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SUMMARY

Results of a preliminary study of a novel space transport concept are reported. The concept consists of a winged orbiter containing ascent propellants and small, twin turbojet-powered boosters used for acceleration to Mach 3.5. Each booster contains sufficient JP fuel for ascent and fly-back functions. The concept offers a fully reusable system capable of horizontal takeoff from conventional runways. Other potential features include lateral offset orbit insertion, ferry-capability, abort and recall landing, and considerable versatility in takeoff site, which may enable round trips to space from many existing airfields. Preliminary performance analyses show this space transport concept, using current structures and rocket technology, has a lower gross takeoff weight for a selected payload than either a single-stage-to-orbit vertical takeoff advanced technology vehicle, or a sled-launched vehicle which applies current rocket propulsion but requires structural advancements.

Alternatives to the baseline concept of a current technology orbiter with turbojet boosters were also studied. A refinement of advancing the orbiter structure offers a 50 percent increase in payload. A further 50 percent increase in payload is indicated by adding a lightweight scramjet under the orbiter, thus doubling the payload over the baseline concept. An alternative to a new orbiter configuration is the concept of stretching the space shuttle orbiter. Preliminary analyses indicate that the stretched shuttle orbiter with turbojet boosters could carry the same payload as the NASA space shuttle

but with about half the gross weight.

Some principal problem areas warranting study to verify the space transport concept using turbojet boosters are configuration refinement, transonic aerodynamic tests, structural design, and engine performance analyses.

INTRODUCTION

Projections for orbiting solar power collecting stations and industrial processing plants (ref. 1) indicate the need for frequent space flights. The mission scenario studied in reference 1 shows that current space shuttle launch costs must be reduced by an order of magnitude before large scale space utilization can become a practical goal. Other desirable space transportation system features, which offer increased operational versatility include horizontal takeoff from conventional runways, lateral offset orbit insertion, and ferry capability.

The dominant factors in the space shuttle launch costs are the replacement of expendable propellant tanks and the recovery, refurbishment, and refueling of the solid rocket motors. A variety of space transportation systems have already been studied which avoid these recurring costs; however, several factors such as high technical risk, high development costs, and lack of versatility, have precluded commitment to any particular system to date. None of the previous systems simultaneously satisfy the low cost and versatility goals.

To provide a comparative base to assess the system proposed in this paper, a brief review of the various space transportation systems studied to date is warranted. Several concepts of fully reusable vehicles with horizontal takeoff (HTO) from runways have been studied. One concept, called the aerospaceplane (ref. 2), required a very low structural mass fraction, scramjet propulsion, and complex air collection equipment. A second reusable HTO vehicle concept, the airbreathing launch vehicle (ABLV, ref. 3), used turbojets, ramjets, and scramjets with hydrogen fuel in a first stage, which separated at a Mach number of about 10. Consequently, the first stage was larger than the orbiter. Furthermore, the high speed and advanced propulsion systems of the launch vehicle required advanced technology with its associated high costs. A third reusable HTO vehicle concept, studied in several variations from the late fifties through the mid-sixties, employed a supersonic aircraft (designed for other missions) as a first stage (refs. 4 and 5). This large and complex booster stage would have been very expensive. Therefore, the three reusable HTO vehicle concepts satisfy the versatility goals but not the low cost goals.

More recent space transportation concepts studied, that avoid the recurring costs of the space shuttle, include single-stage-to-orbit (SSTO) concepts (refs. 1, 6, 7, 8, and 9). Two of these concepts, which represent the two takeoff options, are shown in fig. 1. Fig. 1(a) shows a concept designed for vertical takeoff (VTO), and fig. 1(b) shows a concept designed for horizontal takeoff from a rocket-powered sled. For a space shuttle payload of 29 500 kg (65k lb_m), the VTO vehicle would have a gross weight of 1.26 M kg (2.77M lb_m), and the HTO vehicle a gross weight of 1.22M kg (2.68M lb_m). These weight estimates taken from ref. 6 incorporate some technology advances. Analyses of similar vehicles by NASA contractors show that with more accelerated technology the gross weight of the vehicles can be reduced to 1.14M kg (2.51M lb_m) for the VTO concept and 1.00M kg (2.2M lb_m) for the HTO sled-launched concept. The VTO concepts employ advanced rocket engines using both hydrocarbon and hydrogen fuel. An all-hydrogen-fueled VTO vehicle would have a relatively high gross weight of 1.63M kg (3.6M lb_m) for a 29 500 kg (65k lb_m) payload. The sled-launched HTO concept has been proposed to enable use of hydrogen fuel only (by use of a two position nozzle added to the space shuttle main rocket engines (SSME)) at considerably less gross weight than the all-hydrogen VTO concept. But a sled offers limited takeoff azimuths and few launch sites, thus limiting operational versatility. Neither the VTO nor the sled-launched HTO operational modes offer the convenience of a conventional runway takeoff mode. Thus, the single-stage-to-orbit concepts may satisfy cost objectives but lack versatility.

The object of this paper is to present a concept, with supportive analytical results, for a fully reusable horizontal takeoff space transport that has potentially low initial and operating costs. This potential stems from use of reusable components, no solid rocket boosters, a lighter orbiter than the advanced technology SSTO concepts (even with current structures and rocket technology used for the proposed concept) and smaller boosters (with existing structures technology and SST-type turbojet engines) than the ABLV or supersonic aircraft boosters discussed above. However, some turbojet engine development may be required. In addition, this space transport concept offers the potential of lateral offset orbit insertion, ferry capability, intact abort and recall landing, and versatility in takeoff location, which in combination may enable round trips to space from many existing airfields.

SYMBOLS

Measurements and calculations were made partly in the International System of Units and partly in U.S. Customary Units and data are presented in both systems of units. Mass in the S.I. Units is given in kg, or as required, in millions of kg (M kg).

A_c	inlet area per engine
C_D	drag coefficient
C_L	lift coefficient
C_{L_α}	lift curve slope
C_m	pitching moment coefficient
C_T	thrust coefficient
D_b	zero-lift drag per booster
D_e	engine drag (spillage, bleed, and boattail drags)
M	free-stream Mach number
$\dot{m}_a$	mass flow rate of air based on unit inlet area
$\dot{m}_f$	mass flow rate of fuel
N_b	number of boosters
N_e	number of engines per booster
q	free-stream dynamic pressure
R	stoichiometric fuel/air ratio (turbojet=0.066 and scramjet =0.029)
S_b	booster reference wing area
S_{ref}	orbiter wing area, reference for aerodynamic coefficients
S_{wetted}	wetted surface area of booster
T	net thrust per engine
ΔW	weight change
α	angle of attack
ε	expansion ratio
ϕ	fuel equivalence ratio (actual fuel/air ratio divided by stoichiometric fuel/air ratio)

PROPOSED SPACE TRANSPORT CONCEPT

The proposed space transport concept shown in figure 2 consists of a winged orbiter with rocket propulsion and on-board propellants and two small turbojet-powered boosters mounted under the orbiter wings. The orbiter configuration is similar to those shown in figure 1 for SSTO vehicles. However, since acceleration is achieved by turbojets at relatively high dynamic pressure, aerodynamic drag is of greater concern than for the rocket-powered SSTO vehicles. Moreover, stability is of greater concern during the boost phase since the rockets are not in use to provide controlled flight through gimbaling as for the SSTO vehicles. Consequently, the proposed orbiter is more streamlined and more stable than the SSTO configurations. At staging, the rocket engines are ignited and the orbiter has sufficient on-board propellants to continue ascent to orbit. The rocket engines could be the SSME's with the expansion ratio increased to 155:1 since the engines would operate only at altitudes above 15 km (50 000 ft). Orbiter structure is based on current space shuttle orbiter technology; however, integral wing tanks for lox containment could significantly reduce wing weight.

Figure 3 shows the booster concept in more detail than figure 2. The current booster configuration is a winged body containing a cluster of four turbojets with afterburners and is pylon-mounted to the lower surface of the orbiter wing. An aluminum alloy heat sink structure was selected for the boosters. Each turbojet engine has a two-dimensional, variable geometry inlet. For shuttle size payloads of 29 500 kg (65k lb_m), supersonic transport (SST) class engines with thrust in the 380 kN (85k lb_f) range are required for the selected number of engines. For smaller payloads in the 4500 kg (10k lb_m) range, existing J-58 class turbojets may suffice.

Details of the SST turbojet concept (giving a thrust of 331 kN (74K lb_f) without afterburner) and its performance are available in ref. 10. The engine concept selected for this study is based on increased turbine inlet temperatures over current technology and has a variable stator at the turbine inlet. This later feature may not be required for the space transport application, thereby simplifying the engine.

The twin boosters are essentially flying engine pods that also contain the main landing gear, sized for takeoff at the gross weight of the transport system. JP fuel for ascent, offset range, and flyback is stored in the boosters. Following horizontal takeoff, the boosters accelerate the transport with full afterburner thrust to a staging Mach number of about 3.5. The stage separation procedure may make use of booster thrust, since the thrust-to-weight ratio of the booster exceeds that of the orbiter at staging. After staging, the boosters fly back to the takeoff site. The boosters are considered to be remotely-piloted vehicles.

This proposed space transport concept combines the efficient performance of turbojet engines with efficient staging of the boosters, which contain the turbojets and main landing gear. And, of equal importance, the twin booster concept offers low inert weight of a single booster; thus a potential for low development costs since these are proportional to the inert weight of one booster. The staging and propulsive improvements over the SSTO vehicles enable use of current structures and rocket technology for the orbiter at the same payload and gross weight as the SSTO vehicles which require advanced technologies.

ANALYSES OF BASELINE CONCEPT

The analyses methods used to determine the payload mass for a given gross mass are described in detail in reference 8. The input assumptions in the areas of propulsion, aerodynamics, and structures used for analyses of the baseline transport concept are discussed in the following sections. The consumption of the propellants was calculated by integrating fuel flow rate for an optimum trajectory using the Program to Optimize Simulated Trajectories (POST), the use of which is described in reference 8. Figure 4 shows the ascent trajectory followed for the baseline transport as well as the trajectory on which turbojet performance characteristics are based. Liftoff occurs at a Mach number of 0.38 at an angle of attack of 17° and at a wing loading 1120 kg/m^2 (220 lb$_f$/ft^2). The takeoff velocity may exceed current tire technology requiring further study to lower takeoff velocity or to increase tire speed limits. The vehicle accelerates until the dynamic pressure limit of 90 kPa (1880 psf) is intercepted at a Mach number of 1.3. The dynamic pressure limit is followed until a pull-up maneuver is initiated prior to staging, which occurs at a Mach number of 3.5. The booster is dropped at staging, and the orbiter continues to orbit powered by the space shuttle main engines on an optimized path at lower dynamic pressure.

Propulsion Data

Table I lists turbojet thrust coefficient, sea level mass flow rate of air, fuel equivalence ratio, and thrust specific fuel consumption. The thrust coefficient was assumed to be independent of altitude and for a selected Mach number was obtained from the relationship

$$C_T = \frac{N_e(T-D_e) - D_b}{q\, N_e\, A_c} \qquad (1)$$

in which the net thrust of the engines is reduced by the engine drag and the booster drag. The thrust, drags, and dynamic pressure were evaluated for the turbojet performance trajectory shown in figure 4. To enable calculation of turbojet fuel consumption for other trajectories, the air flow rate was first transformed to sea level conditions (increased by the ratio of air densities at sea level to those at the turbojet performance trajectory altitude). Then, in the POST analysis, at a selected Mach number, the air flow rate was reduced by the ratio of air density at the particular altitude to that at sea level. In effect this procedure approximates the effect of the altitude change between the turbojet performance trajectory and the trajectory selected for space transport study. Using the air flow rate for the baseline concept the fuel flow rate is a function of Mach number and was calculated in the POST analysis from

$$\dot{m}_f = \dot{m}_a R \phi A_c N_b N_e \tag{2}$$

in which the stoichiometric fuel-to-air ratio, R, is multiplied by the fuel equivalence ratio, ϕ. The fuel consumed is obtained by an integration of the fuel flow rate, $\dot{m}_f$, performed by the POST analysis. For reference, table I lists the thrust specific fuel consumption of the turbojet selected for this study. Thrust specific fuel consumption (as tabulated) is based on engine net thrust minus the engine drag, which consists of spillage, bleed, and boattail drags.

The SSME with the increased expansion ratio produces 2.13 MN (478k lb_f) vacuum thrust at a specific impulse of 463 seconds for an exit area of 8.34 m^2 (90 ft^2).

Aerodynamics

Estimated lift and drag characteristics of the orbiter configuration are given in figure 5. Drag coefficient is shown as a function of Mach number for selected angles of attack of 0° and 5°. For a given angle of attack, drag was found by linear interpolation of curves for a more complete set of angles of attack. The lift curve slope used is shown in the figure.

The estimated zero-lift drag coefficient for the booster (based on the reference wing area of the orbiter) is shown in figure 6. This estimate is based on a similar wing-body configuration, studied as a hypersonic research airplane in reference 11. The POST analysis ignored booster induced drag.

The drag of the mated orbiter and boosters was assumed equal to the sum of the drags of the isolated orbiter and booster: no allowance was made for interference drags between the components. The lift of the combination was assumed to include a contribution from the booster which increased the orbiter-alone lift by about 36 percent. The analysis employed did not provide for evaluation of a drag penalty associated with the additional lift.

To determine the effect of an increase in transonic and supersonic drag, analyses were also performed with a 50 percent increase in orbiter drag from M=0.8 to 3.5 for all angles of attack. This increase is believed to be conservative because induced drag was increased as well as drag at zero lift; whereas, interference drag at transonic speeds is primarily a zero-lift wave drag phenomena.

Weights and Structures

The propellant consumption was taken from the trajectory and was input to the ODIN system of computer programs for orbiter sizing, geometry calculations, and mass property calculations. The ODIN system, as used in this analysis, is described and referenced in reference 8. Current space shuttle structures technology was used for ODIN weights. However, the space shuttle wing was designed for a $q\alpha$ product of about 144 kN degrees (3000 psf degrees); whereas, the baseline space transport has a maximum $q\alpha$ of at least 192 kN degrees

(4000 psf degrees). Moreover, the baseline space transport flies at a higher dynamic pressure than the space shuttle. Consequently, the estimated wing weight of the baseline transport is probably less than necessary. However, the baseline transport has a dry wing (no propellants in the wing), and studies (refs. 7 and 9) have shown that the structure weight of the wing can be reduced by storing lox in the wings. The heavy lox produces a load alleviation, thus reducing wing bending moment and the respective wing weight.

The booster weight at staging was the sum of the turbojets, inlets, structure, landing gear (assumed to be 3.0 percent of the gross takeoff weight of the space transport), miscellaneous items, and fly-back fuel weight. Fly-back fuel is based on a range of about 460 Km (250 n.m.). The booster structural concept consists of a center frame (see fig. 3) that serves as the pylon and support for engines, inlet ramps, and landing gear. Conventional structure forms the fuselage shell and wings, except the skins are thickened to provide heat sink thermal protection. Aluminum alloy has been selected for the booster structure. Unit heat load was calculated in the POST analysis for the ascent trajectory. Mass analyses show that 19.5 kg/m^2 (4.0 lb_m/ft^2) of aluminum at a temperature rise of 167K (300°F) can absorb the entire heat load from Mach 0 to 3.5 without benefit of radiation cooling; however, with radiation, a skin weight of about 14.7 kg/m^2 (3.0 lb_m/ft^2) should suffice. A weight estimating procedure based on wing loading at gross weight, ultimate load factor, and wing sweep was used initially to estimate the weight of the booster structure. This weight estimating procedure indicated a weight per unit wetted area of 12.7 kg/m^2 (2.6 lb_m/ft^2) for the conventional fuselage structure and a weight of 20.5 kg/m^2 (4.2 lb_m/ft^2) for the wing structure. Since the wetted wing and fuselage areas are nearly equal, this results in an average structural weight of 16.6 kg/m^2 (3.4 lb_m/ft^2).

About half this weight is for internal structure such as ribs, spars, and fuselage ring frames. This leaves a skin weight of 8.3 kg/m^2 (1.7 lb_m/ft^2), which is not sufficient to absorb the heat load within the allowable temperature rise. Therefore, the heavier 14.7 kg/m^2 (3.0 lb_m/ft^2) heat sink skin weight is used, which results in an average unit weight of 23.0 kg/m^2 (4.7 lb_m/ft^2). Thus, conservatively, an average structural weight per unit of wetted area of 24.4 kg/m^2 (5.0 lb_m/ft^2) was estimated for the booster structure.

RESULTS AND DISCUSSION FOR BASELINE CONCEPT

A discussion of the results for the baseline transport using current technology is given. The optimum trajectory, weight statement, payload performance, and results of aerodynamic calculations are discussed in the following sections.

Optimum Trajectory

The optimum trajectory obtained by the POST analysis for the baseline concept is shown in figure 7 as a function of flight time. Altitude to Mach 6 is shown in figure 4 as a function of Mach number to enable comparison between the trajectories used for the turbojet performance and the baseline transport. Figure 8 shows the available thrust and drag as calculated in the POST analysis. At all Mach numbers - including transonic - the thrust exceeds the drag; however, a 50 percent increase in transonic and supersonic drag would require more thrust. Either larger turbojet engines or a cluster of five or more engines in each booster fuselage may be required instead of the engine size and cluster of four shown for the baseline concept in figures 2 and 3. As seen in figure 7, the winged booster and orbiter space transport flies at low flight path angles unlike vertical takeoff transports. Flight path angles are less than 6° during boost and 3° during rocket ascent, similar to airline-type ascent. Staging occurred at about 12 minutes after takeoff; and after about 9 minutes of rocket ascent, orbital velocity and altitude are achieved. The maximum acceleration was held at 1.7g to avoid high loads which results in little payload penalty.

Weight Statement

Table II is a weight statement for the baseline space transport concept. Orbiter weights are from the ODIN analysis, and all orbiter weights are based on current technology. Unit weight of the orbiter structure plus thermal protection system is 27.5 kg/m^2 (5.65 lb_m/ft^2), comparable to that of the space shuttle orbiter.

Booster weight estimates are based on the heat sink requirement and structural weight estimating procedure discussed earlier, and on unpublished engine and inlet weight data, calculated fly-back fuel weight, and assumed weights for other items. The main landing gear was assumed to weigh 3.0 percent of gross takeoff weight. An estimate of about 3.5 percent of gross takeoff weight might be more representative of current technology.

Performance

The baseline transport concept, as described previously, has space shuttle structures and rocket engine technology. Use of the turbojet boosters provides shuttle payload capability as well as a fully reusable system with conventional horizontal takeoff. The payload to orbit for the baseline transport, as determined by the POST and ODIN analyses, is 29 800 kg (65.5k lb_m). This performance is achieved by use of the increased expansion ratio (ϵ = 155:1) for the space shuttle main engines. At the current expansion ratio (ϵ = 77.5:1) the payload would be reduced to 25 000 kg (55k lb_m). The current SSME has the lower expansion ratio to satisfactorily operate at sea level; however, the baseline transport is launched from the boosters at 17.35 km (57 000 ft), thus the larger expansion ratio may be used for improved SSME performance. The increased SSME rocket nozzle area will increase orbiter base drag requiring further study to assess the real effectiveness of the greater expansion ratio.

Table III shows comparisons of the baseline transport and various single-stage-to-orbit concepts (see ref. 6) for a 29 500 kg (65k lb_m) payload to orbit. Both rocket and structures technologies are compared as well as gross and dry weights. Gross weights reduce from a maximum value of 1.63M kg (3.60M lb_m) for the all-hydrogen VTO concept to 1.26M kg (2.77M lb_m) for dual-fuel VTO with advanced rockets to 1.22M kg (2.68M lb_m) for an all-hydrogen orbiter with a rocket powered sled, which is essentially a M = 0.6 stage, to a minimum value of 1.18M kg (2.6M lb_m) for the HTO Mach 3.5 turbojet booster space transport. Only the baseline transport has a current technology structure.

Total dry weight reduces in the same order as gross weight for the various SSTO vehicles; however, the baseline space transport has a higher total dry weight than the dual-fuel VTO and sled-launched HTO. Should the sled weight be included, only the dual-fuel VTO concept would weigh less than the baseline concept. The baseline concept has the lower weight orbiter, so the boosters are responsible for the higher dry weight than the dual-fuel VTO concept. Since only one booster must be developed, only half of the booster dry weight effects development costs. Also, the booster weight is largely turbojet weight, and since only one turbojet must be developed much of the total turbojet (8 engines) weight is not indicative of development cost. Moreover, the booster structure is a more economical concept than the orbiter structure further indicating potential for low development cost.

Aerodynamic Calculations

Although performance analyses used estimated aerodynamics for the baseline concept, aerodynamic calculations were simultaneously performed to guide configuration definition. Of primary concern was the transonic and supersonic drag of the mated configuration. Initial calculations were for the orbiter and booster separately, since total drag was based on the sum of the drag of each stage. Later analysis of the mated configuration confirmed that total calculated wave drag is nearly equal to the sum of the wave drag of the stages. These analyses used the GEMPAK code (ref. 12) which gives the geometry definition. GEMPAK is coupled with aerodynamic codes used in the analysis of the baseline concept. These coupled codes include a vortex lattice program (ref. 13) for subsonic aerodynamics, the Harris Wave Drag Program (ref. 14) for supersonic aerodynamics, and the Gentry Program (ref. 15) for hypersonic aerodynamics.

Results of the calculated drag for the booster are shown in figure 9 and are compared with that estimated for the booster in the POST analysis. As indicated, the calculated drag is greater than the estimated values; however, the greatest difference amounts to only 15 percent error in the total drag of the mated configuration.

Calculated drag for the orbiter is shown in figure 10 and compared with that estimated for the orbiter in the POST analysis. Also shown is the estimated drag increased by 50 percent in the M = 0.8 to 3.5 range. As indicated, the calculated drag for the baseline transport orbiter is near the 50 percent margin in the critical transonic range, which requires maximum turbojet thrust.

Prior to the calculation of drag, an increase over the estimated value of orbiter drag (used for the POST analysis) of 50 percent in the Mach number range of 0.8 to 3.5 was assumed. Performance analysis with a resized vehicle which increased the turbojet thrust by 25 percent with this increased drag shows a reduced payload by 1800 kg (4k lb_m), or the payload is about 28 100 kg (62k lb_m) for the 1.18M kg (2.6M lb_m) gross takeoff weight. This payload loss indicates that the performance is not extremely sensitive to transonic drag, only a 6.1 percent decrease in payload mass fraction results. However, transonic and supersonic drag will be a major factor affecting concept feasibility since turbojet power is used for acceleration. The required 25 percent increase in thrust may be achieved either by larger turbojets or by a cluster of five engines in each booster instead of the cluster of four engines shown for the baseline concept in figure 3.

Analytical methods do not indicate whether high drag is present as a result of flow separation due to shock impingements on opposing surfaces of the boosters and orbiter. Wind tunnel tests are required to determine if and where flow separation exists and should it exist the necessary configuration changes to reduce the drag. Results to date are based on estimates and preliminary analyses. Radically different configurations may be required to achieve satisfactory results should the wind tunnel derived drag greatly exceed the calculated drag.

Aerodynamic calculations were also made to determine booster landing characteristics and booster and orbiter stability data. These analyses show the booster lands at about 124 m/s (240 knots), is stable, and has sufficient control power to flair for landing. Subsonic stability is shown in figure 11 for various booster configurations studied. The upper configuration is seen to be unstable over part of the lift coefficient, C_L, range as indicated by the positive slope of the curve at low C_L values. The next lower configuration has a more rearward wing and is shown to be stable; however, the elevons did not produce adequate control power for landing. The third configuration has the pylon extended rearward with a horizontal control surface which does provide sufficient control power. However, the vertical tail on this boom interferes with the orbiter wings. The last configuration, shown at the bottom of figure 11, has swept trailing edge wings with tip fins to provide a more rearward elevon location for adequate control power.

Hypersonic, Mach 6, stability for ascent conditions is shown in figure 12 for various orbiter configurations studied. The first configuration had the most forward wing location and was unstable. The second configuration has trailing edge sweep and a more rearward wing than the first and is stable. However, without application of area rule, the calculated drag increase was more than the 50 percent increase estimated for the POST analysis. So a third-more streamlined-configuration was studied; it too is stable. This third configuration is longer and has more wetted area than the first two orbiter configurations. Consequently, recent analysis includes the application of area rule to shorter configurations to achieve a drag reduction with minimal increase in wetted area.

CONCEPT ALTERNATIVES AND REFINEMENTS

To assess the growth potential of the baseline space transport concept, several technology improvements were studied. In addition, a concept of stretching the current space shuttle orbiter as an alternative to an all-new orbiter for two classes of payload is discussed.

Advanced Structure

Applying advanced structure (described in reference 1) to the orbiter results in a structure that is 25 percent lighter than the baseline structure and a payload of about 45 400 kg (100k lb_m). As seen in figure 13, this is 50 percent more than the payload of the baseline concept.

As for the case with the baseline concept using existing structure technology, a 50 percent increase in orbiter transonic drag (now found to be a more realistic estimate) reduces the payload to 43 500 kg (96k lb_m) for the 1.18M kg (2.6M lb_m) gross weight. This loss in payload due to a 50 percent increase in transonic drag is only a 4.0 percent loss in payload mass fraction.

Advanced Rockets

Replacing the improved shuttle rockets with advanced rockets offers a payload of 49 900 kg (110k lb_m), as shown in figure 13. These rockets are more advanced than those listed in Table III for the dual-fuel VTO, SSTO concept. The rockets listed in Table III are separate engines, i.e,, hydrogen-oxygen engines and hydrocarbon-oxygen engines. Whereas, the advanced rockets used in obtaining the data in figure 13 are dual-expander engines, ref. 1. These engines burn both hydrocarbon and hydrogen fuel through different internal ports within the engine; they are considered to require more advanced technology than the separate dual-fuel rockets. A benefit yet to be assessed is the reduced drag due to the reduced orbiter volume made possible by use of the denser hydrocarbon fuel. Consequently, the advanced rockets may offer a greater payload than shown in figure 13. Moreover, the reduced volume also means reduced dry weight and development costs.

Advanced Scramjet

Airbreathing propulsion may be used for the orbiter as well as for the boosters. However, at Mach numbers starting at about 3.5, a dual mode scramjet is required since supersonic transport turbojets are currently limited to about Mach 3.5 (ref. 16). Figure 14 shows the orbiter with a scramjet and SSME rockets and the turbojet boosters. A baseline fixed geometry scramjet has been described in reference 17. Scramjet thrust coefficient, air flow rate, and fuel equivalence ratio are given in Table IV as a function of Mach number and velocity. This data was used in the POST analysis in a like manner to that for the turbojet. Unpublished studies of the baseline scramjet indicate that it will weigh about 1260 kg/m^2 (258 lb_m/ft^2) based on engine inlet area. At this weight, the POST and ODIN analyses indicate the payload with the scramjet is about the same as without the scramjet.

The weight estimate of the scramjet was based on stress analyses of rectangular and circular combustor cross sections, and the combustor length was considered to be a variable. The structural concept analyzed was full-depth honeycomb-core sandwich, which also included a plate-fin sandwich for cooling all interior surfaces. At selected stations an optimum weight and thickness of honeycomb-core sandwich were calculated based on a minimum sum of core and face-sheet weights. The design load was the internal pressure, and material properties were based on local temperatures. Shown in figure 15 is the weight of a scramjet module with the baseline rectangular combustor and with a circular combustor. The baseline scramjet has rectangular sections throughout. At the baseline combustor length, a 40 percent reduction in weight is indicated for a circular combustor. This is due to the fact that a circular cross section is more efficient than a rectangular section for support of the high pressure in the combustor. For a 30 percent reduction in combustor length an added 10 percent reduction in engine weight results, giving a total weight reduction of 50 percent.

With this advanced lightweight scramjet and an advanced structure, the POST and ODIN analyses indicate a payload of 61 400 kg (135K lb_m) for a gross takeoff weight of 1.18M kg (2.6M lb_m). As seen in figure 13, this payload is double that of the baseline space transport concept. However, further study is needed on thrust and weight of the circular combustor scramjet and on ascent and entry cooling of the scramjet when not in use.

Stretched Shuttle Orbiter

Results presented thus far are based on new orbiter configurations; however, a concept of stretching the current shuttle orbiter was also studied and is shown in figures 16 and 17. Figure 16 shows a comparison of the proposed space transport concept (labeled Spacejet) with the current space shuttle. Numerous items from the present shuttle might be used in a new vehicle. For example, the external liquid hydrogen tank may form the forward fuselage of the stretched orbiter as indicated in figure 17. Other possible common components are the crew accommodations, avionics, payload bay with its composite material doors, main rocket engines, and on-orbit propulsion system. The wing, tail, and some of the fuselage of the stretched shuttle cannot be directly taken from the current shuttle, because they must be larger, and operate in a different environment; however, the type of structure is the same as the shuttle orbiter.

Although this composite vehicle has not been analyzed to the depth of the all-new orbiters, tentative results indicate a payload equal to the current shuttle (29 500 kg (65k lb_m)), at a gross weight of only 1.27M kg (2.8M lb_m). This gross weight may be reduced by use of the higher expansion ratio (155:1) SSME nozzles. In addition, the enlarged nozzles require less orbiter stretching than the current nozzle expansion ratio. Gross weight for the stretched shuttle orbiter and turbojet boosters is estimated to be 0.73M kg (1.6M lb_m) less than the current space shuttle principally due to elimination of the solid rocket motors. More study of the stretched shuttle orbiter concept is warranted, because it potentially offers a fully reusable, horizontal takeoff system with significantly less operating cost than the current shuttle and lower development costs than an all-new orbiter.

Small Payload Vehicle Concepts

The proposed turbojet booster space transport concept has been sized for both space shuttle and utility vehicle (ref. 1) class payloads. Figure 18 compares these two payload class vehicles for new orbiter configurations and for stretched shuttle orbiters where each vehicle has current structure and propulsion technology. Results are for dry wing orbiters; should integral wing tanks be used for lox, orbiter size and takeoff weight may be reduced.

As seen for the 29 500 kg (65k lb_m) shuttle payload class transport, the new orbiter is about 65.5 m (215 ft) long, and the stretched shuttle orbiter is about 77.7 m (255 ft) long. For the 4500 kg (10 k lb_m) class payloads, the new orbiter is only 50.3 m (165 ft) long, and the stretched shuttle orbiter is about 61 m (200 ft) long. As seen in figure 18, the gross weights are greatly reduced for the utility vehicle payload. In addition, the booster turbojets may be existing J-58 class engines. Therefore, the proposed turbojet booster transport concept is even more attractive for the smaller payload due to the reduced size and cost.

STUDY STATUS

As indicated, the above results are based on preliminary estimates of weight, drag, and engine performance. Trajectory analysis was current art, and preliminary vehicle sizing techniques were used. Considerable effort is needed to verify the concepts presented and to determine the economic and operational merits. Problem areas requiring early study are: booster and orbiter configuration refinement, wind-tunnel tests particularly at transonic speeds for the individual stages and the mated configuration to improve the aerodynamic estimates, introductory study of staging and sonic boom considerations, structural design and analyses, engine performance analyses, and effect of payload class on design of the turbojet booster transport.

CONCLUSIONS

A preliminary study of a novel space transportation concept employing a winged orbiter with on-board ascent propellants and two small turbojet boosters has been performed. This study based on estimates of aerodynamics, weights, and engine performance has led to the following conclusions:

(1) A horizontal takeoff, fully reusable space transport concept using current structures and rocket technology and SST class turbojets in twin, Mach 3.5 boosters appears to be feasible. This baseline concept is projected to have a payload mass fraction equal to the single-stage-to-orbit vehicles, which require advanced structures technology. Moreover, the proposed space transport concept has potentially much lower operating cost than the NASA space shuttle, similar to the SSTO vehicle concepts and considerably greater operational versatility than the SSTO concepts.

(2) Alternative refinements to the baseline space transport concept were studied and indicate the following:

(a) Use of an advanced structure with 25 percent lower unit-area weight than the present space shuttle orbiter is expected to provide a 50 percent increase in payload.

(b) Use of advanced dual-fuel rockets increase the payload by an additional 10 percent.

(c) Use of an advanced scramjet on the orbiter with advanced orbiter structure increases the payload to twice that of the baseline space transport.

(d) The turbojet boosters may be applied to a stretched version of the present space shuttle orbiter rather than the completely new orbiter of the baseline concept.

(e) The proposed space transport concept appears attractive for smaller payload class utility vehicles with either an all-new orbiter or a stretched shuttle orbiter.

(3) Further effort is warranted in configuration refinement, transonic aerodynamics, staging techniques, sonic boom constraints, structural design and analysis, and engine performance as well as economic and operational aspects to verify the concept of a space transport with two small turbojet-powered boosters.

REFERENCES

1. Henry, Beverly Z. and Eldred, Charles H.: Advanced Technology and Future Earth-Orbit Transportation Systems. AIAA Paper No. 77-530, May 1977.

2. Booda, Larry: USAF Plans Radical New Space Plane. Aviation Week and Space Technology, Vol. 73, No. 18, Oct. 31, 1960, pp. 26.

3. Morris, R. E. and Williams, N. B.: Study of Advanced Air Breathing Launch Vehicles with Cruise Capability - Volume 3, Aerodynamics, Propulsion, and Subsystems (U). Final Report, 2 Jan. - 3 Oct. 1967. Lockheed California Company, NASA CR-73196, Feb. 1968.

4. Keller, R. B. and Wheaton, R. J.: Preliminary Study of Air Breathing First Stage Boost Vehicle. Allison Div., General Motors Corporation Report No. EDR1169, March 17, 1959. (C)

5. Pierpont, P. Kenneth: An Aircraft Launch Vehicle for Military and Scientific Space Missions. Presented at the AIAA Military Aircraft Systems Meeting, Dallas, Texas, October 18-19, 1966.

6. Henry, B. Z. and Decker, J. P.: Future Earth Orbit Transportation Systems/ Technology Implications. Astronautics and Aeronautics, V. 14, No. 9, Sept. 1976, pp. 18-28.

7. Bangsund, Edward L., et al: Technology Requirements for Advanced Earth-Orbital Transportation Systems. NASA CR-2879, 1977.

8. Martin, James A.: An Evaluation of Composite Propulsion for Single-Stage-to-Orbit Vehicles Designed for Horizontal Takeoff. NASA TMX-3554, 1977.

9. Haefeli, Rudolph C., et al: Technology Requirements for Advanced Earth-Orbital Transportation Systems. NASA CR-2866, 1977.

10. Barber, Hal T., Jr. and Swanson, E. E.: Advanced Supersonic Technology Concept AST-100 Characteristics Developed in a Baseline-Update Study. NASA TM X-72815, Jan. 1976.

11. Hearth, D. P. and Preyss, A. E.: Hypersonic Technology - Approach to an Expanded Program. Astronautics and Aeronautics, Vol. 14, No. 12, Dec. 1976, pp. 20-37.

12. Stack, Sharon H., Edwards, C. L. W., and Small, W. J.: GEMPAK: An Arbitrary Aircraft Geometry Generator. NASA TP-1022, 1977.

13. Lamar, J. E. and Gloss, B. B.: Subsonic Aerodynamic Characteristics of Interacting Lifting Surfaces with Separated Flow Around Sharp Edges Predicted by a Vortex-Lattice Method. NASA TN D-7921, Sept. 1975.

14. Harris, Roy V., Jr.: An Analysis and Correlation of Aircraft Wave Drag. NASA TM X-947, 1964.

15. Gentry, Arvel E. and Smyth, Douglas N.: Hypersonic Arbitrary-Body Aerodynamic Computer Program (Mark III Version). Rep. DAC 61552 (Air Force Contract Nos. F33615 67 C 1008 and F33615 67 C 1602), McDonnell Douglas Corp., April 1968. Vol. I - User's Manual (available from DDC as AD 851 811. Vol. II - Program Formulation and Listings (available from DDC as AD 851 812).

16. Denning, R. M. and Hooper, J. A.: Prospects for Improvement in Efficiency of Flight Propulsions Systems. Journal of Aircraft, Vol. 9, No. 1, Jan. 1972.

17. Henry, J. R. and Anderson, G. Y.: Design Considerations for the Airframe-Integrated Scramjet. NASA TM X-2895, Dec. 1973.

TABLE I - BOOSTER PROPULSION DATA

Mach no. at sea level	Velocity m/s (ft/sec)	Thrust coefficient	Air flow rate at sea level per unit inlet area kg/s-m^2 (lb$_m$/sec-ft^2)	Fuel equivalence ratio	Thrust specific fuel consumption g/s-N (lb$_m$/hr-lb$_f$)
0	0 (0)	*	120.6 (24.7)	0.903	0.225 (1.64)
0.2	67.7 (222)	53.30	124.9 (25.6)	0.902	0.235 (1.71)
0.4	135.3 (444)	14.29	137.1 (28.1)	0.904	0.242 (1.76)
0.6	203.0 (666)	7.04	147.4 (30.2)	0.903	0.247 (1.80)
0.8	270.6 (888)	5.11	170.8 (35.0)	0.910	0.246 (1.79)
1.0	338.3 (1110)	3.87	191.3 (39.2)	0.913	0.250 (1.82)
1.4	473.6 (1554)	2.41	272.8 (55.9)	0.896	0.253 (1.84)
1.6	541.3 (1776)	2.33	325.5 (66.7)	0.885	0.251 (1.83)
2.0	676.7 (2220)	2.22	454.8 (93.2)	0.859	0.253 (1.84)
2.4	812.0 (2664)	2.12	610.1 (125.0)	0.827	0.260 (1.89)
2.6	886.4 (2908)	2.07	740.4 (151.7)	0.807	0.264 (1.92)
3.0	1015 (3330)	1.91	1005.4 (206.0)	0.767	0.269 (1.96)
3.5	1184 (3885)	1.84	1419.3 (290.8)	0.706	0.279 (2.03)

*Static thrust per unit of inlet area = 154.6 kN/m^2 (3229.5 lb$_f$/ft^2)

TABLE II - TURBOJET BOOSTER SPACE TRANSPORT WEIGHT STATEMENT

Orbiter component	Weight kg	Weight (lb_m)
Wing group	13 031	(28 728)
Tail group	3 697	(8 151)
Body group	38 344	(84 533)
Thermal protection system	21 858	(48 188)
Landing gear and docking	5 920	(13 052)
Propulsion - ascent	9 417	(20 760)
Propulsion - auxiliary	2 123	(4 681)
Prime power	1 774	(3 912)
Electrical conversion and distribution	1 634	(3 602)
Hydraulic conversion and distribution	1 760	(3 881)
Avionics	2 021	(4 445)
Environmental control	1 857	(4 093)
Personnel provisions	790	(1 742)
Growth - contingency	8 164	(17 998)
Dry weight	99 309	(218 935)
Personnel	705	(1 555)
Cargo - payload	29 769	(65 629)
Attitude control propulsion system reserves	68	(150)
Residuals	4 679	(10 316)
Landing weight	149 734	(330 101)
Attitude control propellant	4 536	(10 000)
Entry weight	154 270	(340 101)
Reserve fluids	1 334	(2 942)
Inflight losses	1 334	(2 942)
Propellant - ascent	667 161	(1 470 813)
Gross weight - orbiter	824 100	(1 816 797)

TABLE II - Continued

Booster component	Weight kg	Weight (lb_m)
Structure group	19 000	(42 000)
Propulsion with inlets	31 800	(70 000)
Landing gear	17 700	(39 000)
Equipment	2 300	(5 000)
Dry weight	70 800	(156 000)
Fly-back fuel	3 600	(8 000)
Staged weight	74 400	(164 000)
Boost fuel	102 000	(225 000)
Gross weight - booster	176 400	(389 000)
Gross weight - two boosters	352 800	(778 000)
Gross weight space transport	1 177 000	(2 595 000)

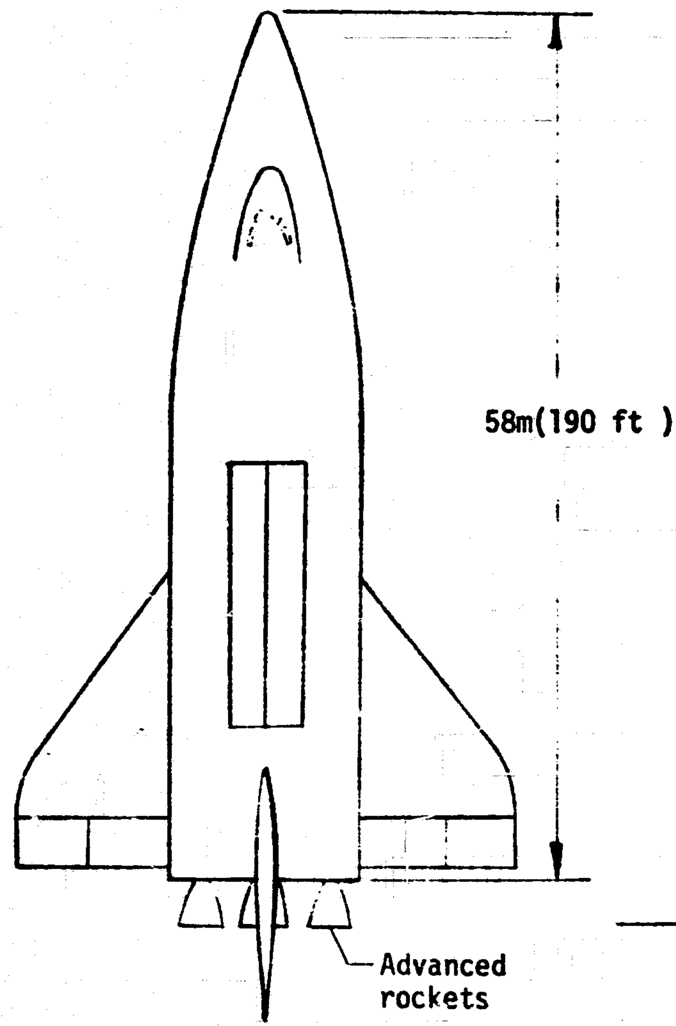
TABLE III.- COMPARISON OF TURBOJET BOOSTER TRANSPORT CONCEPT TO SINGLE-STAGE-TO-ORBIT (SSTO) CONCEPTS FOR A PAYLOAD-TO-ORBIT OF 29 500 kg (65 k lb_m)

Concept	VTO-SSTO (ref. 6)	VTO-SSTO (ref. 6)	HTO-Sled (ref. 6)	HTO-Runway/ Mach 3.5 boosters
Rocket propulsion	SSME/two position nozzle	SSME/two position nozzle plus advanced hydrocarbon rockets	SSME/two position nozzle plus rocket-powered sled	SSME/increased expansion ratio, ϵ = 155:1
Airbreathing propulsion	-	-	-	Afterburning turbojets in boosters
Structure technology	Advanced[a]	Advanced	Advanced	Current
Gross weight M kg (M lb_m)	1.63 (3.60)	1.26 (2.77)	1.22 (2.68)[b]	1.18 (2.60)
Total dry weight M kg (M lb_m)	0.171 (0.377)	0.114 (0.251)	0.128 (0.282)[b]	0.170 (0.375)
Orbiter dry weight M kg (M lb_m)	0.171 (0.377)	0.114 (0.251)	0.128 (0.282)	0.099 (0.219)

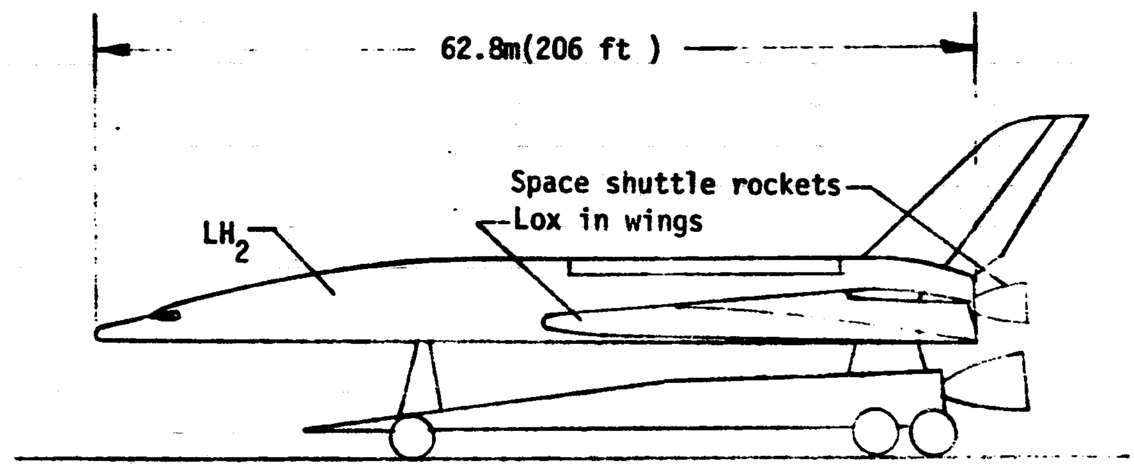
a - 25% weight reduction from current technology
b - excludes sled weight

TABLE IV - BASIC SCRAMJET PROPULSION DATA

Mach no. at sea level	Velocity m/s (ft/sec)	Thrust coefficient	Air flow rate at sea level per unit inlet area kg/s-m^2 (lb$_m$/sec-ft^2)	Fuel equivalence ratio
2.0	677 (2220)	0.739	590.6 (121.0)	1.00
3.0	1015 (3330)	1.136	1290 (264.3)	"
4.0	1353 (4440)	1.448	2057 (421.4)	"
5.0	1692 (5550)	1.414	2826 (579.0)	"
6.0	2030 (6660)	1.268	3649 (747.6)	"
7.0	2368 (7770)	1.050	4745 (972.2)	"
8.0	2706 (8880)	0.864	6027 (1234.9)	"
9.0	3045 (9990)	0.684	6903 (1414.3)	"
10.0	3383 (11100)	0.545	8168 (1673.5)	1.00
11.0	3722 (12210)	0.489	10176 (2084.9)	1.25
12.0	4060 (13320)	0.468	13467 (2759.2)	1.50



(a) A single-stage-to-orbit concept designed for vertical takeoff; Gross weight = 1.26M kg (2.8M lb_m).



(b) A single-stage-to-orbit concept designed for rocket-powered sled launch; Gross weight = 1.22M kg (2.7M lb_m).

Figure 1.- Single-stage-to-orbit vehicle concepts for a payload to orbit of 29 500 kg (65k lb_m) with advanced structures.

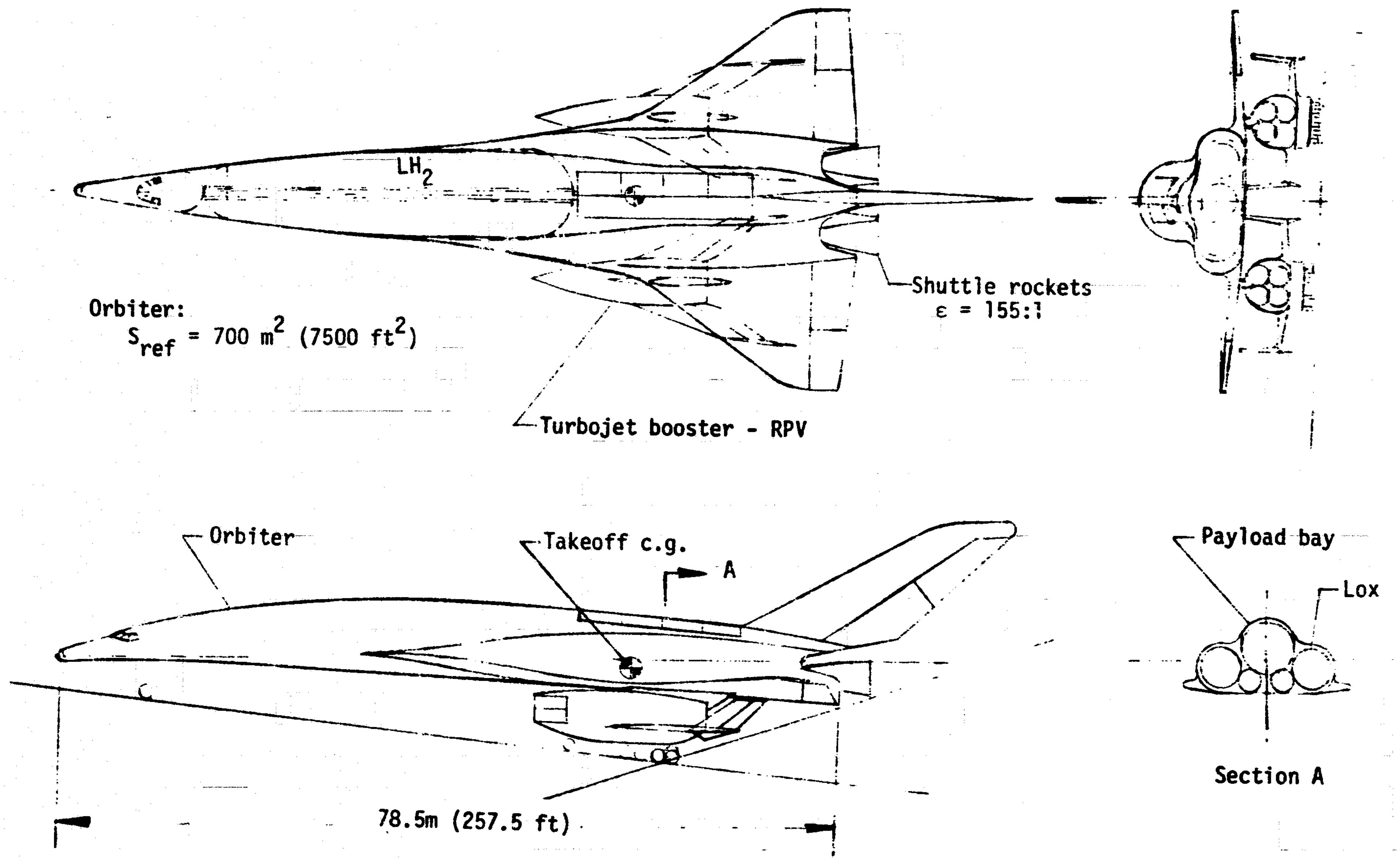
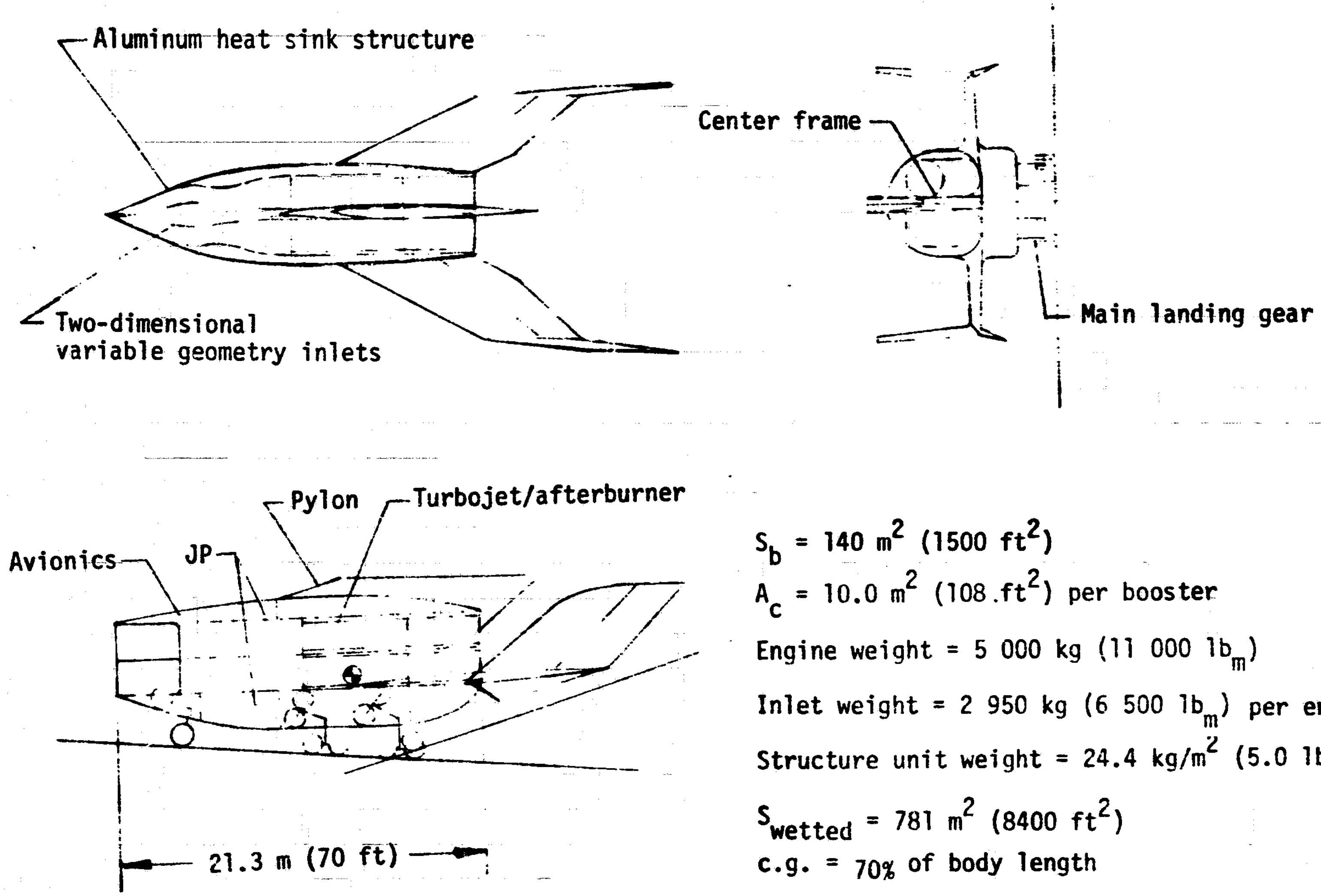


Figure 2.- Baseline configuration of turbojet booster space transport "Spacejet" concept for a 29 500 kg (65 k lb_m) payload at 1.18 Mkg (2.6 M lb_m) gross weight with current structure technology.



S_b = 140 m^2 (1500 ft^2)

A_c = 10.0 m^2 (108 ft^2) per booster

Engine weight = 5 000 kg (11 000 lb$_m$)

Inlet weight = 2 950 kg (6 500 lb$_m$) per engine

Structure unit weight = 24.4 kg/m^2 (5.0 lb$_m$/ft^2)

S_{wetted} = 781 m^2 (8400 ft^2)

c.g. = 70% of body length

Figure 3.- Baseline turbojet booster configuration.

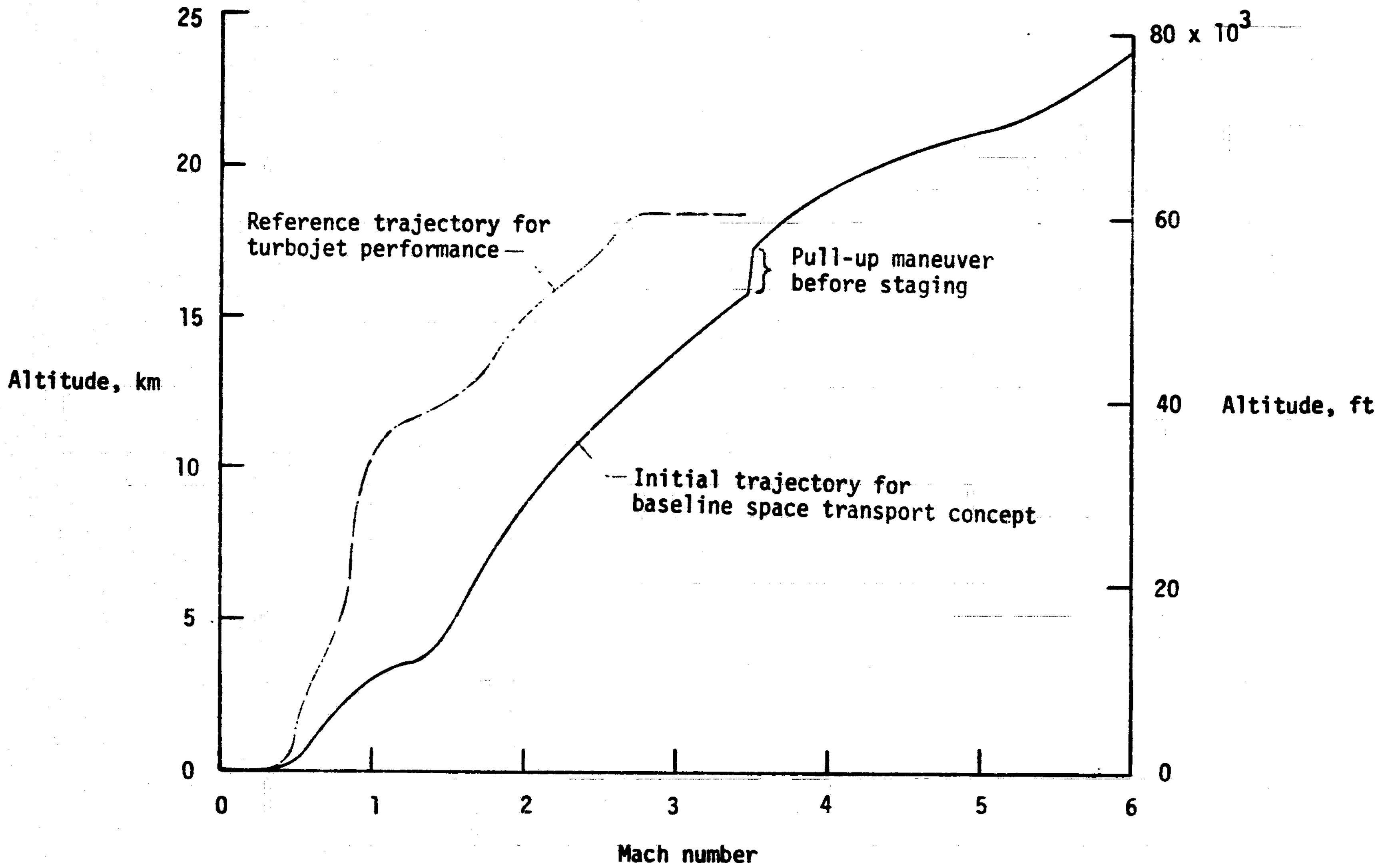


Figure 4.- Initial trajectory for baseline space transport and reference trajectory used for turbojet performance.

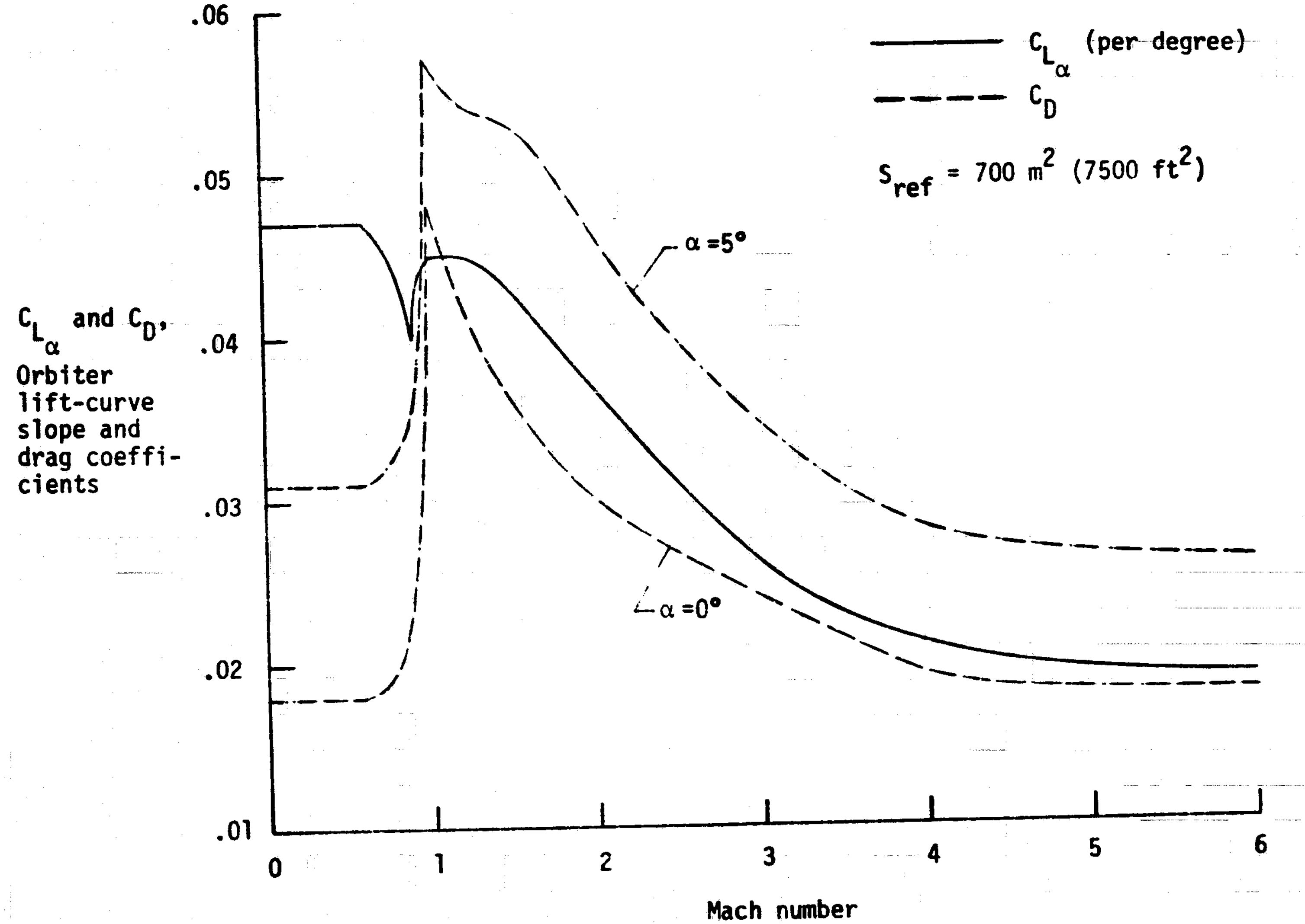


Figure 5.- Orbiter lift-curve slope and drag coefficients as a function of Mach number as used for POST analyses of the baseline transport.

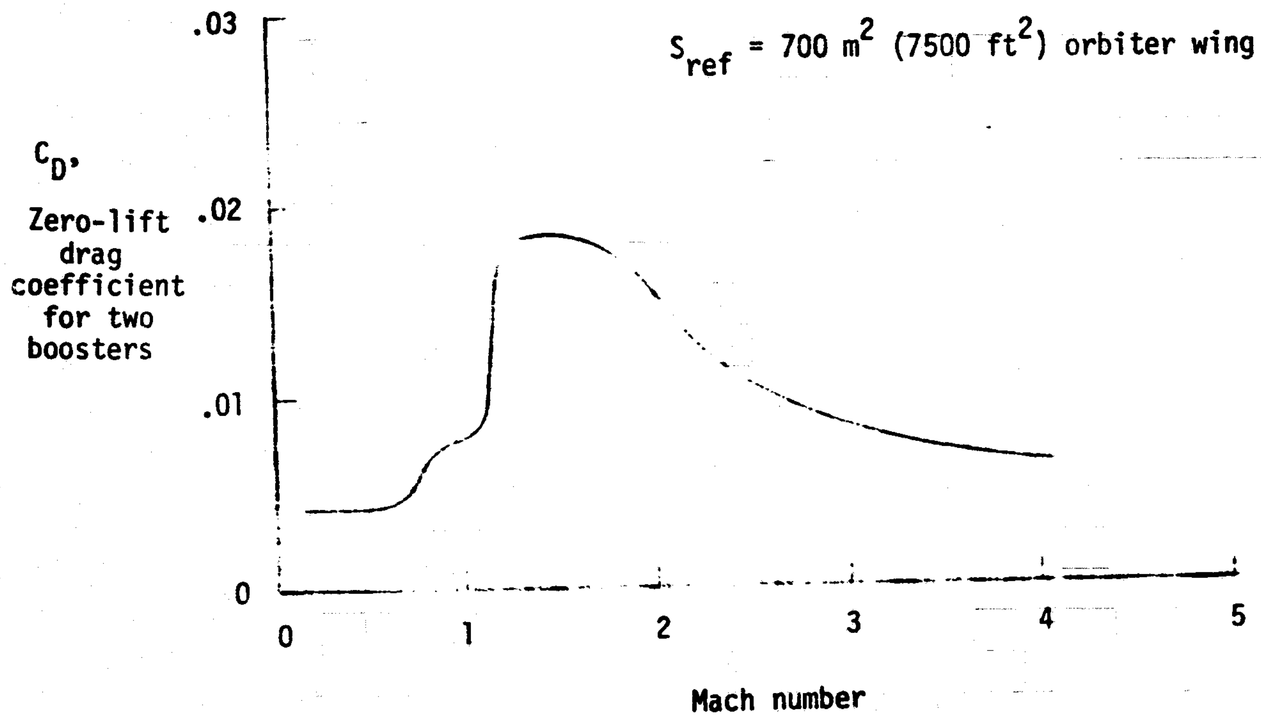


Figure 6.- Estimated zero-lift drag coefficient for two boosters used for POST analyses and expressed as a function of Mach number and orbiter reference wing area.

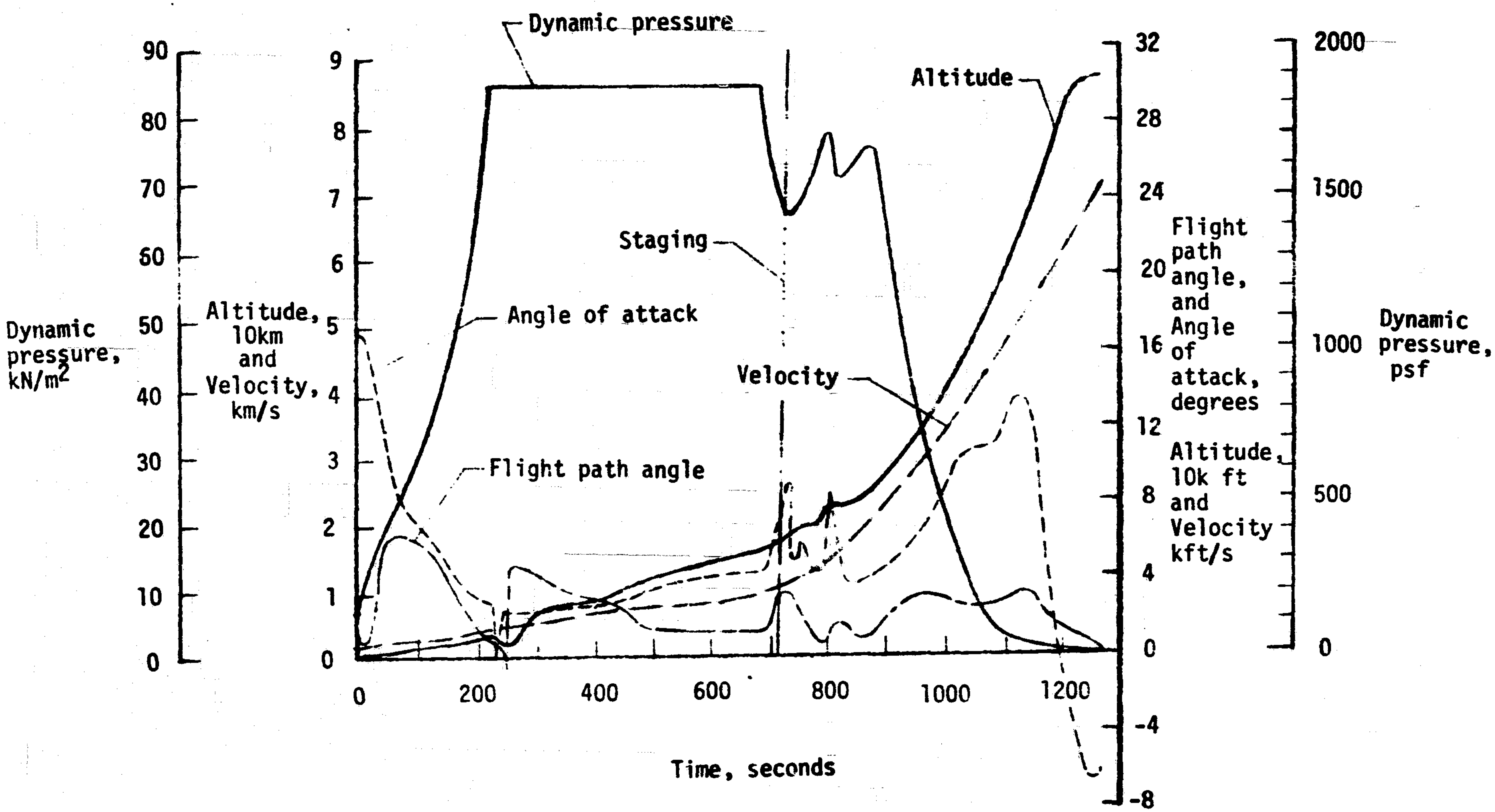


Figure 7.- Optimum trajectory for space transport with turbojet boosters.

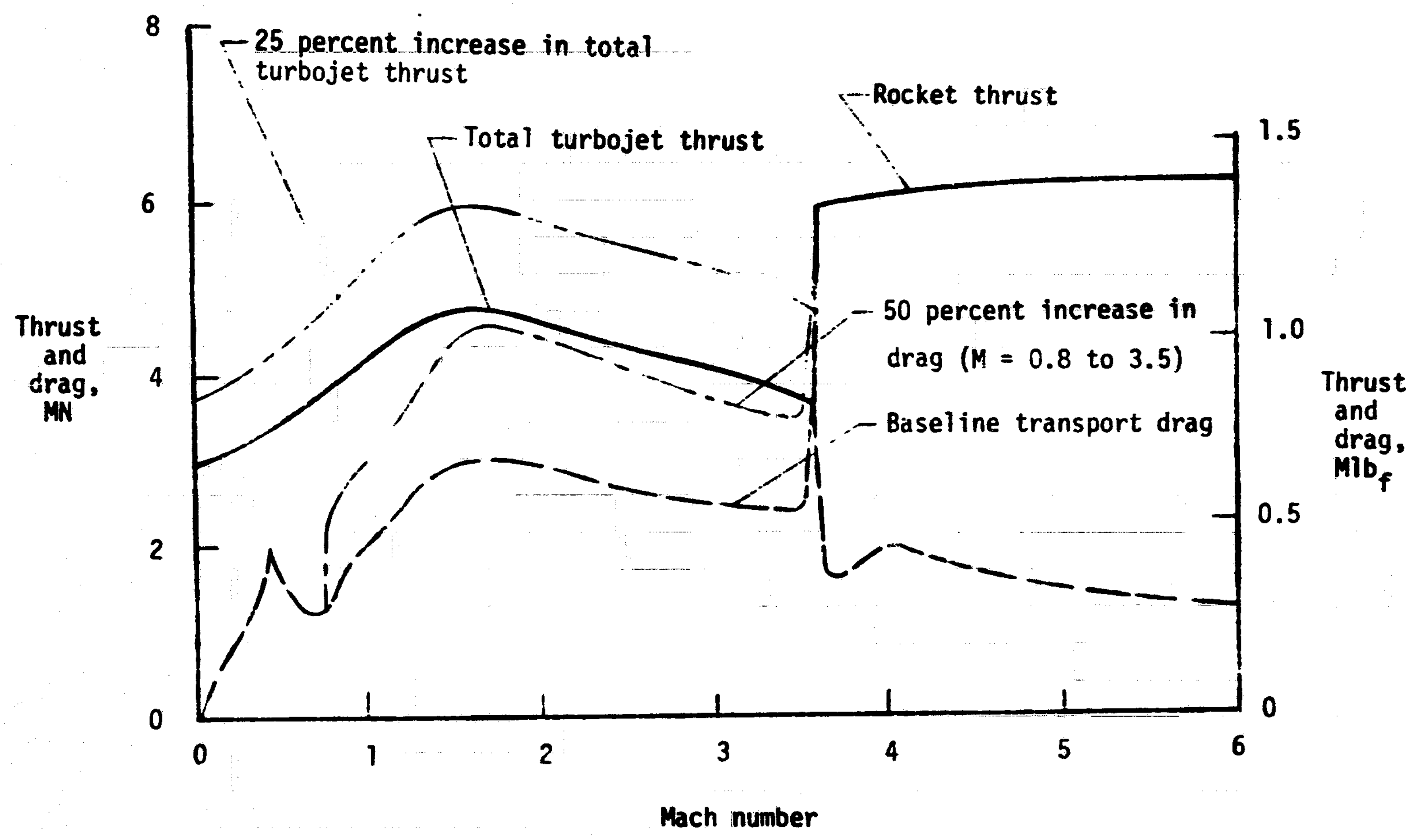


Figure 8.- Available thrust and baseline space transport drag obtained from POST analysis and shown as functions of Mach number.

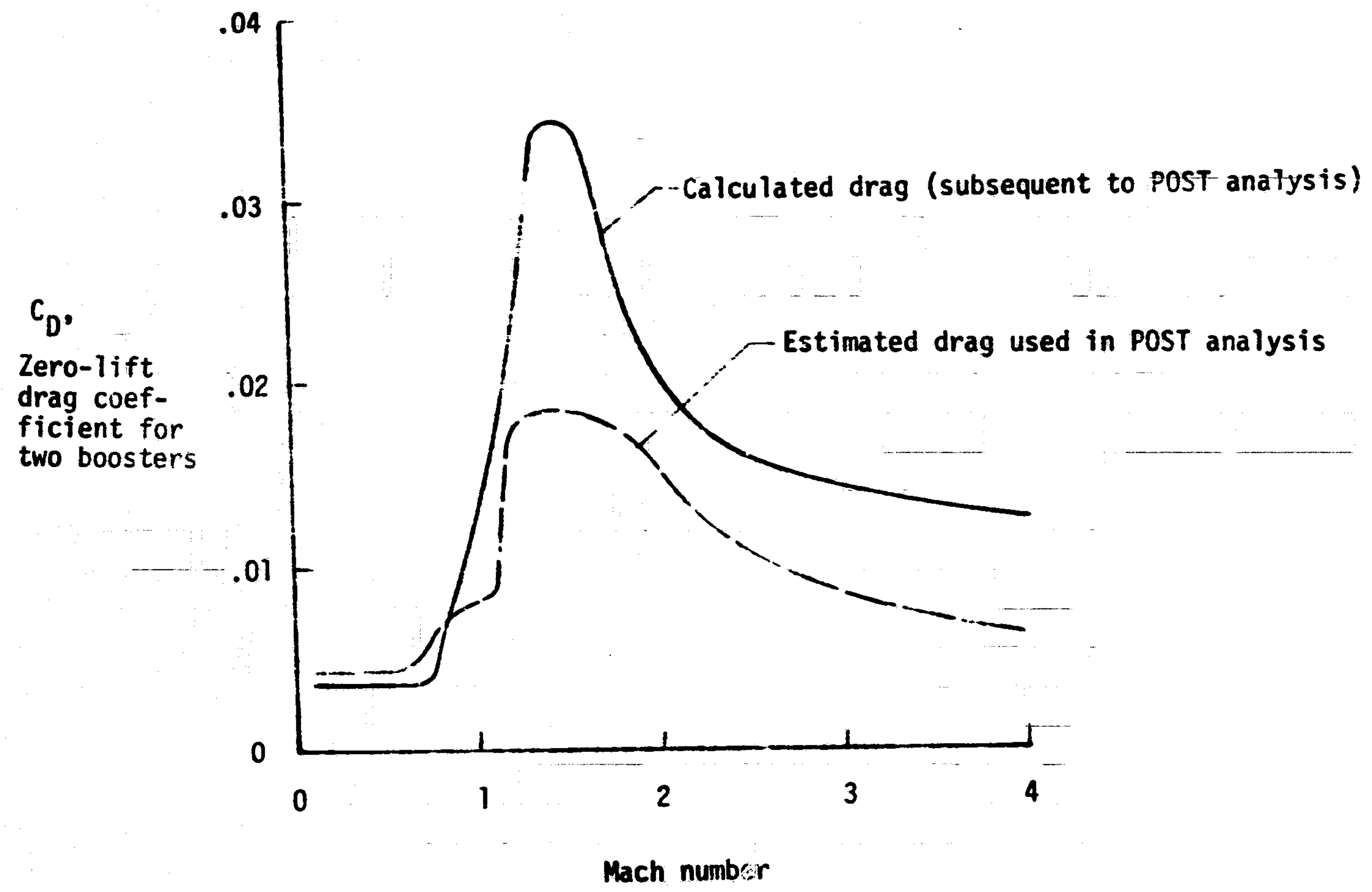


Figure 9.- Zero-lift drag coefficients for two boosters expressed as a function of Mach number and orbiter reference wing area.

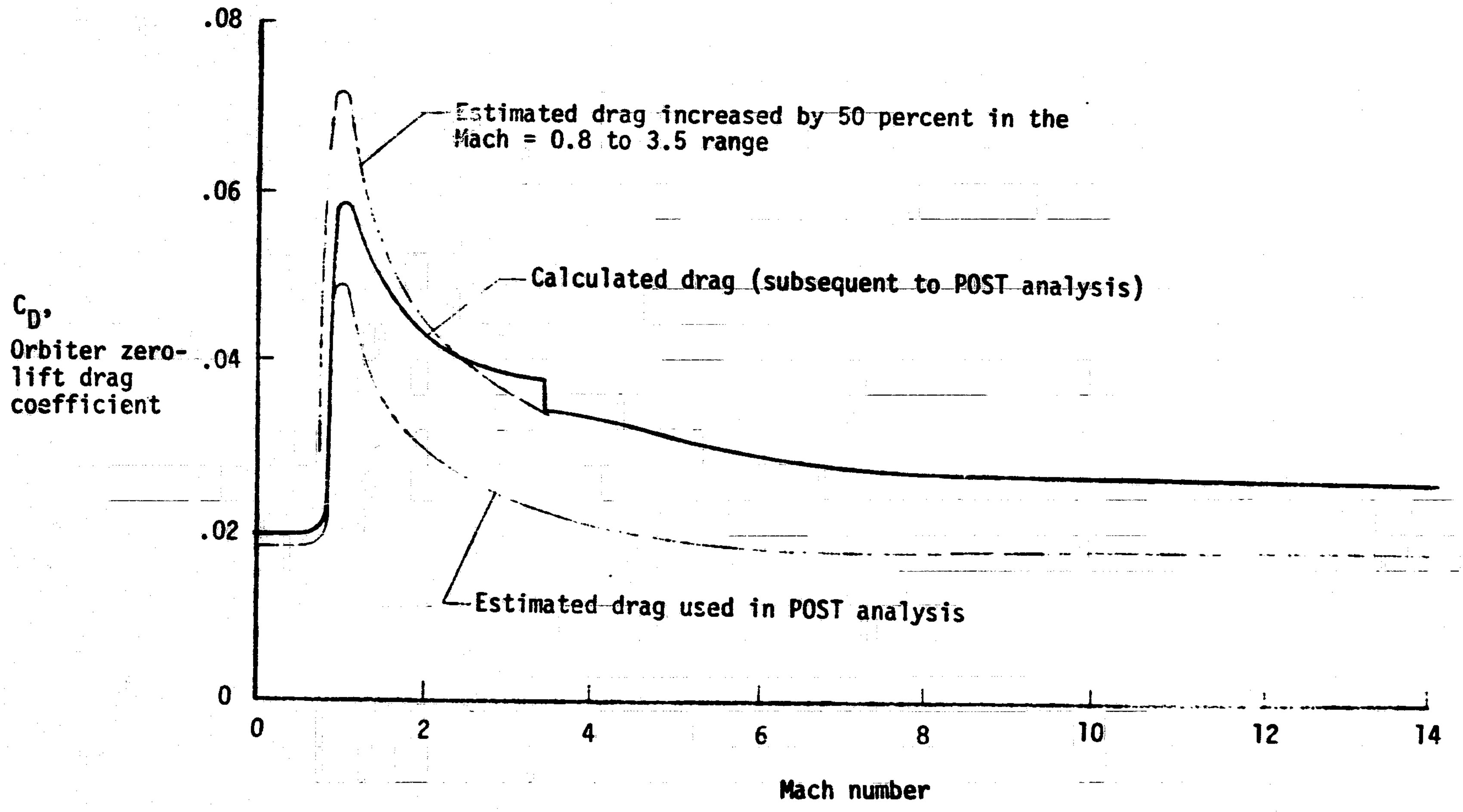


Figure 10.- Orbiter zero-lift drag coefficients as a function of Mach number for the orbiter reference wing area.

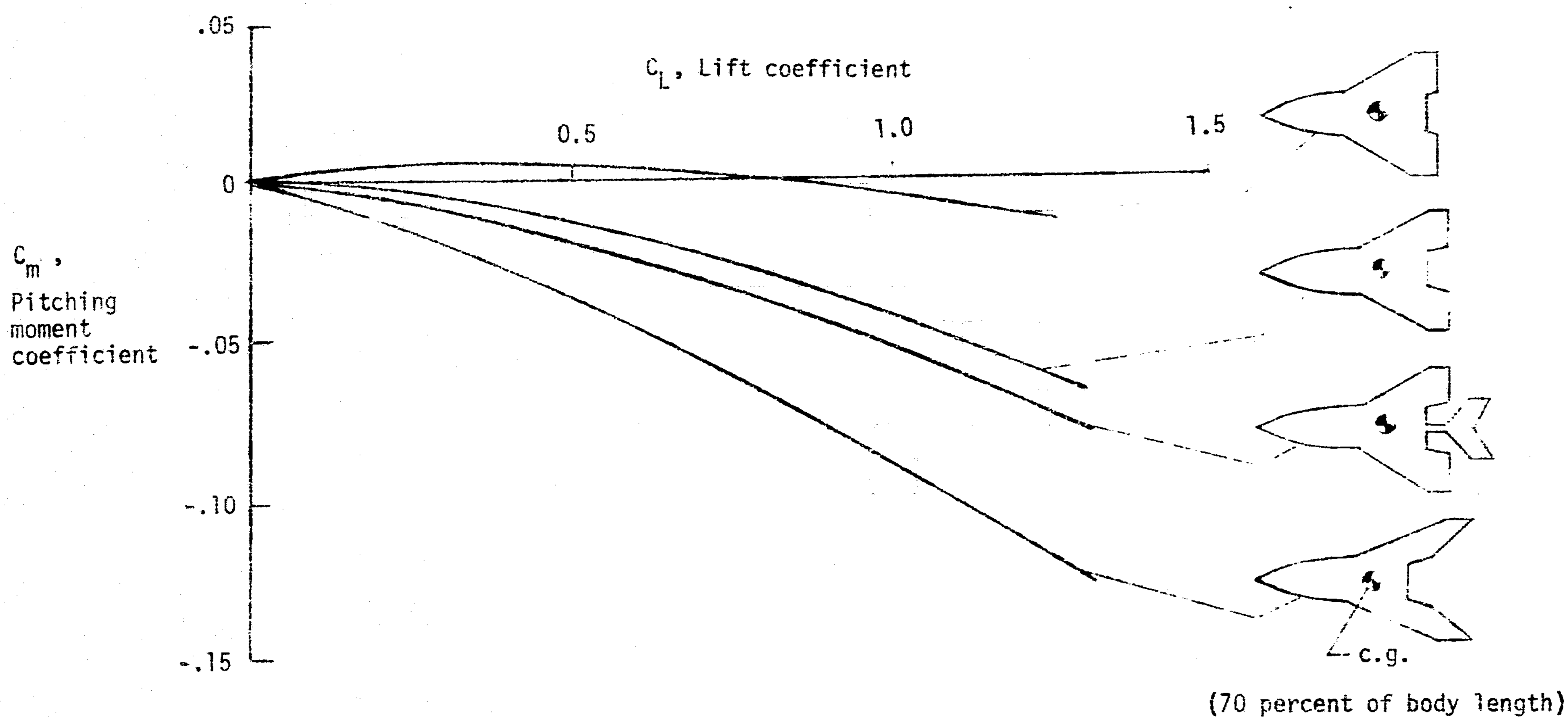


Figure 11.- Pitching moment coefficient vs. lift coefficient for various study booster configurations at Mach = 0.3 and reference wing area 140 m^2 (1500 ft^2).

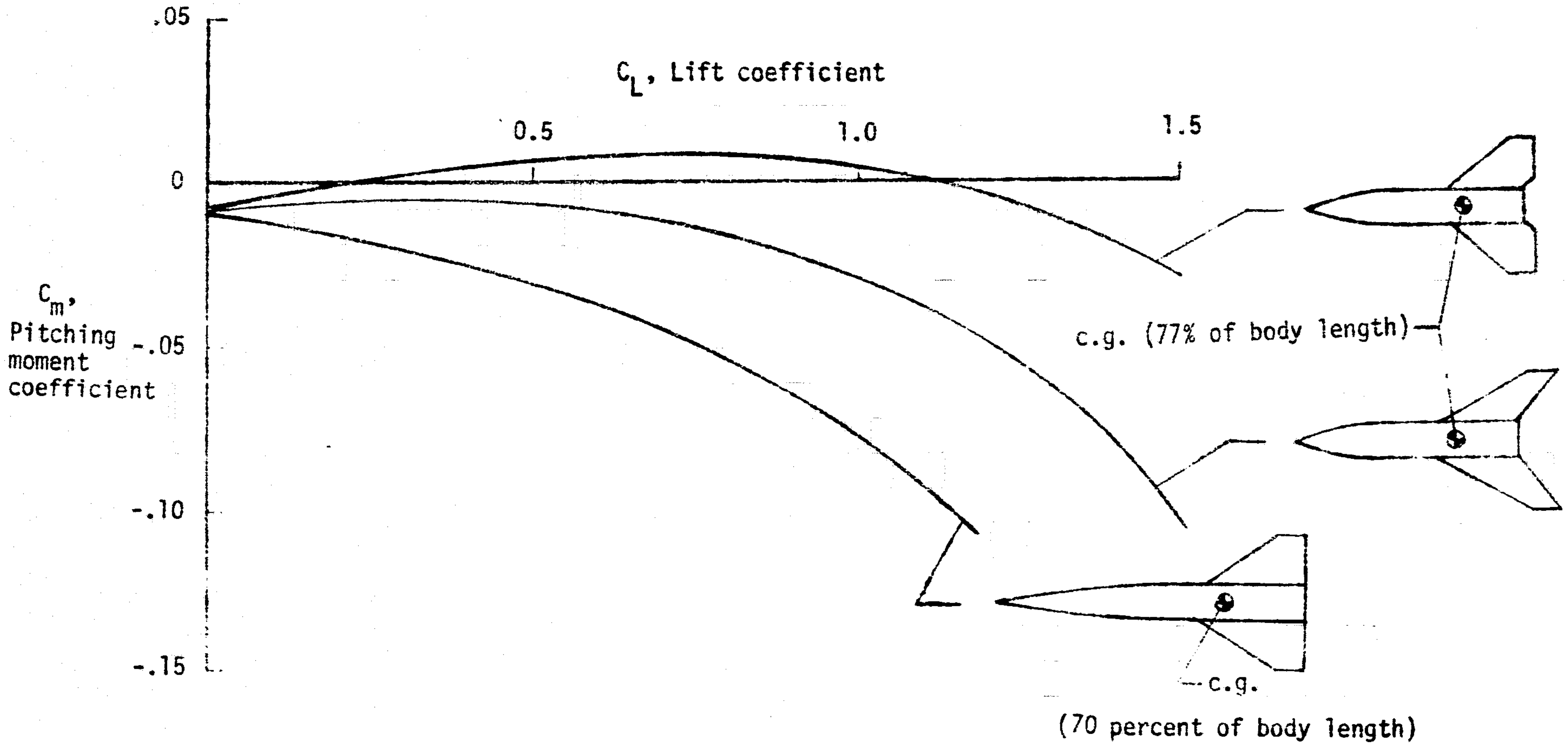
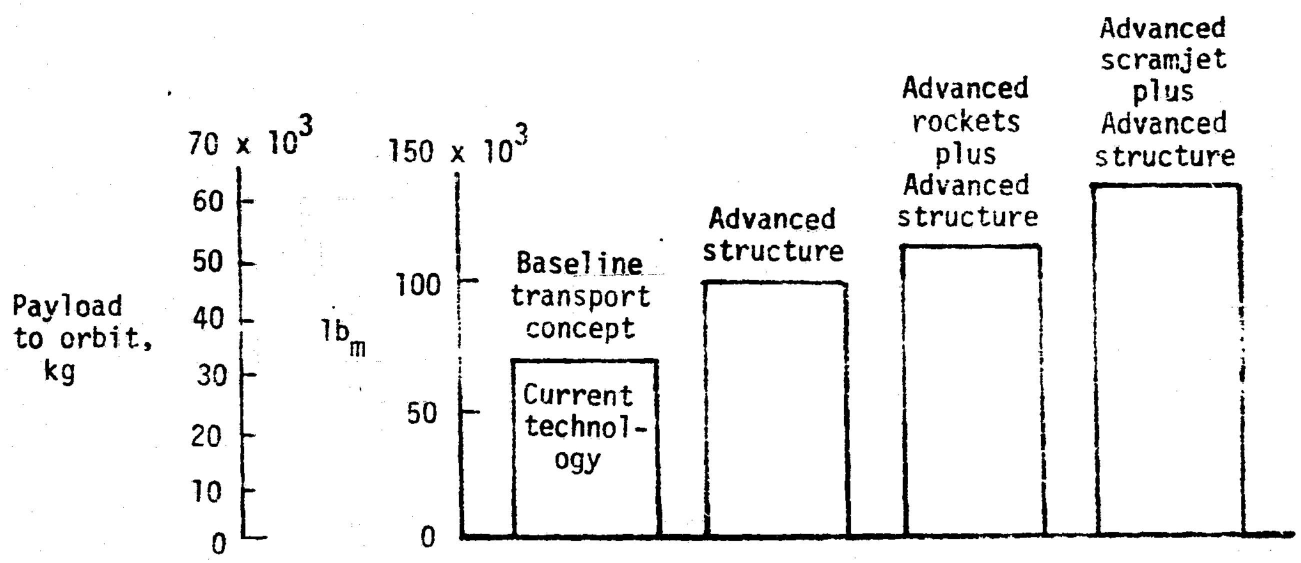


Figure 12.- Pitching moment coefficient vs. lift coefficient for various study orbiters at Mach = 6 and reference wing area of 700 m^2 (7500 ft^2).



Each alternative except the advanced rocket alternative uses SSME rockets modified to an expansion ratio of 155:1.

Advanced structure assumes a 25 percent lower unit weight than the space shuttle.

Advanced scramjet assumes a 50 percent lower structural weight from estimates of current concepts by a circularized and shortened combustor.

Figure 13.- Payload comparison of alternative technology advancements with the baseline transport concept at 1.18 M kg (2.6M lb_m) gross weight.

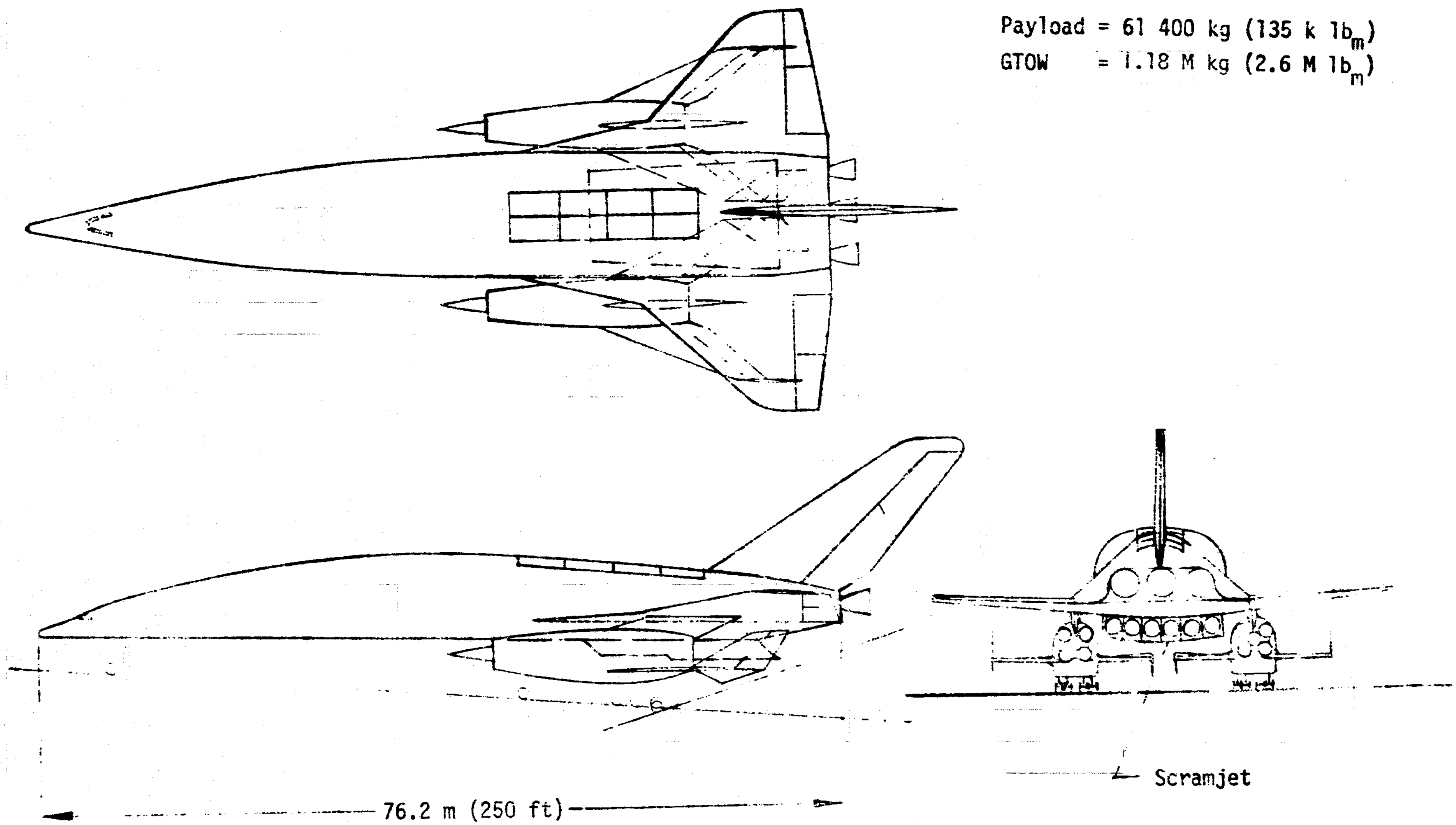


Figure 14.- Turbojet booster space transport concept with scramjet propulsion for the orbiter.

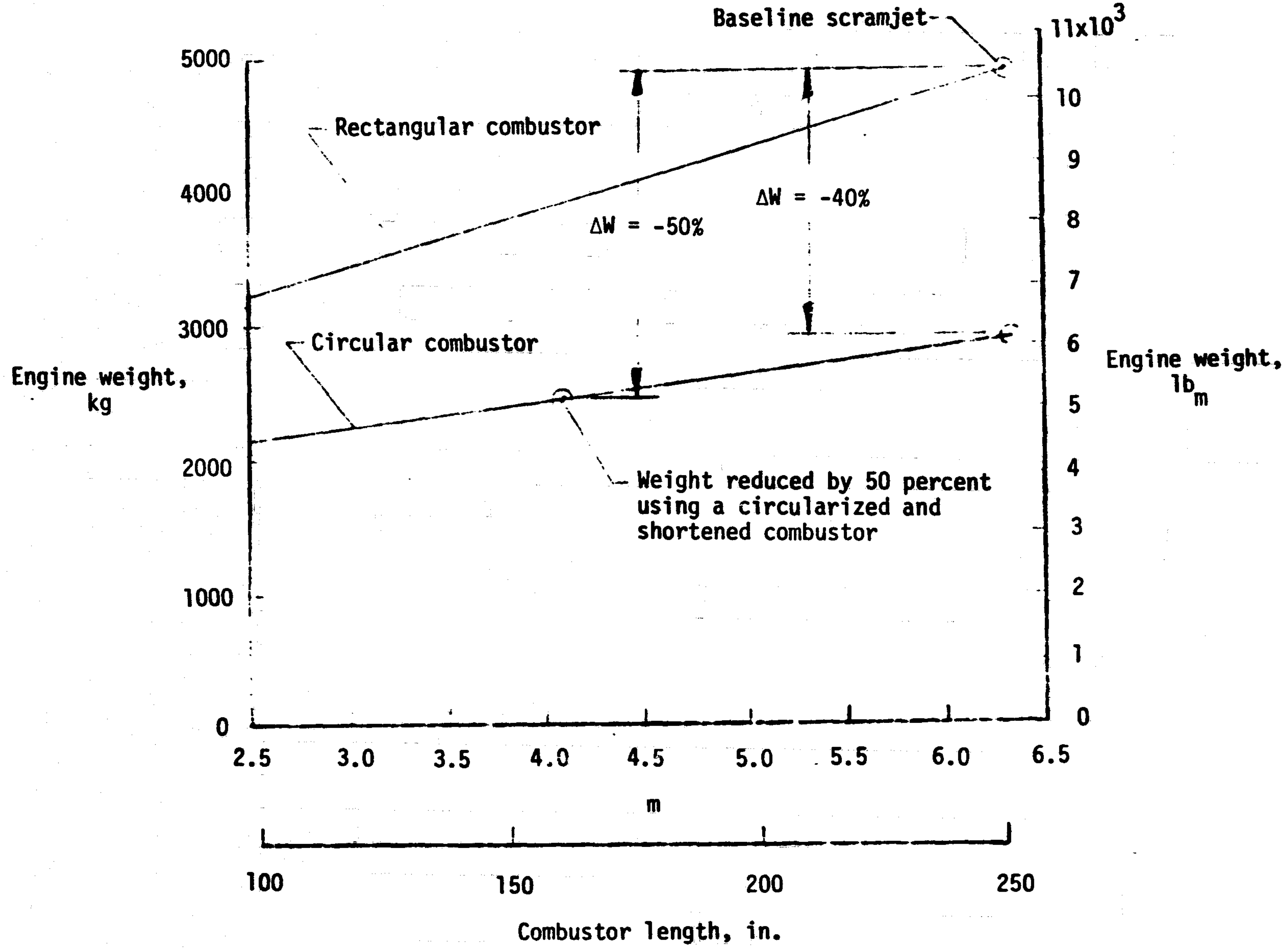


Figure 15.- Estimated weight for a scramjet engine with a two-dimensional inlet and exhaust nozzle and 4.65 m^2 (50 ft^2) capture area as a function of combustor length for rectangular and circular combustor cross sections.

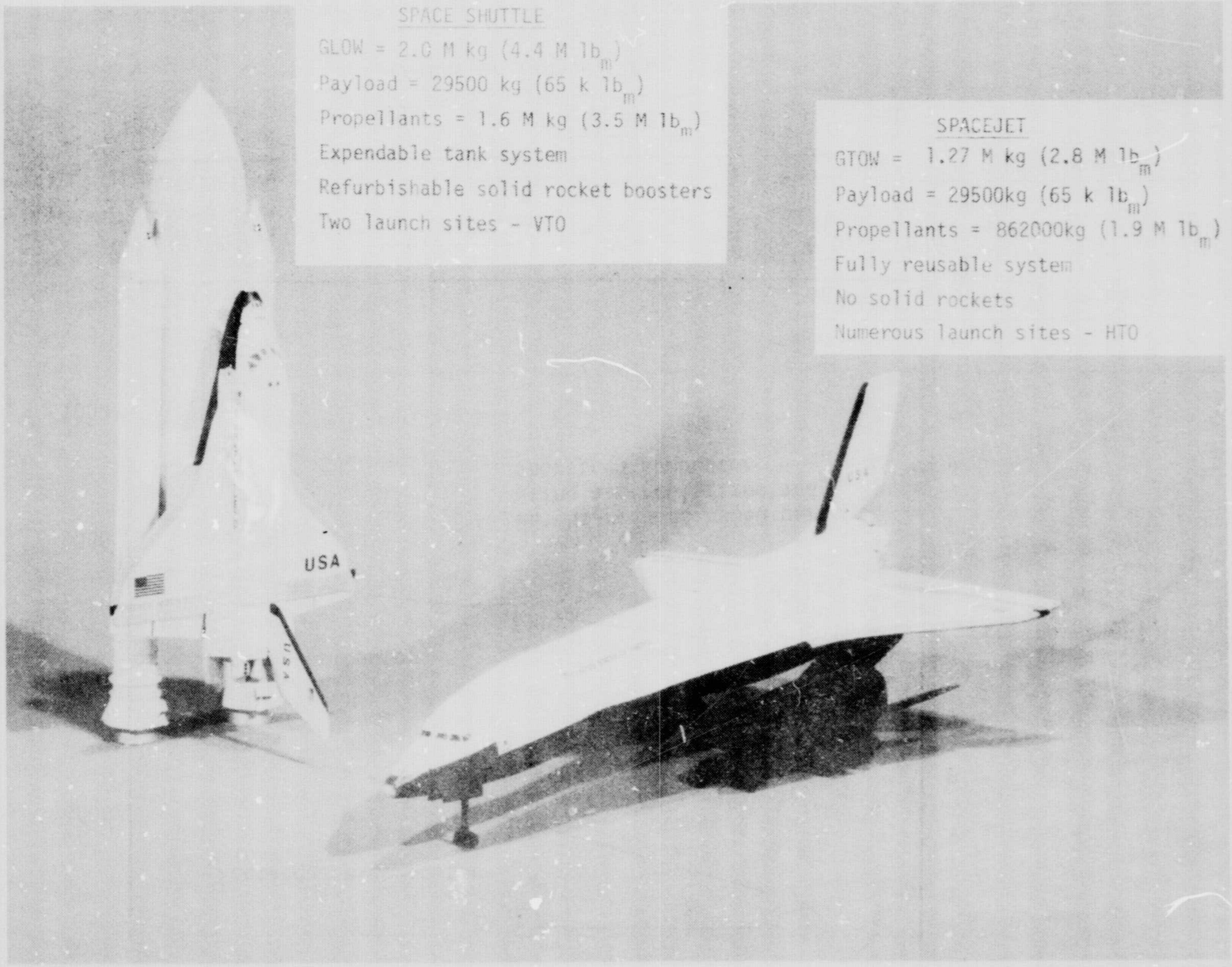


Figure 16.- Comparison of proposed turbojet booster space transport "Spacejet" with the NASA space shuttle.

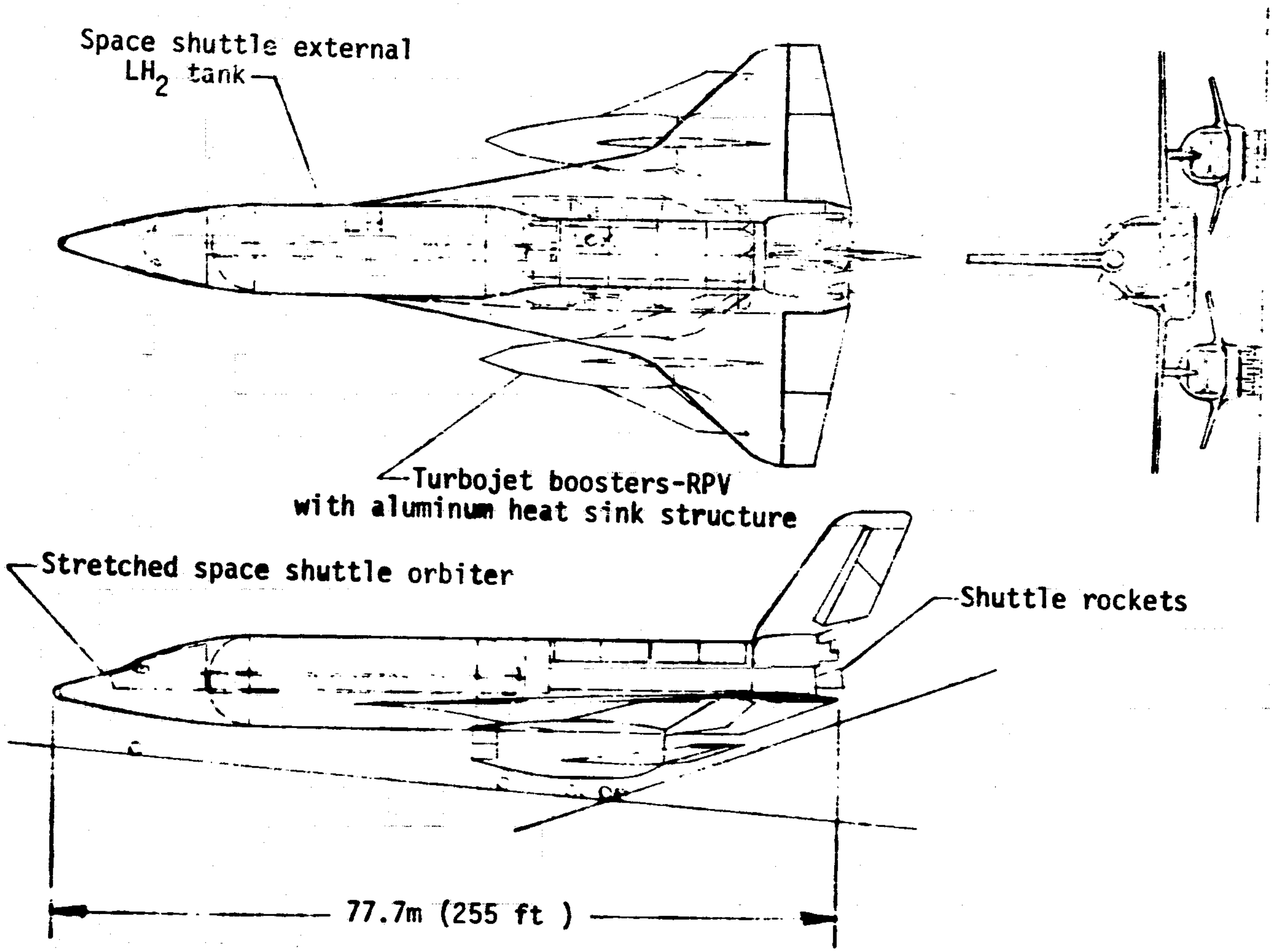


Figure 17.- Stretched space shuttle orbiter concept with turbojet boosters for a payload of 29 500 kg (65k lb_m) at a gross weight of 1.27M kg (2.8M lb_m).

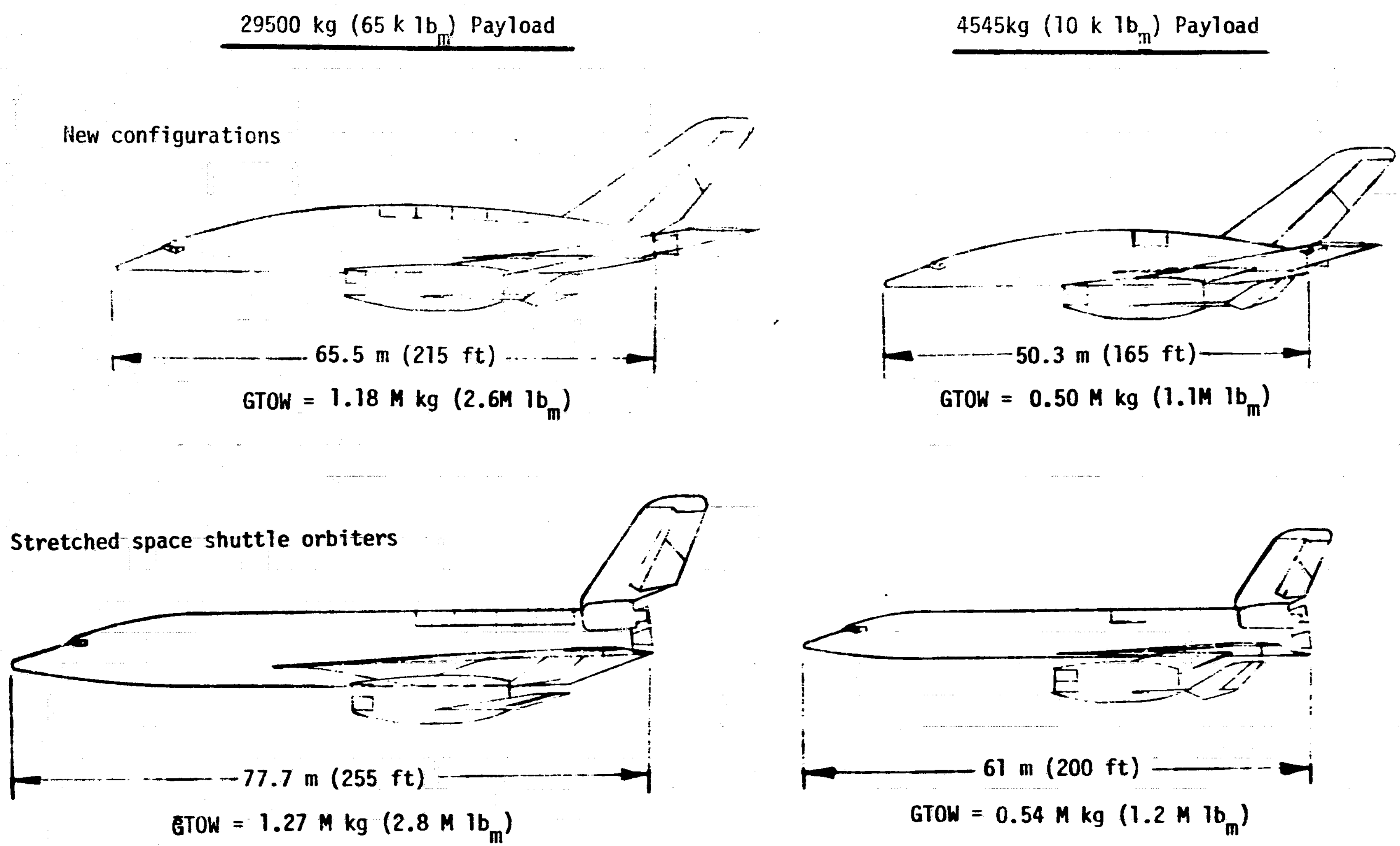


Figure 18.- Turbojet booster space transport designs (with dry wings) for two payload requirements.

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15. Supplementary Notes

16. Abstract

Results of a preliminary study of a novel space transport concept are presented. The concept consists of a winged orbiter containing ascent propellants and two small turbojet-powered winged boosters, used for acceleration to supersonic speeds. The concept offers full reuse and horizontal takeoff from numerous existing airports. With current structure and rocket technology this transport concept has lower gross weight for a selected payload than single-stage-to-orbit concepts, which require structural advancements. Discussion includes alternatives to the baseline space transport concept which improve performance; such as advanced structures, dual-fuel rockets, and lightweight scramjets for the orbiter. Moreover, a concept of using a stretched shuttle orbiter instead of an all-new configuration is discussed for two payload-class vehicles.

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