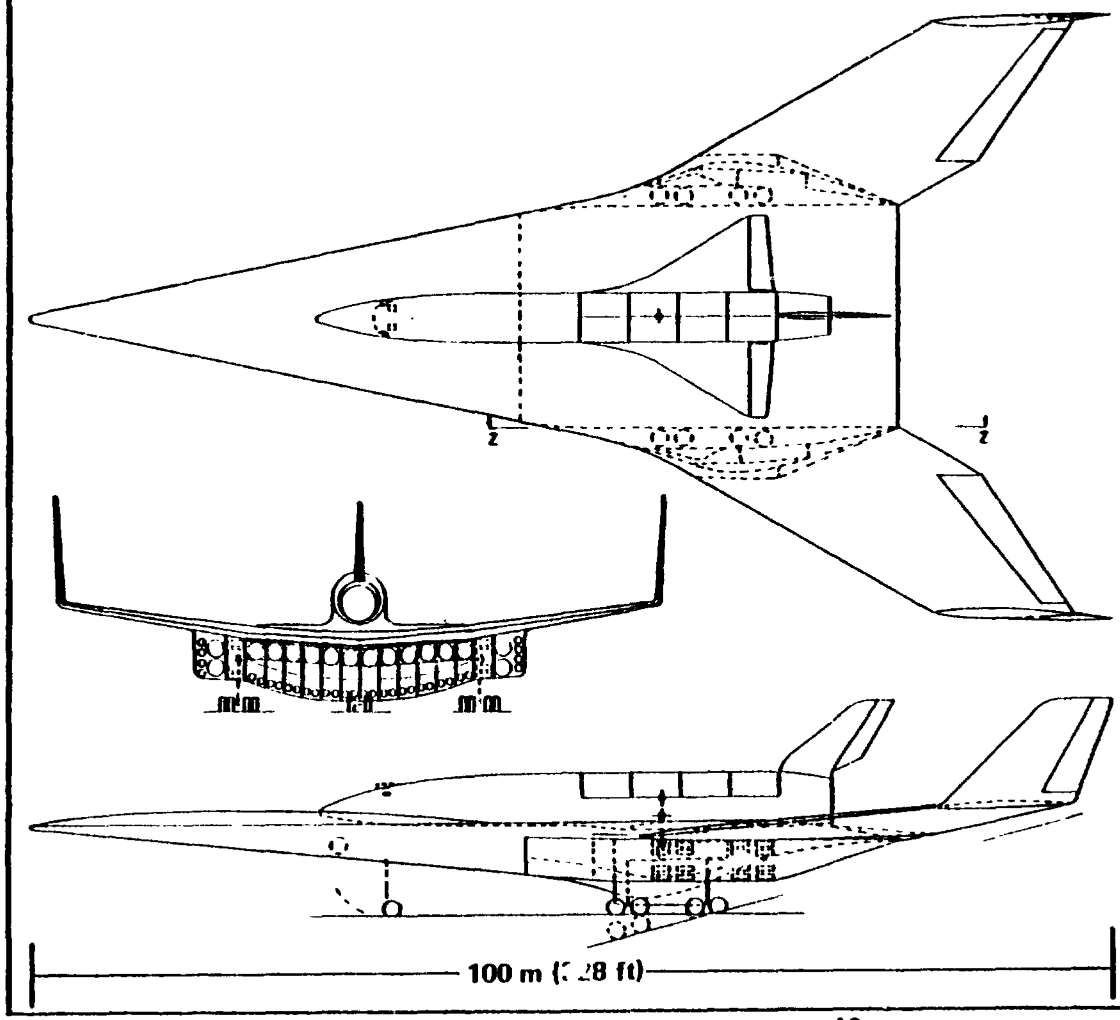
Analysis of the scramjet booster indicates that the decreasing thrust coefficient at the Mach number characteristic of scramjets is more of a limiting factor on staging Mach number than is specific impulse. The booster has a scramjet capture area equal to about one-tenth the aerodynamic wing reference area. It appears to be quite difficult to achieve a higher ratio, at least for integrated vehicle/propulsion concepts. Consequently, a drag coefficient of 0.0200 translates into a coefficient of 0.200 when referenced to the capture area. Above about Mach 10 or perhaps Mach 12, the thrust available above drag requirements is likely to be marginal for acceleration and climb. This design has a staging Mach number of 10.

4.8 SUBSONIC-STAGED TWIN AIR-BREATHING BOOSTER PARALLEL-LIFT VEHICLE

The advantage of twin boosters over a single booster is in development cost and the costs of support facilities. The vehicle design (Fig. 4-9) was available only late in this study, and hence is considered only in the cost analyses (Sec. 7). It is noted, though, that relative to the single-booster design the use of Rolls Royce RB211-524B engines decreases fuel consumption and increases the capability for extended range operations, despite the heavier engine weight.

Figure 4-8

HYPERSONIC-STAGED AIR-BREATHING TWO-STAGE LAUNCH VEHICLE



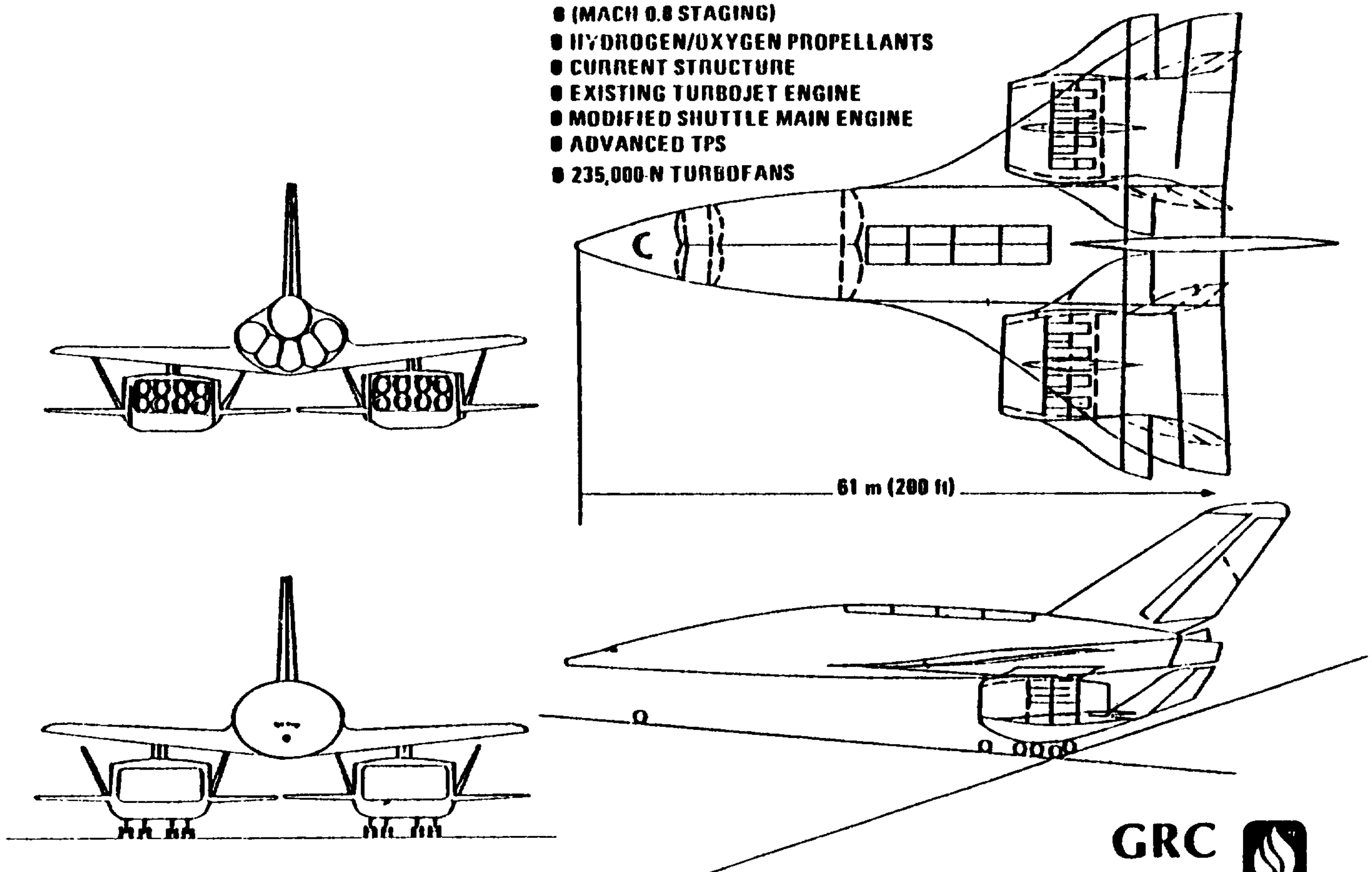
- TURBOJET PLUS SCRAMJET BOOSTER
- (Mach 10 Staging)
- ALL HYDROGEN/OXYGEN PROPELLANTS
- ADVANCED STRUCTURE
- ADVANCED SUPERSONIC TURBOJET
- ADVANCED SCRAMJET
- MODIFIED SHUTTLE MAIN ENGINE
- ADVANCED TPS

GRC

Figure 4-9

SUBSONIC-STAGED PARALLEL-LIFT LAUNCH VEHICLE (Twin Booster)

- TURBOJET BOOSTER
- (MACH 0.8 STAGING)
- HYDROGEN/OXYGEN PROPELLANTS
- CURRENT STRUCTURE
- EXISTING TURBOJET ENGINE
- MODIFIED SHUTTLE MAIN ENGINE
- ADVANCED TPS
- 235,000-N TURBOFANS



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4.9 VEHICLE WEIGHTS

The weight breakdowns for the seven candidate vehicles are shown in Fig. 4-10, and detailed weight statements for all vehicles are in Appendix A. The system dry weight is a better indicator of cost than is the total system weight.

As staging Mach number increases, the increase in booster weight is more than compensated by the reduction in orbiter weight, resulting in an overall decrease in total system weight at launch. The apparent discrepancy between the subsonic-staged orbiter and the sled-launched orbiter (their weights are comparable) is due to the advanced structure used in the sled-assisted vehicle compared to the current-structure technology of the subsonic vehicle. The Boeing-designed sled-launched vehicle also employed a slightly lighter, hot-structure TPS compared to a non-metallic reusable surface insulation (RSI) on the subsonic vehicle. The Martin VTO single-stage-to-orbit vehicle also uses advanced structure but with RSI.

For the air-breathing vehicles, the total dry weight increases slowly with staging Mach number, and all air-breathing vehicles are heavier than the single-stage-to-orbit vehicles. The dry weight of subsonic and supersonic air-breathing systems is approximately triple that of the single-stage-to-orbit vehicles due in large part to different assumptions regarding structure technology and engine weight.

4.10 FLIGHT PARAMETER DATA

The main flight parameters associated with each launch vehicle are summarized in Fig. 4-11. The two hypersonic systems (the all-rocket, C, and the air-breathing booster, F) actually stage at approximately equivalent energy conditions--the Mach number shown for the rocket booster is due to lower sonic velocity at the high staging altitude.

Figure 4-10

LAUNCH VEHICLE WEIGHT DATA

29,000-kg (65,000-lbm) Payload

92.5 x 185-km (50 x 100 n mi), 28° Orbit

VEHICLE OPTIONS

STAGING TAKEOFF PROPULSION STAGING MACH NO.	SSTO VTO R -	SSTO HTO R -	TS HTO R/R 10	TS HTO TJ/R 0.8	TS HTO TJ/R 3.5	TS HTO TJ-SJ/R 10+
GROSS WT	1207 (2660)	1250 (2750)	1050 (2314)	1371 (3022)	1285 (2833)	1049 (2313)
ORBITER WT	1207 (2660)	1250 (2750)	216 (476)	1104 (2433)	824 (1817)	216 (476)
BOOSTER WT	- -	249* (549)	834 (1838)	267 (589)	460 (1016)	833 (1837)
TOTAL DRY WT	114 (251)	99 (218)	196 (432)	336 (741)	351 (775)	422 (930)

All weights ×000.

*Sled weight not included in gross.

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Figure 4-11

FLIGHT PARAMETER DATA

	A	B	C	D	E	F
STAGING	SSTO	SSTO	TS	TS	TS	TS
TAKEOFF	VTO (HL)	HTO	HTO	HTO	HTO	HTO
PROPULSION	R	R	R/R	TJ/R	TJ/R	TJ-SC/R
STAGING CONDITIONS						
MACH NO.	0	0.5	10.9	0.8	3.5	10
VELOCITY (m/sec)	0	183	3100	251	1033	3200
ALTITUDE (m)	0	0	75,000	6700	1740	43,000
DYNAMIC PRESSURE (N/m^2)	0	20,500	200	20,000	72,000	13,400
MAX. DYNAMIC PRESSURE (N/m^2)	35,000	45,000	45,000	45,000	90,000	72,000
WING LOADINGS (N/m^2)						
BOOSTER AT TAKEOFF	–	–	11,000	13,400	8100	6700
ORBITER AT TAKEOFF	27,300	11,000	–	6200	11,500	–
ORBITER AT STAGING	–	–	11,800	*1,000	11,500	11,800
ORBITER AT LANDING	3100	1600	4000	1700	2100	4000
THRUST/WEIGHT						
TAKEOFF	1.3	0.7	0.81	0.54*	0.39	0.48
STAGING	–	–	1.16	0.60	0.78	1.16
AZIMUTH CAPABILITY	360°	±90°	±90°	360°	360°	360°
OFFSET CAPABILITY (km)	93	93	93	200	200	200

*Parallel Burn

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The maximum dynamic pressure is held to under 50,000 N/m^2 (1000 psf), except for the supersonic and hypersonic air-breathing booster systems. For these systems, the thrust-to-drag ratio generally improves with increasing dynamic pressure. Therefore, higher dynamic pressures are considered, although some system modifications for the supersonic-staging vehicle (E) may be necessary. The hypersonic vehicle (F) can better tolerate high dynamic pressure because of its more advanced technology. Aerodynamic heating is a key consideration in limiting the maximum dynamic pressure. The SSTO-VTO, A, and the hypersonic-staged orbiters, C and F, tend to have higher wing loadings during reentry and landing, resulting in hotter reentries and faster landings, comparable to or somewhat less demanding than with the current Shuttle.

5 TECHNOLOGY ASSESSMENT

An assessment of the key technology needs for each launch vehicle is performed using a methodology previously developed for NASA Headquarters,[11] and extended here to include a technology deficiency cost factor (TDCF). This factor is used to derive a technology deficiency cost that can be added to the traditional RDT&E costs. This technology readiness assessment methodology has proved useful for generating future technology program needs and for indicating the technological risk inherent in proposed flight programs.

In order to formalize a technology readiness methodology, it is necessary to establish a measure by which the status and objectives of technology readiness can be defined. The technology readiness evaluation criteria are shown in Fig. 5-1 as different levels of readiness, using a seven-level scale (which has subsequently been used by OAST, the Office of Aeronautics and Space Technology, NASA Headquarters, to assist in establishing technology needs for advanced programs, and technology readiness estimates for proposed space programs). Each element of a proposed system can be evaluated to determine its current status and the effort remaining before incorporation into a new program.

Although the methodology requires subjective inputs (representative of a class of decision tools categorized as a Delphi process), it has been shown that the process of assigning current status and required status for technology readiness is conducive to an overall consensus. A technology assessment involves many decisions; large disagreements in any single decision do not significantly change the overall results.

Figure 5-1

TECHNOLOGY READINESS EVALUATION CRITERIA

LEVEL 1	BASIC PRINCIPLES OBSERVED AND REPORTED
LEVEL 2	CONCEPTUAL DESIGN FORMULATED
LEVEL 3	CONCEPTUAL DESIGN TESTED ANALYTICALLY OR EXPERIMENTALLY
LEVEL 4	CRITICAL FUNCTION/CHARACTERISTIC DEMONSTRATED
LEVEL 5	COMPONENT/BREADBOARD TESTED IN RELEVANT ENVIRONMENT
LEVEL 6	PROTOTYPE/ENGINEERING MODEL TESTED IN RELEVANT ENVIRONMENT
LEVEL 7	ENGINEERING MODEL TESTED IN SPACE

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5.1 METHODOLOGY FOR ESTIMATING TECHNOLOGY DEFICIENCY COSTS

Items requiring equivalent gains in technology readiness levels may not be achievable with the same degree of effort. To account for differences in effort, technology risk criteria have been established and are shown in Fig. 5-2. The numerical values of risk (3, 6, and 9) have been selected such that risk and the gain in readiness level have approximately the same weighting in determining technology readiness.

Several factors that are useful in evaluating the cost associated with technical risk are defined in Fig. 5-3. The technology deficiency index (TDI) is the gain in technology level required to achieve readiness (difference between levels in Fig. 5-1) times the risk, summed over the individual elements of the system. In comparing competing alternatives, the TDI indicates the relative risk to be expected due to technology deficiencies.

The technology deficiency factor (TDF) indicates the degree of technology deficiency (a normalized value of the TDI). One minus the TDF id an indication of how near technology readiness is to being achieved. The TDF is incorporated into the technology deficiency cost factor (TDCF), which is used to estimate the cost associated with technology uncertainty in the development of a new system. RDT&E cost estimates are multiplied by the TDCF to account for technology risk.

Additional effort is needed to define more precisely an appropriate cost factor to account for technology deficiencies at program initiation if more accurate program cost estimates are to be made. It is hoped that the impact of technology deficiencies on program cost as indicated in this analysis is sufficient to stimulate additional work.

Figure 5-2

TECHNOLOGY RISK ASSESSMENT CRITERIA

LEVEL OF RISK	CRITERIA
LOW (3)	• TECHNOLOGY EXISTS AND HAS BEEN DEMONSTRATED IN OTHER EQUIPMENT • ALTERNATIVES ARE BEING DEVELOPED, ALTHOUGH THEY ARE NOT YET PROVEN • PARALLEL DEVELOPMENTS ARE POSSIBLE
MEDIUM (6)	• TECHNOLOGY EXISTS BUT HAS NEVER BEEN DEMONSTRATED • ALTERNATIVES ARE POSSIBLE BUT ARE COSTLY IN TERMS OF DOLLARS • RESOURCES AND SCHEDULE ARE MARGINAL FOR PARALLEL DEVELOPMENTS BUT PARALLEL DEVELOPMENTS ARE STILL POSSIBLE
HIGH (9)	• TECHNOLOGY DOES NOT EXIST AND MUST BE DEVELOPED • ALTERNATIVES DO NOT EXIST • PARALLEL DEVELOPMENTS ARE NOT POSSIBLE

GRC

Figure 5-3

TECHNOLOGY READINESS ASSESSMENT FACTORS

$$\text{Technology Deficiency Index (TDI)} = \sum_{I=1}^{N} (\text{Gain in Readiness Level})_I \times (\text{Risk})_I$$

$$\text{Technology Deficiency Factor (TDF)} = \frac{\text{TDI}}{9 \times \sum_{I=1}^{N} (\text{Technology Readiness Level Required})_I}$$

$$\text{Technology Deficiency Cost Factor (TDCF)} = \frac{1}{1 - \text{TDF}}$$

GRC

5.2 TECHNOLOGY DEFICIENCY COSTS

The data used in the technology readiness analysis are presented in Appendix B, and the results of the assessment are summarized in Figs. 5-4 and 5-5. As expected, the subsonic parallel-lift vehicle has the lowest TDI. Only the TPS and the internalized contour-configured propellant tanks (including a cryogenic wet wing) appear to require significant technology advances. The TDI increases rapidly with staging Mach number because of increased thermal protection requirements--the scramjet-powered booster represents very advanced technology, as it is similar to a second orbiter, but complicated by air-breathing propulsion requirements. It is interesting to note that the sled-assisted SSTO vehicle has a higher TDI than either the VTO SSTO or the supersonic-staged parallel-lift vehicle. The hot metal TPS and the advanced structure (cryogenic wet wing, sled assist) of the HTO SSTO represents higher technological risk than the development of large jet engines for the supersonic parallel-lift vehicle.

The relative ranking of the launch vehicle candidates based on TDCF parallels the ranking based on the TDI, as is to be expected. The higher the technology risk, the higher the TDCF should be.

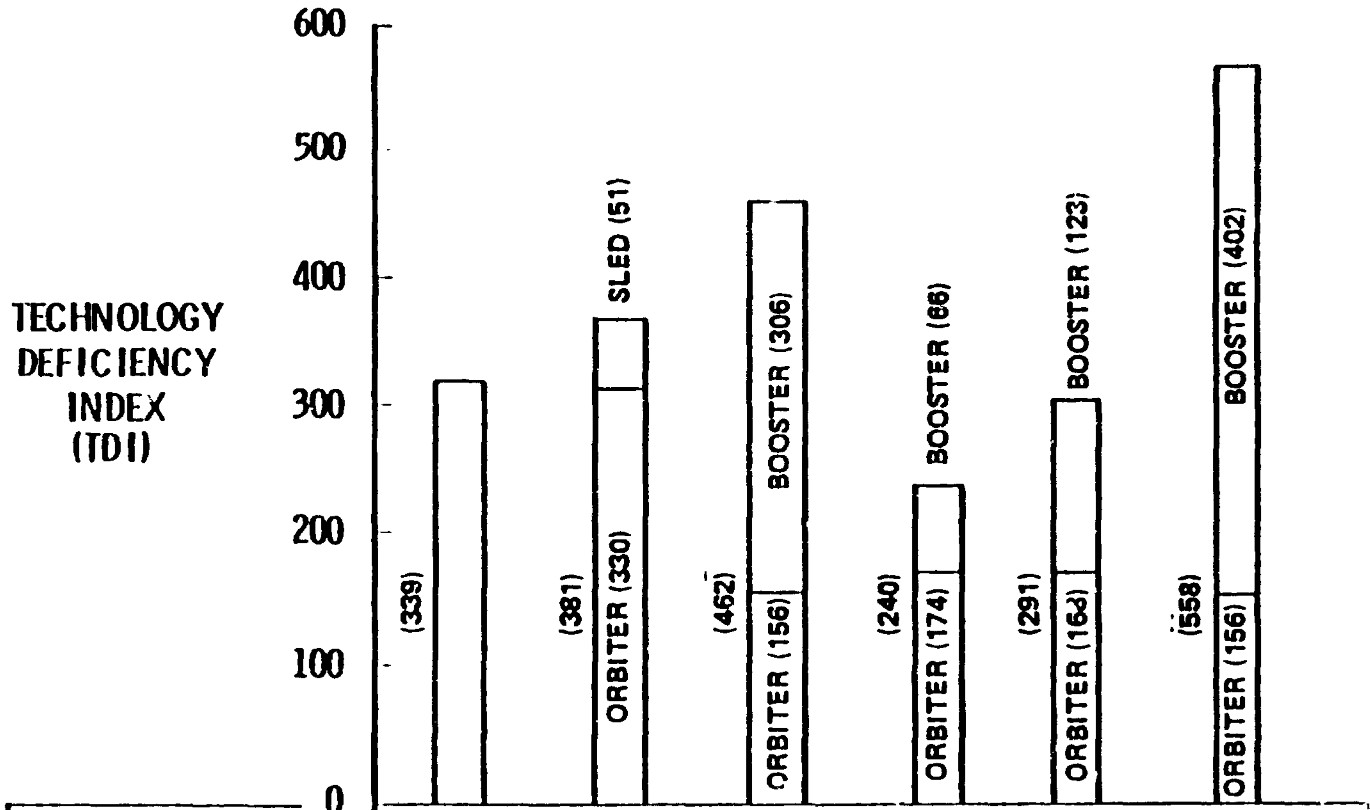
5.3 KEY TECHNOLOGY NEEDS

The evaluation of the TDI for each element in the launch vehicle provides an easy quantitative method for determining technology needs. A TDI value of 18 or greater was arbitrarily selected for determining key technology needs, which are shown in Fig. 5-6.

The evaluation shows that a fully reusable advanced TPS compatible with scheduled maintenance was the only key technology that was required by every launch vehicle option. The hypersonic

Figure 5-4

COMPARISON OF TDI VALUES



STAGING	SSTO	SSTO	TS	TS	TS	TS
TAKEOFF	VTO	HTO	HTO	HTO	HTO	HTO
PROPULSION	R	R	R/R	TJ/R	TJ/R	TJ-SJ/R
STAGING MACH NO.	—	—	10	0.8	3.5	10+

VEHICLE OPTIONS

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Figure 5-5

TECHNOLOGY DEFICIENCY COST FACTOR

	VEHICLE OPTIONS					
STAGING	SSTO	SSTO	TS	TS	TS	TS
TAKEOFF	VTO	HTO	HTO	HTO	HTO	HTO
PROPULSION	R	R	R/R	TJ/R	TJ/R	TJ-SJ/R
STAGING MACH NO.	—	—	10	0.8	3.5	10+
TECHNOLOGY DEFICIENCY COST FACTOR	1.16	1.14	1.12	1.06	1.08	1.15

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Figure 5-6

KEY TECHNOLOGY NEEDS*

TECHNOLOGY NEEDS	STAGING / TAKEOFF / PROPULSION / STAGING MACH NO.	VEHICLE OPTIONS					
		SSTO VTO R —	SSTO HTO R —	TS HTO R/R 10	TS HTO TJ/R 0.8	TS HTO TJ/R 3.5	TS HTO TJ-SJ/R 10+
STRUCTURES & MATERIALS							
– AEROSURFACES (WET WING)			X		X	X	
– BODY/TANK		X	X				
– LANDING GEAR/TIRES		X	X				
THERMAL PROTECTION SYSTEM		X	X	X	X	X	X
PROPULSION							
– HIGH-PRESSURE LH_2-LO_2 ROCKET ENGINE		X					
– SUPERSONIC TURBOJET						X	
– SCRAMJET							X
AERODYNAMICS							
– CONFIGURATION				X		X	X
– SEPARATION				X			X
MANUFACTURING		X	X				X
TEST HARDWARE		X	X	X			X
TEST FACILITIES							X

*Individual technology Gain x Risk ≥18

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scramjet-powered booster has the most needs, and the subsonic turbojet-powered booster the fewest. The following additional points are noted:

1. All horizontal takeoff vehicles benefit significantly if they use a cryogenic wet wing.

2. The scramjet propulsion system is in a very early stage of development, requires new test facilities, and is extremely sensitive to vehicle configuration and structural weight.

3. Both of the single-stage vehicles require significant improvements in advanced materials, structures, assembly, and manufacturing capabilities.

4. The development of new test hardware to assist in quality control during manufacturing is an important area that is often overlooked.

6 COST ASSESSMENT

The model developed by Aerospace Corporation[12] to evaluate costs of Earth-to-orbit and orbital transfer vehicles is used in this study. Based on subsystem cost-estimating relationships, the model generates PDT&E, investment, operations, and maintenance cost estimates.

6.1 LIFE CYCLE COSTS

The life cycle cost estimates for each launch vehicle considered in the study are shown in Fig. 6-1. The total program costs for vehicles A, B, D, E, and G are for all practical purposes the same, whereas both the hypersonic two-stage launch vehicles (C and F) are significantly more costly. The HTO single-stage-to-orbit is the least expensive vehicle by a narrow margin. For two-stage vehicles, higher staging numbers lead to lower orbiter costs, but higher booster costs.

Figure 6-1 shows that almost a billion dollars in RDT&E costs can be saved by developing the Langley-designed subsonic twin booster vehicle instead of the larger single booster. Investment costs do not change significantly between single and twin boosters, and the learning curve plus lower first unit cost tends to compensate for the larger number of twin boosters required. The overall result in going from a single to a twin booster is to reduce program costs by approximately $1B.

Without the inclusion of technology deficiency costs, the supersonic parallel-lift vehicle (E) is less expensive than either subsonic vehicle (D and G). With the inclusion of technology deficiency costs, though, the twin-booster subsonic parallel-lift vehicle (G) is less expensive. However, the differences are relatively small and are not significant because of the uncertainty of the cost estimates. Appendix C shows detailed cost data for each launch vehicle.

Figure 6-1

LIFE CYCLE COST
($B, 1976)

5-VEHICLE FLEET
10-YR OPERATIONS
4197 FLIGHTS

	A	B	C	D	E	F	G
STAGING	SSTO	SSTO	TS	TS	TS	TS	TS
TAKEOFF	VTO	HTO	HTO	HTO	HTO	HTO	HTO
PROPULSION	R	R	R/R	TJ/R	TJ/R	TJ-SJ/R	TJ/R
STAGING MACH NO.	—	—	10	0.8	3.5	10+	0.8*
RDT&E	7.6 (8.8)	5.9 (6.7)	9.0 (10.1)	9.0 (9.5)	8.9 (9.6)	13.2 (15.2)	8.3 (8.8)
INVESTMENT	2.6	3.7	2.9	3.2	3.3	4.1	
TOTAL INITIAL COST	10.2	9.6	11.9	12.2	12.0	17.3	11.5
OPERATIONS	12.5	12.4	17.3	11.4	10.4	17.9	11.2
TOTAL PROGRAM	2.7 (23.9)	22.0 (22.8)	29.2 (30.3)	23.6 (24.1)	22.4 (23.3)	35.2 (37.2)	22.7 (23.2)

( ) includes cost associated with technology risk.
* Subsonic Twin Booster.

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In order to provide a rough indication of the accuracy of the cost models, operations costs per flight for the current Shuttle are derived using Boeing, Martin, and Aerospace models (see Fig. 6-2). Martin and Boeing estimates agree with current average costs quoted for the Shuttle, whereas the Aerospace model appears to be in agreement with the projected low user costs given in two NASA publications.[13,14] The differences among the estimates are due primarily to differences in manpower requirements--the Aerospace values assume a manpower forecast representative of mature operations. Also, the RDT&E costs generated by the Aerospace model appear high compared to the costs estimated for the Shuttle. However, when actual RDT&E costs are available, the Aerospace model estimates may well prove to be more realistic since traditionally RDT&E projected costs have been underestimated.

The Martin model is based on manpower time estimates, which are converted to costs using labor rates, whereas the Aerospace model is based on subsystem cost projections plus operations and maintenance manning estimates. Differences between the Martin and Aerospace models in estimating investment and operations costs appear to be simply bookkeeping; some of the operations cost associated with facilities in the Martin model are considered in the Aerospace model to be investment costs.

6.2 MISSION MODEL FOR COST EVALUATION

The cost estimates presented in Fig. 6-1 are based on 10-year operations of a 5-vehicle fleet capable of completing 4197 flights. The utilization rate for the vehicles is high compared to that for the Shuttle because of two factors: (1) a 1-day average mission duration (compared to a 14-day average mission duration for the Shuttle), and (2) scheduled maintenance. A 1-day average mission is proposed as realistic for these vehicles based on the mission assessment in which a new

Figure 6-2

SHUTTLE COST COMPARISON OPERATIONS COST PER FLIGHT ($M, 1976)

COST MODEL	COST ELEMENT	COST
BOEING	– PROGRAM SUPPORT (GROUND OPERATIONS, FLIGHT OPERATIONS, & PROGRAM RESERVES)	5.17
	– SPARES	1.20
	– SRM	4.40
	– EXTERNAL TANK	2.31
	– ENGINES	0.30
	– FUEL AND PROPELLANTS	0.41
	TOTAL	13.79
MARTIN*	– KSC CIVIL SERVICE	0.67
	– LAUNCH OPERATIONS	2.75
	– FLIGHT OPERATIONS (JSC)	2.92
	– REFURBISHMENT	0.55
	– SRM	4.40
	– EXTERNAL TANK	2.31
	– ENGINES	0.30
	TOTAL	13.90
AEROSPACE	– OPERATIONS	2.27
	– SPARES AND PROPELLANTS	2.34
	– RANGE/BASE SUPPORT	0.25
	– EXPENDABLE HARDWARE	7.71
	TOTAL	11.57

*Based on 15-year Operations, 1016 Launches

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launch vehicle in the future would deliver cargo and/or passengers to a limited number of destinations.

Scheduled maintenance appears to be more appropriate for a fully reusable launch vehicle than an as-you-go maintenance philosophy associated with a partially resuable launch vehicle such as the Shuttle, where recovery and refurbishment operations are required. Figure 6-3 presents a maintenance schedule which spans the entire operational lift of the vehicle. It is proposed that after 112 missions the orbiter will undergo an engine changeout. After 448 missions it is overhauled, and after two overhauls it is retired. Overhauls and engine changeouts are made in centralized maintenance facilities.

As noted in Sec. 2.3, turnaround times for two-stage air-breathing vehicles are estimated to be 60 hours. Similar turnaround times have been proposed by the Martin Company for the SSTO-VTO vehicle, and the Boeing Company has estimated a 180-hour turnaround time for the SSTO-HTO. However, assuming a fully reusable protection system is developed, the SSTO-HTO might also achieve a 60-hour turnaround time. So as not to unrealistically penalize the SSTO-HTO, a 60-hour turnaround time was assumed for costing purposes.

The mission capability (Fig. 6-4) of each launch vehicle is determined by combining the maintenance schedule (including unscheduled maintenance, $R_R = 0.95^*$), average flight duration, and the turnaround time. A total expected vehicle lifetime of 5932 days (16.25 years) is projected. The mission factor (total number of missions divided by vehicle lifetime) is 0.23, compared to approximately 0.14 for the Shuttle (not including overhaul time). Based on a mission factor of 0.23, each launch vehicle would be capable of 839 missions during a 10-year operating period; or, for a

*Reprogrammable reliability.

Figure 6-3

PROPOSED MAINTENANCE SCHEDULE

7 MISSIONS, ⇨	2 DAYS MAINTENANCE
28 MISSIONS, ⇨	7 DAYS MAINTENANCE
112 MISSIONS, ⇨	30 DAYS MAINTENANCE
448 MISSIONS, ⇨	180 DAYS, VEHICLE OVERHAUL #1
896 MISSIONS, ⇨	180 DAYS, VEHICLE OVERHAUL #2
1344 MISSIONS, ⇨	RETIRE VEHICLE

TOTAL SCHEDULED MAINTENANCE DAYS: 1170

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Figure 6-4

MISSION POTENTIAL

1344	MISSIONS PER VEHICLE (MAINTENANCE CYCLE)
1344	MISSION DAYS (1 DAY AVERAGE MISSION DURATION)
3360	TURNAROUND DAYS (60 HR – 3 SHIFT OPERATIONS)
1170	SCHEDULED MAINTENANCE DAYS
58	UNSCHEDULED MAINTENANCE DAYS ($R_R = 0.95$)
5932	VEHICLE LIFETIME, DAYS
0.23	MISSION FACTOR
839	MISSIONS PER VEHICLE IN A 10-YEAR PERIOD
4197	MISSIONS FOR A 5-VEHICLE FLEET

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five-vehicle fleet, 4197 missions could be flown. Compared to current operational projections of launch vehicle demand, 420 missions per year is unrealistic. However, to avoid discussion about the validity of specific mission models, cost comparisons between the launch vehicle options considered in the study are based on the maximum potentials of the launch vehicles, which provide an indication of the minimum cost per flight that may be achievable with each.

6.3 OPERATIONS COSTS PER FLIGHT

A comparison of estimated operations costs per flight is shown in Fig. 6-5, indicating that costs per flight between $2.5M and $3M could be achieved with a fully reusable launch vehicle. The lower estimate corresponds to the two-stage subsonic, parallel-lift vehicle and the higher to single-stage vehicles, with the twin booster designs in the middle. The costs of the hypersonic-staged vehicles (not parallel lift) are higher, and probably not competitive. Compared to the SSTO-VTO, the reduction in orbiter size for a two-stage vehicle results in significant propellant cost savings. In the case of the SSTO-HTO vehicle, the sled assist increases operations costs to a level just above those for the subsonic and supersonic parallel-lift vehicles.

The elimination of expendable hardware provides substantial savings relative to the Shuttle; deleting just the solid-rocket boosters and the external propellant tank accounts for a reduction of almost 40%. The manning cost for operations and maintenance is about equal for the single- and two-stage launch vehicles, but increased efficiency in ground crew and facilities due to an increased launch rate provides an additional 33% reduction. Altogether it is estimated that a fully reusable launch vehicle can reduce manpower requirements by approximately 80% compared to those of the Shuttle. Compared to a single-stage-to-orbit launch vehicle, a two-stage parallel-lift vehicle eliminates the need for a launch pad, but requires a comparable expenditure for a separate propellant-service and assembly facility. A comparison of manning estimates is shown in Fig. 6-6.

Figure 6-5

OPERATIONS COST PER FLIGHT
($M, 1976)

5-VEHICLE FLEET
10-YEAR OPERATIONS
4197 FLIGHTS

VEHICLE OPTIONS

STAGING	SSTO	SSTO	TS	TS	TS	TS	TS
TAKEOFF	VTO	HTO	HTO	HTO	HTO	HTO	HTO
PROPULSION	R	R	R/R	TJ/R	TJ/R	TJ-SJ/R	TJ/R
STAGING MACH NO.	—	—	10	0.8	3.5	10+	0.8*
OPERATIONS (RECURRING COSTS)	3.0	3.0	4.1	2.8	2.5	4.3	2.7

*Twin Booster Subsonic Parallel-Lift Launch Vehicle

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Figure 6-6

OPERATIONS AND MAINTENANCE MANNING

(Hours Per Flight)

● SHUTTLE		18,158
● SINGLE-STAGE-TO-ORBIT*		
– INCREASED GROUND CREW UTILIZATION, 53% TO 86%	–4,817	
– DELETE SOLID ROCKET BOOSTERS	–6,157	
– DELETE EXTERNAL ORBITER TANK	–744	
– DELETE VERTICAL INSTALLATION	–620	
– REPLACE RSI WITH METALLIC TPS	–360	
– REDUCTION IN HYPERGOLIC PROPELLANT UTILIZATION	–230	
– REDUCED PAYLOAD SUPPORT	–275	
– INCREASED EFFICIENCY	–990	
– ADDITION OF GROUND SLED	+310	
– ADDITION OF INTERNAL LH_2/LO_2 TANKS	+65	
NET CHANGE	–13,818	4,340
● TWO-STAGE-TO-ORBIT, HTO (AIR-BREATHING BOOSTER)		
– DELETE HYPERGOLIC PROPELLANTS	–200	
– REPLACE METALLIC TPS WITH ADVANCED RSI	+360	
– DELETE LAUNCH PAD	–1,783	
– ADD AIR-BREATHING BOOSTERS	+620	
– ADD LH_2/LO_2 SERVICE FACILITY	+1,089	
NET CHANGE	+83	4,423

*BOEING SINGLE-STAGE-TO-ORBIT STUDY

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Altogether, the operating cost per flight of a fully reusable launch vehicle is reducible by approximately 50% (relative to the Shuttle) by eliminating expendable hardware. In addition, reductions in labor-intensive operations can reduce the remaining operations costs by approximately 50%, for total savings of roughly 60-80% of Shuttle costs.

6.4 COST SAVINGS FROM VEHICLE ATTRIBUTES

The advantages of various operational and hardware components of the alternative launch vehicles are discussed in Sec. 2.4. That discussion is summarized in Fig. 6-7, which also includes the cost savings over 10 years (4200 flights) that can be attributed to each characteristic. Note that just reuse of the entire launch vehicle accounts for an estimated saving of $34B over 10 years, relative to the Shuttle, which is greater than the estimated total cost of the proposed program.

Figure 6-7

ATTRIBUTE ASSESSMENT SUMMARY

CONCEPT	ATTRIBUTE	TOTAL COST SAVING 10 YR, 4194 FLIGHTS
FULL REUSABLE LAUNCH VEHICLE	REDUCED COST, INCREASED LAUNCH VEHICLE UTILIZATION, INLAND LAUNCH, 360° AZIMUTH FROM ANY LAUNCH SITE	\$34B*
HORIZONTAL ASSEMBLY AND TAKEOFF	INCREASED EFFICIENCY OF LAUNCH, MAINTENANCE, AND GROUND OPERATIONS COMPARED TO VERTICAL ASSEMBLY	\$418M
	REDUCED GROUND EQUIPMENT AND FACILITIES COMPARED TO VERTICAL LAUNCH	\$20M PER SITE
	ELIMINATION OF VERTICAL LAUNCH PAD INVESTMENT AND OPERATIONS COST	\$188M PER LAUNCH SITE, AND \$836M IN OPERATIONS COST
	POTENTIAL LAUNCH OPERATIONS FROM EXISTING AIRFIELDS (REQUIRES HYDROGEN AND OXYGEN CRYOGENIC PROPELLANT SUPPLY)	
EXTENDED RANGE	CENTRALIZED MAINTENANCE OPERATIONS FOR DISPERSED LAUNCH OPERATIONS	\$100 PER MAINTENANCE FACILITY PER LAUNCH SITE
	REMOTE LAUNCH SITE UTILIZATION (EQUATORIAL, FOREIGN COUNTRY), FOREIGN LEASE, DISPERSED LAUNCH OPERATIONS	

*Based on Shuttle Expendable Hardware, Manning, Recovery, and Refurbishment Costs

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Figure 6-7 (Cont.)

ATTRIBUTE ASSESSMENT SUMMARY (Cont.)

CONCEPT	ATTRIBUTE	TOTAL COST SAVING 10 YR, 4194 FLIGHTS
OFFSET ORBIT INJECTION	INCREASED LAUNCH OPPORTUNITIES, 360° LAUNCH AZIMUTH CAPABILITY FROM ANY LAUNCH SITE	
LOITER	LAUNCH BEFORE MISSION FINAL COMMITMENT	
PARALLEL BURN	REDUCED TIME-TO-ORBIT, INCREASED LAUNCH VEHICLE RELIABILITY	
SCHEDULED MAINTENANCE	INCREASED MAINTENANCE EFFICIENCY, INCREASED LAUNCH VEHICLE UTILIZATION	

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APPENDIX A

LAUNCH VEHICLE WEIGHT AND PERFORMANCE DATA

TABLE A-1

SINGLE-STAGE-TO-ORBIT VTO (MARTIN)

kilograms, (pounds)

BOOSTER	Not Applicable					
ORBITER						
Structure			74,716	(164,722)		
Body Group	33,441	(73,725)				
Wing Group	7,049	(15,541)				
Tail Group	1,857	(4,094)				
Thermal Protection System	21,365	(47,103)				
Landing Gear	4,211	(9,284)				
Contingency	6,793	(14,975)				
Propulsion			27,885	(61,475)		
Rocket Engines	20,998	(46,292)				
Propellant System	3,625	(7,993)				
RCS	2,512	(5,538)				
Contingency	749	(1,652)				
Equipment			11,427	(25,193)		
Crew/Payload Provisions	769	(1,695)				
Flight Controls	1,542	(3,400)				
Electrical and Power	3,050	(6,724)				
Hydraulic System	1,464	(3,228)				
Environmental Control System	1,721	(3,795)				
Avionics	1,965	(4,333)				
Contingency	915	(2,018)				
Orbiter Empty Weight					114,029	(251,390)

TABLE A-1 (Cont.)

SINGLE-STAGE-TO-ORBIT VTO (MARTIN)
kilograms (pounds)

<u>ORBITER</u> (Cont.)						
Injected Load			43,971	(96,939)		
Crew	1,199	(2,644)				
Residuals	2,202	(4,854)				
RCS Propellants	1,220	(2,690)				
OMS Propellants	6,851	(15,104)				
Reserves	3,014	(6,644)				
Retained Fluids	---					
Payload	29,483	(65,000)				
Injected Weight					157,998	(348,326)
Ascent Propellants/Fluids			1,049,221	(2,313,137)		
LO_2/LH_2	1,041,766	(2,296,700)				
Dumped Fluids	5,843	(12,882)				
In-Flight Losses	1,613	(3,555)				
Orbiter Gross Weight					1,207,219	(2,661,463)
Gross Launch Vehicle Weight					1,207,219	(2,661,463)

TABLE A-2

SINGLE-STAGE-TO-ORBIT HTO (BOEING)
kilograms (pounds)

<u>GROUND ACCELERATOR/SLED</u>				
Gross Weight			249,022	(549,000)
Propellants (usable)	103,937	(229,142)		
Taped Residuals	1,559	(3,437)		
Structure, Avionics, Hydraulics, and Power	143,526	(316,421)		
<u>ORBITER</u>				
Structure			74,687	(164,658)
Body Group	35,264	(77,746)		
Wing Group	26,172	(57,700)		
Tail Group	3,270	(7,210)		
Thermal Protection System	(Integral)			
Landing Gear	3,342	(7,368)		
Contingency	6,638	(14,634)		
Propulsion			17,500	(38,582)
Rocket Engines	13,457	(29,669)		
Propellant System	1,709	(3,769)		
RCS	1,500	(3,307)		
Contingency	833	(1,837)		

TABLE A-2 (Cont.)

SINGLE-STAGE-TO-ORBIT HTO (BOEING)
kilograms (pounds)

ORBITER (Cont.)						
Equipment			7,094	(15,640)		
Crew/Payload Provisions	361	(797)				
Flight Controls	998	(2,220)				
Electrical and Power	1,978	(4,360)				
Hydraulic System	986	(2,173)				
Environmental Control System	1,134	(2,500)				
Avionics	1,306	(2,880)				
Contingency	331	(730)				
Orbiter Empty Weight					99,282	(218,880)
Injected Load			40,957	(90,295)		
Crew	263	(580)				
Residuals	1,539	(3,394)				
RCS Propellant	1,294	(2,753)				
OMS Propellant	5,114	(11,275)				
Reserves	2,218	(4,890)				
Retained Fluids	1,090	(2,403)				
Payload	29,483	(65,000)				
Injected Weight					140,239	(309,175)
Ascent Propellants/Fluids			859,658	(1,895,222)		
LO_2/LH_2						

TABLE A-2 (Cont.)

SINGLE-STAGE-TO-ORBIT HTO (BOEING)
kilograms (pounds)

ORBITER (Cont.)			
Ascent Propellants/Fluids		859,658 (1,895,222)	
LO_2/LH_2	854,568 (1,884,000)		
Dumped Fluids	5,090 (11,222)		
In-Flight Losses	---		
Orbiter Gross Weight			999,898 (2,204,397)
Gross Launch Vehicle Weight			1,248,919 (2,753,397)

TABLE A-3

TWO-STAGE-TO-ORBIT (ALL ROCKET POWERED)

Kilograms (pounds)

BOOSTER						
Structure			122,697	(270,500)		
Body/Nacelle Group	34,609	(76,300)				
Wing Group	25,809	(56,900)				
Tail Group	3,447	(7,600)				
Thermal Protection System	21,409	(47,200)				
Landing Gear	36,514	(80,500)				
Engine Section	907	(2,000)				
Contingency	---					
Propulsion			27,352	(60,300)		
Turbine Engines	5,443	(12,000)				
Rocket Engines	14,969	(33,000)				
Air In-Suction and Exhaust	---					
Fuel/Propellant System	5,443	(12,000)				
Other	1,497	(3,300)				
Contingency	---					
Equipment			6,668	(14,700)		
Flight Controls	2,086	(4,600)				
Electrical System	1,179	(2,600)				
Hydraulic System	1,724	(3,800)				
Power	544	(1,200)				
Avionics	1,134	(2,500)				
Booster Empty Weight					156,716	(345,500)

TABLE A-3 (Cont.)

TWO-STAGE-TO-ORBIT (ALL ROCKET POWERED)

Kilograms (pounds)

BOOSTER (Cont.)						
Staging Load			24,040	(53,000)		
Residuals	1,814	(4,000)				
Reserves and Landing	6,350	(14,000)				
Flyback Fuel	15,875	(35,000)				
Booster Weight At Staging					180,756	(398,500)
Boost Propellants			653,173	(1,440,000)		
JP	87,090	(192,000)				
LO_2/LH_2	566,083	(1,248,000)				
Booster Gross Weight					833,930	(1,838,500)
ORBITER						
Structure			28,585	(63,020)		
Body Group	10,433	(23,000)				
Wing Group	4,196	(9,250)				
Tail Group	835	(1,840)				
Thermal Protection System	8,300	(18,300)				
Landing Gear	2,223	(4,900)				
Contingency	2,599	(5,730)				

TABLE A-3 (Cont.)

TWO-STAGE-TO-ORBIT (ALL ROCKET POWERED)
Kilograms (pounds)

ORBITER (Cont..						
Propulsion			5,434	(11,980)		
Rocket Engines	3,747	(8,260)				
Propellant System	635	(1,400)				
RCS and OMS	794	(1,750)				
Contingency	259	(570)				
Equipment			5,525	(12,180)		
Crew/Payload Provisions	363	(800)				
Flight Controls	680	(1,500)				
Electrical Power	1,361	(3,000)				
Hydraulic System	453	(1,000)				
Environmental Control System	1,134	(2,500,				
Avionics	1,270	(2,800)				
Contingency	263	(580)				
Orbiter Empty Weight					39,544	(87,180)
Injected Load			35,367	(77,970)		
Crew	263	(580)				
Residuals	499	(1,100)				
RCS Propellant	662	(1,460)				
OMS Propellant	2,708	(5,970)				
Reserves	1,175	(2,590)				
Retained Fluids	576	(1,270)				
Payload	29,483	(65,000)				

TABLE A-3 (Cont.)

TWO-STAGE-TO-ORBIT (ALL ROCKET POWERED)

Kilograms (pounds)

<u>ORBITER (Cont.)</u>						
Orbiter Injected Weight					74,911	(165,150)
Ascent Propellant/Fluids			141,452	(311.850)		
LO_2/LH_2	140,654	(310,090)				
Dumped Fluids	798	(1,760)				
In-Flight Losses	---					
Orbiter Gross Weight					216,364	(477,000)
System Gross Weight					1,050,293	(2,315,500)

TABLE A-4

TWO-STAGE-TO-ORBIT (SUBSONIC STAGING, SINGLE BOOSTER, COMPACT CARGO BAY)

Kilograms (pounds)

BOOSTER WEIGHT ESTIMATE

Structure			149,277	(329,100)
Wing Group	65,998	(145,500)		
Tail Group	9,072	(20,000)		
Body Group (includes nacelles)	27,215	(60,000)		
Landing Gear	42,456	(93,600)		
Launch Structure	4,536			
Propulsion			52,617	(116,000)
Turbofans (12 JT-9D-70B)*	49,832	(109,860)		
Fuel System	2,268	(5,000)		
Other	517	(1,140)		
Equipment			8,210	(18,100)
Flight Controls	2,721	(6,000)		
Electrical	1,542	(3,400)		
Hydraulic	2,268	(5,000)		
Auxiliary Power System	544	(1,200)		
Avionics	1,134	(2,500)		
Crew Provisions	---			

*Use of 16 F-100-PW- [illegible] engines in place of 12 JT-9D-70B engines would have the following estimate impact on weight statement: (1) engine weight would decrease to about 21,772 kg (48,000 lb) from 49,832 kg (109,860 lb); (2) the nacelle weight would decrease by about 6,804 kg (15,000 lb); (3) gross weight would remain about the same since fuel flows would increase about 2.5 times.

TABLE A-4 (Cont.)

TWO-STAGE-TO-ORBIT (SUBSONIC STAGING, SINGLE BOOSTER, COMPACT CARGO BAY)

Kilograms (pounds)

BOOSTER WEIGHT ESTIMATE (Cont.)						
Booster Empty Weight					210,104	(463,200)
Crew			---			
Residuals			227	(500)		
Reserves, Short Flyback, and Landing			20,412	(45,000)		
Offset Fuel				(IFR)		
Booster Weight at Staging					230,742	(508,700)
Booster Propellants (Mach 0.38/SL to Mach 0.8/22 kft)						
JP (< 5000 lb)			2,268	(5,000)		
LOX (in orbiter tanks)			---			
LH_2 (in orbiter tanks)			---			
Booster Gross Weight (excluding booster propellants in orbiter)					233,010	(513,700)
Booster Propellants in Orbiter			102,512	(226,000)		
LOX	88,844	(195,867)				
LH_2	13,668	(30,133)				
Orbiter Gross Weight at Staging			852,754	(1,880,000)		
System Gross Weight at Lift-Off					1,188,276	(2,619,700)
Taxi Propellants (JP)			6,350	(14,000)		

TABLE A-4 (Cont.)

TWO-STAGE-TO-ORBIT (SUBSONIC STAGING, SINGLE BOOSTER, COMPACT CARGO BAY)

Kilograms (pounds)

BOOSTER WEIGHT ESTIMATE (Cont.)						
Runway Propellants			50,802	(112,000)		
JP	1,814	(4,000)				
LOX (in orbiter)	42,456	(93,600)				
LH_2 (in orbiter)	6,532	(14,400)				
Ramp Gross Weight					1,245,429	(2,745,700)
ORBITER WEIGHT ESTIMATE						
Structure			69,899	(154,100)		
Wing Group	19,248	(42,435)				
Tail Group	2,415	(5,325)				
Body Group	22,328	(49,225)				
Thermal Protection System (external)	16,413	(36,185)				
Landing Gear	3,139	(6,920)				
Structure Contingency (10%)	6,355	(14,010)				
Propulsion			15,150	(33,400)		
Rocket Engines (three 596,000 lb_{VAC})	11,562	(25,490)				
RCS and OMS	1,415	(3,120)				
Propellant System/Misc.	1,452	(3,200)				
Propulsion Contingency (5%)	721	(1,590)				

TABLE A-4 (Cont.)

TWO-STAGE-TO-ORBIT (SUBSONIC STAGING, SINGLE BOOSTER, COMPACT CARGO BAY)

Kilograms (pounds)

ORBITER WEIGHT ESTIMATE (Cont.)

Equipment			6,704	(14,780)		
Crew/Payload Provisions	363	(800)				
Flight Controls	907	(2,000)				
Electrical	1,814	(4,000)				
Hydraulic	862	(1,900)				
Environmental Control System	1,134	(2,500)				
Avionics	1,306	(2,880)				
Equipment Contingency (5%)	318	(700)				
Orbiter Empty Weight					91,753	(202,280)
Injected Load			40,741	(89,820)		
Crew	263	(580)				
Residuals	1,633	(3,600)				
RCS Propellants (100 ft/sec)	1,179	(2,600)				
OMS Propellants (650 ft/sec)	4,881	(10,650)				
Reserves	2,096	(4,620)				
Subsystem Retained Fluids	998	(2,200)				
Payload	29,742	(65,570)				
Injected Weight					132,494	(292,100)

TABLE A-4 (Cont.)

TWO-STAGE-TO-ORBIT (SUBSONIC STAGING, SINGLE BOOSTER, COMPACT CARGO BAY)

Kilograms (pounds)

ORBITER WEIGHT ESTIMATE (Cont.)			
Post-Staging Ascent Propellants		720,259 (1,587,900)	
LOX	616,525 (1,357,000)		
LH_2	99,337 (219,000)		
Dumped Fluids	5,398 (11,900)		
In-Flight Losses	---		
Orbiter Gross Weight at Staging			852,754 (1,880,000)
Booster Propellants in Orbiter		102,512 (226,000)	
LOX	88,844 (195,867)		
LH_2	13,668 (30,133)		
Orbiter Lift-Off Weight			955,265 (2,106,000)
Runway Propellants (in orbiter)		48,988 (108,000)	
LOX	42,456 (93,600)		
LH_2	6,532 (14,400)		
Orbiter Ramp Weight			1,049,612 (2,314,000)

TABLE A-5

(SUBSONIC STAGING, SINGLE BOOSTER, PARAMETRICALLY RESIZED FOR SHUTTLE CARGO BAY)

Kilograms (pounds)

BOOSTER WEIGHT ESTIMATE				
Structure			162,340	(357,900)
Wing Group	72,575	(160,000)		
Tail Group	9,979	(22,000)		
Body Group (includes nacelles)	28,576	(63,000)		
Landing Gear	46,675	(102,900)		
Launch Structure	4,536	(10,000)		
Propulsion			61,280	(135,100)
Turbofans (twelve JT-9D-70B)	58,137	(128,170)		
Fuel	2,585	(5,700)		
Other	558	(1,230)		
Equipment			8,618	(19,000)
Flight Controls	2,903	(6,400)		
Electrical	1,633	(3,600)		
Hydraulic	2,404	(5,300)		
Auxiliary Power System	544	(1,200)		
Avionics	1,134	(2,500)		
Crew Provisions	---			

TABLE A-5 (Cont.)

(SUBSONIC STAGING, SINGLE BOOSTER, PARAMETRICALLY RESIZED FOR SHUTTLE CARGO BAY)

Kilograms (pounds)

BOOSTER WEIGHT ESTIMATE (Cont.)						
Booster Empty Weight					232,239	(512,000)
Crew	---					
Residuals	272	(600)				
Reserves, Short Flyback and Landing	22,679	(50,000)				
Offset Fuel		(1FR)				
Booster Weight at Staging					255,191	(562,600)
Boost Propellants (Mach 0.38/5.1 to Mach 0.8/22 kft)						
JP (< ~ 5000 lb)			2,495	(5,500)		
LOX (in orbiter tanks)			---			
LH_2 (in orbiter tanks)			---			
Booster Gross Weight (excludes boost propellants in orbiter)					257,685	(568,100)
Boost Propellants in Orbiter			112,717	(248,500)		
LOX	97,681	(215,350)				
LH_2	15,036	(33,150)				
Orbiter Gross Weight at Staging			937,575	(2,067,000)		
System Gross Weight at Lift-Off					1,307,979	(2,883,600)
Taxi Propellants (JP)			7,257	(16,000)		

TABLE A-5 (Cont.)

(SUBSONIC STAGING, SINGLE BOOSTER, PARAMETRICALLY RESIZED FOR SHUTTLE CARGO BAY)

Kilograms (pounds)

BOOSTER WEIGHT ESTIMATE (Cont.)						
Runway Propellants			55,973	(123,400)		
JP	2,132	(4,700)				
LOX (in orbiter)	46,675	(102,900)				
LH_2 (in orbiter)	7,167	(15,800)				
Ramp Gross Weight					1,371,209	(3,023,000)
ORBITER WEIGHT ESTIMATE						
Structure			80,431	(177,320)		
Wing Group	21,088	(46,490)				
Tail Group	2,644	(5,830)				
Body Group	28,440	(62,700)				
Thermal Protection System (external)	17,509	(38,600)				
Landing Gear	3,438	(7,580)				
Structure Contingency (10%)	7,312	(16,120)				
Propulsion			16,597	(36,590)		
Rocket Engines (three 596,000 lb_{VAC})	12,664	(27,920)				
RCS and OMS	1,552	(3,420)				
Propellant System/Misc.	1,592	(3,510)				
Propulsion Contingency (10%)	789	(1,740)				

TABLE A-5 (Cont.)

(SUBSONIC STAGING, SINGLE BOOSTER, PARAMETRICALLY RESIZED FOR SHUTTLE CARGO BAY)

Kilograms (pounds)

ORBITER WEIGHT ESTIMATE (Cont.)

Equipment			7,135	(15,730)		
Crew/Payload Provisions	363	(800)				
Flight Controls	998	(2,200)				
Electrical	1,996	(4,400)				
Hydraulic	998	(2,200)				
Environmental Control System	1,134	(2,500)				
Avionics	1,306	(2,880)				
Equipment Contingency (5%)	340	(750)				
Orbiter Empty Weight					104,163	(229,640)
Injected Load			41,508	(91,510)		
Crew	263	(580)				
Residuals	1,787	(3,940)				
RCS Propellants (100 ft/sec)	1,293	(2,850)				
OMS Propellants (650 ft/sec)	5,271	(11,620)				
Reserves	2,295	(5,060)				
Subsystem Retained Fluids	1,093	(2,410)				
Payload	29,483	(65,000)				
Injected Weight					145,671	(321,150)

TABLE A-5 (Cont.)

(SUBSONIC STAGING, SINGLE BOOSTER, PARAMETRICALLY RESIZED FOR SHUTTLE CARGO BAY)

Kilograms (pounds)

<u>ORBITER WEIGHT ESTIMATE (Cont.)</u>			
Post-Staging Ascent Propellants		791,904 (1,745,850)	
LOX	676,760 (1,492,000)		
LH_2	109,225 (240,800)		
Dumped Fluids	5,919 (13,050)		
In-Flight Losses	---		
Orbiter Gross Weight at Staging			937,575 (2,067,000)
Boost Propellants in Orbiter		112,718 (248,500)	
LOX	97,681 (215,350)		
LH_2	15,037 (33,150)		
Orbiter Lift-Off Weight			1,050,293 (2,315,500)
Runway Propellants (in orbiter)		53,841 (118,700)	
LOX	46,675 (102,900)		
LH_2	7,167 (15,800)		
Orbiter Ramp Weight			1,104,134 (2,434,200)

TABLE A-6

TWO-STAGE-TO-ORBIT (SUPERSONIC STAGING, TWIN BOOSTER)
kilograms (pounds)

BOOSTER (both boosters)						
Structure			161,161	(355,300)		
Body/Nacelle Group	72,802	(160,500)				
Wing Group	30,300	(66,800)				
Tail Group	7,530	(16,600)				
Thermal Protection System	---					
Landing Gear	43,091	(95,000)				
Engine Section	998	(2,200)				
Contingency	6,441	(14,200)				
Propulsion			81,374	(179,400)		
Turbine Engines	64,229	(141,600)				
Scranjet Engines	---					
Air Induction and Exhaust	17,145	(37,800)				
Fuel/Propellant System	---					
Contingency	---					
Equipment			9,298	(20,500)		
Flight Controls	---					
Electrical System	---					
Hydraulic System	---					
Power	---					
Avionics	---					
Booster Empty Weight					251,834	(555,200)

TABLE A-6 (Cont.)

TWO-STAGE-TO-ORBIT (SUPERSONIC STAGING, TWIN BOOSTER)
kilograms (pounds)

BOOSTER (Cont.)						
Staging Loading						
Residuals	---					
Reserves and Landing	15,875	(35.000)				
Flyback Fuel	8,618	(19,000)				
Booster Weight at Staging					259,908	(573,000)
Boost Propellants						
JP	184,612	(407,000)				
LO_2/LH_2	---					
Booster Gross Weight (both boosters)					460,940	(1,016,200)
ORBITER						
Structure			80,308	(177,050)		
Body Group	29,483	(65,000)				
Wing Group	18,144	(40,000)				
Tail Group	2,268	(5,000)				
Thermal Protection System	17,009	(37,500)				
Landing Gear	6,123	(13,500)				
Contingency	7,280	(16,050)				

TABLE A-6 (Cont.)

TWO-STAGE-TO-ORBIT (SUPERONIC STAGING, TWIN BOOSTER)
kilograms (pounds)

ORBITER (Cont.)						
Propulsion			12,746	(28,100)		
Rocket Engines	9,416	(20,760)				
Propellant System	1,361	(3,000)				
RCS and OMS	1,361	(3,000)				
Contingency	608	(1,340)				
Equipment			6,765	(14,915)		
Crew/Payload Provisions	363	(800)				
Flight Controls	907	(2,000)				
Electrical Power	1,814	(4,000)				
Hydraulic System	907	(2,000)				
Environmental Control System	1,134	(2,500)				
Avionics	1,306	(2,880)				
Contingency	333	(735)				
Orbiter Empty Weight					99,819	(220,065)
Injected Load			41,417	(91,308)		
Crew	263	(580)				
Residuals	1,251	(2,758)				
RCS Propellant	1,352	(2,980)				
OMS Propellant	5,534	(12,200)				
Reserves	2,399	(5,290)				
Retained Fluids	1,134	(2,500)				
Payload	29,483	(65,000)				

TABLE A-6 (Cont.)

TWO-STAGE-TO-ORBIT (SUPERSONIC STAGING, TWIN BOOSTER)
kilograms (pounds)

ORBITER (Cont.)			
Orbiter Injected Weight			141,236 (311,373)
Ascent Propellants/Fluids		683,192 (1,506,180)	
LO_2/LH_2	677,658 (1,493,980)		
Dumped Fluids	4,218 (9,300)		
In-Flight Losses	1,315 (2,900)		
Orbiter Gross Weight			824,428 (1,817,554)
System Gross Weight			1,285,368 (2,833,753)

TABLE A-7

TWO-STAGE-TO-ORBIT (HYPERSONIC STAGING)
kilograms (pounds)

BOOSTER						
Structure			187,334	(413,000)		
Body/Nacelle Group	70,307	(155,000)				
Wing Group	31,751	(70,000)				
Tail Group	10,886	(24,000)				
Thermal Protection System	31,751	(70,000)				
Landing Gear	41,730	(92,000)				
Engine Section	907	(2,000)				
Contingency	---					
Propulsion			188,241	(415,000)		
Turbine Engines	75,296	(166,000)				
Scramjet Engines	49,895	(110,000)				
Air Induction and Exhaust	53,524	(118,000)				
Fuel/Propellant System	9,072	(20,000)				
Contingency	454	(1,000)				
Equipment			6,668	(14,700)		
Flight Controls	2,086	(4,600)				
Electrical System	1,179	(2,600)				
Hydraulic System	1,724	(3,800)				
Power	544	(1,200)				
Avionics	1,134	(2,500)				
Booster Empty Weight					382,243	(842,700)

TABLE A-7 (Cont.)

TWO-STAGE-TO-ORBIT (HYPERSONIC STAGING)
kilograms (pounds)

BOOSTER (Cont.)						
Staging Load			67,494	(148,800)		
Residuals	2,404	(5,300)				
Reserves and Landing	15,195	(33,500)				
Flyback Fuel	49,895	(110,000)				
Booster Weight at Staging					449,737	(991,500)
Boost Propellants			383,285	(845,000)		
JP	156,489	(345,000)				
LH_2	226,796	(500,000)				
Booster Gross Weight					833,022	(1,836,500)
ORBITER						
Structure			28,585	(63,020)		
Body Group	10,432	(23,000)				
Wing Group	4,196	(9,250)				
Tail Group	834	(1,840)				
Thermal Protection System	8,300	(18,300)				
Landing Gear	2,223	(4,900)				
Contingency	2,599	(5,730)				

TABLE A-7 (Cont.)

TWO-STAGE-TO-ORBIT (HYPERSONIC STAGING)

kilograms (pounds)

ORBITER (Cont.)						
Propulsion			5,434	(11,980)		
Rocket Engines	3,747	(8,260)				
Ropellant System	635	(1,400)				
RCS and OMS	793	(1,750)				
Contingency	258	(570)				
Equipment			5,525	(12,180)		
Crew/Payload Provisions	363	(800)				
Flight Controls	680	(1,500)				
Electrical Power	1,361	(3,000)				
Hydraulic System	453	(1,000)				
Environmental Control System	1,134	(2,500)				
Avionics	1,270	(2,800)				
Contingency	263	(580)				
Orbiter Empty Weight					39,544	(87,180)
Injected Load			35,366	(77,970)		
Crew	263	(580)				
Residuals	499	(1,100)				
RCS Propellant	662	(1,460)				
OMS Propellant	2,708	(5,970)				
Reserves	1,175	(2,590)				
Retained Fluids	576	(1,270)				
Payload	29,483	(65,000)				

TABLE A-7 (Cont.)

TWO-STAGE-TO-ORBIT (HYPERSONIC STAGING)

kilograms (pounds)

<u>ORBITER (Cont.)</u>				
Orbiter Injected Weight				74,911 (165,150)
Ascent Prepellants/Fluids			141,453 (311,850)	
LO_2/LH_2	140,654	(310,090)		
Dumped Fluids	798	(1,760)		
In-Flight Losses	---			
Orbiter Gross Weight				216,363 (477,000)
System Gross Weight				1,049,386 (2,313,500)

TABLE A-8

UPRATED SSME CHARACTERISTICS

Chamber Pressure (psi)	3450
Expansion Ratio	82/150

Altitude (ft)	Thrust Newtons	(lb)	Specific Impulse, N-s/kg
0	2,015,489	(453,100)	3469
10,000	2,231,672	(501,700)	3840
20,000	2,349,995	(528,300)	4044
30,000	2,439,405	(548,400)	4197
40,000	2,498,565	(561,700)	4299
50,000	2,535,041/2,532,372	(569,900/569,300)	4362/4358
60,000	2,579,041	(580,000)	4439
70,000	2,607,992	(586,300)	4487
80,000	2,623,561	(589,800)	4515
90,000	2,633,347	(592,000)	4532
100,000	2,639,574	(593,400)	4542
150,000	2,641,798	(593,900)	4546
≤200,000	2,651,139	(596,000)	4562

TABLE A-9

AERODYNAMIC CHARACTERISTICS--ROCKET BOOSTER AND SUBSONICALLY LAUNCHED ORBITER*

M_n	C_{D_O}	$\Delta C_D/C_L^2$	C_{L_α} (per deg)	C_{L_O}
0.2	0.0250	0.18	0.040	0
0.4	0.0250	0.18	0.040	0
0.5	0.0250	0.18	0.041	0
0.8	0.0250	0.19	0.043	0
0.9	0.0400	0.20	0.045	0
1.0	0.0490	0.21	0.047	0
1.1	0.0500	0.23	0.050	0
1.2	0.0500	0.25	0.480	0
1.3	0.0478	0.27	0.042	0
1.4	0.0465	0.30	0.040	0
1.6	0.0435	0.34	0.037	0
2.0	0.0410	0.43	0.031	0
3.0	0.0360	0.68	0.021	0
4.0	0.0350	0.90	0.018	0
5.0	0.0350	1.08	0.018	0
6.0	0.0350	1.2	0.018	0
40.0	0.0350	2.0	0.018	0

Rocket Booster: $S_{REF} = 935\ m^2\ (10{,}064\ ft^2)$

Subsonically Launched Orbiter: $S_{REF} = 508\ m^2\ (5468\ ft^2)$

*Private communication from J. Watt, Aerodynamic Coefficient Data and Scramjet Performance Data Package, July 1977.

TABLE A-10

AERODYNAMIC DATA FOR SCRAMJET BOOSTER WITH ORBITER*

S_{REF} = 1570 m^2 (16,900 ft^2)

M_n	C_{D_O}	$\Delta C_D/C_L^2$	C_{L_α} (per deg)	C_{L_O}
0.2	0.0225	0.200	0.042	0
0.4	0.0225	0.200	0.042	0
0.6	0.0225	0.200	0.042	0
0.8	0.0225	0.200	0.042	0
0.9	0.0275	0.210	0.045	0
1.0	0.0425	0.220	0.046	0
1.1	0.0450	0.230	0.047	0
1.2	0.0450	0.240	0.046	0
1.3	0.0430	0.270	0.045	0
1.4	0.0410	0.320	0.044	0
1.6	0.0375	0.360	0.041	0
2.0	0.0325	0.440	0.035	0
2.4	0.0295	0.540	0.032	0
2.6	0.0287	0.580	0.030	0
3.0	0.0270	0.680	0.027	0
3.5	0.0250	0.760	0.025	0
4.0	0.0235	0.850	0.024	0
5.0	0.0217	0.920	0.020	0
6.0	0.0200	1.000	0.018	0
40.0	0.0200†	2.000	0.018	0

*Source: see footnote to Table A-9

†Excludes viscous drag

TABLE A-11

AIR-BREATHING ENGINE CHARACTERISTICS FOR SCRAMJET BOOSTER*

$F_N = C_T q A_C$

Turbojet Engines (A_C = 2.2 m^2/engine)			Scramjet (A_C = 157 m^2 total)		
M_n	C_T	Specific Impulse (JP Fuel) (N-sec/kg)	M_n	C_T	Specific Impulse (LH_2 Fuel), N-s/kg
0.2	53.51	20,643	2.0	0.739	--
0.4	14.43	20,054	3.0	1.136	36,285
0.6	7.19	19,613	4.0	1.448	35,794
0.8	5.31	19,711	5.0	1.414	32,166
1.0	4.25	19,417	6.0	1.268	28,930
1.4	2.99	19,221	7.0	1.050	25,497
1.6	2.79	19,319	8.0	0.864	22,751
2.0	2.50	19,221	9.0	0.684	20,202
2.4	2.37	18,682	10.0	0.545	17,652
2.6	2.29	18,387	11.0	0.489	15,396
3.0	2.12	18,044	12.0	0.468	12,945
3.5	2.05	17,407			

*Source: see footnote to Table A-9

APPENDIX B

TECHNOLOGY READINESS DATA BASE

TABLE B-1

SINGLE-STAGE-TO-ORBIT

(Martin VTO)

Technology Need	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk
Launch Vehicle				
• Structure				
– Aerodynamic Surfaces				
• Wings (dry wings)	3	6	3	M(6)
• Horizontal and Vertical Stabilizers	3	6	3	M(6)
• Control Surfaces, Fins, and Fairings	3	6	3	M(6)
– Body and Tanks				
• Integral Propellant Tanks (insulation, heat sink, sealing)	3	6	3	L(3)
• Load Carrying Structure (thrust, intertank, wing body, interstage)	3	6	3	M(6)
• Propellant Feed, Fill, Drain, and Transfer (pressurization, anti-slosh)	3	6	3	M(6)
– Landing Gear				
• Struts, Braces, and Deployment Devices	3	6	3	M(6)
• Shock Attenuation Devices	3	4	1	L(3)
• Tires	4	5	1	L(3)

TABLE B-1 (Cont.)

SINGLE-STAGE-TO-ORBIT

(Martin VTO)

Technology Need	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk
Launch Vehicle (Cont.)				
• Thermal Protection System (TPS)				
– Cover Panels (RSI, hot structures, bonding materials, local ablators, structural interface)	3	5	2	H(9)
– Insulation	4	5	1	L(3)
– Metal Heak Sink	4	5	1	L(3)
– Transparent Areas	5	5	–	–
• Guidance and Navigation				
– Guidance Reference	5	5	–	–
– Guidance Evaluation and Control Output	5	5	–	–
• Communications				
– Antenna Systems	5	5	–	–
– Transmitter Equipment	5	5	–	–
– Transceiver Equipment	5	5	–	–
– Television System	5	5	–	–
• Instrumentation Panels				
– Sensors	5	5	–	–
– Signal Processing, Transmission, and Display	5	5	–	–
– Crew Station and Flight Controls	5	5	–	–

TABLE B-1 (Cont.)

SINGLE-STAGE-TO-ORBIT
(Martin VTO)

Technology Need	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk
Launch Vehicle (Cont.)				
• Power Supply and Distribution				
– Electrical				
• Power Generation (engine generator unit, fuel cells, batteries, RTG, gas generator)	4	5	1	L(3)
• Power Conversion and Distribution	5	5	–	–
– Hydraulics				
• Power Conversion and Distribution (hydraulic, pneumatic)	4	5	1	L(3)
• Environmental Control and Life Support				
– Personnel Accommodations and Equipment	5	5	–	–
– Life Support Equipment	5	5	–	–
– Environmental Systems (temperature and atmospheric control)	5	5	–	–
• Aerodynamics				
– Configuration	3	5	2	L(3)
• Liquid Rocket Engine(s)				
– SSME (potential modifications, nozzle, lifetime, performance)	–	–	–	–
– New High Pressure LH_2-LO_2	3	6	3	M(6)
– New High Pressure HD-LO_2 (possibly dual-fuel)	–	–	–	–
– OMS (existing MMH/N_2O_4, modifications N_2H_4/N_2O_4, or LH_2-LO_2	3	6	3	M(6)

TABLE B-1 (Cont.)

SINGLE-STAGE-TO-ORBIT
(Martin VTO)

Technology Need	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk
Launch Vehicle (Cont.)				
• Attitude Control Engines				
– Existing Thrusters (MMH/N_2O_4)	–	–	–	–
– New Thrusters (N_2H_4/N_2O_4 or LH_2-LO_2)	4	6	2	L(3)
• Air-Breathing Engines				
– Subsonic Turbofan Jet Engine (existing engine)	–	–	–	–
– New Subsonic Turbofan Jet Engine (70-80,000 lbf)	–	–	–	–
– Existing Supersonic Turbojet or Turbofan (J-58, GE-4)	–	–	–	–
– New Supersonic Turbojet (70-85,000 lbf)	–	–	–	–
– Scramjet (supersonic burning)	–	–	–	–
– Combined Ramjet-Scramjet (subcnsic plus supersonic burning)	–	–	–	–
Manufacturing				
• Manufacturing Process and Methods	2	4	2	M(6)
• Tooling				
– Planning, Design, Fabrication, Assembly of Tools, Dies, Jigs, and Fixtures	2	4	2	M(6)
– Test Equipment to Support Manufacturing	2	4	2	M(6)
– Programming and Preparation of Tapes and Machines for Numerically Controlled Equipment	5	6	1	L(3)

TABLE B-1 (Cont.)

SINGLE-STAGE-TO-ORBIT
(Martin VTO)

Technology Need	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk
Ground Equipment				
• Planning, Design, Fabrication, and Testing	3	5	2	L(3)
• Instrumentation and Test Equipment (automated checkout and maintenance)	3	5	2	L(3)
Test Hardware				
• Ground Test (structural, dynamic, propulsion and system integration, wind tunnel)	2	5	3	M(6)
• Flight Test (instrumentation, test articles, and special equipment)	2	5	3	M(6)
Facilities and Equipment				
• Vehicle Test Facilities	5	6	1	L(3)
• Engine Test Facilities	6	6	-	-
• Launch Facilities	-	-	-	-
• Operational and Maintenance Facilities	2	4	2	M(6)
• Manufacturing Facilities	-	-	-	-
• Wind Tunnel Facilities	-	-	-	-
• Propellant Production Facilities	4	6	2	M(6)

TABLE B-1 (Cont.)

SINGLE-STAGE-TO-ORBIT
(Martin VTO)

Technology Need	Technology Rerdiness Level	Technology Readiness Level Required	Required Gain	Risk
Simulators and Special Timing Equipment				
• Flight	2	4	2	L(3)
• Operations	2	4	2	L(3)
• Maintenance	2	4	2	M(6)

TABLE B-2

SINGLE-STAGE-TO-ORBIT

(Boeing HTO)

Technology Need	Orbiter: Technology Readiness Level	Orbiter: Technology Readiness Level Required	Orbiter: Required Gain	Orbiter: Risk	Sled: Technology Readiness Level	Sled: Technology Readiness Level Required	Sled: Required Gain	Sled: Risk
Launch Vehicle								
• Structure								
– Aerodynamic Surfaces								
• Wings (cryogenic wet wing-sealing, heat sink)	2	6	4	M(6)	-	-	-	-
• Horizontal and Vertical Stabilizers	3	6	3	M(6)	-	-	-	-
• Control Surfaces, Fins, and Fairings	3	6	3	M(6)	-	-	-	-
– Body and Tanks								
• Integral Propellant Tanks (insulation, heat sink, sealing)	3	6	3	L(3)	3	4	1	L(3)
• Load Carrying Structure (thrust, intertank, wing-body, interstage)	3	6	3	M(6)	3	4	1	L(3)
• Propellant Feed, Fill, Drain, and Transfer (pressurization, anti-slosh)	3	6	3	M(6)	3	4	1	L(3)
– Landing Gear								
• Struts, Braces, and Deployment Devices	3	6	3	M(6)	-	-	-	-
• Shock Attenuation Devices	3	4	1	L(3)	-	-	-	-
• Tires	4	5	1	L(3)	-	-	-	-

TABLE B-2 (Cont.)

SINGLE-STAGE-TO-ORBIT
(Boeing HTO)

Technology Need	Orbiter: Technology Readiness Level	Orbiter: Technology Readiness Level Required	Orbiter: Required Gain	Orbiter: Risk	Sled: Technology Readiness Level	Sled: Technology Readiness Level Required	Sled: Required Gain	Sled: Risk
Launch Vehicle (Cont.)								
• Thermal Protection System (TPS)								
– Cover Panels (RSI, hot structures, bonding materials, local ablators)	3	5	2	H(9)	-	-	-	-
– Insulation	4	5	1	L(3)	4	5	1	L(3)
– Metal Head Sink	4	5	1	L(3)	-	-	-	-
– Transparent Areas	5	5	-	-	-	-	-	-
• Guidance and Navigation								
– Guidance Reference	5	5	-	-	-	-	-	-
– Guidance Evaluation and Control Output	5	5	-	-	-	-	-	-
• Communications								
– Antenna Systems	5	5	-	-	-	-	-	-
– Transmitter Equipment	5	5	-	-	-	-	-	-
– Transceiver Equipment	5	5	-	-	-	-	-	-
– Television System	5	5	-	-	-	-	-	-
• Instrumentation Panels								
– Sensors	5	5	-	-	-	-	-	-
– Signal Processing, Transmission, and Display	5	5	-	-	-	-	-	-
– Crew Station and Flight Controls	5	5	-	-	-	-	-	-

TABLE B-2 (Cont.)

SINGLE-STAGE-TO-ORBIT
(Boeing HTO)

Technology Need	Orbiter: Technology Readiness Level	Orbiter: Technology Readiness Level Required	Orbiter: Required Gain	Orbiter: Risk	Sled: Technology Readiness Level	Sled: Technology Readiness Level Required	Sled: Required Gain	Sled: Risk
Launch Vehicle (Cont.)								
• Power Supply and Distribution								
– Electrical								
•* Power Generation (engine generator unit, fuel cells, batteries, RTG, gas generator)	4	5	1	L(3)	5	5	-	-
•* Power Conversion and Distribution	5	5	-	-	5	5	-	-
– Hydraulics								
• Power Conversion and Distribution (hydraulic, pneumatic)	4	5	1	L(3)	5	5	-	-
• Environmental Control and Life Support								
– Personnel Accommodations and Equipment	5	5	-	-	-	-	-	-
– Life Support Equipment	5	5	-	-	-	-	-	-
– Environmental Systems (temperature and atmospheric control)	5	5	-	-	-	-	-	-
• Aerodynamics								
– Configuration	3	5	2	L(3)	-	-	-	-

TABLE B-2 (Cont.)

SINGLE-STAGE-TO-ORBIT
(Boeing HTO)

Technology Need	Orbiter: Technology Readiness Level	Orbiter: Technology Readiness Level Required	Orbiter: Required Gain	Orbiter: Risk	Sled: Technology Readiness Level	Sled: Technology Readiness Level Required	Sled: Required Gain	Sled: Risk
Launch Vehicle (Cont.)								
• Liquid Rocket Engine(s)								
– SSME (potential modifications, nozzle, lifetime, performance)	5	6	1	L(3)	5	6	1	L(3)
– New High Pressure LH_2-LO_2	–	–	–	–	–	–	–	–
– New High Pressure HD-LO_2	–	–	–	–	–	–	–	–
– OMS (existing MMH/N_2O_4, modifications N_2H_4/N_2O_4, or LH_2-LO_2)	3	6	3	M(6)	–	–	–	–
• Attitude Control Engines								
– Existing Thrusters (MMH/N_2O_4)	–	–	–	–	–	–	–	–
– New Thrusters (N_2H_4/N_2O_4, or LH_2-LO_4)	4	6	2	L(3)	–	–	–	–
• Air-Breathing Engines								
– Subsonic Turbofan Jet Engine (existing engine)	–	–	–	–	–	–	–	–
– New Subsonic Turbofan Jet Engine (70-80,000 lbr)	–	–	–	–	–	–	–	–
– Existing Supersonic Turbojet or Turbofan (J-58, GE-4)	–	–	–	–	–	–	–	–
– New Supersonic Turbojet (70-85,000 lbf)	–	–	–	–	–	–	–	–
– Scramjet (supersonic burning)	–	–	–	–	–	–	–	–
– Combined Ramjet-Scramjet (subsonic plus supersonic burning)	–	–	–	–	–	–	–	–

TABLE B-2 (Cont.)

SINGLE-STAGE-TO-ORBIT
(Boeing HTO)

Technology Need	Orbiter: Technology Readiness Level	Orbiter: Technology Readiness Level Required	Orbiter: Required Gain	Orbiter: Risk	Sled: Technology Readiness Level	Sled: Technology Readiness Level Required	Sled: Required Gain	Sled: Risk
Manufacturing								
• Manufacturing Process and Methods	2	4	2	M(6)	6	6	-	-
• Tooling								
- Planning, Design, Fabrication, Assembly of Tools, Dies, Jigs, and Fixtures	2	4	2	M(6)	6	6	-	-
- Test Equipment to Support Manufacturing	2	4	2	M(6)	6	6	-	-
- Programming and Preparation of Tapes and Machines for Numerically Controlled Equipment	5	6	1	L(3)	5	6	1	L(3)
Ground Equipment								
• Planning, Design, Fabrication, and Testing	3	5	2	L(3)	4	5	1	L(3)
• Instrumentation and Test Equipment (automated checkout and maintenance)	3	5	2	L(3)	4	5	1	L(3)
Test Hardware								
• Ground Test (structural, dynamic, propulsion and system integration, wind tunnel)	2	5	3	M(6)	5	6	1	L(3)
• Flight Test (instrumentation, test articles, and special equipment)	2	5	3	M(6)	5	6	1	L(3)

TABLE B-2 (Cont.)

SINGLE-STAGE-TO-ORBIT
(Boeing HTO)

Technology Need	Orbiter				Sled			
	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk
Facilities and Equipment								
• Vehicle Test Facilities	5	6	1	L(3)	5	6	1	L(3)
• Engine Test Facilities	6	6	-	-	6	6	-	-
• Launch Facilities	-	-	-	-	-	-	-	-
• Operational and Maintenance Facilities	2	4	2	M(6)	2	4	2	L(3)
• Manufacturing Facilities	-	-	-	-	-	-	-	-
• Wind Tunnel Facilities	-	-	-	-	-	-	-	-
• Propellant Production Facilities	4	6	2	M(6)	-	-	-	-
Simulators and Special Timing Equipment								
• Flight	2	4	2	L(3)	-	-	-	-
• Operations	2	4	2	L(3)	2	4	2	L(3)
• Maintenance	2	4	2	M(6)	2	4	2	L(3)

TABLE B-3

TWO-STAGE-VEHICLE
(Rocket Booster)

Technology Need	Booster				Orbiter			
	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk
Launch Vehicle								
• Structure								
– Aerodynamic Surfaces								
• Wings (cryogenic wet wing-sealing, heat sink)	2	6	4	M(6)	4	6	2	L(3)
• Horizontal and Vertical Stabilizers	5	6	1	L(3)	5	6	1	L(3)
• Control Surfaces, Fins, and Fairings	5	6	1	L(3)	5	6	1	L(3)
– Body and Tanks								
• Integral Propellant Tanks (insulation, heat sink, sealing)	4	6	2	L(3)	3	6	3	L(3)
• Land Carrying Structure (thrust, intertank wing-body, interstage)	4	6	2	L(3)	4	6	2	L(3)
• Propellant Feed, Fill, Drain, and Transfer (pressurization, anti-slosh)	6	6	2	L(3)	4	6	2	L(3)
– Landing Gear								
• Struts, Braces, and Deployment Devices	5	5	-	-	3	4	1	L(3)
• Shock Attenuation Devices	5	5	-	-	3	4	1	L(3)
• Tires	4	5	1	M(6)	4	5	1	L(3)

TABLE B-3 (Cont.)

TWO-STAGE-VEHICLE
(Rocket Booster)

Technology Need	Booster: Technology Readiness Level	Booster: Technology Readiness Level Required	Booster: Required Gain	Booster: Risk	Orbiter: Technology Readiness Level	Orbiter: Technology Readiness Level Required	Orbiter: Required Gain	Orbiter: Risk
Launch Vehicle (Cont.)								
• Thermal Protection System (TPSO								
- Cover Panels (RSI, hot structures, bonding materials, local ablators)	3	5	2	M(6)	3	5	2	H(9)
- Insulation	4	5	1	L(3)	4	5	1	L(3)
- Metal Heat Sink	4	5	1	L(3)	4	5	1	L(3)
- Transparent Areas	5	5	-	-	5	5	-	-
• Guidance and Navigation								
- Guidance Reference	5	6	1	L(3)	5	5	-	-
- Guidance Evaluation and Control Output	5	6	1	L(3)	5	5	-	-
• Communications								
- Antenna Systems	5	5	-	-	5	5	-	-
- Transmitter Equipment	5	5	-	-	5	5	-	-
- Transceiver Equipment	5	5	-	-	5	5	-	-
- Television System	5	5	-	-	5	5	-	-
• Instrumentation Panels								
- Sensors	5	5	-	-	5	5	-	-
- Signal Processing, Trnasmission, and Display	4	6	2	L(3)	5	5	-	-
- Crew Station and Flight Controls	-	-	-	-	5	5	-	-

TABLE B-3 (Cont.)

TWO-STAGE-VEHICLE
(Rocket Booster)

Technology Need	Booster				Orbiter			
	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk
Launch Vehicle (Cont.)								
• Power Supply and Distribution								
- Electrical								
• Power Generation (engine generation unit, fuel cells, batteries, RTG, gas generator)	5	5	-	-	5	5	-	-
• Power Conversion and Distribution	5	5	-	-	-	5	-	-
- Hydraulics								
• Power Conversion and Distribution (hydraulic, pneumatic)	5	5	-	-	4	5	1	L(3)
• Environmental Control and Life Support								
- Personnel Accommodations and Equipment	-	-	-	-	5	5	-	-
- Life Support Equipment	-	-	-	-	5	5	-	-
- Environmental Systems (temperature and atmospheric control)	5	5	-	-	5	5	-	-
• Aerodynamics								
- Configuration	2	5	3	H(9)	-	-	-	-
- Aeroelasticity	2	5	3	M(6)	-	-	-	-
- Separation	2	5	3	H(9)	-	-	-	-

TABLE B-3 (Cont.)

TWO-STAGE-VEHICLE

(Rocket Booster)

Technology Need	Booster: Technology Readiness Level	Booster: Technology Readiness Level Required	Booster: Required Gain	Booster: Risk	Orbiter: Technology Readiness Level	Orbiter: Technology Readiness Level Required	Orbiter: Required Gain	Orbiter: Risk
Launch Vehicle (Cont.)								
• Liquid Rocket Engine(s)								
– SSME (potential modifications, nozzle, lifetime, performance)	4	6	2	L(3)	5	6	1	L(3)
– New High Pressure LH_2-LO_2	–	–	–	–	–	–	–	–
– New High Pressure HD-LO_2 *(possibly dual-fuel)*	–	–	–	–	–	–	–	–
– OMS (existing MMH/N_2O_4, modifications N_2H_4/N_2O_4, or LH_2-LO_2)	–	–	–	–	–	–	–	–
• Attitude Control Engines								
– Existing Thrusters (MMH/N_2O_4)		–	–	–	–	–	–	–
– *New Thrusters (N_2H_4/N_2O_4 or LH_2-LO_2)*	4	6	2	L(3)	4	6	2	L(3)
• Air-Breathing Engines								
– Subsonic Turbofan Jet Engine (existing engine)	–	–	–	–	–	–	–	–
– New Subsonic Turbofan Jet engine (70-80,000 lbf)	–	–	–	–	–	–	–	–
– Existing Supersonic Turbojet or Turbofan (J-58, GE-4)	–	–	–	–	–	–	–	–
– New Supersonic Turbojet (70-85,000 lbf)	–	–	–	–	–	–	–	–
– Scramjet (supersonic burning)	–	–	–	–	–	–	–	–
– Combined Ramjet-Scramjet (subsonic plus supersonic burning)	–	–	–	–	–	–	–	–

TABLE B-3 (Cont.)

TWO-STAGE-VEHICLE
(Rocket Booster)

Technology Need	Booster: Technology Readiness Level	Booster: Technology Readiness Level Required	Booster: Required Gain	Booster: Risk	Orbiter: Technology Readiness Level	Orbiter: Technology Readiness Level Required	Orbiter: Required Gain	Orbiter: Risk
Manufacturing								
• Manufacturing Process and Methods	2	4	2	M(6)	3	4	1	L(3)
• Tooling								
– Planning, Design, Fabrication, Assembly of Tools, Dies, Jigs, and Fixtures	2	4	2	M(6)	3	4	1	L(3)
– Test Equipment to Support Manufacturing	2	4	2	M(6)	3	4	1	L(3)
– Programming and Preparation of Tapes and Machines for Numerically Controlled Equipment	5	6	1	L(3)	5	6	1	(L3)
Ground Equipment								
• Planning, Design, Fabrication, and Testing	3	5	2	L(3)	4	5	1	L(3)
• Instrumentation and Test Equipment (automated checkout and maintenance)	3	5	2	L(3)	4	5	1	L(3)
Test Hardware								
• Ground Test (structural, dynamic, propulsion and system integration, wind tunnel)	2	5	3	M(6)	3	5	2	M(6)
• Flight Test (instrumentation, test articles, and special equipment)	2	5	3	M(6)	3	5	2	M(6)

TABLE B-3 (Cont.)

TWO-STAGE-VEHICLE
(Rocket Booster)

Technology Need	Booster				Orbiter			
	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk
Facilities and Equipment								
• Vehicle Test Facilities	5	6	1	L(3)	5	6	1	L(3)
• Engine Test Facilities	6	6	-	-	6	6	-	-
• Launch Facilities	-	-	-	-	-	-	-	-
• Operational and Maintenance Facilities	2	4	2	M(6)	2	4	2	M(6)
• Manufacturing Facilities	-	-	-	-	-	-	-	-
• Wind Tunnel Facilities	-	-	-	-	-	-	-	-
• Propellant Production Facilities	4	6	2	L(3)	4	6	2	L(3)
Simulators and Special Training Equipment								
• Flight	2	4	2	L(3)	4	4	-	-
• Operations	2	4	2	M(6)	4	4	2	M(6)
• Maintenance	2	4	2	M(6)	2	4	2	M(6)

TABLE B-4

TWO-STAGE-VEHICLE
(Air-Breathing Booster, Subsonic Staging)

Technology Need	Booster				Orbiter			
	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk
Launch Vehicle								
• Structure								
– Aerodynamic Services								
• Wings (cryogenic wet wing-sealing, heat sink)	5	5	–	–	2	6	4	M(6)
• Horizontal and Verticel Stabilizers	5	5	–	–	5	6	1	L(3)
• Control Surfaces, Fins, and Fairings	5	5	–	–	5	6	1	L(3)
– Body and Tanks								
• Integral Propellant Tanks (insulation, heat sink, sealing)	–	–	–	–	3	6	3	L(3)
• Loading Carrying Structure (thrust, intertank, wing-body, interstage)	5	5	–	–	4	6	2	L(3)
• Propellant Feed, Fill, Drain, and Transfer (pressurization, anti-slosh)	5	5	–	–	4	6	2	L(3)
– Landing Gear								
• Struts, Braces, and Deployment Devices	5	5	–	–	3	4	1	L(3)
• Shock Attenuation Devices	5	5	–	–	3	4	1	L(3)
• Tires	3	5	2	M(6)	4	4	1	L(3)

TABLE B-4 (Cont.)

TWO-STAGE VEHICLE

(Air-Breathing Booster, Subsonic Staging)

Technology Need	Booster: Technology Readiness Level	Booster: Technology Readiness Level Required	Booster: Required Gain	Booster: Risk	Orbiter: Technology Readiness Level	Orbiter: Technology Readiness Level Required	Orbiter: Required Gain	Orbiter: Risk
Launch Vehicle (Cont.)								
• Thermal Protection System (TPS)								
- Cover Panels (RSI, hot structures, bonding materials, local ablators)	-	-	-	-	3	5	2	H(9)
- Insulation	-	-	-	-	4	5	1	L(3)
- Metal Heat Sink	-	-	-	-	4	5	1	L(3)
- Transparent Areas	-	-	-	-	5	5	-	-
• Guidance and Navigation								
- Guidance Reference	5	6	1	L(3)	5	5	-	-
- Guidance Evaluation and Control Output	5	6	1	L(3)	5	5	-	-
• Communications								
- Antenna Systems	5	5	-		5	5	-	-
- Transmitter Equipment	5	5	-		5	5	-	-
- Transceiver Equipment	5	5	-		5	5	-	-
- Television System	5	5	-		5	5	-	-
• Instrumentation Panels								
- Sensors	5	5	-	-	5	5	-	-
- Signal Processing, Transmission, and Display	4	6	2	L(3)	5	5	-	-
Crew Station and Flight Controls	-	-	-	-	5	5	-	-

TABLE B-4 (Cont.)

TWO-STAGE-ORBIT
(Air-Breathing Booster, Subsonic Staging)

Technology Need	Booster: Technology Readiness Level	Booster: Technology Readiness Level Required	Booster: Required Gain	Booster: Risk	Orbiter: Technology Readiness Level	Orbiter: Technology Readiness Level Required	Orbiter: Required Gain	Orbiter: Risk
Launch Vehicle (Cont.)								
• Power Supply and Distribution								
- Electrical								
. Power Generation (engine generator unit, fuel cells, batteries, RTG, gas generator)	5	5	-	-	5	5	-	-
. Power Conversion and Distribution	5	5	-	-	5	5	-	-
- Hydraulics								
. Power Conversion and Distribution (hydraulic, pneumatic)	5	5	-	-	4	5	1	L(3)
• Environmental Control and Life Support								
- Personnel Accommodations and Equipment	-	-	-	-	5	5	-	-
- Life Support Equipment	-	-	-	-	5	5	-	-
- Environmental Systems (temperature and atmospheric control)	5	5	-	-	5	5	-	-
• Aerodynamics								
- Configuration	2	5	3	L(3)	-	-	-	-
- Aeroelasticity	2	5	3	L(3)	-	-	-	-
- Separation at Staging	2	4	2	L(3)	-	-	-	-

TABLE B-4 (Cont.)

TWO-STAGE-VEHICLE

(Air-Breathing Booster, Subsonic Staging)

Technology Need	Booster: Technology Readiness Level	Booster: Technology Readiness Level Required	Booster: Required Gain	Booster: Risk	Orbiter: Technology Readiness Level	Orbiter: Technology Readiness Level Required	Orbiter: Required Gain	Orbiter: Risk
Launch Vehicle (Cont.)								
• Liquid Rocket Engine(s)								
- SSME (potential modifications, nozzle, lifetime, performance)	-	-	-	-	5	6	1	L(3)
- New High Pressure LH_2LO_2	-	-	-	-	-	-	-	-
- New High Pressure HD-LO_2 (possibly dual-fuel)	-	-	-	-	-	-	-	-
- OMS (existing MMH/N_2O_4, modifications N_2H_4/N_2O_4, or LH_2-LO_2)	-	-	-	-	-	-	-	-
• Attitude Control Engines								
- Existing Thrusters (MMH/N_2O_4)	-	-	-	-	-	-	-	-
- New Thrusters (N_2H_4/N_2O_4 or LH_2-LO_2)	-	-	-	-	4	6	2	L(3)
• Air-Breathing Engines								
- Subsonic Turbofan Jet Engine (existing engine)	6	6	-	-	-	-	-	-
- New Subsonic Turbofan Jet Engine (70-80,000 lbf)	-	-	-	-	-	-	-	-
- Existing Supersonic Turbojet or Turbofan (J-58, GE-4)	-	-	-	-	-	-	-	-
- New Supersonic Turbojet (70-85,000 lbf)	-	-	-	-	-	.	-	-
- Scramjet (supersonic burning)	-	-	-	-	-	-	-	-
- Combined Ramjet-Scramjet (subsonic plus supersonic burning)	-	-	-	-	-	-	-	-

TABLE B-4 (Cont.)

TWO-STAGE-VEHICLE
(Air-Breathing Booster, Subsonic Staging)

Technology Need	Booster: Technology Readiness Level	Booster: Technology Readiness Level Required	Booster: Required Gain	Booster: Risk	Orbiter: Technology Readiness Level	Orbiter: Technology Readiness Level Required	Orbiter: Required Gain	Orbiter: Risk
Manufacturing								
• Manufacturing Process and Methods	4	4	-	-	2	4	2	L(3)
• Tooling								
- Planning, Design, Fabrication, Assembly of Tools, Dies, Jigs, and Fixtures	4	4	-	-	3	4	1	L(3)
- Test Equipment to Support Manufacturing	4	4	-	-	3	4	1	L(3)
- Programming and Preparation of Tapes and Machines for Numerically Controlled Equipment	5	6	1	L(3)	5	6	1	L(3)
Ground Equipment								
• Planning, Design, Fabrication, and Testing	4	5	1	L(3)	4	5	1	L(3)
• Instrumentation and Test Equipment (automated checkout and maintenance)	4	5	1	L(3)	4	5	1	L(3)
Test Hardware								
• Ground Test (structural, dynamic, propulsion and system integration, wind tunnel)	5	6	1	L(3)	3	5	2	M(6)
• Flight Test (instrumentation, test articles, and special equipment)	5	6	1	L(3)	3	5	2	M(6)

TABLE B-4 (Cont.)

TWO-STAGE-VEHICLE
(Air-Breathing Booster, Subsonic Staging)

Technology Need	Booster: Technology Readiness Level	Booster: Technology Readiness Level Required	Booster: Required Gain	Booster: Risk	Orbiter: Technology Readiness Level	Orbiter: Technology Readiness Level Required	Orbiter: Required Gain	Orbiter: Risk
Facilities								
• Vehicle Test Facilitied	5	6	1	L(3)	5	6	1	L(3)
• Engine Test Facilities	6	6	-	-	6	6	-	-
• Launch Facilities	-	-	-	-	-	-	-	-
• Operational and Maintenance Facilities	4	4	-	-	2	4	2	M(6)
• Manufacturing Facilities	-	-	-	-	-	-	-	-
• Wind Tunnel Facilities	-	-	-	-	-	-	-	-
• Propellant Production Facilities	-	-	-	-	4	6	2	L(3)
Simulators and Special Training Equipment								
• Flight	4	4	-	-	4	4	-	-
• Operations	4	4	-	-	4	4	-	-
• Maintenance	4	4	-	-	2	4	2	M(6)

TABLE B-5

TWO-STAGE-VEHICLE
(Air-Breathing Booster, Supersonic Staging)

Technology Need	Booster				Orbiter			
	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk
Launch Vehicle								
• Structure								
– Aerodynamic Surfaces								
• Wings (cryogenic wet wing-sealing, heat sink)	4	6	2	L(3)	4	6	2	M(6)
• Horizontal and Vertical Stabilizers	5	6	1	L(3)	5	6	1	L(3)
• Control Surfaces, Fins, and Fairings	5	6	1	L(3)	5	6	1	L(3)
– Body and Tanks								
• Integral Propellant Tanks (insulation, heat sink, sealing)	5	6	1	L(3)	3	6	3	L(3)
• Load Carrying Structure (thrust, intertank, wing-body, interstage)	5	6	1	L(3)	4	6	2	L(3)
• Propellant Feed, Fill, Drain, and Transfer (pressurization, anti-slosh)	5	6	1	L(3)	4	6	2	L(3)
– Landing Gear								
• Struts, Braces, and Deployment Devices	5	5	-	-	3	4	1	L(3)
• Shock Attenuation Devices	5	5	-	-	3	4	1	L(3)
• Tires	3	5	2	M(6)	4	5	1	L(3)

TABLE B-5 (Cont.)

TWO-STAGE-VEHICLE
(Air-Breathing Booster, Supersonic Staging)

Technology Need	Booster				Orbiter			
	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk
Launch Vehicle (Cont.)								
• Thermal Protection System (TPS)								
– Cover Panels (RSI, hot structures, bonding materials, local ablators)	–	–	–	–	3	5	2	H(9)
– Insulation	–	–	–	–	4	5	1	L(3)
– Metal Heat Sink	5	5	–	–	4	5	1	L(3)
– Transparent Areas	–	–	–	–	5	5	–	–
• Guidance and Navigation								
– Guidance Reference	5	6	1	L(3)	5	5	–	–
– Guidance Evaluation and Control Output	5	6	1	L(3)	5	5	–	–
• Communications								
– Antenna Systems	5	5	–	–	5	5	–	–
– Transmitter Equipment	5	5	–	–	5	5	–	–
– Transceiver Equipment	5	5	–	–	5	5	–	–
– Television System	5	5	–	–	5	5	–	–
• Instrumentation Panels								
– Sensors	5	5	–	–	5	5	–	–
– Signal Processing, Transmission, and Display	4	6	2	L(3)	5	5	–	–
– Crew Station and Flight Controls	–	–	–	–	5	5	–	–

TABLE B-5 (Cont.)

TWO-STAGE-VEHICLE
(Air-Breathing Booster, Supersonic Staging)

Technology Need	Booster				Orbiter			
	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk
Launch Vehicle (Cont.)								
• Power Supply and Distribution								
– Electrical								
• Power Generation (engine generator unit, fuel cells, batteries, RTG, gas generator)	5	5	–	–	5	5	–	–
• Power Conversion and Distribution	5	5	–	–	5	5	–	–
– Hydraulics								
• Power Conversion and Distribution (hydraulic, pneumatic)	5	5	–	–	4	5	1	L(3)
• Environmental Control and Life Support								
– Personnel Accommodations and Equipment	–	–	–	–	5	5	–	–
– Life Support Equipment	–	–	–	–	5	5	–	–
– Environmental Systems (temperature and atmospheric control)	5	5	–	–	5	5	–	–
• Aerodynamics								
– Configuration	2	5	3	M(6)	–	–	–	–
– Aeroelasticity	2	5	3	L(3)	–	–	–	–
– Separation at Staging	2	4	2	M(6)	–	–	–	–

TABLE B-5 (Cont.)

TWO-STAGE-VEHICLE
(Air-Breathing Booster, Supersonic Staging)

Technology Need	Booster				Orbiter			
	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk
Launch Vehicle (Cont.)								
• Liquid Rocket Engine(s)								
– SSME (potential modifications, nozzle, lifetime, performance)	–	–	–	–	5	6	1	L(3)
– New High Pressure LH_2-LO_2	–	–	–	–	–	–	–	–
– New High Pressure HD-LO_2 (possibly dual-fuel)	–	–	–	–	–	–	–	–
– OMS (existing MMH/N_2O_4, modifications N_2H_4/N_2O_4, or LH_2-LO_2)	–	–	–	–	–	–	–	–
• Attitude Control Engines								
– Existing Thrusters (MMH/N_2O_4)	–	–	–	–	–	–	–	–
– New Thrusters (N_2H_4/N_2O_4 or LH_2-LO_2)	–	–	–	–	4	6	2	L(3)
• Air-Breathing Engines								
– Subsonic Turbofan Jet Engine (existing engine)	–	–	–	–	–	–	–	–
– New Subsonic Turbofan Jet Engine (70-80,000 lbf)	–	–	–	–	–	–	–	–
– Existing Supersonic Turbojet or Turbofan (J-58, GE-4)	–	–	–	–	–	–	–	–
– New Supersonic Turbojet (70-85,000 lbf)	3	6	3	M(6)	–	–	–	–
– Scramjet (supersonic burning)	–	–	–	–	–	–	–	–
– Combined Ramjet-Scramjet (subsonic plus supersonic burning)	–	–	–	–	–	–	–	–

TABLE B-5 (Cont.)

TWO-STAGE-VEHICLE
(Air-Breathing Booster, Supersonic Staging)

Technology Need	Booster				Orbiter			
	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk
Manufacturing								
• Manufacturing Process and Methods	4	4	-	-	2	4	2	L(3)
• Tooling								
- Planning, Design, Fabrication, Assembly of Tools, Dies, Jigs, and Fix* res	4	4	-	-	3	4	2	L(3)
- Test Equipment to Support Manufacturing	4	4	-	L(3)	3	4	2	L(3)
- Programming and Preparation of Tapes and Machines for Numerically Controlled Equipment	5	6	1	-	5	6	1	L(3)
Ground Equipment								
• Planning, Design, Fabrication, and Testing	4	5	1	L(3)	4	5	1	L(3)
• Instrumentation and Test Equipment (automated checkout and maintenance)	4	5	1	L(3)	4	5	1	L(3)
Test Hardware								
• Ground Test (structural, dynamic, propulsion and system integration, wind tunnel)	5	6	1	L(3)	3	5	2	M(6)
• Flight Test (instrumentation, test articles, and special equipment)	5	6	1	L(3)	3	5	2	M(6)

TABLE B-5 (Cont.)

TWO-STAGE-VEHICLE
(Air-Breathing Booster, Supersonic Staging)

Technology Need	Booster: Technology Readiness Level	Booster: Technology Readiness Level Required	Booster: Required Gain	Booster: Risk	Orbiter: Technology Readiness Level	Orbiter: Technology Readiness Level Required	Orbiter: Required Gain	Orbiter: Risk
Facilities and Equipment								
• Vehicle Test Facilities	5	6	1	L(3)	5	6	1	L(3)
• Engine Test Facilities	5	6	1	L(3)	6	6	-	-
• Launch Facilities	-	-	-	-	-	-	-	-
• Operational and Maintenance Facilities	4	4	-	-	2	4	2	M(6)
• Manufacturing Facilities	-	-	-	-	-	-	-	-
• Wind Tunnel Facilities	-	-	-	-	-	-	-	-
• Propellant Production Facilities	-	-	-	-	4	6	2	L(3)
Simulators and Special Training Equipment								
• Flight	4	4	-	-	4	4	-	-
• Operations	4	4	-	-	4	4	-	-
• Maintenance	4	4	-	-	2	4	2	M(6)

TABLE P-6

TWO-STAGE-VEHICLE

(Air-Breathing Booster, Hypersonic Staging)

Technology Need	Booster: Technology Readiness Level	Booster: Technology Readiness Level Required	Booster: Required Gain	Booster: Risk	Orbiter: Technology Readiness Level	Orbiter: Technology Readiness Level Required	Orbiter: Required Gain	Orbiter: Risk
Launch Vehicle								
• Structure								
– Aerodynamic Surfaces								
• Wings (cryogenic wet wing-sealing, heat sink)	2	6	4	M(6)	4	6	2	L(3)
• Horizontal and Vertical Stabilizers	5	6	1	L(3)	5	6	1	L(3)
• Control Surfaces, Fins, and Fairings	5	6	1	L(3)	5	6	1	L(3)
– Body and Tanks								
• Integral Propellant Tanks (insulation, heat sink, sealing)	4	6	2	L(3)	3	6	3	L(3)
• Load Carrying Structure (thrust, intertank, wing-body, interstage)	4	6	2	L(3)	4	6	2	L(3)
• Propellant Feed, Fill, Drain, and Transfer (pressurization, anti-slosh)	4	6	2	L(3)	4	6	2	L(3)
– Landing Gear								
• Struts, Braces, and Deployment Devices	5	5	–	–	3	4	1	L(3)
• Shock Attenuation Devices	5	5	–	–	3	4	1	L(3)
• Tires	3	5	2	M(6)	4	5	1	L(3)

TABLE B-6 (Cont.)

TWO-STAGE-VEHICLE

(Air-Breathing Booster, Hypersonic Staging)

Technology Need	Booster: Technology Readiness Level	Booster: Technology Readiness Level Required	Booster: Required Gain	Booster: Risk	Orbiter: Technology Readiness Level	Orbiter: Technology Readiness Level Required	Orbiter: Required Gain	Orbiter: Risk
Launch Vehicle (Cont.)								
• Thermal Protection System (TPS)								
- Cover Panels (RSI, hot structures, bonding materials, local ablators)	3	5	2	H(6)	3	5	2	H(9)
- Insulation	4	5	1	L(3)	4	5	1	L(3)
- Metal Heat Sink	4	5	1	L(3)	4	5	1	L(3)
- Transparent Areas	5	5	-	-	5	5	-	-
• Guidance and Navigation								
- Guidance Reference	5	6	1	L(3)	5	5	-	-
- Guidance Evaluation and Control Output	5	6	1	L(3)	5	5	-	-
• Communications								
- Antenna Systems	5	5	-	-	5	5	-	-
- Transmitter Equipment	5	5	-	-	5	5	-	-
- Transceiver Equipment	5	5	-	-	5	5	-	-
- Television System	5	5	-	-	5	5	-	-
• Instrumentation Panels								
- Sensing	5	5	-	-	5	5	-	-
- Signal Processing, Transmission, and Display	4	6	2	L(3)	5	5	-	-
- Crew Station and Flight Controls	-	-	-	-	5	5	-	-

TABLE B-6 (Cont.)

TWO-STAGE-VEHICLE

(Air-Breathing Booster, Hypersonic Staging)

Technology Need	Booster				Orbiter			
	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk
Launch Vehicle (Cont.)								
• Power Supply and Distribution								
– Electrical								
• Power Generation (engine generator unit, fuel cells, batteries, RTG, gas generator)	5	5	–	–	5	5	–	–
• Power Conversion and Distribution	5	5	–	–	5	5	–	–
– Hydraulics								
• Power Conversion and Distribution (hydraulic, pneumatic)	5	5	–	–	4	5	1	L(3)
• Environmental Control and Life Support								
– Personnel Accommodations and Equipment	–	–	–	–	5	5	–	–
– Life Support Equipment	–	–	–	–	5	5	–	–
– Environmental Systems (temperature and atmospheric control)	5	5	–	–	5	5	–	–
• Aerodynamics								
– Configuration	2	5	3	H(9)	–	–	–	–
– Aeroelasticity	2	5	3	H(6)	–	–	–	–
– Separation at Staging	2	5	3	H(9)	–	–	–	–

TABLE B-6 (Cont.)

TWO-STAGE-VEHICLE
(Air-Breathing Booster, Hypersonic Staging)

	Booster				Orbiter			
Technology Need	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk
Launch Vehicle (Cont.)								
• Liquid Rocket Engine(s)								
- SSME (potential modifications, nozzle, lifetime, performance)	-	-	-	-	5	6	1	L(3)
- New High Pressure LH_2-LO_2	-	-	-	-	-	-	-	-
- New High Pressure HD-LO_2 (possible dual-fuel)	-	-	-	-	-	-	-	-
- OMS (existing MMH/N_2O_4, modifications N_2H_4/N_2O_4, or LH_2-LO_2)	-	-	-	-	-	-	-	-
• Attitude Control Engines								
- Existing Thrusters (MMH/N_2O_4)	-	-	-	-	-	-	-	-
- New Thrusters (N_2H_4/N_2O_4 or LH_2- LO_2)	-	-	-	-	4	6	2	L(3)
• Air-Breathing Engines								
- Subsonic Turbofan Jet Engine (existing engine)	-	-	-	-	-	-	-	-
- New Subsonic Turbofan Jet Engine (70-80,000 lbf)	-	-	-	-	-	-	-	-
- Existing Supersonic Turbojet or Turbofan (J-58, GE-4)	-	-	-	-	-	-	-	-
- New Supersonic Turbojet (70-85,000 lbf)	3	6	3	M(6)	-	-	-	-
- Scramjet (supersonic burning)	-	-	-	-	-	-	-	-
- Combined Ramjet-Scramjet (subsonic plus supersonic burning)	1	6	5	H(9)	-	-	-	-

TABLE B-6 (Cont.)

TWO-STAGE-VEHICLE

(Air-Breathing Booster, Hypersonic Staging)

Technology Need	Booster: Technology Readiness Level	Booster: Technology Readiness Level Required	Booster: Required Gain	Booster: Risk	Orbiter: Technology Readiness Level	Orbiter: Technology Readiness Level Required	Orbiter: Required Gain	Orbiter: Risk
Manufacturing								
• Manufacturing Process and Methods	2	4	2	M(6)	2	4	2	L(3)
• Tooling								
- Planning, Design, Fabrication, Assembly of Tools, Dies, Jigs, and Fixtures	2	4	2	M(6)	3	4	1	L(3)
- Test Equipment to Support Manufacturing	2	4	2	M(6)	3	4	1	L(3)
- Programming and Preparation of Tapes and Machines for Numerically Controlled Equipment	5	6	1	L(3)	5	6	1	L(3)
Ground Equipment								
• Planning, Design, Fabrication, and Testing	3	5	2	L(3)	4	5	1	L(3)
• Instrumentation and Test Equipment (automated checkout and maintenance)	3	5	2	L(3)	4	5	1	L(3)
Test Hardware								
• Ground Test (structural, dynamic, propulsion and system integration, wind tunnel)	2	5	3	M(6)	3	5	2	M(6)
• Flight Test (instrumentation, test articles, and special equipment)	2	5	3	M(6)	3	5	2	M(6)

TABLE B-6 (Cont.)

TWO-STAGE-VEHICLE

(Air-Breathing Booster, Hypersonic Staging)

Technology Need	Booster				Orbiter			
	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk	Technology Readiness Level	Technology Readiness Level Required	Required Gain	Risk
Facilities and Equipment								
• Vehicle Test Facilities	2	6	4	M(6)	5	6	1	L(3)
• Engine Test Facilities	2	6	4	M(6)	6	6	-	-
• Launch Facilities	-	-	-	-	-	-	-	-
• Operational and Maintenance Facilities	2	4	2	M(6)	2	4	2	M(6)
• Manufacturing Facilities	-	-	-	-	-	-	-	-
• Wind Tunnel Facilities	-	-	-	-	-	-	-	-
• Propellant Production Facilities	4	6	2	L(3)	4	6	2	L(3)
Simulators and Special Training Equipment								
• Flight	2	4	2	L(3)	4	4	-	-
• Operations	2	4	2	L(3)	4	4	-	-
• Maintenance	2	4	2	M(6)	2	4	2	M(6)

APPENDIX C
COST DATA BASE

Tables C-1 and C-2 provide the values of the various cost estimating factors that were used in the cost model of Ref. 12 to generate vehicle costs. Tables C-3 through C-8 show the cost estimates, in millions of dollars, for the alternative launch vehicles.

TABLE C-1

COST ESTIMATING INPUT FACTORS

Development	Two-Stage Vehicles: System	Orbiter	Mach 10 Booster	Mach 3.5 Booster	Mach 0.8 Booster	Single-Stage VTO
Concept Formulation	NA	--	--	--	--	NA
Supporting Technology Programs	NA	--	--	--	--	NA
Structure						
• Aerodynamic Surfaces Complexity Factor	--	(1.06)	(1.06)	(0.96)	(0.8)	(1.20)
- Commonality Factor	--	0.8	0.8	0.8	0.8	1.0
- Configuration Factor	--	1.2	1.2	1.0	1.0	1.2
- Material Factor	--	1.1	1.1	1.2	1.0	1.0
• Body/Tank Complexity Factor	--	(2.20)	(2.64)	(1.20)	(1.20)	(2.64)
- Commonality Factor	--	1.0	1.0	1.0	1.0	1.0
- Configuration Factor	--	1.0	1.2	1.2	1.2	1.2
- Material Factor	--	1.1	1.1	1.0	1.0	1.1
- Propellant Factor	--	2.0	2.0	1.0	1.0	2.0
• Thermal Protection System Complexity Factor (90% weight in panels; 10% weight in insulation)	--	(1.1)	(0.79)	NA	NA	(1.1)
- Commonality Factor	--	1.0	0.6	--	--	1.0
- Configuration Factor	--	1.0	1.2	--	--	1.0
- Material Factor	--	1.1	1.1	--	--	1.1

TABLE C-1 (Cont.)

COST ESTIMATING INPUT FACTORS

Development	Two-Stage Vehicles					Single-Stage VTO
	System	Orbiter	Mach 10 Booster	Mach 3.5 Booster	Mach 0.8 Booster	
Avionics Factor[1]	--	(1.0)	(0.3)	(0.3)	(0.3)	(1.0)
• Commonality Factor	--	1.0	0.3	0.3	0.3	1.0
• Complexity Factor	--	1.0	1.0	1.0	1.0	1.0
Electrical Power Factor	--	1.0	1.0	1.0	1.0	1.2
Hydraulic Power Factor	--	1.0	1.0	1.0	1.0	1.0
Environmental Control/ Life Support Factor	--	1.0	NA	NA	NA	1.0
Drop Tank Complexity Factor	--	--	--	--	--	--
Emergency Recovery	NA					NA
Propulsion						
• Primary Rocket Engine Factor	--	(0.25)	--	--	(0.097)	(1.2)RP-1 (2.1)H_2
- Commonality Factor	--	0.25	--	--	0.5	1.0 RP-1 1.0 H_2
- Complexity Factor	--	1.0	--	--	1.93	1.2 RP-1 2.1 H_2

[1] In..udes guidance and navigation, communicat ons, and instrumentation/panels.

TABLE C-1 (Cont.)

COST ESTIMATING INPUT FACTORS

Development	Two-Stage Vehicles					Single-Stage VTO
	System	Orbiter	Mach 10 Booster	Mach 3.5 Booster	Mach 0.8 Booster	
Propulsion (Cont.)						
• Reaction Control Engines Factor	--	(2.0)	--	--	--	(2.0)
- Commonality Factor	--	1.0	--	--	--	1.0
- Complexity Factor	--	2.0	--	--	--	2.0
• Air-Breathing Engines						
- Turbojet Engine Factor	--	--	(1.0)	(1.0)	(1.0)	--
• Commonality Factor	--	--	1.0	0.6	0.1	--
• Complexity Factor	--	--	1.0	1.0	1.0	--
- Scramjet Engine Factor	--	--	--	(1.0)	--	--
• Commonality Factor	--	--	--	1.0	--	--
• Complexity Factor	--	--	--	4.0	--	--
Number of Equivalent Hardware Units						
• Ground Test	--	1.5	1.5	1.5	1.5	1.5
• Flight Test	--	1.0	1.0	2.0	1.0	1.0
Number of Equivalent Full Duration Static Tests	--	10	10	10	10	10
Vertical Flight Test Duration Months	18	--	--	--	--	18

TABLE C-1 (Cont.)

COST ESTIMATING INPUT FACTORS

Development	Two-Stage Vehicles					Single-Stage VTO
	System	Orbiter	Mach 10 Booster	Mach 3.5 Booster	Mach 0.8 Booster	
Number of Vertical Flight Tests	5	--	--	--	--	5
Wind Tunnel Test						
• Hours	--	Included with Booster	60,000	30,000	32,000	60,000
• Complexity	--		1.8	1.8	1.8	1.8
Facilities and Equipment						
• Vehicle Test Facility Commonality Factor	--	0.5	1.0	0.5	0.5	1.0
• Engine Test Facility Commonality Factor	--	0.5	1.0	0.5	0.5	1.0
• Launch Facilities	NA	--	--	--	--	1.0
• Operational and Maintenance Facilities						
- Number	1	--	--	--	--	1
- Number of Vehicles Maintaned	--	5	5	10	5	5
• Number of Vehicles Manufactured Concurrently	--	2	2	4	4	2

TABLE C-1 (Cont.)

COST ESTIMATING INPUT FACTORS

	Two-Stage Vehicles					
Development	System	Orbiter	Mach 10 Booster	Mach 3.5 Booster	Mach 0.8 Booster	Single-Stage VTO
Training						
• Flight Crew Personnel	20	--	--	--	--	20
• Ground Crew Personnel	200	--	--	--	--	200
Government Program Management and Personnel (man-years)	2100	--	--	--	--	2100
Propellant Cost						
• LH_2	50¢/lb	--	--	--	--	50¢/lb
• LOX/LH_2	21¢/lb	--	--	--	--	21¢/lb
• JP	10¢/lb	--	--	--	--	10¢/lb

TABLE C-1 (Cont.)

COST ESTIMATING INPUT FACTORS

First Unit Cost	Two-Stage Vehicles					Single-Stage VTO
	System	Orbiter	Mach 10 Booster	Mach 3.5 Booster	Mach 0.8 Booster	
Structure						
• Aerodynamic Surfaces Complexity Factor	--	(2.03)	(2.09)	(1.27)	(0.95)	(2.09)
– Configuration Factor	--	1.2	1.2	1.2	1.0	1.2
– Material/Construction Factor	--	1.69	1.74	1.06	0.95	1.74
• Body/Tank Structure Complexity Factor	--	(2.74)	(3.53)	(1.64)	(1.39)	(3.53)
– Configuration Factor	--	1.0	1.4	1.4	1.4	1.4
– Material/Construction Factor	--	1.37	1.26	1.17	0.99	1.26
– Propellant Factor						
• Thermal Protection System Complexity Factor (90% panel weight; 10% insulation weight)	--	(4.0)	(3.11)	--	--	(4.0)
– Configuration Factor	--	1.2	1.2	--	--	1.2
– Material/Construction Factor	--	3.33	2.59	--	--	3.33
• Guidance and Navigation Complexity Factor	--	1.0	1.5	1.5	1.5	1.5
• Instrumentation/Panels Complexity Factor	--	1.0	1.0	1.0	1.0	1.0

TABLE C-1 (Cont.)

COST ESTIMATING INPUT FACTORS

First Unit Cost	Two-Stage Vehicles System	Two-Stage Vehicles Orbiter	Two-Stage Vehicles Mach 10 Booster	Two-Stage Vehicles Mach 3.5 Booster	Two-Stage Vehicles Mach 0.8 Booster	Single-Stage VTO
Structure (Cont.)						
• Hydraulic Complexity Factor	--	1.0	1.0	1.0	1.0	1.0
• Propulsion						JP-1 / LH_2
– Rocket Engine Complexity Factor		3.15	--	--	--	1.30 / 3.30
– Reaction Control Complexity Factor	--	1.0	--	--	--	1.0
– Air-Breathing Engines						
• Turbojet Complexity Factor	--	--	2.2	2.2	1.0	--
• Scramjet Complexity Factor	--	--	5.0	--	--	--
– Drop Tank Complexity Factor	--	--	--	--	--	--

TABLE C-1 (Cont.)

COST ESTIMATING INPUT FACTORS

Investment	Two-Stage Vehicles					Single-Stage VTO
	System	Orbiter	Mach 10 Booster	Mach 3.5 Booster	Mach 0.8 Booster	
Number of Launch Sites (total)	1	--	--	--	--	1
Number of Launches/Year	140	--	--	--	--	140
Ground Support Equipment (percent of R&D)	70%	--	--	--	--	70%
Number of Additional Liquid Propellant Facilities	1	--	--	--	--	1
Number of New Vehicles	--	4	4	8	4	4
Number of R&D Vehicles Modified	--	1	1	2	1	1
Production Time (months)	--	15	15	15	15	15
Learning Curve	--	92%	92%	92%	92%	92%
Number of Vehicles Maintained at Site	--	5	5	10	5	5
Government Program Management (man-years)	1200	--	--	--	--	1200

TABLE C-1 (Cont.)

COST ESTIMATING INPUT FACTORS

Operating and Maintenance	Two-Stage Vehicles					Single-Stage VTO
	System	Orbiter	Mach 10 Booster	Mach 3.5 Booster	Mach 0.8 Booster	
Years of Operation	10	--	--	--	--	10
Number of Launches per Year	140	--	--	--	--	140
Number of Launches Between Overhauls	448	--	--	--	--	448
Annual Man-Years (command and control)	140	--	--	--	--	140
Annual Man-Years (site program int. and mgt.)	180	--	--	--	--	180
Annual Man-Years (in-plant engineering support)	400	--	--	--	--	400
Spares Factors per Launch						
• Structure	--	0.0015	0.0015	0.00015	0.00015	0.0015
• Thermal Protection System	--	0.005	0.005	--	--	0.005
• Rocket Engines	--	0.0044	--	--	0.0048	0.0044
• Air-Breathing Engines	--	--	0.001625	0.00155	0.00155	--
• Subsystems	--	0.009	0.009	0.0009	0.0009	0.009
Annual Man-Years (base support)	300	--	--	--	--	300

TABLE C-2

STRUCTURE MATERIAL/CONSTRUCTION FACTORS
VTO - SINGLE-STAGE-TO-ORBIT

AERO SURFACES	
Aluminum Sheet	0.06
Aluminum S/S/F[1]	0.10
Titanium Sheet	0.28
Titanium S/S/F	0.92
S S Steel[2]	0.07
L 605 Alloy	0.31
Combined factor	1.74
BODY/TANK STRUCTURE	
Aluminum Sheet	0.06
Aluminum S/S/F	0.40
Titanium Sheet	0.06
Titanium S/S/F	0.35
S S Steel	0.39
Rene '41, etc.	--
Combined factor	1.26
THERMAL PROTECTION SYSTEM	
Columbium	0.43
Titanium	1.44
L 605 Alloy	0.93
S S Steel	--
Rene '41, etc.	0.53
Combined factor	3.33

[1]Skin/stringer/frame.
[2]Super stainless steel (high temperature).

TABLE C-2 (Cont.)

STRUCTURE MATERIAL/CONSTRUCTION FACTORS

ORBITER

AERO SURFACES

Aluminum Sheet		0.06
Aluminum S/S/F		0.10
Titanium Sheet		0.28
Titanium S/S/F		0.81
S S Steel		0.13
L 605 Alloy		0.31
	Combined factor	1.69

BODY/TANK STRUCTURE

Aluminum Sheet		0.06
Aluminum S/S/F		0.40
Titanium Sheet		0.11
Titanium S/S/F		0.58
S S Steel		0.17
Rene '41, etc.		0.05
	Combined factor	1.37

THERMAL PROTECTION SYSTEM

Columbium		0.43
Titanium		0.44
L 605 Alloy		0.93
S S Steel		--
Rene '41, etc.		0.53
	Combined factor	3.33

TABLE C-2 (Cont.)

STRUCTURE MATERIAL/CONSTRUCTION FACTORS
MACH NO. 10 BOOSTER

AERO SURFACES		
Aluminum Sheet		0.06
Aluminum S/S/F		0.10
Titanium Sheet		0.28
Titanium S/S/F		0.92
S S Steel		0.07
L 605 Alloy		0.31
	Combined factor	1.74
BODY/TANK STRUCTURE		
Aluminum Sheet		0.06
Aluminum S/S/F		0.40
Titanium Sheet		0.06
Titanium S/S/F		0.35
S S Steel		0.39
Rene '41, etc.		--
	Combined factor	1.26
THERMAL PROTECTION SYSTEM		
Columbium		--
Titanium		1.38
L 605 Allow		0.37
S S Steel		0.31
Rene '41 etc.		0.53
	Combined factor	2.59

TABLE C-2 (Cont.)

STRUCTURE MATERIAL/CONSTRUCTION FACTORS
MACH NO. 3.5 BOOSTER

<u>AERO SURFACES</u>

Aluminum Sheet	0.21
Aluminum S/S/F	0.50
Titanium Sheet	--
Titanium S/S/F	0.35
S S Steel	--
L 605 Alloy	--
Combined factor	1.06

<u>BODY/TANK STRUCTURE</u>

Aluminum Sheet	0.06
Aluminum S/S/F	0.70
Titanium Sheet	0.06
Titanium S/S/F	0.35
S S Steel	--
Rene '41, etc.	--
Combined factor	1.17

TABLE C-2 (Cont.)

STRUCTURE MATERIAL/CONSTRUCTION FACTORS

MACH NO. 0.8 BOOSTER

AERO SURFACES	
Aluminum Sheet	0.27
Aluminum S/S/F	0.45
Titanium Sheet	--
Titanium S/S/F	0.23
S S Steel	--
L 605 Alloy	--
Combined factor	0.95

BODY/TANK STRUCTURE	
Aluminum Sheet	0.21
Aluminum S/S/F	0.55
Titanium Sheet	--
Titanium S/S/F	0.23
S S Steel	--
Rene '41, etc.	--
Combined factor	0.99

TABLE C-3

SINGLE-STAGE-TO-ORBIT (VTO)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
1000	TOTAL RDT&E				760.7
1100	CONCEPTUAL AND DEFINTION PHASE				47.2
1110	Conceptual Studies (Contractor)				3.4
1120	Program Definition Studies (Contractor)				30.3
1130	Other Study Support				13.5
1140	SE/TD Contractor(s)				--
1200	ENGINEERING DEVELOPMENT PHASE				6792.0
1210	Air Frame				2623.1
1211	Structure				999.9
1211-1	Aerodynamic Surface				196.4
1211-2	Body/Tank Structure				803.5
1211-3	Nonintegral Tanks				--
1211-4	Other				--
1212	Landing Gear				--
1213	Thermal Protection System				317.6
1214	Avionics				547.9
1214-1	Guidance and Navigation				117.0
1214-2	Communications				144.8
1214-3	Instrumentation/Panels				286.1
1215	Power Supply and Distribution				338.8
1215-1	Electrical Power				268.5
1215-2	Hydraulic Power				70.3
1216	Environmental Control & Life Support				418.9
1217	Emergency				--
1218	Drop Tanks				--
1220	Propulsion				1234.5
1221	Rocket Engines – Primary				1118.0
1222	Rocket Engines – Secondary				--
1223	Air-Breathing Engines				--
1224	Orientation Control				116.5
1230	Vehicle Integration				129.6
1240	Initial Tooling				303.9

TABLE C-3 (Cont.)

SINGLE-STAGE-TO-ORBIT (VTO)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
1250	Ground Equipment				156.9
1260	Test Hardware				1054.3
1261	Ground Test				632.6
1262	Flight Test				421.7
1270	Test Operations				414.0
1271	Ground Test				157.0
1272	Flight Test				137.5
1272-1	Horizontal				68.2
1272-2	Vertical				69.3
1273	Wind Tunnel Test				119.5
1280	Facilities and Equipment				756.9
1281	Vehicle Test Facilities				126.3
1282	Engine Test Facilities				119.9
1283	Launch Facilities				178.0
1284	Operational & Maintenance Facilities				141.8
1285	Manufacturing Facilities				7.6
1286	Wind Tunnel Facilities				--
1287	Propellant Production Facilities				57.8
1288	Support Equipment				--
1289	Activation				125.5
1290	Training				118.8
1291	Personnel				34.5
1291-1	Flight Crew				29.7
1291-2	Ground Crew				4.8
1292	Simulators and Equipment				84.3
1300	SYSTEM INTEGRATION ENGINEERING				219.3
1310	Contractor Program Management				401.6
1320	SE/TD Contractor(s)				--
1400	TECHNOLOGY SUPPORT PHASE				--
1410	Aerothermo Technology				--
1420	Structure/Material Technology				--
1430	Propulsion Technology				--

TABLE C-3 (Cont.)

SINGLE-STAGE-TO-ORBIT (VTO)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
1440	Other Technology				--
1500	GOVERNMENT PROGRAM MGMT.				141.6
2000	TOTAL INVESTMENT				2561.0
2100	FACILITIES AND EQUIPMENT				308.9
2110	Launch Facilities				--
2120	Operational & Maintenance Facilities				--
2130	Manufacturing Facilities				--
2140	Propellant Production Facilities				57.8
2150	Ground Equipment				139.5
2160	Support Equipment				--
2170	Activation				111.6
2200	REUSABLE VEHICLE FLEET				2191.2
2210	New Vehicle Manufacturing				1428.3
2220	R&D Vehicle Modifications				126.5
2230	Initial Spares				142.8
2240	Sustaining Tooling				45.6
2250	Engineering Support				285.7
2260	Contractor Program Management				162.3
2270	SE/TD Contractor(s)				--
2300	EXPENDABLE HARDWARE				--
2310	Hardware Manufacturing				--
2320	Spares Support				--
2330	Engineering Support				--
2340	Additional and Sustaining Tooling				--
2350	Contractor Program Management				--
2400	GOVERNMENT PROGRAM MGMT.				80.9
3000	TOTAL OPERATIONS				12,460.4
3100	OPERATIONS				1618.8
3110	Launch Operations				55.0
3120	Recovery Operations				25.7
3130	Command and Control				148.6
3140	Replacement Training				50.6

TABLE C-3 (Cont.)

SINGLE-STAGE-TO-ORBIT (VTO)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
3150	Facility & Equipment Maintenance				387.1
3151	Launch & Maintenance Facilities				159.9
3152	Ground & Support Equipment				227.2
3160	Vehicle Maintenance				513.7
3161	Ground-Based Maintenance Operations				513.7
3162	Space-Based Maintenance Operations				--
3170	In-Plant Engineering Support				269.6
3180	Program Integration and Management				168.5
3200	SPARES AND PROPELLANT SUPPORT				10,671.1
3210	Follow-On Spares				8645.5
3211	Structure				678.8
3212	Thermal Protection System				3019.7
3213	Rocket Engines				886.4
3214	Air-Breathing Engines				--
3215	Subsystems				4060.6
3216	Other				--
3217	Transportation (Space-Based)				--
3220	Propellants and Gases				2025.6
3221	Basic Cost (Ground-Based)				2025.6
3222	Transportation Cost (Space-Based)				--
3300	RANGE/BASE SUPPORT				170.5
4000	AIR VEHICLE FIRST UNIT COST				421.7
4100	AIR FRAME				331.9
4110	Structure				107.8
4111	Aerodynamic Surfaces				41.6
4112	Body/Tank Structure				66.2
4113	Nonintegral Tanks				--
4114	Other				--
4120	Landing Gear				0.3
4130	Thermal Protection System				143.9
4140	Avionics				26.6
4141	Guidance and Navigation				12.2

TABLE C-3 (Cont.)

SINGLE-STAGE-TO-ORBIT (VTO)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
4142	Communication				10.1
4143	Instrumentation/Panels				14.0
4150	Power Supply & Distribution				33.8
4151	Electrical Power				25.6
4152	Hydraulic Power				8.2
4160	Environmental Control & Life Support				19.5
4170	Emergency Recovery				--
4200	PROPULSION				75.3
4210	Rocket Engines – Primary				48.0
4220	Rocket Engines – Secondary				--
4230	Air-Breathing Engines				--
4240	Orientation Control Thrusters				27.3
4300	INTEGRATION, ASSEMBLY, CHECKOUT, AND TEST				14.5
5000	DROP TANK FIRST UNIT COST				--

TABLE C-4

TWO-STAGE

(Subsonic Staging, Single-Booster)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
1000	TOTAL RDT&E	5432.6	3159.1	797.3	9022.6
1100	CONCEPTUAL AND DEFINTION PHASE			47.2	47.2
1110	Conceptual Studies (Contractor)			3.4	
1120	Program Definition Studies (Contractor)			30.3	
1130	Other Studv Support			13.5	
1140	SE/TD Contractor(s)				
1200	ENGINEERING DEVELOPMENT PHASE	4907.2	2842.3	591.4	8340.9
1210	Air Frame	2353.4	1264.3		3617.7
1211	Structure	947.4	852.8		
1211-1	Aerodynamic Surface	314.4	507.0		
1211-2	Body/Tank Structure	633.0	345.8		
1211-3	Nonintegral Tanks				
1211-4	Other				
1212	Landing Gear				
1213	Thermal Protection System	294.6			
1214	Avionics	547.9	140.3		
1214-1	Guidance and Navigation	117.2	35.2		
1214-2	Communications	144.8	20.6		
1214-3	Instrumentation/Panels	286.1	84.5		
1215	Power Supply and Distribution	250.8	271.2		
1215-1	Electrical Power	199.5	212.0		
1215-2	Hydraulic Power	51.3	59.2		
1216	Environmental Control & Life Support	312.7			
1217	Emergency				
1218	Drop Tanks				
1220	Propulsion	242.6	90.4		333.0
1221	Rocket Engines – Primary	126.2			
1222	Rocket Engines – Secondary				
1223	Air-Breathing Engines		90.4		
1224	Orientation Control	116.4			
1230	Vehicle Integration	106.2	52.4		158.6
1240	Initial Tooling	325.2	501.3		826.5

TABLE C-4 (Cont.)

TWO-STAGE

(Subsonic Staging, Single-Booster)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
1250	Ground Equipment	135.6	58.2		193.8
1260	Test Hardware	968.0	507.0		1475.0
1261	Ground Test	580.8	304.2		
1262	Flight Test	387.2	202.8		
1270	Test Operations	206.0	184.1	127.1	517.2
1271	Ground Test	137.8	115.9		
1272	Flight Test	68.2	68.2	70.5	
1272-1	Horizontal	68.2	68.2		
1272-2	Vertical			70.5	
1273	Wind Tunnel Test			56.6	
1280	Facilities and Equipment	126.4	144.0	429.8	700.2
1281	Vehicle Test Facilities	58.3	63.2		
1282	Engine Test Facilities	59.9	59.9		
1283	Launch Facilities				
1284	Operational & Maintenance Facilities				
1285	Manufacturing Facilities	8.2	20.9	217.0	
1286	Wind Tunnel Facilities				
1287	Propellant Production Facilities				
1288	Support Equipment			57.8	
1289	Activation			155.0	
1290	Training	77.4	40.6	34.5	152.5
1291	Personnel			34.5	
1291-1	Flight Crew			29.7	
1291-2	Ground Crew			4.8	
1292	Simulators and Equipment	77.4	40.6		
1300	SYSTEM INTEGRATION ENGINEERING	177.7	100.2	6.4	284.3
1310	Contractor Program Management	347.7	216.6	10.7	575.0
1320	SE/TD Contractor(s)				
1400	TECHNOLOGY SUPPORT PHASE				
1410	Aerothermo Technology				
1420	Structure/Material Technology				
1430	Propulsion Technology				

TABLE C-4 (Cont)

TWO-STAGE

(Subsonic Staging, Single-Booster)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
1440	Other Technology				
1500	GOVERNMENT PROGRAM MGMT.				
2000	TOTAL INVESTMENT	2166.3	1165.8	268.1	3600.2
2100	FACILITIES AND EQUIPMENT	112.9	48.8	187.2	
2110	Launch Facilities				
2120	Operational & Maintenance Facilities				
2130	Manufacturing Facilities				
2140	Propellant Production Facilities			57.8	57.8
2150	Ground Equipment	112.9	48.8		
2160	Support Equipment				
2170	Activation			129.4	129.4
2200	REUSABLE VEHICLE FLEET	2053.4	1117.0		3170.4
2210	New Vehicle Manufacturing	1311.4	686.9		1998.3
2220	R&D Vehicle Modifications	116.2	60.8		177.0
2230	Initial Spares	131.1	68.7		199.8
2240	Sustaining Tooling	55.6	80.5		136.1
2250	Engineering Support	296.7	137.4		434.1
2260	Contractor Program Management	142.4	82.7		225.1
2270	SE/TD Contractor(s)				
2300	EXPENDABLE HARDWARE				
2310	Hardware Manufacturing				
2320	Spares Support				
2330	Engineering Support				
2340	Additional and Sustaining Tooling				
2350	Contractor Program Management				
2400	GOVERNMENT PROGRAM MGMT.			80.9	80.9
3000	TOTAL OPERATIONS				
3100	OPERATIONS				
3110	Launch Operations				
3120	Recovery Operations				
3130	Command and Control				
3140	Replacement Training				

5 BOOSTERS/5 ORBITERS

TABLE C-4 (Cont.)

TWO-STAGE

(Subsonic Staging, Single-Booster)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
1440	Other Technology				
1500	GOVERNMENT PROGRAM MGMT.			141.6	141.6
2000	TOTAL INVESTMENT	2166.3	725.3	268.1	3159.7
2100	FACILITIES AND EQUIPMENT	112.9	48.8	187.2	348.9
2110	Launch Facilities				
2120	Operational & Maintenance Facilities				
2130	Manufacturing Facilities				
2140	Propellant Production Facilities			57.8	57.8
2150	Ground Equipment	112.9	48.8		161.7
2160	Support Equipment				
2170	Activation			129.4	129.4
2200	REUSABLE VEHICLE FLEET	2053.4	676.5		2729.9
2210	New Vehicle Manufacturing	1311.4	373.2		1684.6
2220	R&D Vehicle Modifications	116.2	60.8		177.0
2230	Initial Spares	131.1	37.3		168.4
2240	Sustaining Tooling	55.6	80.5		136.1
2250	Engineering Support	296.7	74.6		371.3
2260	Contractor Program Management	142.4	50.1		192.5
2270	SE/TD Contractor(s)				
2300	EXPENDABLE HARDWARE				
2310	Hardware Manufacturing				
2320	Spares Support				
2330	Engineering Support				
2340	Additional and Sustaining Tooling				
2350	Contractor Program Management				
2400	GOVERNMENT PROGRAM MGMT.			80.9	80.9
3000	TOTAL OPERATIONS	9067.1	551.1	1736.4	11,354.6
3100	OPERATIONS			1594.4	1594.4
3110	Launch Operations			55.0	
3120	Recovery Operations			25.7	
3130	Command and Control			148.6	
3140	Replacement Training			50.6	

3 BOOSTERS/5 ORBITERS

TABLE C-4 (Cont.)

TWO-STAGE

(Subsonic Staging, Single-Booster)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
3150	Facility & Equipment Maintenance			362.7	
3151	Launch & Maintenance Facilities			108.5	
3152	Ground & Support Equipment			254.2	
3160	Vehicle Maintenance			513.7	
3161	Ground-Based Maintenance Operations			513.7	
3162	Space-Based Maintenance Operations				
3170	In-Plant Engineering Support			269.6	
3180	Program Integration and Management			168.5	
3200	SPARES AND PROPELLANT SUPPORT	9067.1	551.1		9618.2
3210	Follow-On Spares	7543.9	540.3		
3211	Structure	745.4	60.8		
3212	Thermal Protection System	2797.2			
3213	Rocket Engines	280.7			
3214	Air-Breathing Engines		261.5		
3215	Subsystems	3720.6	218.0		
3216	Other				
3217	Transportation (Space-Based)				
3220	Propellants and Gases	1523.2	10.8		
3221	Basic Cost (Ground-Based)	1523.2	10.8		
3222	Transportation Cost (Space-Based)				
3300	RANGE/BASE SUPPORT			142.0	142.0
4000	AIR VEHICLE FIRST UNIT COST	387.2	202.8		590.0
4100	AIR FRAME	322.9	154.2		477.1
4110	Structure	118.4	96.5		214.9
4111	Aerodynamic Surfaces	73.3	73.5		146.8
4112	Body/Tank Structure	45.1	23.0		68.0
4113	Nonintegral Tanks				
4114	Other				
4120	Landing Gear	0.2	0.9		1.1
4130	Thermal Protection System	133.3			133.3
4140	Avionics	26.6	29.7		56.3
4141	Guidance and Navigation	12.2	18.3		30.5

TABLE C-4 (Cont.)

TWO-STAGE

(Subsonic Staging, Single-Booster)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
4142	Communication	6.4	3.5		13.6
4143	Instrumentation/Panels	8.0	7.9		21.9
4150	Power Supply & Distribution	24.9	27.1		52.0
4151	Electrical Power	19.0	20.2		39.2
4152	Hydraulic Power	5.9	6.9		12.8
4160	Environmental Control & Life Support	19.5			19.5
4170	Emergency Recovery				
4200	PROPULSION	50.1	40.2		90.3
4210	Rocket Engines – Primary	22.8			22.8
4220	Rocket Engines – Secondary				
4230	Air-Breathing Engines		40.2		40.2
4240	Orientation Control Thrusters	27.3			27.3
4300	INTEGRATION, ASSEMBLY, CHECKOUT, AND TEST	14.2	8.4		22.6
5000	DROP TANK FIRST UNIT COST				

TABLE C-5

TWO-STAGE

(Subsonic Staging, Twin-Booster)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER (one)	SYSTEM	EOS TOTAL
1000	TOTAL RDT&E	5432.6	2077.4	797.3	8307.3
1100	CONCEPTUAL AND DEFINTION PHASE				
1110	Conceptual Studies (Contractor)				
1120	Program Definition Studies (Contractor)				
1130	Other Study Support				
1140	SE/TD Contractor(s)				
1200	ENGINEERING DEVELOPMENT PHASE		2077.4		
1210	Air Frame		758.5		
1211	Structure		483.5		
1211-1	Aerodynamic Surface		243.8		
1211-2	Body/Tank Structure		239.7		
1211-3	Nonintegral Tanks				
1211-4	Other				
1212	Landing Gear				
1213	Thermal Protection System				
1214	Avionics		140.3		
1214-1	Guidance and Navigation				
1214-2	Communications				
1214-3	Instrumentation/Panels				
1215	Power Supply and Distribution		134.7		
1215-1	Electrical Power				
1215-2	Hydraulic Power				
1216	Environmental Control & Life Support				
1217	Emergency				
1218	Drop Tanks				
1220	Propulsion		90.4		
1221	Rocket Engines – Primary				
1222	Rocket Engines – Secondary				
1223	Air-Breathing Engines				
1224	Orientation Control				
1230	Vehicle Integration		30.9		
1240	Initial Tooling		251.4		

TABLE C-5 (Cont.)

TWO-STAGE

(Subsonic Staging, Twin-Booster)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER (one)	SYSTEM	EOS TOTAL
1250	Ground Equipment		37.2		
1260	Test Hardware		352.8		
1261	Ground Test		368.7		
1262	Flight Test		245.8		
1270	Test Operations		200.6		
1271	Ground Test		105.1		
1272	Flight Test		95.5		
1272-1	Horizontal		95.9		
1272-2	Vertical				
1273	Wind Tunnel Test				
1280	Facilities and Equipment		127.9		
1281	Vehicle Test Facilities		63.2		
1282	Engine Test Facilities		60.0		
1283	Launch Facilities				
1284	Operational & Maintenance Facilities				
1285	Manufacturing Facilities		4.7		
1286	Wind Tunnel Facilities				
1287	Propellant Production Facilities				
1288	Support Equipment				
1289	Activation				
1290	Training		24.6		
1291	Personnel				
1291-1	Flight Crew				
1291-2	Ground Crew				
1292	Simulators and Equipment		24.6		
1300	SYSTEM INTEGRATION ENGINEERING		65.4		
1310	Contractor Program Management		137.7		
1320	SE/TD Contractor(s)				
1400	TECHNOLOGY SUPPORT PHASE				
1410	Aerothermo Technology				
1420	Structure/Material Technology				
14[illegible]	Propulsion Technology				

TABLE C-5 (Cont.)

TWO-STAGE

(Subsonic Staging, Twin-Booster)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER (one)	SYSTEM	EOS TOTAL
1440	Other Technology				
1500	GOVERNMENT PROGRAM MGMT.				
2000	TOTAL INVESTMENT	2166.3	730.8	268.1	3165.2
2100	FACILITIES AND EQUIPMENT		26.0		
2110	Launch Facilities				
2120	Operational & Maintena. ce Facilities				
2130	Manufacturing Facilities				
2140	Propellant Production Facilities				
2150	Ground Equipment		26.0		
2160	Support Equipment				
2170	Activation				
2200	REUSABLE VEHICLE FLEET		704.8		
2210	New Vehicle Manufacturing		416.3		
2220	R&D Vehicle Modifications		73.7		
2230	Initial Spares		41.6		
2240	Sustaining Tooling		37.7		
2250	Engineering Support		83.3		
2260	Contractor Program Management		52.2		
2270	SE/TD Contractor(s)				
2300	EXPENDABLE HARDWARE				
2310	Hardware Manufacturing				
2320	Spares Support				
2330	Engineering Support				
2340	Additional and Sustaining Tooling				
2350	Contractor Program Management				
2400	GOVERNMENT PROGRAM MGMT.				
3000	TOTAL OPERATIONS	9067.1	412.1	1736.4	11215.6
3100	OPERATIONS				
3110	Launch Operations				
3120	Recovery Operations				
3130	Command and Control				
3140	Replacement Training				

6 BOOSTERS/5 ORBITERS

TABLE C-5 (Cont.)

TWO-STAGE

(Subsonic Staging, Twin-Booster)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER (one)	SYSTEM	EOS TOTAL
3150	Facility & Equipment Maintenance				
3151	Launch & Maintenance Facilities				
3152	Ground & Support Equipment				
3160	Vehicle Maintenance				
3161	Ground-Based Maintenance Operations				
3162	Space-Based Maintenance Operations				
3170	In-Plant Engineering Support				
3180	Program Integration and Management				
3200	SPARES AND PROPELLANT SUPPORT				
3210	Follow-On Spares		379.9		
3211	Structure		28.3		
3212	Thermal Protection System				
3213	Rocket Engines				
3214	Air-Breathing Engines		188.0		
3215	Subsystems		163.6		
3216	Other				
3217	Transportation (Space-Based)				
3220	Propellants and Gases		32.2		
3221	Basic Cost (Ground-Based)		32.2		
3222	Transportation Cost (Space-Based)				
3300	RANGE/BASE SUPPORT				
4000	AIR VEHICLE FIRST UNIT COST	387.2	122.9		
4100	AIR FRAME		88.2		
4110	Structure		45.0		
4111	Aerodynamic Surfaces		35.2		
4112	Body/Tank Structure		9.8		
4113	Nonintegral Tanks				
4114	Other				
4120	Landing Gear		39.8		
4130	Thermal Protection System				
4140	Avionics		29.7		
4141	Guidance and Navigation				

TABLE C-5 (Cont.)

TWO-STAGE

(Subsonic Staging, Twin-Booster)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
4142	Communication				
4143	Instrumentation/Panels				
4150	Power Supply & Distribution		13.5		
4151	Electrical Power				
4152	Hydraulic Power				
4160	Environmental Control & Life Support				
4170	Emergency Recovery				
4200	PROPULSION		28.9		
4210	Rocket Engines – Primary				
4220	Rocket Engines – Secondary				
4230	Air-Breathing Engines				
4240	Orientation Control Thrusters				
4300	INTEGRATION, ASSEMBLY, CHECKOUT, AND TEST		5.8		
5000	DROP TANK FIRST UNIT COST				

TABLE C-6

TWO-STAGE

(Supersonic Staging)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER (one)	SYSTEM	EOS TOTAL
1000	TOTAL RDT&E	4763.7	3386.4	760.3	8910.4
1100	CONCEPTUAL AND DEFINTION PHASE			47.2	47.2
1110	Conceptual Studies (Contractor)			3.4	
1120	Program Definition Studies (Contractor)			30.3	
1130	Other Study Support			13.5	
1140	SE/TD Contractor(s)				
1200	ENGINEERING DEVELOPMENT PHASE	4279.0	3111.2	547.4	7937.6
1210	Air Frame	2280.6	973.0		3253.6
1211	Structure	928.1	698.0		
1211-1	Aerodynamic Surface	287.2	311.7		
1211-2	Body/Tank Structure	640.9	386.3		
1211-3	Nonintegral Tanks				
1211-4	Other				
1212	Landing Gear				
1213	Thermal Protection System	274.9			
1214	Avionics	547.9	140.3		
1214-1	Guidance and Navigation	117.2	35.2		
1214-2	Communications	144.8	20.6		
1214-3	Instrumentation/Panels	286.1	84.5		
1215	Power Supply and Distribution	217.8	134.7		
1215-1	Electrical Power	176.7	102.5		
1215-2	Hydraulic Power	41.1	32.2		
1216	Environmental Control & Life Support	312.7			
1217	Emergency				
1218	Drop Tanks				
1220	Propulsion	242.6	692.8		935.4
1221	Rocket Engines – Primary	126.2			
1222	Rocket Engines – Secondary				
1223	Air-Breathing Engines		692.8		
1224	Orientation Control	116.4			
1230	Vehicle Integration	42.0	52.8		94.8
1240	Initial Tooling	371.0	360.6		731.6

TABLE C-6 (Cont.)

TWO-STAGE

(Supersonic Staging)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER (one)	SYSTEM	EOS TOTAL
1250	Ground Equipment	130.0	40.2		170.2
1260	Test Hardware	837.0	660.8		1497.8
1261	Ground Test	502.2	283.2		
1262	Flight Test	334.8	377.6		
1270	Test Operations	177.5	164.1	144.7	486.3
1271	Ground Test	109.3	95.9		
1272	Flight Test	68.2	68.2	70.1	
1272-1	Horizontal	68.2	68.2		
1272-2	Vertical			70.1	
1273	Wind Tunnel Test			74.6	
1280	Facilities and Equipment	131.3	129.1	368.2	628.6
1281	Vehicle Test Facilities	58.3	63.2		
1282	Engine Test Facilities	60.0	60.0		
1283	Launch Facilities				
1284	Operational & Maintenance Facilities			174.2	
1285	Manufacturing Facilities	13.0	5.9		
1286	Wind Tunnel Facilities				
1287	Propellant Production Facilities			57.8	
1288	Support Equipment				
1289	Activation			136.2	
1290	Training	67.0	37.8	34.5	139.3
1291	Personnel			34.5	
1291-1	Flight Crew			29.7	
1291-2	Ground Crew			4.8	
1292	Simulators and Equipment	67.0	37.8		
1300	SYSTEM INTEGRATION ENGINEERING	164.8	92.6	9.0	266.4
1310	Contractor Program Management	319.9	182.7	15.1	517.7
1320	SE/TD Contractor(s)				
1400	TECHNOLOGY SUPPORT PHASE				
1410	Aerothermo Technology				
1420	Structure/Material Technology				
1430	Propulsion Technology				

TABLE C-6 (Cont.)

TWO-STAGE

(Supersonic Staging)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
1440	Other Technology				
1500	GOVERNMENT PROGRAM MGMT.			141.6	141.6
2000	TOTAL INVESTMENT	1989.2	1128.4	278.8	3396.4
2100	FACILITIES AND EQUIPMENT	149.7	25.4	197.9	373.0
2110	Launch Facilities				
2120	Operational & Maintenance Facilities				
2130	Manufacturing Facilities				
2140	Propellant Production Facilities			57.8	
2150	Ground Equipment	149.7	25.4		
2160	Support Equipment				
2170	Activation			140.1	
2200	REUSABLE VEHICLE FLEET	1839.5	1103.0		2942.5
2210	New Vehicle Manufacturing	1186.5	668.6		
2220	R&D Vehicle Modifications	105.1	118.4		
2230	Initial Spares	118.7	66.9		
2240	Sustaining Tooling	55.7	33.7		
2250	Engineering Support	237.3	133.7		
2260	Contractor Program Management	136.2	81.7		
2270	SE/TD Contractor(s)				
2300	EXPENDABLE HARDWARE				
2310	Hardware Manufacturing				
2320	Spares Support				
2330	Engineering Support				
2340	Additional and Sustaining Tooling				
2350	Contractor Pr‑ ram Management				
2400	GOVERNMENT PROGRAM MGMT.			80.9	80.9
3000	TOTAL OPERATIONS				
3100	OPERATIONS				
3110	Launch Operations				
3120	Recovery Operations				
3130	Command and Control				
3140	Replacement Training				

6 BOOSTERS/5 ORBITERS

TABLE C-6 (Cont.)

TWO-STAGE

(Supersonic Staging)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
1440	Other Technology				
1500	GOVERNMENT PROGRAM MGMT.				
2000	TOTAL INVESTMENT	1989.2	1917.3	278.8	4185.3
2100	FACILITIES AND EQUIPMENT	149.7	25.4	197.9	373.0
2110	Launch Facilities				
2120	Operational & Maintenance Facilities				
2130	Manufacturing Facilities				
2140	Propellant Production Facilities			57.8	
2150	Ground Equipment	149.7	25.4		
2160	Support Equipment				
2170	Activation			140.1	
2200	REUSABLE VEHICLE FLEET	1839.5	1891.9		3731.4
2210	New Vehicle Manufacturing	1186.5	1230.5		
2220	R&D Vehicle Modifications	105.1	118.4		
2230	Initial Spares	118.7	123.1		
2240	Sustaining Tooling	55.7	33.7		
2250	Engineering Support	237.3	246.1		
2260	Contractor Program Management	136.2	140.1		
2270	SE/TD Contractor(s)				
2300	EXPENDABLE HARDWARE				
2310	Hardware Manufacturing				
2320	Spares Support				
2330	Engineering Support				
2340	Additional and Sustaining Tooling				
2350	Contractor Program Management				
2400	GOVERNMENT PROGRAM MGMT.			80.9	80.9
3000	TOTAL OPERATIONS	7890.9	769.8	1729.1	10,389.8
3100	OPERATIONS			1587.1	1587.1
3110	Launch Operations			55.0	
3120	Recovery Operations			25.7	
3130	Command and Control			148.6	
3140	Replacement Training			30.6	

10 BOOSTERS/5 ORBITERS

TABLE C-6 (Cont.)

TWO-STAGE
(Supersonic Staging)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
3150	Facility & Equipment Maintenance			355.4	
3151	Launch & Maintenance Facilities			87.1	
3152	Ground & Support Equipment			268.3	
3160	Vehicle Maintenance			513.7	
3161	Ground-Based Maintenance Operations			513.7	
3162	Space-Based Maintenance Operations				
3170	In-Plant Engineering Support			269.6	
3180	Program Integration and Management			168.5	
3200	SPARES AND PROPELLANT SUPPORT	7890.9	769.8		8660.7
3210	Follow-On Spares	6897.8	1076.6		
3211	Structure	628.9	46.6		
3212	Thermal Protection System	2362.9			
3213	Rocket Engines	280.7			
3214	Air-Breathing Engines		411.8		
3215	Subsystems	3599.8	166.6		
3216	Other				
3217	Transportation (Space-Based)				
3220	Propellants and Gases	1018.6	144.8		
3221	Basic Cost (Ground-Based)	1018.6	144.8		
3222	Transportation Cost (Space-Based)				
3300	RANGE/BASE SUPPORT			142.0	142.0
4000	AIR VEHICLE FIRST UNIT COST	350.3	197.4		
4100	AIR FRAME	295.6	126.8		
4110	Structure	113.3	83.0		
4111	Aerodynamic Surfaces	66.9	50.2		
4112	Body/Tank Structure	46.4	32.8		
4113	Nonintegral Tanks				
4114	Other				
4120	Landing Gear	0.3	0.3		
4130	Thermal Protection System	114.3			
4140	Avionics	26.6	29.7		
4141	Guidance and Navigation	12.2	18.3		

TABLE C-6 (Cont.)

TWO-STAGE
(Supersonic Staging)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL*
4142	Communication	6.4	3.5		
4143	Instrumentation/Panels	8.0	7.9		
4150	Power Supply & Distribution	21.6	13.5		
4151	Electrical Power	16.9	9.8		
4152	Hydraulic Power	4.7	3.7		
4160	Environmental Control & Life Support	19.5			
4170	Emergency Recovery				
4200	PROPULSION	42.5	63.3		
4210	Rocket Engines – Primary	15.2			
4220	Rocket Engines – Secondary				
4230	Air-Breathing Engines		63.3		
4240	Orientation Control Thrusters	27.3			
4300	INTEGRATION, ASSEMBLY, CHECKOUT, AND TEST	12.2	7.3		
5000	DROP TANK FIRST UNIT COST				

*A 92% learning curve was used to determine vehicle cost in calculating total investment costs.

TABLE C-7

TWO-STAGE

(Hypersonic Staging)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
1000	TOTAL RDT&E	4179.8	8700.7	728.8	13,242.9
1100	CONCEPTUAL AND DEFINTION PHASE			47.2	47.2
1110	Conceptual Studies (Contractor)			3.4	
1120	Program Definition Studies (Contractor)			30.3	
1130	Other Study Support			13.5	
1140	SE/TD Contractor(s)				
1200	ENGINEERING DEVELOPMENT PHASE	3788.5	7928.2	649.7	12,366.4
1210	Air Frame	1793.4	2483.3		4276.7
1211	Structure	568.2	1776.8		
1211-1	Aerodynamic Surface	122.6	737.0		
1211-2	Body/Tank Structure	445.6	1039.8		
1211-3	Nonintegral Tanks				
1211-4	Other				
1212	Landing Gear				
1213	Thermal Protection System	178.8	290.3		
1214	Avionics	547.9	140.3		
1214-1	Guidance and Navigation	117.2	35.2		
1214-2	Communications	144.8	20.6		
1214-3	Instrumentation/Panels	286.1	84.5		
1215	Power Supply and Distribution	185.8	275.9		
1215-1	Electrical Power	152.6	205.8		
1215-2	Hydraulic Power	33.2	70.1		
1216	Environmental Control & Life Support	312.7			
1217	Emergency				
1218	Drop Tanks				
1220	Propulsion	609.0	1817.2		2059.8
1221	Rocket Engines – Primary	126.2			
1222	Air-Breathing Engines – Secondary		692.8		
1223	Air-Breathing Engines		1124.4		
1224	Orientation Control	116.4			
1230	Vehicle Integration	83.9	135.7		219.6
1240	Initial Tooling	232.4	715.6		948.0

TABLE C-7 (Cont.)

TWO-STAGE

(Hypersonic Staging)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
1250	Ground Equipment	119.6	83.0		202.6
1260	Test Hardware	619.0	1956.3		2575.3
1261	Ground Test	371.4	1173.8		
1262	Flight Test	247.6	782.5		
1270	Test Operations	159.2	323.7	203.5	686.4
1271	Ground Test	91.0	255.5		
1272	Flight Test	68.2	68.2	84.0	
1272-1	Horizontal	68.2	68.2		
1272-2	Vertical			84.0	
1273	Wind Tunnel Test			119.5	
1280	Facilities and Equipment	122.5	256.9	411.7	791.1
1281	Vehicle Test Facilities	58.3	126.3		
1282	Engine Test Facilities	60.0	119.9		
1283	Launch Facilities				
1284	Operational & Maintenance Facilities			191.8	
1285	Manufacturing Facilities	4.2	10.7		
1286	Wind Tunnel Facilities				
1287	Propellant Production Facilities			57.8	
1288	Support Equipment				
1289	Activation			162.1	
1290	Training	49.5	1[illegible]	34.5	240.5
1291	Personnel			[illegible]5	
1291-1	Flight Crew			[illegible].7	
1291-2	Ground Crew			[illegible].8	
1292	Simulators and Equipment	49.5	156.5		
1300	SYSTEM INTEGRATION ENGINEERING	135.9	281.7	11.9	429.5
1310	Contractor Program Management	255.4	490.8	20.0	766.2
1320	SE/TD Contractor(s)				
1400	TECHNOLOGY SUPPORT PHASE				
1410	Aerothermo Technology				
1420	Structure/Material Technology				
1430	Propulsion Technology				

TABLE C-7 (Cont.)

TWO-STAGE

(Hypersonic Staging)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
1440	Other Technology				
1500	GOVERNMENT PROGRAM MGMT.				
2000	TOTAL INVESTMENT	1379.1	2455.6	257.1	4091.8
2100	FACILITIES AND EQUIPMENT	83.7	64.3	176.2	324.2
2110	Launch Facilities				
2120	Operational & Maintenance Facilities				
2130	Manufacturing Facilities				
2140	Propellant Production Facilities			57.8	57.8
2150	Ground Equipment	83.7	64.3		148.0
2160	Support Equipment				
2170	Activation			118.4	118.4
2200	REUSABLE VEHICLE FLEET	1295.4	2391.3		3686.7
2210	New Vehicle Manufacturing	838.6	1440.1		2278.7
2220	R&D Vehicle Modifications	74.3	234.8		309.1
2230	Initial Spares	83.9	144.0		227.[illegible]
2240	Sustaining Tooling	34.9	107.3		14[illegible]
2250	Engineering Support	167.7	288.0		45[illegible]
2260	Contractor Program Management	96.0	177.1		273.[illegible]
2270	SE/TD Contractor(s)				
2300	EXPENDABLE HARDWARE				
2310	Hardware Manufacturing				
2320	Spares Support				
2330	Engineering Support				
2340	Additional and Sustaining Tooling				
2350	Contractor Program Management				
2400	GOVERNMENT PROGRAM MGMT.			80.9	80.9
3000	TOTAL OPERATIONS				
3100	OPERATIONS				
3110	Launch Operations				
3120	Recovery Operations				
3130	Command and Control				
3140	Replacement Training				

3 BOOSTERS/5 ORBITERS

TABLE C-7 (Cont.)

TWO-STAGE

(Hypersonic Staging)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
1440	Other Technology				
1500	GOVERNMENT PROGRAM MGMT.			141.6	141.6
2000	TOTAL INVESTMENT	1379.1	4154.8	257.1	5791.0
2100	FACILITIES AND EQUIPMENT	83.7	64.3	176.2	324.2
2110	Launch Facilities				
2120	Operational & Maintenance Facilities				
2130	Manufacturing Facilities				
2140	Propellant Production Facilities			57.8	57.8
2150	Ground Equipment	83.7	64.3		148.0
2160	Support Equipment				
2170	Activation			118.4	118.4
2200	REUSABLE VEHICLE FLEET	1295.4	4090.5		5385.9
2210	New Vehicle Manufacturing	838.6	2650.3		3488.9
2220	R&D Vehicle Modifications	74.3	234.8		309.1
2230	Initial Spares	83.9	265.0		348.9
2240	Sustaining Tooling	34.9	107.3		142.2
2250	Engineering Support	167.7	530.1		697.8
2260	Contractor Program Management	96.0	303.0		399.0
2270	SE/TD Contractor(s)				
2300	EXPENDABLE HARDWARE				
2310	Hardware Manufacturing				
2320	Spares Support				
2330	Engineering Support				
2340	Additional and Sustaining Tooling				
2350	Contractor Program Management				
2400	GOVERNMENT PROGRAM MGMT.			80.9	80.9
3000	TOTAL OPERATIONS	5972.4	994[illegible].4	1993.5	17,912.3
3100	OPERATIONS			1851.5	1851.5
3110	Launch Operations			55.0	
3120	Recovery Operations			25.7	
3130	Command and Control			148.6	
3140	Replacement Training			[illegible]0.6	

5 BOOSTERS/5 ORBITERS

TABLE C-7 (Cont.)

TWO-STAGE

(Hypersonic Staging)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
3150	Facility & Equipment Maintenance			333.5	
3151	Launch & Maintenance Facilities			95.9	
3152	Ground & Support Equipment			237.6	
3160	Vehicle Maintenance			513.7	
3161	Ground-Based Maintenance Operations			513.7	
3162	Space-Based Maintenance Operations				
3170	In-Plant Engineering Support			269.6	
3180	Program Integration and Management			121.3	
3200	SPARES AND PROPELLANT SUPPORT	5972.4	9946.4		15,918.8
3210	Follow-On Spares	5707.5	8832.9		
3211	Structure	370.8	1866.8		
3212	Thermal Protection System	1690.4	2977.5		
3213	Rocket Engines	108.9			
3214	Air-Breathing Engines		834.6		
3215	Subsystems	3527.9	882.1		
3216	Other				
3217	Transportation (Space-Based)				
3220	Propellants and Gases	274.4	1188.9		
3221	Basic Cost (Ground-Based)	274.4	1188.9		
3222	Transportation Cost (Space-Based)				
3300	RANGE/BASE SUPPORT			142.0	142.0
4000	AIR VEHICLE FIRST UNIT COST	237.6	782.5		1030.1
4100	AIR FRAME	204.5	498.7		703.2
4110	Structure	48.5	297.8		356.7
4111	Aerodynamic Surfaces	28.5	177.4		212.3
4112	Body/Tank Structure	20.0	120.4		144.4
4113	Nonintegral Tanks				
4114	Other				
4120	Landing Gear	0.2	0.9		1.1
4130	Thermal Protection System	80.9	142.5		223.4
4140	Avionics	26.6	29.7		56.3
4141	Guidance and Navigation	12.2	13.3		30.5

TABLE C-7 (Cont.)

TWO-STAGE
(Hypersonic Staging)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
4142	Communication	6.4	3.5		9.9
4143	Instrumentation/Panels	8.0	7.9		15.9
4150	Power Supply & Distribution	18.4	27.8		46.2
4151	Electrical Power	14.6	19.6		34.2
4152	Hydraulic Power	3.8	8.2		12.0
4160	Environmental Control & Life Support	19.5			19.5
4170	Emergency Recovery				
4200	PROPULSION	33.2	263.9		297.1
4210	Rocket Engines – Primary	5.9			5.9
4220	Air-Breathing Engines – Secondary			135.6	135.6
4230	Air-Breathing Engines			128.3	128.3
4240	Orientation Control Thrusters	27.3			27.3
4300	INTEGRATION, ASSEMBLY, CHECKOUT, AND TEST	9.9	19.9		29.8
5000	DROP TANK FIRST UNIT COST				

TABLE C-8

TWO-STAGE

(Rocket-Powered HTO)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
1000	TOTAL RDT&E	4179.8	4334.5	831.0	8978.9
1100	CONCEPTUAL AND DEFINTION PHASE			47.2	47.2
1110	Conceptual Studies (Contractor)			3.4	
1120	Program Definition Studies (Contractor)			30.3	
1130	Other Study Support			13.5	
1140	SE/TD Contractor(s)				
1200	ENGINEERING DEVELOPMENT PHASE	3788.5	3897.3	610.3	8296.1
1210	Air Frame	1793.4	1716.0		3509.4
1211	Structure	568.2	1058.4		
1211-1	Aerodynamic Surface	122.6	251.9		
1211-2	Body/Tank Structure	445.6	806.5		
1211-3	Nonintegral Tanks				
1211-4	Other				
1212	Landing Gear				
1213	Thermal Protection System	178.8	263.8		
1214	Avionics	547.9	140.3		
1214-1	Guidance and Navigation	177.2	35.2		
1214-2	Communications	144.8	20.6		
1214-3	Instrumentation/Panels	266.1	84.5		
1215	Power Supply and Distribution	185.8	253.5		
1215-1	Electrical Power	152.6	205.8		
1215-2	Hydraulic Power	33.2	47.7		
1216	Environmental Control & Life Support	312.7			
1217	Emergency				
1218	Drop Tanks				
1220	Propulsion	242.6			242.6
1221	Rocket Engines – Primary	126.2			
1222	Rocket Engines – Secondary				
1223	Air-Breathing Engines				
1224	Orientation Control	116.4			
1230	Vehicle Integration	83.9	68.6		152.5
1240	Initial Tooling	232.4	465.0		697.4

TABLE C-8 (Cont.)

TWO-STAGE

(Rocket-Powered HTO)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
1250	Ground Equipment	119.6	65.8		185.4
1260	Test Hardware	619.0	1030.0		1649.0
1261	Ground Test	371.4	618.0		
1262	Flight Test	247.6	412.0		
1270	Test Operations	159.2	211.8	203.1	574.1
1271	Ground Test	91.0	143.6		
1272	Flight Test	68.2	68.2	83.6	
1272-1	Horizontal	68.2	68.2		
1272-2	Vertical			83.6	
1273	Wind Tunnel Test			119.5	
1280	Facilities and Equipment	122.5	257.7	372.7	752.9
1281	Vehicle Test Facilities	58.3	126.3		
1282	Engine Test Facilities	60.0	119.9		
1283	Launch Facilities				
1284	Operational & Maintenance Facilities			166.6	
1285	Manufacturing Facilities	4.2	11.5		
1286	Wind Tunnel Facilities				
1287	Propellant Production Facilities			57.8	
1288	Support Equipment				
1289	Activation			148.3	
1290	Training	49.5	82.4	34.5	166.4
1291	Personnel			34.5	
1291-1	Flight Crew			29.7	
1291-2	Ground Crew			4.8	
1292	Simulators and Equipment	49.5	82.4		
1300	SYSTEM INTEGRATION ENGINEERING	135.9	135.2	11.9	283.0
1310	Contractor Program Management	255.4	302.0	20.0	577.4
1320	SE/TD Contractor(s)				
1400	TECHNOLOGY SUPPORT PHASE				
1410	Aerothermo Technology				
1420	Structure/Material Technology				
1430	Propulsion Technology				

TABLE C-8 (Cont.)

TWO-STAGE

(Rocket-Powered HTO)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
1440	Other Technology				
1500	GOVERNMENT PROGRAM MGMT.				
2000	TOTAL INVESTMENT	1379.1	1329.8	265.4	2974.3
2100	FACILITIES AND EQUIPMENT	83.7	56.5	184.5	324.7
2110	Launch Facilities				
2120	Operational & Maintenance Facilities				
2130	Manufacturing Facilities				
2140	Propellant Production Facilities			57.8	57.8
2150	Ground Equipment	83.7	56.5		140.2
2160	Support Equipment				
2170	Activation			126.7	126.7
2200	REUSABLE VEHICLE FLEET	1295.4	1273.3		2568.7
2210	New Vehicle Manufacturing	838.6	758.2		9144.2
2220	R&D Vehicle Modifications	74.3	123.6		197.9
2230	Initial Spares	83.9	75.8		159.7
2240	Sustaining Tooling	34.9	69.8		104.7
2250	Engineering Support	167.7	151.6		319.3
2260	Contractor Program Management	96.0	94.3		190.3
2270	SE/TD Contractor(s)				
2300	EXPENDABLE HARDWARE				
2310	Hardware Manufacturing				
2320	Spares Support				
2330	Engineering Support				
2340	Additional and Sustaining Tooling				
2350	Contractor Program Management				
2400	GOVERNMENT PROGRAM MGMT.			80.9	80.9
3000	TOTAL OPERATIONS				
3100	OPERATIONS				
3110	Launch Operations				
3120	Recovery Operations				
3130	Command and Control				
3140	Replacement Training				

3 BOOSTERS/5 ORBITERS

TABLE C-8 (Cont.)

TWO-STAGE
(Rocket-Powered HTO)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
1440	Other Technology				
1500	GOVERNMENT PROGRAM MGMT.			141.6	141.6
2000	TOTAL INVESTMENT	1379.1	2224.5	265.4	3869.0
2100	FACILITIES AND EQUIPMENT	83.7	56.5	184.5	324.7
2110	Launch Facilities				
2120	Operational & Maintenance Facilities				
2130	Manufacturing Facilities				
2140	Propellant Production Facilities			57.8	57.8
2150	Ground Equipment	83.7	56.5		140.2
2160	Support Equipment				
2170	Activation			126.7	126.7
2200	REUSABLE VEHICLE FLEET	1295.4	2168.0		3463.4
2210	New Vehicle Manufacturing	838.6	1395.4		2234.0
2220	R&D Vehicle Modifications	74.3	123.6		197.9
2230	Initial Spares	83.9	139.5		223.4
2240	Sustaining Tooling	34.9	69.8		104.7
2250	Engineering Support	167.7	279.1		446.8
2260	Contractor Program Management	96.0	160.6		256.6
2270	SE/TD Contractor(s)				
2300	EXPENDABLE HARDWARE				
2310	Hardware Manufacturing				
2320	Spares Support				
2330	Engineering Support				
2340	Additional and Sustaining Tooling				
2350	Contractor Program Management				
2400	GOVERNMENT PROGRAM MGMT.			80.9	80.9
3000	TOTAL OPERATIONS	5972.4	9329.0	1993.3	17,294.7
3100	OPERATIONS			1851.3	1851.3
3110	Launch Operations			55.0	
3120	Recovery Operations			25.7	
3130	Command and Control			148.6	
3140	Replacement Training			50.6	

5 BOOSTERS/5 ORBITERS

TABLE C-8 (Cont.)

TWO-STAGE
(Rocket-Powered HTO)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	ORBITER	BOOSTER	SYSTEM	EOS TOTAL
4142	Communication	6.4	3.5		9.9
4143	Instrumentation/Panels	8.0	7.9		15.9
4150	Power Supply & Distribution	18.4	25.1		43.5
4151	Electrical Power	14.6	19.6		34.2
4152	Hydraulic Power	3.8	5.5		9.3
4160	Environmental Control & Life Support	19.5			19.5
4170	Emergency Recovery				
4200	PROPULSION	33.2	50.7		83.9
4210	Rocket Engines – Primary	5.9	23.4		29.3
4220	Rocket Engines – Secondary				
4230	Air-Breathing Engines				
4240	Orientation Control Thrusters	27.3	27.3		54.6
4300	INTEGRATION, ASSEMBLY, CHECKOUT, AND TEST	9.9	12.4		22.3
5000	DROP TANK FIRST UNIT COST				

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