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TWO-STAGE REUSABLE LAUNCH SYSTEM UTILIZING A WINGED CORE VEHICLE AND GLIDEBACK BOOSTERS

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By

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ABSTRACT

A near-term technology launch system is described in which Space Shuttle main engines are used on a manned orbiter and also on twin strap-on unmanned boosters. The orbiter is configured with a circular body and clipped delta wings. The twin strap-on boosters have a circular body and deployable oblique wings for the glideback recovery. The dry and gross weights of the system, capable of delivering 70 klb of cargo to orbit, are compared with the values for the current Shuttle and a core vehicle with hydrocarbon-fueled boosters.

INTRODUCTION

In recent conceptual design studies of launch vehicles (Ref. 1), emphasis has been placed on reducing operational complexity by employing commonality in systems and propellants. In this regard, a launch vehicle has been configured in which liquid oxygen, liquid hydrogen, and current Space Shuttle main engines are used in both a manned core vehicle (orbiting stage) and its strap-on unmanned boosters. The principal objective of this study was to investigate the size and performance of an all-oxygen/hydrogen system using fixed numbers of Shuttle main engines. A parametric analysis was conducted to determine the optimum number of engines in the boosters and core vehicle in the presence of varying payload weights and volumes. The performance of the resulting vehicles was then compared with a recent study in which an oxygen/hydrogen propulsion subsystem was used in the core vehicle, but a lower performing, higher density hydrocarbon was used in the boosters.

ABBREVIATIONS AND SYMBOLS

CBV	Circular body vehicle	RCS	Reaction control system
GLOW	Gross liftoff weight	SRB	Solid Rocket booster
g	Gravitational constant, 32.2 ft/sec^2	SSME	Space Shuttle Main Engine
LOX	Liquid oxygen	TSLS	Thrust (Sealevel static)
LH_2	Liquid hydrogen	T/W	Thrust-to-weight ratio
OMS	Orbital maneuver system		
P/L	Payload		
POST	Program to Optimize Simulated Trajectories		

Ixx, Iyy, Izz moments of inertia about x, y, and z axes, respectively
Xcg, Ycg, Zcg, center of gravity locations in x, y, and z directions

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DESCRIPTION OF LAUNCH SYSTEM

In the current study, the launch system elements are similar in geometry to the systems described in reference 2; the most visible change is in the relative sizes of the boosters and core vehicles. The same core and booster geometries were used for both the all-LOX/LH_2 and the LOX/LH_2-RP propulsion system to enhance the accuracy of the comparisons.

In all the designs, both the core and booster vehicles are simple circular shapes having ogive forebodies. The booster bodies are geometric replicas of the core vehicle body; however, an oblique wing is used in lieu of the clipped delta wing (fig. 1).

Core Vehicle

The manned orbiter is a circular body vehicle with clipped delta wings, similar to the core vehicle detailed in reference 1. Core vehicle geometry is shown in figures 2 and 3. The core vehicle is designed for vertical takeoff with the two strap-on boosters but lands horizontally. Crew accommodations are located in the mid-body section, between the LH_2 propellant tank and the payload bay. The payload bay is located immediately aft of the crew station, and its shape is dissimilar to that of the current Shuttle payload. The payload bay on the study configuration is circular in cross section and spans the inner diameter of the mid-body section.

No provision is made for a canopy or windshield in the cockpit. This minimizes structural cut-outs and results in a significant savings in structural weight and a reduction in aerodynamic drag. Flush mounted viewports provide exterior visual access, while additional ports allow observation from the cockpit into the payload bay. A remote camera system deployed from the nose is used for forward pilot vision during final approach and landing.

The core vehicle employs tip fins for energy management and as a redundant method for directional control. The characteristics of the tip fins are detailed in reference 3. The core vehicle employs a forward-mounted dorsal fin for primary directional control. Subsonic control characteristics for the dorsal fin are reported in reference 4. The forward placement of the dorsal fin requires an active control system, but it eliminates the need for a large vertical control surface at the rear of the vehicle, thus reducing ascent drag and structural weight.

Boosters

The unmanned boosters used in this study are also very similar to their counterparts in reference 2. The propellant tanks are integral with the body. Relative body dimensions (ogive section dimensions and body radii as fractions of reference length) equal those of the core vehicle. For the purposes of this study, the structure of the boosters is entirely Shuttle-technology skin stringer aluminum. Booster propellant tank weights, however, represent a 10-percent increase over current Shuttle external tank weights to allow for the weight of additional tank structure necessary to make the tanks reusable. Booster vehicle geometry is shown in figures 4 and 5. The boosters employ oblique wings to facilitate an unpowered glide back to the launch site after staging. To allow for the unpowered return, the boosters are staged from the core vehicles at Mach 3. As in the designs shown in reference 2, the pivot assemblies for the oblique wings on the boosters are mounted on linear bearings with a worm lead screw and motor drive so that the wing can be driven rearward during deployment to the approximate body station for trimmed flight. Wings without the translational feature are currently under study for use in subsonic and transonic aircraft (ref. 5). The boosters shown here in the launch vehicle booster application are conceptual. The booster propellants are crossfed to the core vehicle until staging. Advanced avionics and propellant management subsystems are assumed, as well as electric actuators for control surfaces. Because the boosters do not exceed Mach 3 during ascent or return, heating is moderate, and the heat sink capability of the all-aluminum structure is relied upon to accommodate the thermal load.

APPROACH

The engines on both the orbiter and boosters were assumed to be current SSMEs. Mission-related assumptions include ascent of the core vehicle plus payload to a 50- by 100-nautical-mile orbit from a due East launch. Accommodation for two crew members and a mission duration of not more than 72 hours were assumed. An ascent acceleration limit of 3 g was also assumed.

A weights and sizing program, described in reference 6, was used for estimating the weights of the various subsystems. Structural weights are based on size or loading or combinations of both. Other subsystem weights and sizes were based on such factors as mission length, crew size, power requirements, and control surface sizes. The types of subsystems, structural materials, and the general configurations were selected from the program.

A propellant weight fraction is used herein. It is defined as the ratio of propellant weight to gross system weight. The required values were obtained from the Program to Optimize Simulated Trajectories (POST) (Ref. 7). The propellant weight fractions from POST were inputs for the weights and sizing program. When supplied with these inputs, the weights and sizing program iterates until the specified propellant weight fraction is obtained. This involved the trending of propellant loads (and therefore tank sizes), body volumes, and all related subsystem weights.

From the weights and sizing program outputs, a plot was made of propulsion system weights versus payload weights (Fig. 6). From this plot, two core vehicles with propulsion system weights corresponding to two and three SSMEs, were selected for further analysis. The two-engine core vehicle requires a weight allocation of 20 klb for the propulsion system, whereas the three-engine configuration requires 30 klb. The allocations for the propulsion subsystem weights include 7500 lb for each SSME and 2500 lb per engine for the pressurization and feed system. In the study, the core vehicle mass properties were then held constant, and the program was used again to size the boosters. Considerable iteration was necessary to size the boosters such that an integral number of engines were selected for each booster and that the system thrust-to-weight ratio at lift-off was 1.3 or higher.

Boosters with main propulsion subsystems having three and four SSMEs satisfied the minimum thrust-to-weight ratio requirement of 1.3. This yielded two launch system configurations--a two-engine core matched to two three-engine boosters (2-3-3 configuration) and a three-engine core matched to two four-engine boosters (3-4-4 configuration). Lift-off thrust-to-weight ratios were approximately 1.5 for each configuration. Launch configurations for the 2-3-3 and 3-4-4 systems are shown in figure 1.

After the basic core and booster vehicle subsystems and weights were established, further study was conducted on the weight of the additional structure necessary to accommodate the booster oblique wing. Equations for the weight of an oblique wing for a supersonic transport aircraft are found in reference 8. The basic weight equations developed in reference 8 were modified and applied to the glideback boosters. A provision was also made for the weight of the electric motors used to pivot the wing assembly.

RESULTS

The two-engine core, three-engine boosters (2-3-3) combination resulted in a payload capability (ascent and return) of 37 klb. System GLOW for the 2-3-3 configuration, with a 37-klb ascent/return payload, was 1,940 klb. The three-engine core, four-engine boosters (3-4-4) combination yielded a 70-klb payload. System GLOW for the 3-4-4 configuration, with a 70-klb ascent and return payload, was 2,901 klb. Launch vehicle comparisons are made in Table 1 for the two all-LOX/LH_2 vehicles, the current Shuttle system, and three other systems from an earlier report (Ref. 2). The launch vehicles are ranked according to ratios of payload to dry weight and payload to gross weight.

Based on the highest ratio of payload to dry weight, the five-engine core with RP strap-on boosters ranks number one. In this launch system, LOX/LH_2 propellants are crossfed from tanks within the booster to the orbiter. Tanks dedicated to the LH_2 crossfeed propellant are required within the RP boosters. Based on the payload-to-gross-weight ratio, the all-LOX/LH_2 3-4-4 launch system ranks number one. If cost is assumed to be proportional to payload-to-dry-weight ratio, then the LOX/LH_2 core with RP boosters would be the most economical system. In reality, the all-LOX/LH_2 launch vehicles would probably yield the lowest cost system, since no new main engine development is required. A new RP engine would have to be developed for a LOX/LH_2/RP propellant launch system. The five-engine, fully reusable core vehicle with Shuttle SRBs having filament wound cases ranks fourth for both payload-to-dry-weight and payload-to-gross-weight ratios.

Factors which could affect the rankings (Table 1) if the vehicles were to be normalized for mission and payload capabilities are as follows:

(1) The current Shuttle is capable of remaining in orbit for approximately 8 days and can accommodate a crew of at least seven. It has a 15-ft-diameter by 60-ft-long cargo bay. The launch vehicles with which the Shuttle is compared can accommodate a crew of two for 3 days. The cargo bays are 30 ft in diameter by 15 ft long.

(2) The vehicles compared in Table 1 have somewhat different payloads as an outgrowth of the many sizing constraints, principally that of engine size. If the launch vehicles were to be resized for equal payloads the ratios would change slightly.

The 2-3-3 launch configuration reaches 3 g at staging without throttling either core or booster engines (Fig. 7). The 2-3-3 boosters stage 86 seconds after launch at an altitude of 86,000 ft, and the orbiter reaches orbit 516 seconds after launch. The 3-4-4 system only reaches 2.8 g at staging (Fig. 8). The 3-4-4 boosters stage 93 seconds after launch, also at an altitude of 86,000 ft, and the orbiter reaches orbit in 528 seconds. For both configurations, throttling of the core vehicle engines only becomes necessary for approximately the last 75 seconds of flight.

Weights of the core and booster vehicles taken from the weights and sizing program are shown in Table 2. Moments of inertia and center-of-gravity locations are shown in Table 3 for various stages of the mission. The moments of inertia are outputs from the program and are provided for possible future use in dynamic analysis of separation and flight of the boosters and the orbiter. The Z-axis center-of-gravity locations for the boosters are positive values (above vehicle centerline) due to the high location of the oblique wing and pivot mechanism. The X-axis center-of-gravity locations in the core vehicle range between 69.3 and 71.6 percent of body reference length during entry and are within trimmable limits for the original CBV design (Ref. 4).

When compared with the systems studied in reference 2, all of which employed high-density propellants in the boosters, the size increase required for boosters using an all-LOX/LH_2 propulsion subsystem was substantial. However, system performance and weights compared quite favorably. This indicates that the use of a single propellant would not imply serious performance penalties when used as in this study. Certainly, a system using the same engines and propellants for both the orbiter and boosters would simplify operations and would result in reduced development, inventory, and manufacturing costs.

CONCLUSIONS

The results of this study suggest that:

(1) A fully reusable, two-stage manned launch system utilizing all-LOX/LH_2 propellants, SSMEs, and near-term technology would weigh approximately 2.9 Mlb at lift off for delivery of 70 klb of payload to low-Earth orbit.

(2) The all-LOX/LH_2 system yielded the highest payload-to-gross-weight ratio when compared with other launch systems that used lower performing solids or RP in the boosters for the same type of logistics mission.

(3) The payload-to-dry-weight ratio of the all-LOX/LH_2 3-3-4 system ranked second to that of the launch system utilizing LOX/LH_2 in the core vehicle and RP in the boosters.

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Table 1. Vehicle Weights Comparison

Vehicle	Payload, klb	Dry wt, klb	Gross wt, klb	P/L-to-dry-wt		P/L-to-gross-wt	
				Ratio	Rank*	Ratio	Rank*
Shuttle	47.0	615.0	4500	0.0764	5	0.0104	5
CBV (ref. 2) 5 LOX/LH2 SSMEs with Shuttle SRBs	66.0	649.5	5000	0.1016	4	0.0132	4
CBV (ref. 2) 5 LOX/LH2 SSMEs with graphite case Shuttle SRBs	83.0	474.5	4800	0.1749	3	0.0173	3
CBV (ref. 2) 5 LOX/LH2 SSMEs with 6 LOX/RP engine crossfeed boosters	84.0	417.5	4100	0.2012	1	0.0205	2
2-3-3 CBV System, all-LOX/LH2	37.1	272.5	1941	0.1361	**	0.0191	**
3-4-4 CBV System, all-LOX/LH2	70.4	379.3	2902	0.1856	2	0.0243	1

* For rankings, '1' represents the best vehicle for the particular characteristic, while '5' implies the worst.

** Not ranked because of the large difference in payload capability compared with other vehicles in the matrix; hence, the secondary effects of vehicle size makes the data not comparable.

Table 2. Two-Stage Manned Launch Vehicle Weights Summary

Component	Weight, lb			
	2-3-3 Configuration		3-4-4 Configuration	
	Core	2 Boosters	Core	2 Boosters
1.0 Wing Group	8,852	26,658	12,197	37,086
2.0 Tail Group	106	295	146	410
3.0 Body Group	44,044	56,343	63,662	81,702
Crew Module	559	0	559	0
Forebody	450	4,712	600	8,870
Mid Fuselage	4,662	11,096	5,543	13,390
Aft Fuselage	4,767	9,235	6,569	13,324
Thrust Structure	1,799	4,676	2,732	7,000
Body Flap	211	315	291	438
Fuel Tank (LH2)	22,542	18,772	33,783	27,586
Oxidizer Tank (LOX)	9,054	7,537	13,585	11,094
4.0 Thermal Protection System	18,058	0	26,017	0
5.0 Landing Gear	4,536	6,209	6,904	9,058
6.0 Main Propulsion	19,785	59,434	30,052	76,992
7.0 RCS Propulsion	2,409	0	3,668	0
8.0 OMS Propulsion	3,475	0	5,279	0
9.0 Prime Power	847	1,269	1,037	1,576
10.0 Elec. Conv. and Distr.	2,639	1,836	2,829	2,142
12.0 Surface Controls	3,179	3,172	4,095	4,078
13.0 Avionics	2,678	4,048	3,149	4,656
14.0 Environmental Control	1,169	508	1,169	508
15.0 Personnel Provisions	900	0	900	0
16.0 Margin	11,267	15,177	14,110	21,822
Inert (Dry) Weight	123,944	174,949	175,214	240,030

Table 2. Continued

Component	Weight, lb			
	2-3-3 Configuration		3-4-4 Configuration	
	Core	2 Boosters	Core	2 Boosters
17.0 Personnel	653	0	653	0
18.0 Payload Accommodations	4,200	0	2,200	0
19.0 Payload Returned	37,100	0	70,400	0
20.0 Residual Fluids	536	709	815	1,065
Landed Weight	166,433	175,658	249,282	241,095
21.0 OMS and RCS Reserves	0	0	0	0
Insertion Weight	166,433	175,658	249,282	241,095
22.0 RCS Propellant (Entry)	1,085	0	1,652	0
Descent Weight	167,518	175,658	250,934	241,095
23.0 OMS and RCS Propellant	22,460	0	34,118	0
24.0 Payload Discharged	0	0	0	0
Injected Weight	189,978	175,658	285,052	241,095
25.0 Ascent Reserves & Residual	402	532	611	798
26.0 Inflight Losses	3,839	3,553	5,231	5,330
27.0 Ascent Propellant	858,176	709,029	1,305,457	1,057,927
Gross Lift-Off Weight	1,052,395	888,772	1,596,351	1,305,150
TOTAL SYSTEM GLOW	1,941,167		2,901,501	

Table 3. Moments of Inertia and Centers of Gravity

(a) Core and boosters

Configuration		Moments of Inertia*, slug-ft^2, and c.g.**, percent		
		Gross	**Landed**	**Inert**
2-3-3 Configuration				
Core	I_{xx}	1,100,000	990,000	800,000
	I_{yy}	26,000,000	10,000,000	5,600,000
	I_{zz}	30,000,000	12,000,000	6,800,000
	X_{cg}	73.7	69.8	71.6
	Y_{cg}	0.0	0.0	0.0
	Z_{cg}	-0.1	-1.0	-1.5
Booster	I_{xx}	190,000	530,000	170,000
	I_{yy}	6,800,000	3,900,000	2,300,000
	I_{zz}	7,800,000	4,000,000	2,100,000
	X_{cg}	45.0	72.6	72.8
	Y_{cg}	0.0	0.0	0.0
	Z_{cg}	0.3	1.8	1.9
3-4-4 Configuration				
Core	I_{xx}	2,000,000	1,800,000	1,500,000
	I_{yy}	51,000,000	19,000,000	11,000,000
	I_{zz}	60,000,000	22,000,000	13,000,000
	X_{cg}	73.3	69.3	71.5
	Y_{cg}	0.0	0.0	0.0
	Z_{cg}	-0.1	-0.9	-1.4
Booster	I_{xx}	360,000	970,000	320,000
	I_{yy}	13,000,000	7,200,000	4,200,000
	I_{zz}	15,000,000	7,500,000	3,900,000
	X_{cg}	43.9	72.9	73.1
	Y_{cg}	0.0	0.0	0.0
	Z_{cg}	0.3	1.7	1.8

* The propellants are treated as a viscous fluid when calculating moments of inertia for the gross weight condition. Moments of inertia for the boosters for the landed condition are with wings deployed.

** Centers of gravity are given as percentages of body length taken from the nose of the vehicle to the base heat shield. Y and Z are zero on the nose centerline. Z is positive upward.

Table 3. Concluded

(b) System

Configuration	c.g., percent	
	Liftoff	Staging
Core with 2 Boosters		
2-3-3 System		
X_{-cg}	65.91	74.38
Z_{-cg}	1.63	0.66
3-4-4 System		
X_{-cg}	65.36	73.99
Z_{-cg}	1.42	0.53

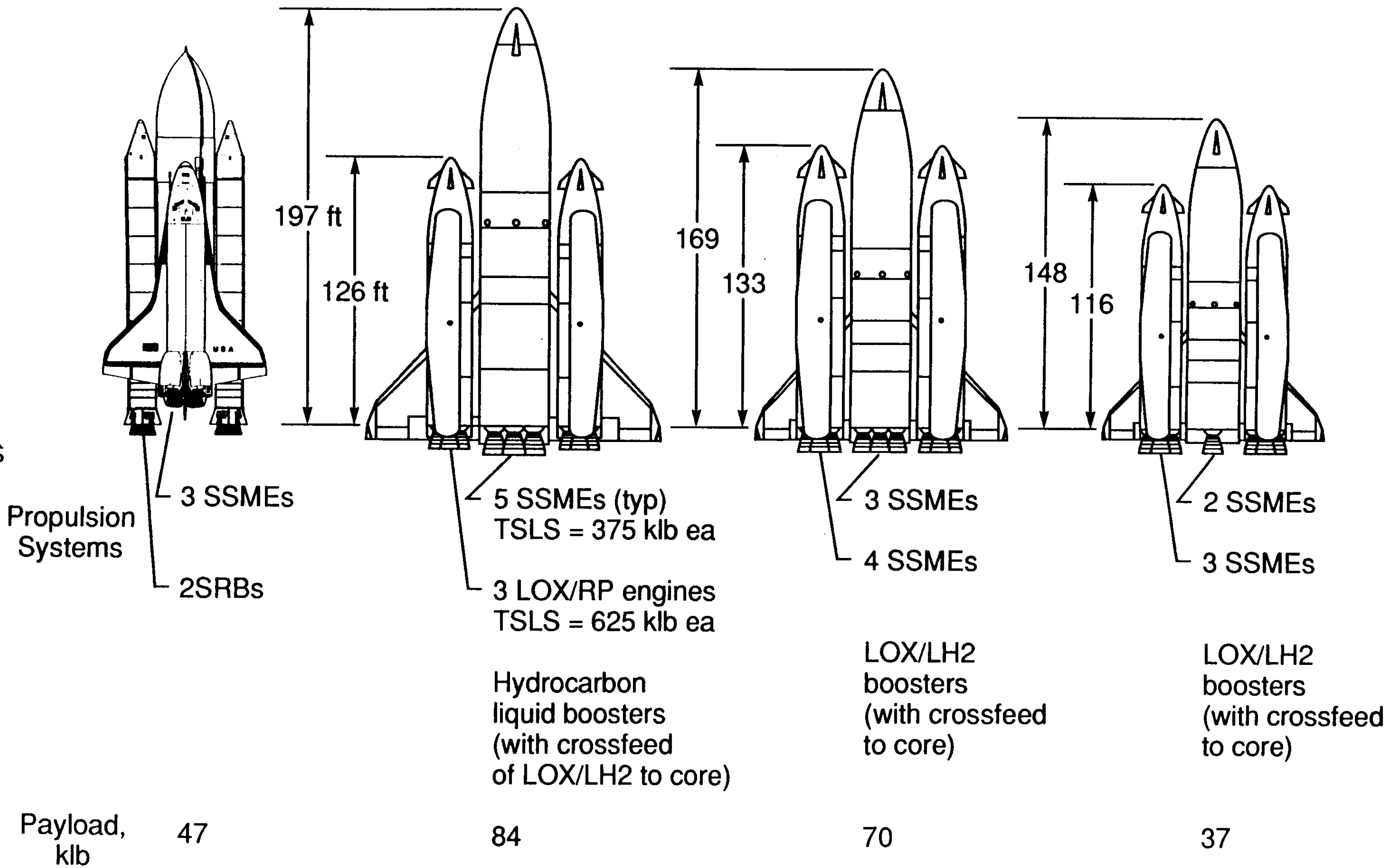

Figure 1. Launch vehicle comparisons.

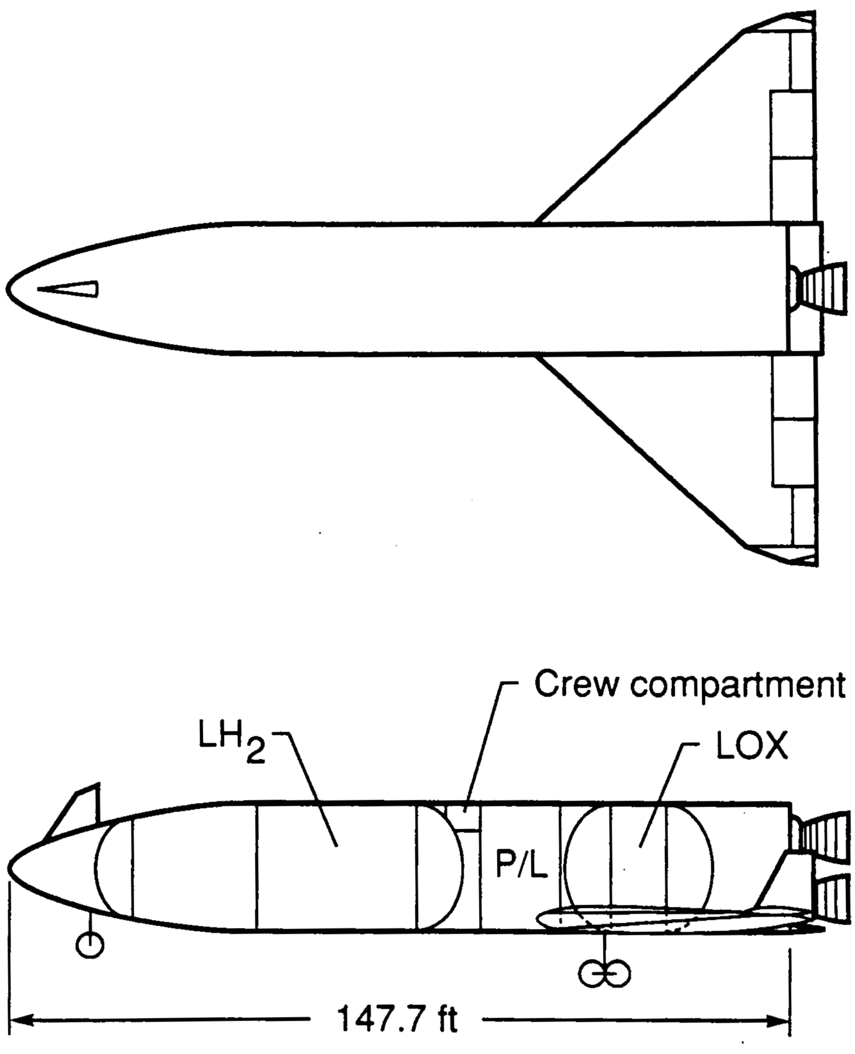

Figure 2. Two-engine orbiter.

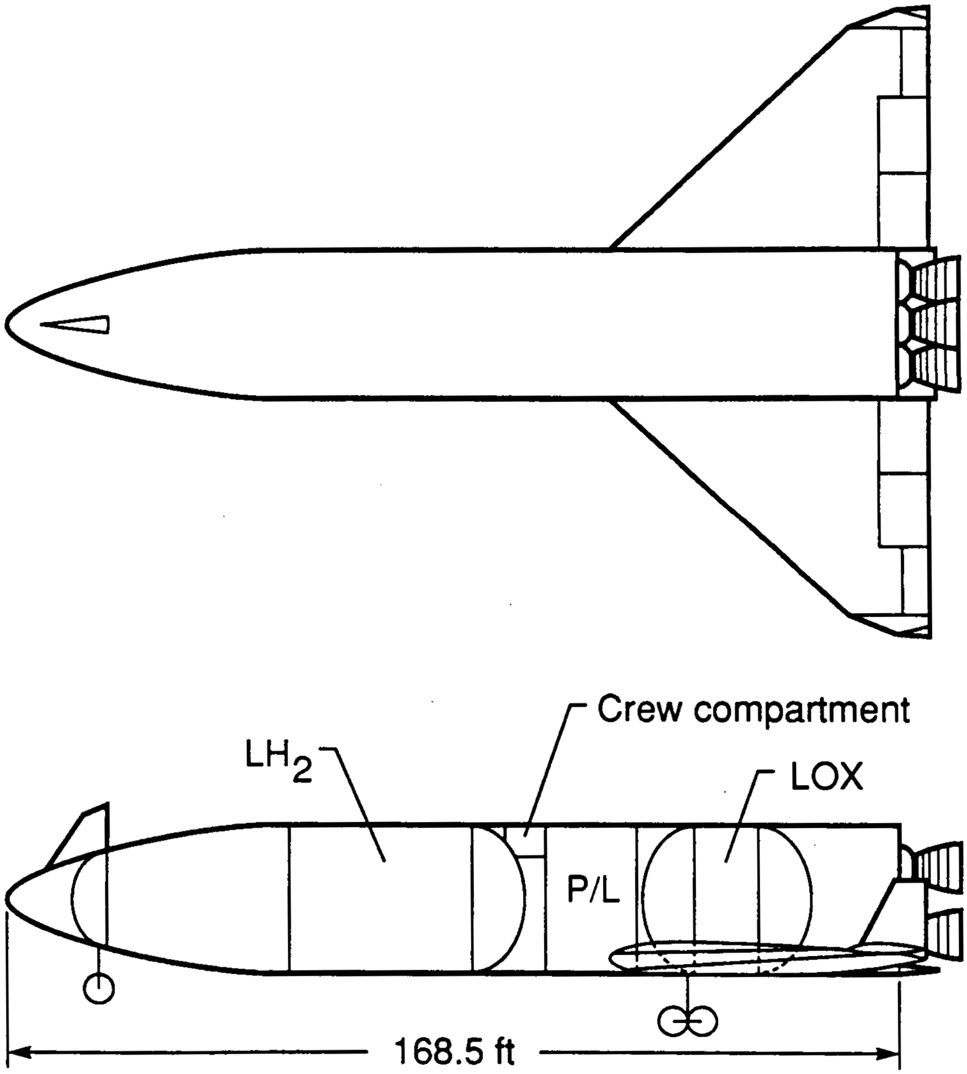

Figure 3. Three-engine orbiter.

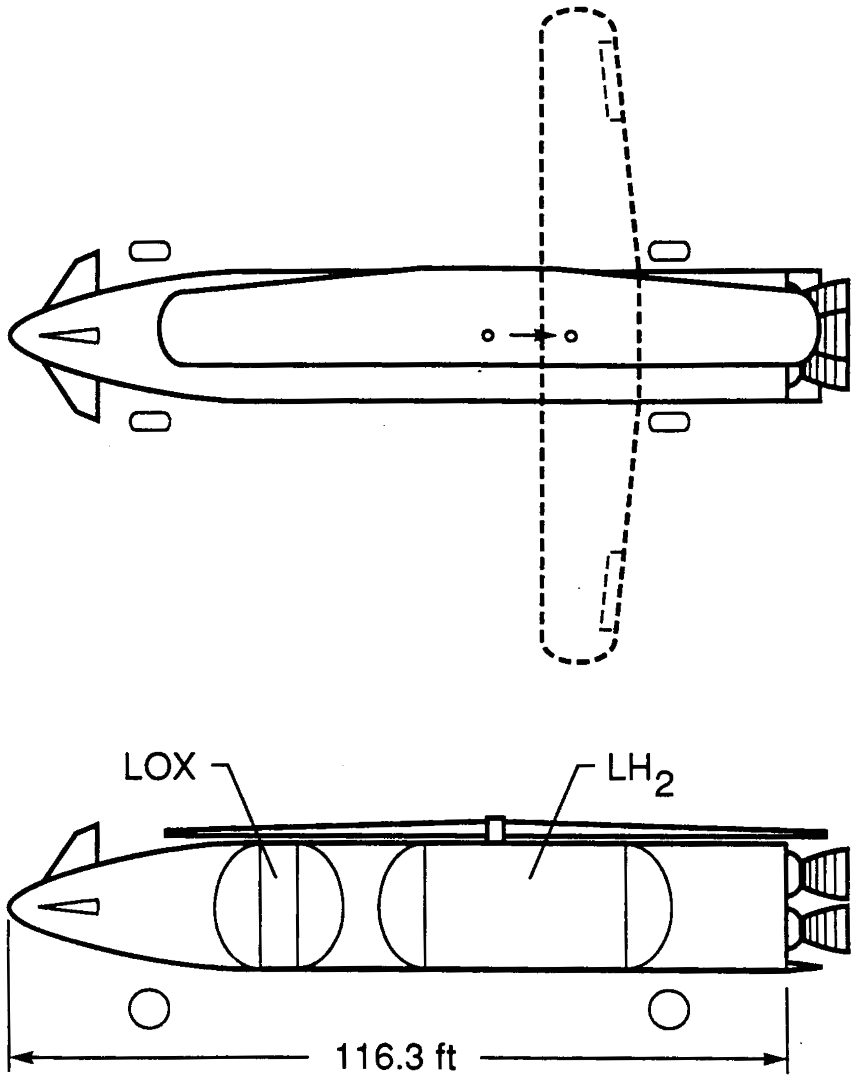

Figure 4. Three-engine booster.

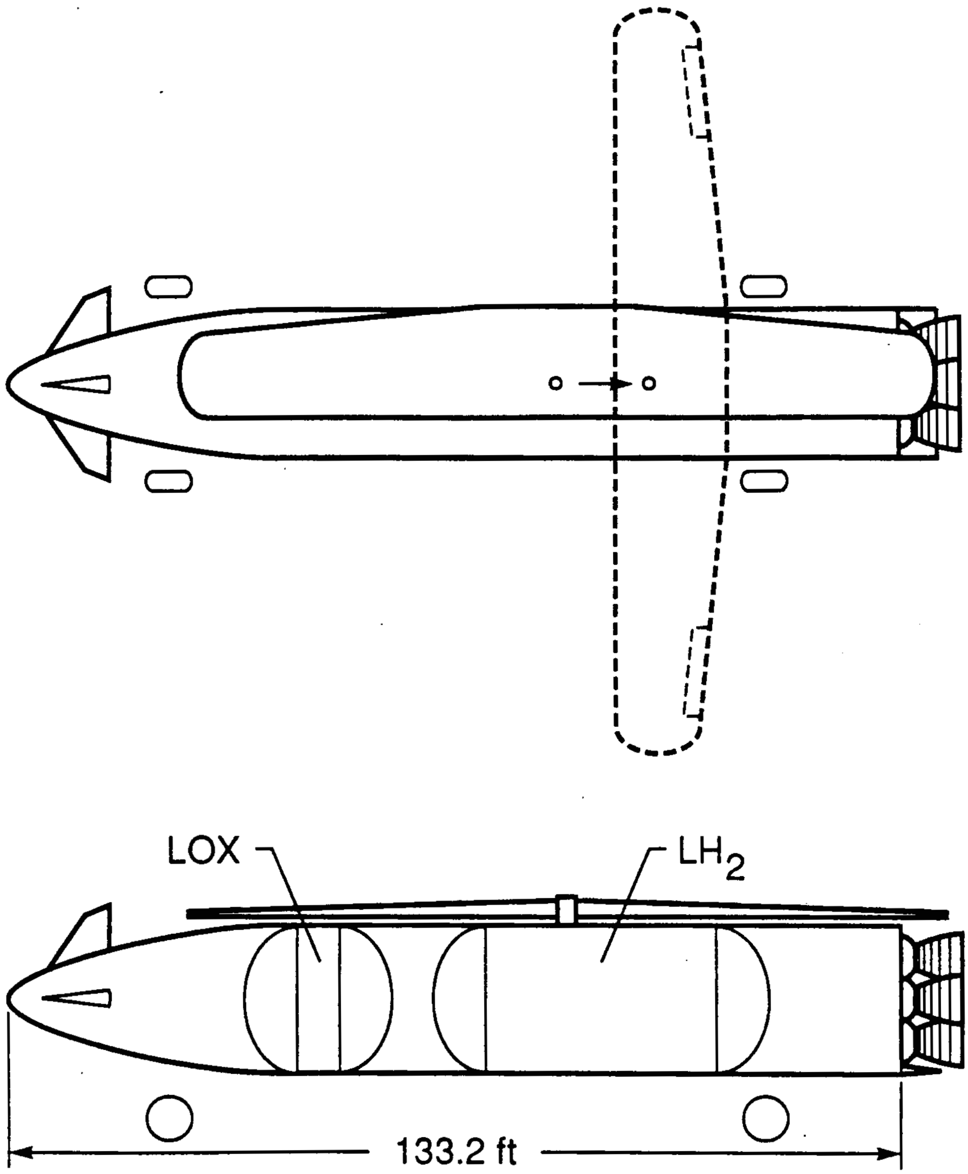

Figure 5. Four-engine booster.

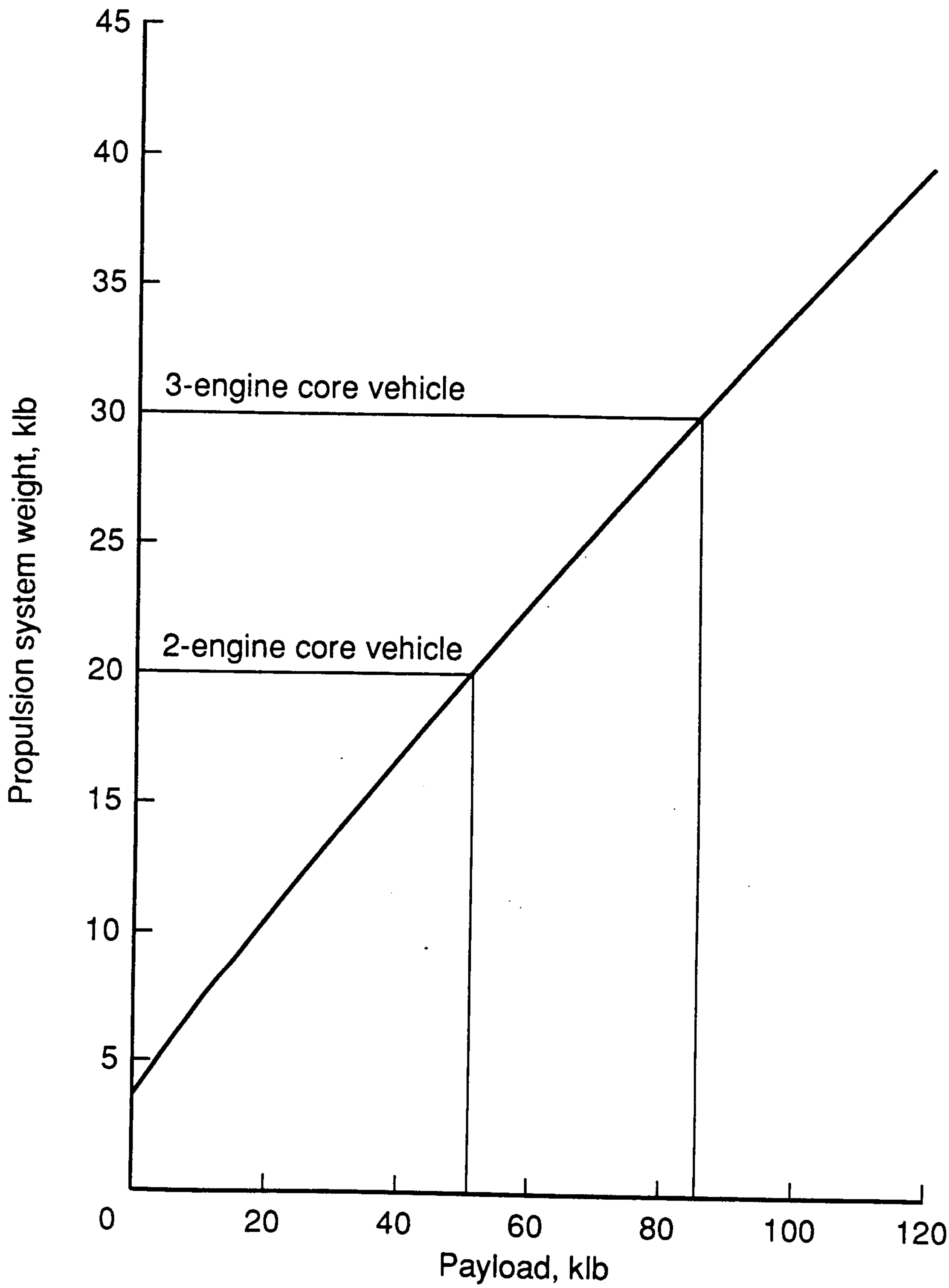

Figure 6. Plot of main propulsion subsystem weight versus payload.

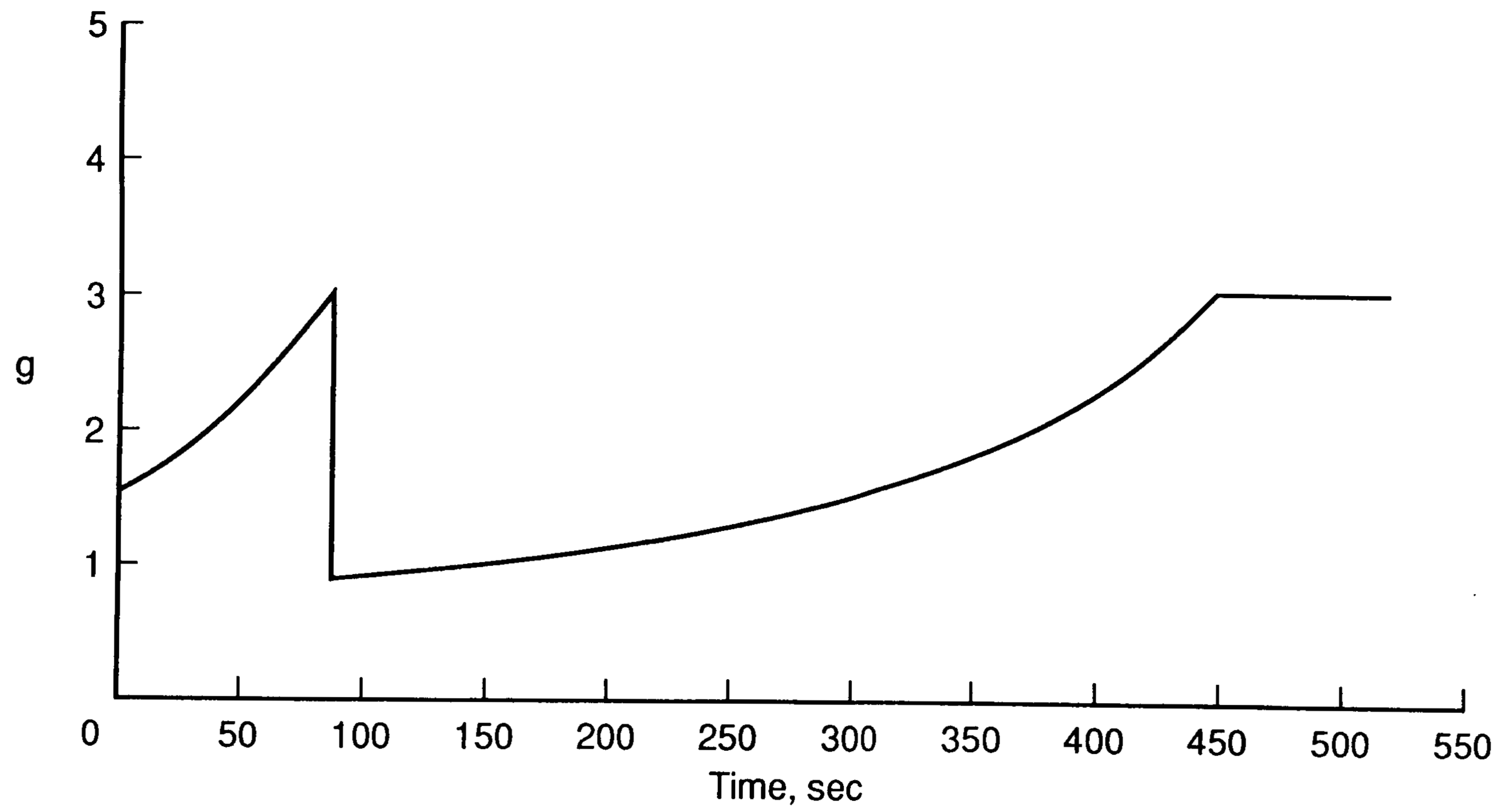

Figure 7. Two-engine core with three-engine boosters, thrust-to-weight history.

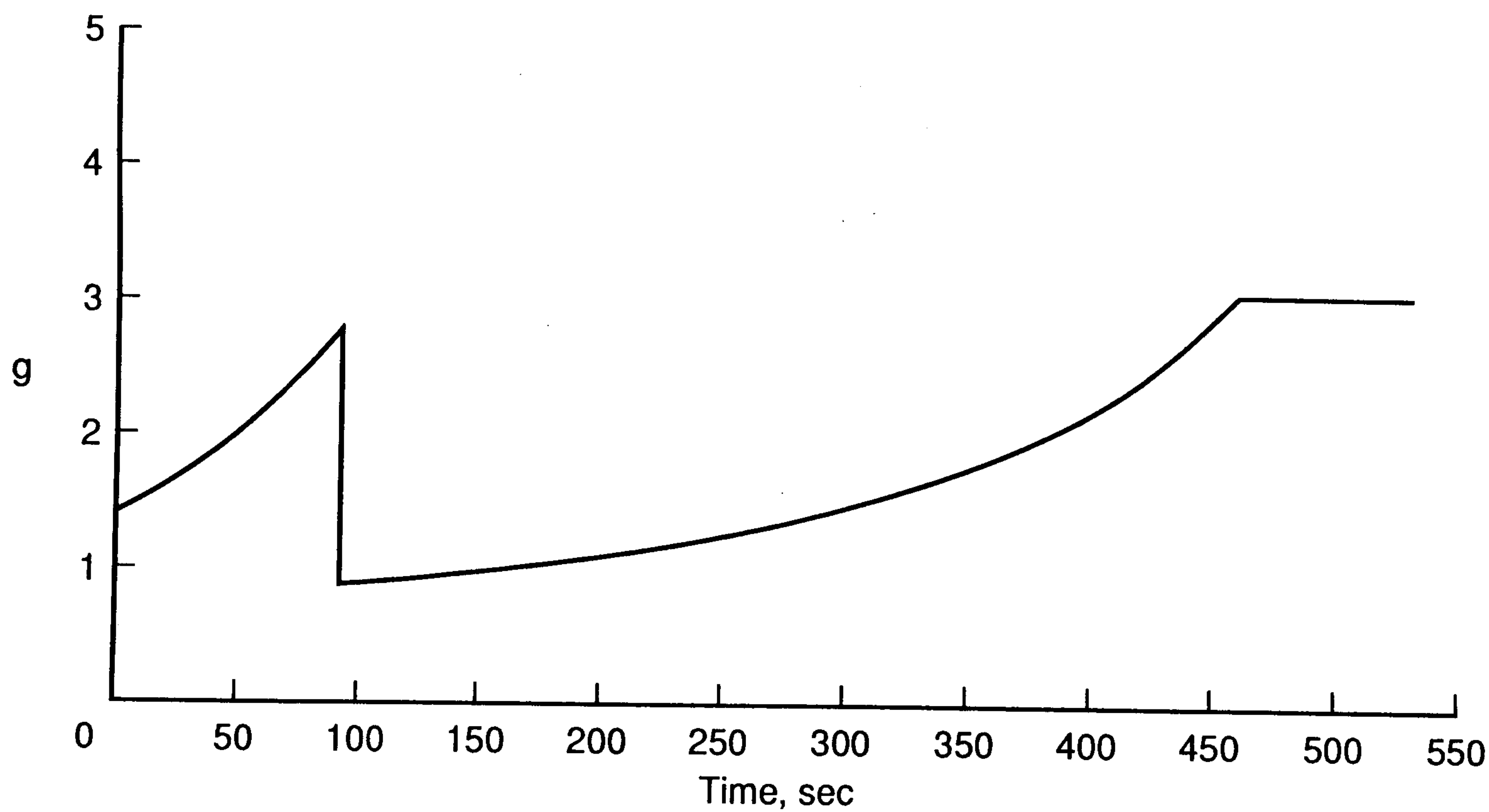

Figure 8. Three-engine core with four-engine boosters, thrust-to-weight history.

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15. Supplementary Notes

James S. Wood and Miles O. Duquette are graduate students in the joint NASA-George Washington University Graduate Program.

16. Abstract

A near-term technology launch system is described in which Space Shuttle main engines are used on a manned orbiter and also on twin strap-on unmanned boosters. The orbiter has a circular body and clipped delta wings. The twin strap-on boosters have a circular body and deployable oblique wings for a glideback recovery. The dry and gross weights of the system, capable of delivering 70klb of cargo to orbit, are compared with a similar system with hydrocarbon-fueled boosters and with the current Shuttle.

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