NASA TECHNICAL
MEMORANDUM

NASA TM X-62,479

NASA TM X-62,479

(NASA-TM-X-62479) HIGH PERFORMANCE DASH ON WARNING AIR MOBILE, MISSILE SYSTEM (NASA) 127 p HC $5.75 CSCL 01A

N76-10088

Unclas
G3/05 39366

HIGH PERFORMANCE DASH ON WARNING AIR MOBILE MISSILE SYSTEM

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September 1975

1. Report No. TM X-62,479	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle

HIGH PERFORMANCE DASH ON WARNING AIR MOBILE MISSILE SYSTEM

5. Report Date

6. Performing Organization Code

7. Author(s)

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8. Performing Organization Report No.
A-6260

9. Performing Organization Name and Address

Ames Research Center, Moffett Field, Calif. 94035
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Aerophysics Research Corporation, Bellevue, Wash. 98009

10. Work Unit No.
791-40-04

11. Contract or Grant No.

12. Sponsoring Agency Name and Address

National Aeronautics and Space Administration
Washington, D. C. 20546

13. Type of Report and Period Covered
Technical Memorandum

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

At the request of the USAF, NASA-Ames Research Center studied the dash on warning class of air mobile ICBM system. On receipt of warning, the aircraft-missile system performs a high acceleration takeoff followed by a supersonic dash to a "safe" distance from the launch site, at which time a subsonic long endurance mode is entered. The study objectives were: determine technological feasibility of the dash on warning concept; provide initial definition of the aircraft and boost trajectory requirements; and provide partial cost estimates for a fleet of aircraft which provide 200 missiles on airborne alert. Three aircraft boost propulsion systems were studied: an unstaged cryogenic rocket; an unstaged storable liquid; and a solid rocket staged system. Wing planforms considered were: a two-position wing; a conventional variable sweep wing; and a fixed wing. Aircraft gross weight was minimized for the combined dash and endurance mission profile. The results indicate that the dash on warning concept will meet the study performance criteria. This can be accomplished using existing technology, such as all-aluminum aircraft and existing high-bypass-ratio turbofan engines. Dynamic pressures during the supersonic dash are on the order of 500 lb/ft^2 (23,940 N/m^2), comparable to those encountered by current subsonic jet transports. Vehicle gross weights are on the order of one million pounds (453,592 kg), with endurance flight weights and empty weights on the order of current wide body jet transports.

17. Key Words (Suggested by Author(s)) Air mobile missile system Airborne ICBM Aircraft synthesis	18. Distribution Statement Unlimited STAR Categories — 05,15

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	127	$5.75

*For sale by the National Technical Information Service, Springfield, Virginia 22151

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This study was conducted by the Advanced Vehicle Concepts Branch, NASA-Ames Research Center, in response to a USAF-Space and Missile Systems Organization (SAMSO) request for support. The study was conducted by:

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HIGH PERFORMANCE DASH ON WARNING AIR MOBILE MISSILE SYSTEM

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SUMMARY

At the request of the USAF, NASA-Ames Research Center studied one class of an air mobile ICBM system; the dash-on-warning vehicle. The dash on warning vehicle carries the USAF ICBMs within the fuselage of a large high performance subsonic-supersonic aircraft. This vehicle is maintained on ground alert status prior to warning of an impending attack. On receipt of warning, the aircraft-missile system performs a high acceleration takeoff followed by a supersonic dash to a "safe" distance from the launch site. On completion of the dash segment a subsonic long endurance mode is entered. This segment provides time to assess the threat and its potential outcome prior to launch of a retaliatory strike. In the event an air alert status is to be maintained beyond cruise endurance capability, the dash on warning aircraft-missile system has the capability to land, refuel and takeoff in a conventional manner.

The aircraft considered in this study were designed specifically for the combination of the supersonic dash on warning and the subsonic endurance role. The designs were not compromised for any other missions. Technology levels considered for the aircraft were state-of-the-art, as much as possible; consistent with an Initial and Operational Capability (IOC) in the early 1980's.

Three aircraft boost propulsion concepts were studied: an unstaged cryogenic rocket system; an unstaged earth storable liquid system; and a solid rocket staged system. Wing planform geometries considered were: a two-position wing; a conventional variable-sweep wing; and a fixed-wing. All systems used vertical takeoff in the nominal trajectory but alternate concepts included horizontal-takeoff, an all airbreathing vehicle, a cryogenic rocket system and a modified version of the Space Shuttle Vehicle.

Vehicle design optimization studies minimized aircraft gross weight for the combined dash and endurance mission profile. Endurance flight was accomplished at best speed and altitude. Variations in payload, endurance, dynamic pressure and airframe material technology were made to provide sensitivity information. Development and acquisition costs for a fleet of aircraft, fuel costs for a 10-year period and cost sensitivity to the total number of missiles airborne were estimated. Total system cost, including basing, operations, etc. was not estimated.

The number of missiles carried, aircraft endurance and boost dynamic pressure are important in the aircraft design. Low values of endurance and number of missiles airborne imply lighter aircraft at lower cost but greater number of vehicles. High boost dynamic pressures, except for the two-position wing geometry, imply heavier structures and more costly aircraft.

The study results indicate that the dash on warning concept will meet the study performance criteria. This can be accomplished using existing technology such as all aluminum aircraft and existing high-bypass-ratio turbofan engines. Dynamic pressures during the supersonic dash can be low, on the order of 500 lb/ft^2 (23,940 N/m^2) and are comparable to dynamic pressures encountered by current subsonic jet transports.

INTRODUCTION

Various mobile ballistic missile system concepts are being studied as alternatives to silo-based ICBM weapons. Ground mobile, air mobile and hardened stationary systems are being considered as a means for increasing the survivability of the missile force.

The air mobile concept may be divided into two categories: continuous airborne alert; and dash on warning. For either concept the requirement is to maintain a specified number of ICBM class missiles on air alert prior to incurring damage from an attacking force. The continuous airborne alert system has been studied by the USAF Aeronautical Systems Division (ASD) (ref. 1). The dash on warning system is described here.

Dash on Warning Concept

The dash on warning concept is illustrated in figure 1. Prime threats to the missile force are submarine launched ballistic missiles (SLRM) flying trajectories against missile bases located within the continental United States. A dash on warning concept has a retaliatory ICBM force aboard aircraft which are maintained on ground alert status. Upon detection of a threat the aircraft perform a rapid takeoff and a supersonic dash of 50 n. mi. to create a large area of uncertainty as to the location of the missile force. Speed at the end of 50 n. mi. is a function of the time required for the dash portion of the mission profile. For example, a dash time of 2 min requires a terminal Mach number of nearly 7 at the 50 n. mi. radius; a 3-min dash requires a terminal Mach number of about 3.

At the end of the dash the aircraft establish an air alert status for times varying between 4 to 10 hr, with 6 hr being nominal. This time period provides sufficient time to assess the threat or its damage. If the threat is an attack, the aircraft can release a retaliatory strike by launching the ICBMs aboard. If an air alert status longer than the nominal 6 hr is required, the aircraft can maintain air alert by either air-to-air refueling or by conventional landing at existing airfields with missiles still aboard, refuel and takeoff in a conventional horizontal manner with the cruise engines alone. At the conclusion of the alert the aircraft return to base and resume the ground alert status.

Objective

The objective of this study was to determine the technological feasibility of the dash on warning concept and to provide an initial definition of the aircraft system and boost trajectory requirements. Another objective was to provide partial cost estimates (development, acquisition and fuel) of a fleet of the aircraft which provide 200 missiles on an air alert status for a 6-hr time period.

Scope

The study is comprised of three main areas of investigation: endurance aircraft design optimization; boost trajectory fuel optimization; and partial cost analysis. The design and cost of the missiles to be carried were not investigated in this study. The missiles were considered as payload for the aircraft and their characteristics were provided by the USAF-SAMSO.

Requirements

The requirements for the mission profile and payloads to be carried were provided by USAF-SAMSO. The nominal requirements were:

Dash time	3 min
Payload	200,000 lb (90,718 kg) [2 × 100,000-lb (45,359 kg) missiles]
Endurance	6 hr at best speed and altitude
Minimum endurance altitude	10,000 ft (3,048 m)
Number of missiles airborne	200

Land and takeoff conventionally with the missiles aboard

Variations from the nominal mission were:

Dash time	2 min
Payload	160,000 - 320,000 lb (72,575 - 145,150 kg) [2 & 4 × 80,000-lb missiles (36,287 kg)]
Endurance	to 10 hr
Number of missiles airborne	100 - 400

The design of the three-stage missiles to be carried as payload are shown in figure 2. The nominal missile design weighed 100,000 lb (45,359 kg), was 58.7 ft (17.89 m) long, and 6.2 ft (1.89 m) in diam. An alternate missile design which weighed 80,000 lb (36,287 kg) with a length of 57.1 ft (17.40 m), and a diam of 5.5 ft (1.68 m) was also considered.

AIRCRAFT CONCEPTS

The matrix of concepts studied and reported herein are shown in figure 3. System boost propulsion concepts studied were: staged rockets; unstaged rockets; and all airbreathing.

The staged rocket (SR) concepts use a single solid rocket booster similar to that used on the NASA Space Shuttle, and this rocket was mounted centrally beneath the fuselage. The vacuum specific impulse of the solid propellent is 262 sec. This concept is launched in a vertical takeoff (VTO) mode and the booster is separated from the aircraft at burnout.

Unstaged rocket (UR) concepts were studied with two liquid rocket boost propulsion systems. One system was a cryogenic propellent, liquid-hydrogen and liquid-oxygen (LOX/H_2), with a vacuum specific impulse of 456 sec. The four main rocket engines are the same as will be used in the NASA Space Shuttle Vehicle now under development. The other system employed a storable propellent rocket engine using nitrogen tetroxide as the oxidizer and unsymmetrical-dymethal hydrazine-hydrazine in a 50-50 mix as the fuel (UDMH), with a vacuum specific impulse of 320 sec. The unstaged rocket used VTO and carried the four boost propulsion engines and propellent tanks aboard during the entire mission profile.

The all airbreathing concept used ten duct-burning afterburning engines for the horizontal takeoff (HTO) boost. The maximum sea-level static thrust per engine was 200,000 lb (889.6 kN). At the conclusion of the dash six engines had to be shut down for cruise. Shrouds were required to reduce the cruise drag of the shutdown engines.

For the staged and unstaged rockets several alternative wing geometries were considered. These were: a two-position wing (2P); a conventional variable-sweep wing (VS); and a fixed wing (FW).

The two-position wing is constrained so that it does not exceed the fuselage length to provide clearance for the twin vertical tails during wing rotation to the cruise configuration. This constraint also ensures that the wing does not overhang the boost propulsion system exhaust. Near the beginning of the subsonic endurance portion of the mission, the wing is rotated to the cruise configuration. The four body-mounted cruise engines are shrouded fore and aft during boost. The forward shroud is provided for cruise engine protection and drag reduction during supersonic flight. The aft shroud is provided for base drag reduction. The cruise engine shrouds are separated prior to rotation of the wing.

The conventional variable-sweep configuration performs the boost portion of the mission with wings swept in the aft position. The wings are rotated forward at the beginning of the cruise leg. The four body-mounted engines are shrouded during boost. The all airbreathing concept and a cryogenic rocket propulsion system using HTO were considered using this wing geometry.

The fixed wing configuration has four wing pylon-mounted engines which are shrouded during boost. It should be noted that this configuration will require the use of a low sweep wing employing a subsonic-type airfoil in the supersonic flight regime. This poses a novel aerodynamic feature worthy of additional detailed study. This wing configuration will have high drag during boost, but it may be speculated that the longitudinal stability problems resulting from shifts in the center of pressure should be less than for a variable-sweep aircraft.

The modified Space Shuttle was studied as an alternate configuration because it will soon become an available piece of hardware. Modifications to the basic Shuttle were: removing equipment required for out-of-atmosphere flight; strengthening the landing gear; changing the vertical tail for missile clearance during release; adding tankage for boost and cruise fuels; and adding cruise engines. The modifications increased the gross weight to 600,000 lb (272,155 kg). For this fixed configuration the payload and endurance capability were estimated. This concept does not satisfy the desired payload and endurance requirements but did satisfy the nominal dash time requirement of 3 min to a 50 n. mi. radius.

METHOD OF ANALYSIS

Synthesis Program

A computerized aircraft synthesis (ACSYNT) developed by NASA-Ames was used for this study (ref. 2). This program has been developed to provide rapid conceptual design information. The level of information obtained indicates an accuracy of about 10 percent in gross weight based upon correlations of existing military and civil aircraft. This modularized program consists of a control module and technology modules for geometric, mass, aerodynamic, propulsive and cost information for a vehicle concept. There are modules to provide automatic design convergence, sensitivity and optimization calculations as well as graphical output. Figure 4 presents a block diagram of the ACSYNT system.

Inputs to the various modules include control parameters, initial vehicle definition parameters, mission profile and several initial assumptions to start the program. Output includes vehicle characteristics required to accomplish the mission profile, such as component weights and geometry, fuel and time requirements for the various phases of the mission profile, aerodynamic and propulsion characteristics. Finally, vehicle cost is computed.

Control Program

The control program sequences the order in which the modules are executed and transfers information to all the other modules. Limits of the various program loops, number of passes to be made through the program and criteria for convergence of the vehicle are controlled within this module. Convergence of the vehicle is determined by a regula-falsi procedure (ref. 3). If the vehicle is either too light or too heavy, compared to the input estimate of the vehicle gross weight, the entire synthesis program is recycled until the updated input and calculated gross weights agree within a specified tolerance.

Geometry Module

Based on input configuration parameters, some fixed and some requiring an initial estimate, this module performs initial sizing of a vehicle to be used in the remaining parts of the program. Initial estimates of fuselage, engine, wing- and tail-surfaces are made. The characteristics of these components are updated at each pass through the program based upon information supplied by the other technology modules or by the control program. The fuselage is sized to contain the missiles, electronic support and all internal tanks. The wing is sized on the basis of an input wing loading and shape parameters. Balance is calculated on the basis of a specified static margin and tail volume coefficient, or the static margin is determined for a fixed ratio of tail area to wing area. The module calculates the final geometric vehicle properties that will satisfy the mission.

Aerodynamics Module

The aerodynamic characteristics for a given altitude and Mach number are determined from the geometric characteristics. The trajectory module specifies lift, drag or angle of attack at a Mach number and altitude and the aerodynamics module determines the remaining variables. Calculation procedures employ both theoretical methods and empirical information. Results have been calibrated with existing aircraft and with wind tunnel data for configurations at both high and low angles of attack. Friction drag estimates are based on the method of Bertram (ref. 4), with an empirical correction for thickness-induced pressure fields made according to the method of Koelle (ref. 5). Base drag is computed using base pressure coefficient as a function of Mach number. Lift and drag-due-to-lift are calculated for angles of attack from zero to beyond maximum lift using a nonlinear theory currently under development at NASA-Ames. This method, developed by Axelson (ref. 6), is derived from a combination of potential theory and momentum integrations for a flow model using a disturbance-velocity gradient.

Propulsion Module

The propulsion module is a one-dimensional cycle analysis program developed by Morris of NASA-Ames (ref. 7). On the basis of vehicle thrust-to-weight ratio, this module sizes an engine and afterburner (if used), calculates engine performance and other characteristics at any specified altitude and Mach number. The engine weight and length are calculated using the results obtained from the MARS system (ref. 8). Variations in power settings are available: maximum afterburning; 100-percent rpm; maximum continuous; and percentages of maximum continuous. The throttle setting and specific fuel consumption are calculated from information supplied by the trajectory and aerodynamic modules. The basic engine thrust and fuel consumption are corrected for installation losses associated with the inlet and nozzle. Engine characteristics in this study are state-of-the-art and no performance improvements have been used that might be considered advanced propulsion system technology.

Rocket propulsion performance is obtained by specifying the vacuum thrust and fuel flow. Variation of back pressure with altitude is used to account for rocket engine thrust variation. For the solid propellent rocket a mass fraction of 0.89 was used.

Trajectory Modules

Two trajectory modules were employed in the present study. The first module performs the boost trajectory optimization calculation. This module, Atmospheric Trajectory Optimization Program (ATOP) (refs. 9 and 10), is a three-degree-of-freedom program employing realistic aircraft and atmospheric characteristics. Optimization calculations are performed using either a multiple-control multiple-arc variational calculus procedure (refs. 11 and 12), or by approximate parameterized methods (ref. 13), based on multivariable search procedures (refs. 14 and 15). Trajectories are integrated using a fourth-order Runge-Kutta method or by any of several standard predictor-corrector methods. The boost trajectory program was run as an independent program from ACSYNT. The second trajectory module is an approximate multisegment mission analysis module and is an integral part of the ACSYNT program. Takeoff, climb, acceleration, cruise, endurance, descent and landing performance are calculated. Equations of motion neglect flight-path-angle rate terms and integration is by approximate step-by-step procedures.

Mass Properties Module

Weights are calculated in this module using procedures based on correlations of existing data, resulting in empirical equations for the weights of the various vehicle components. The basic airframe weights are calculated using the method of Sanders (ref. 16). The wing weight is a function of load factor, aspect ratio, leading-edge sweep, taper ratio, thickness-to-chord ratio, design dynamic pressure and structural material. Load factor, length, surface area and diameter are the parameters used in determination of the fuselage weight. Weights of the remaining components are determined by similar empirical methods.

Optimizer

This module is coupled to the synthesis program to provide an automatic closed loop optimization of the vehicle. The optimization algorithm is based on Zoutendijk's method of feasible directions (ref. 17). The optimization procedure and computer program are described in refs. 18 and 19. The best combination of user specified design variables to minimize vehicle weight (or to minimize or maximize any other parameter) is determined subject to prescribed bounds on the vehicle or mission parameters.

Economics Module

The development and acquisition costs were determined using a modified version of the cost-estimating relationships developed by the Rand Corporation (ref. 20). The DAPCA computer program used was supplied by USAF-ASD. The estimating equations were derived by statistical multiple regression techniques. The airframe engineering hours equation was modified (by ASD) from one based on the total aircraft spectrum to an equation based only on cargo, tanker and subsonic bomber aircraft. When correlated against the C-5 and 747 aircraft, the resulting equation required a 10-percent adjustment upward (ref. 1).

Boost-Endurance Interaction

The approach used for this study was a computerized design procedure using the ACSYNT program. The aerodynamic, propulsion, trajectory, mass properties and economics characteristics were all calculated. To do this it is necessary to specify the vehicle concept in terms of its general shape and component arrangements, the mission profile and technology levels to be employed. Technology levels that must be stated are those associated with the boost propulsion engines and fuel, the cruise engine-cycle to be used and the airframe material.

The aircraft design was optimized by finding the combination of aspect ratio, wing sweep, wing area, thrust-to-weight ratio and cruise engine bypass ratio that minimized aircraft endurance weight. Approximately 60 design evaluations were required before the optimum endurance aircraft design was obtained for each concept geometry combination. Calculations indicated that best endurance occurred at a Mach number of 0.55. Depending upon the concept, the best altitude for endurance was between 22,000 ft (6,706 m) and 27,000 ft (8,230 m).

Boost trajectories were optimized by determining the throttle history and angle of attack schedule which minimized boost fuel weight, subject to a boost dynamic pressure constraint. There is necessarily an iteration between the boost trajectory and aircraft design optimization procedure to provide an optimum aircraft design for the entire mission profile.

Sensitivities to changes in payload, endurance, dynamic pressure and materials technology were obtained. Partial cost (development, acquisition and fuel) estimates were determined for purchasing a fleet of aircraft which provide 200 missiles on air alert.

RESULTS

Boost Trajectory Optimization

Boost trajectories were optimized to minimize boost fuel weight for a dash of 50 n. mi. in 3 min with a constraint on the maximum dynamic pressure. Two flight profiles were considered: a ballistic, or zero-lift, boost trajectory using a parametric approach; and a shaped trajectory which utilized lift and thrust control determined by variational calculus procedures.

Ballistic Mission Profile

The mission profile for the ballistic boost trajectory is shown in figure 5. The vehicle rises vertically for 1,000 ft (305 m), then pitches over. Initial pitch angle and burn time are determined by multivariable search (ref. 13), so that the vehicle reaches 50 n. mi. within the specified time constraint with minimum boost fuel expenditure. The boost occurs at zero-lift. Peak dynamic pressure occurs about the midpoint of the powered ascent. Peak accelerations are on the order of 3 g's in the axial direction and occur immediately prior to burnout. The vehicle then follows a ballistic ascent to apogee followed by a lifting flare-out to keep the reentry dynamic pressures low. Configuration geometry is changed prior to beginning the endurance cruise portion of the mission profile. At the end of the endurance leg, the vehicle lands horizontally with the missiles aboard, refuels and takes off in a conventional horizontal manner powered only by the cruise engines.

Thrust-to-Weight Ratio Effect

Figure 6 depicts typical minimum boost fuel fraction and thrust-to-weight ratio variations as a function of burn time for the cryogenic propulsion system. These results were obtained using an aerodynamically "clean" configuration. As the burn time is increased, the required thrust-to-weight ratio declines from a value of 3.5 for a burn time of 40 sec to about 1.25 for a burn time of 10 sec. Correspondingly, the fuel fraction initially begins to fall as the burn time is increased from 40 sec until about 70 sec, at which time the fuel fraction then begins a marked rise. The minimum fuel fraction of slightly under 30 percent of gross weight is achieved with a burn time of slightly more than 70 sec, requiring an initial thrust-to-weight ratio of about 1.9. The boost fuel fraction minimum results from two conflicting effects. First, in an efficient dash, velocity should build up rapidly in order to develop a high average speed for a given impulse. Second, if velocity builds up too quickly high drag forces in the lower atmosphere consume the boost energy. It follows that if too short a burn time is employed the drag integral raises boost fuel fraction. Conversely, if the boost is too long the average speed for a given impulse falls and more boost fuel is required.

Boost Fuel Fraction

Boost fuel fraction has a major impact on aircraft design characteristics. For the boost portion of the trajectory, it is desirable to have a supersonic configuration with high fineness ratio body and thin wings. For the endurance portion of the mission profile it is desirable to have thick wings and low fineness ratio bodies, much on the order of current wide body jets. Figure 7 shows the effect of aircraft design characteristics on the boost fuel fraction, represented as burn time required to reach 50 n. mi. An aircraft designed for the endurance portion of the mission requires a burn time of nearly 80 sec; the supersonic aircraft design requires a burn time nearly 20 percent less. The final designs employed in the present study represent a compromise between the two boundaries where the effect of boost design geometry is coupled with the endurance requirements. The final designs lie essentially between the wholly subsonic and supersonic designs. Therefore, the final design has wings which are somewhat thicker than would be expected for a supersonic aircraft, but thinner than would be anticipated for a subsonic vehicle. The fuselage has a somewhat higher fineness ratio than those for subsonic aircraft, but lower than those found in modern supersonic designs.

Effect of Dash Time

The effect of dash time to reach 50 n. mi. was briefly studied and the results are shown in figure 8. These results were obtained using the modified Space Shuttle Vehicle. Dash times of two- and three-min were studied with no constraint on the maximum dynamic pressure. The 3-min dash was achieved at a maximum dynamic pressure of about 1,700 psf (81,396 N/m^2) and required a boost fuel fraction of 54.2 percent for a thrust-to-weight ratio of 2. The 2-min dash required dynamic pressures of about 3,000 psf (143,641 N/m^2). For a thrust-to-weight ratio of 2, the boost fuel fraction was 69.7 percent. Increasing the thrust-to-weight ratio to three reduced the fuel fraction to 66.3 percent. Because the dynamic pressure requirements and boost fuel fractions are much larger for the 2-min dash, only the 3-min dash was considered for further investigation.

A typical altitude-range profile for both the two- and three-min dash is shown in figure 9. The 3-min dash requires a burn time of about 76 sec; the 2-min dash requires a burn all the way (120 sec), and is about 1 n. mi. short of reaching 50 n. mi. The Mach numbers at the end of the dash were slightly over 3 for the 3-min dash and nearly 7 for the 2-min dash. The 2-min dash would therefore require aircraft designed for hypersonic flight conditions.

The parametric approach and ballistic ascent indicates that lowering the boost dynamic pressure will rapidly increase the required boost fuel fractions from those shown in figure 8. It becomes apparent that a lifting, variable-thrust, shaped trajectory will be a better approach to simultaneously control the dynamic pressure and to determine the path that will minimize the boost fuel fraction.

Throttle and Alpha Control Profile

Path controlled trajectories were obtained using the variational calculus option of the program cited in reference 9. The mission profile for a typical path control trajectory is shown in figure 10. After a vertical rise of 1,000 ft (305 m) the vehicle is pitched over to follow a lifting boost path to burnout. The path is determined by varying the throttle setting and angle of attack (alpha) to remain within the specified dynamic pressure constraint. Peak dynamic pressure typically occurs at supersonic speeds beginning about the middle of the burn period, with the maximum acceleration of about 3 g's occurring near burnout. The lifting vehicle coasts to apogee at nearly constant energy. A gliding reentry is performed to keep entry dynamic pressures low. After the gliding reentry the vehicle geometry is changed near the beginning of the subsonic endurance portion of the mission profile. A subsonic cruise endurance segment is then flow. At the end of the endurance portion of the mission profile the vehicle has the capability to land, refuel and takeoff in a horizontal mode under the power of the cruise engines alone.

Flight Profile

A typical Mach-altitude path is shown in figure 11. The vehicle accelerates at low altitudes and reaches a Mach number of 1 at an altitude of slightly over 20,000 ft (6,096 m). The dynamic pressure placard, in this case 500 psf (23,940 N/m^2) is picked up supersonically and followed to burnout. Burnout occurs near a Mach number of 3 and at an altitude of 70,000 ft (21,336 m). The vehicle then follows a nearly constant energy path to an apogee of about 100,000 ft (30,480 m). The 50-n. mi. point is reached at a Mach number slightly over 2.5 at an altitude of about 80,000 ft (24,384 m). A constant dynamic pressure path on the order of 200- to 300-psf (9,576 - 14,364 N/m^2) is then followed to the best speed and altitude for the endurance portion of the mission profile. For the configurations studied, the best Mach number for endurance flight is 0.55 at an altitude between 22,000 ft (6,706 m) and 27,000 ft (8,230 m), depending upon the vehicle geometry, mass, propulsive, and aerodynamic characteristics.

Typical dynamic pressure histories for the shaped trajectory for a staged-rocket fixed-wing and an unstaged-rocket two-position wing are shown in figure 12. The constraint on maximum boost dynamic pressure is 500 psf (23,940 N/m^2) and is imposed by driving the line integral of the dynamic pressure violation to zero by the method of ref. 11. To minimize the boost fuel fraction the vehicle trajectory reaches the dynamic pressure placard quickly and then maintains the placard boundary throughout boost. After burnout there is a decay in dynamic pressure as the vehicle coasts at nearly constant energy to apogee and then a rise in dynamic pressure occurs as reentry begins. The entry dynamic pressures and those following the descent to the endurance flight conditions have a maximum value about 60 percent of the boost dynamic pressure placard level. There is a slight violation of the 500 psf (23,940 N/m^2) boundary during boost which with further shaping could be removed. However, the violation is only about 5 percent greater than the constraint value and does not have a significant effect on either the boost fuel fraction or on the vehicle design.

A typical control history of throttle setting and angle of attack schedule for the 500 psf (23,940 N/m^2) dynamic pressure placard are shown in figure 13. The history shown is for an unstaged rocket which has a limit on the vacuum thrust of the four Shuttle engines of 2.12 million lb (9.43×10^6 N). This thrust level constraint is also imposed as a violation integral. There is an initial violation of the thrust level, but only over a short period of time. Further refinements can reduce the level, but the violation shown has little effect on the fuel fraction. The thrust decays initially as the dynamic pressure placard is reached and then begins to rise towards the end of the main burn. After termination of the main burn there is a low level thrust requirement of about 20-percent thrust from one engine until the end of the 3-min dash. It is assumed that this deep throttle of the boost engines can be achieved by design changes of the present boost propulsion system. The angle of attack schedule followed shows variations of about $-3°$ to $+1°$ angle of attack until apogee is reached. The 10° angle of attack is required during the reentry to maintain low dynamic pressure.

A straightforward explanation of the optimal boost path is possible. The path which the vehicle must follow is indicated by the optimal boost corridor shown in figure 14. The corridor through which the vehicle must fly is shown in the altitude-velocity plane. Minimum velocity at a given altitude during boost is that velocity for which the flight-path angle remains vertical. This lower bound is shown for a thrust-to-weight ratio of 1.5. The maximum velocity at a given altitude is defined by the dynamic pressure constraint, in this case 500 psf (23,940 N/m^2). Increasing the thrust-to-weight ratio moves the minimum velocity boundary closer to the dynamic pressure boundary and can close the corridor. Similarly, decreasing the dynamic pressure moves the maximum velocity boundary towards the minimum velocity boundary and can also close the corridor. Therefore considerable care must be given to the choice of both the thrust-to-weight ratio and dynamic pressure limits to ensure that a corridor remains open along the entire flight profile. The actual variational optimum path followed by the vehicle is indicated on the figure. The vehicle initially remains close to the thrust-to-weight ratio velocity boundary, begins a transition flight path and achieves the maximum velocity boundary near Mach 1 at an altitude of about 20,000 ft (6,096 m). From that point until burnout the vehicle maintains a path along the maximum allowable dynamic pressure boundary. Burnout is terminated when the vehicle energy is sufficient to meet the time constraint to reach 50 n. mi. at minimum boost fuel fraction.

Boost Fuel Fraction

The boost fuel fraction as a function of dynamic pressure is shown in figure 15. Curves are presented for the staged rocket configuration which used the solid strap-on boost system, for the two unstaged rocket configurations which use either the storable liquid propellent, UDMH, or the cryogenic liquid propellent, LOX/H_2. For the staged rocket configurations the boost fuel fraction shown includes the casing weight to hold the propellent. Fuel fractions are highest at the lowest dynamic pressure limit. For the fixed-wing configurations at a boost dynamic pressure of 500 psf (23,940 N/m^2), the staged rocket systems have the highest fuel fraction. This is a result of the lower energy content of the boost propellent. For the staged system, the fraction is about 65 percent of the vehicle gross weight. For the unstaged rocket, the storable liquid system requires a boost fuel fraction of about 50 percent. The cryogenic propellent, being the most energetic of those studied, requires a boost fuel fraction of about 40 percent. For the variable geometry configurations, the required boost fuel fraction is less, indicating the more favorable drag characteristics compared to the fixed-wing configuration. As the boost dynamic pressure is permitted to increase to about 1,000 psf (47,880 N/m^2) there is a rapid reduction in the boost fuel requirement. For dynamic pressures greater than 1,000 psf (47,880 N/m^2) there is only a slight further reduction in the boost fuel fraction.

A change in the weight of the vehicle, which may arise with changes in materials technology, payload or other mission parameters, is shown in figure 16. A reduction in gross weight from the nominal value of about 1.1 million lb (498,952 kg) to a vehicle weighing approximately 800,000 lb (362,874 kg) requires about 10 percent greater boost fuel fraction. Increasing the weight to slightly over 1.2 million lb (544,311 kg) reduces the boost fuel fraction about 3 percent. Although the boost fuel fraction is larger for the lighter vehicle the boost fuel mass is less than for the nominal vehicle.

Dynamic Pressure Effect on Structure

As indicated in figure 15, higher dynamic pressure decreases the boost fuel fraction. However, boost fuel is only one aspect of the problem. The effect of dynamic pressure on the vehicle structural weight must also be taken into account. As the boost dynamic pressure is increased the vehicle structure becomes heavier. This tradeoff between design dynamic pressure and gross weight is shown in figure 17. Results are presented for the unstaged rocket using cryogenic propellent. The trends for the other rocket systems are similar.

The design dynamic pressure has a margin of 40 percent over the boost dynamic pressure. Therefore a design dynamic pressure of 700 psf (33,516 N/m^2) is required for a boost dynamic pressure of 500 psf (23,940 N/m^2). The 700 psf (33,516 N/m^2) design dynamic pressure is typical of current jet transports; 1,100 psf (52,668 N/m) represents a value for fighter aircraft such as the F-5A; and the F-111 has been designed for a dynamic pressure of about 2,000 psf (95,761 N/m^2).

The variable sweep aircraft is the lightest vehicle at the lowest dynamic pressure, but becomes the heaviest vehicle at the maximum pressure of 1,300 psf (62,244 N/m^2) considered. The fixed-wing aircraft is somewhat heavier than the variable sweep aircraft at the nominal design dynamic pressure and does not rise as rapidly as the variable-sweep wing aircraft. Conversely, the two-position wing indicates a reverse trend with increasing dynamic pressure. This configuration is the heaviest at the lowest design dynamic pressure and becomes lighter with increasing dynamic pressure. This converse behavior is due to the wing being aligned with the fuselage during boost and attached rigidly to the fuselage near the wing tips. Therefore it is not subjected to high dynamic pressure loads during the boost portion of the flight. There is a slight increase in the weight of the tails and flight controls with increasing dynamic pressure, but the wing is a larger fraction of the airframe weight. The overall trend is for a lower gross weight vehicle since the higher boost dynamic pressures require lower boost fuel fraction.

The curves represent vehicles which have been optimized for each dynamic pressure and therefore are not the same vehicle operated at different dynamic pressures. The lower weight vehicles have a relatively high aspect ratio wing; those vehicles designed for the highest dynamic pressures have a low aspect ratio wing. This is true for both the fixed-wing and variable-sweep wing aircraft. For the two-position wing the aspect ratio remains the same since it is aligned with the fuselage and requires no design changes to withstand the higher boost dynamic pressures.

The boost fuel fractions and variations with vehicle weight were used to obtain the gross weight of the final designs. Characteristics of the design of two vehicles which will satisfy the dash on warning concept are discussed in the next section.

Vehicle Design

Staged Rocket

A staged rocket with the two-position wing is shown in figure 18. The single solid-propellent booster is attached to the underside of the fuselage with the thrust axis passing through the vehicle center of gravity. The two-position wing is aligned with the fuselage and held rigidly to it during boost. Near the beginning of the endurance segment of the mission profile the wing is rotated to the cruise configuration. The wing span is constrained to provide clearance for the twin vertical tails during wing rotation and to clear the boost propulsion system exhaust plume. The tails are mounted high on the fuselage. They cannot be located at the mid-position due to impingement of the cruise engine exhaust. A low tail would result in impingement of the exhaust plume from the boost propulsion system. The four cruise engines are shrouded for engine protection and drag reduction during supersonic flight. They are staged from the engines prior to wing rotation.

The fuselage diameter is determined by the diameter of the missiles carried. Fuselage weight penalties associated with attachments for the solid propellent booster are taken to be 4 percent of the fuselage weight. The empty rocket casing weight was 11 percent of the boost fuel.

There are also weight penalties associated with the pivoting mechanism for the variable geometry aircraft. The pivot weight penalty was taken to be 15 percent of the wing weight. References 21 through 23 indicate the pivot weight can vary between 12 to 20 percent of the wing weight. The Special Projects Office of Rockwell International indicate a pivot penalty between 15 to 30 percent for the B-1 supersonic bomber. The major difficulty in assessing pivot weight lies in the fact wings are not designed both with and without pivots. Also, the pivot structure may have multiple uses for items such as launching gear, engine attachment, etc. As noted above, pivot weight estimates tend to vary even after detailed studies. Studies conducted by the Boeing Company indicate a weight penalty of 7 to 10 percent for the two-position wing. Because an oblique wing has not been manufactured, a 15-percent wing weight penalty was used for all variable geometry aircraft.

Details of the pivot mechanism for the two-position wing are shown in figures 19 and 20 (ref. 24). The wing pivot is located between the top of the fuselage and underside of the wing. This provides uninterrupted carry-through structures for both the wing and fuselage. The diameter of the pivot is about 80 percent of the body diameter. This provides lift load paths which are eaily passed into the body through members under tension loads only. In consequence, the pivot for the two-position wing takes lift loads only and not primary bending loads which occur on outboard mounted pivots of conventional variable-sweep aircraft. Separate bearings are used for drag loads and for lift loads due to both vertical shear and asymmetrical wing bending. The small asymmetrical wing bending loads are caused by aileron deflection; not primary wing lift. The drive forces required for pivoting are low compared to conventional variable-sweep aircraft since the drag forces are balanced from each wing.

Unstaged Rocket

A design for an unstaged rocket fixed-wing aircraft is shown in figure 21. The length of the fuselage is determined by the length of missiles, boost propellent tanks, electronics and crew compartment. The diameter of the fuselage is dictated by the diameter and placement of four rocket engines. The rocket engines and propellent tanks remain with the aircraft throughout the mission profile.

The four cruise engines are shrouded during supersonic flight. A deployable aft fuselage shroud is provided to reduce base drag during cruise. The concept of deployable base shrouds is not new and has been studied on the NASA M1-L lifting body vehicles shown in figure 22. This particular configuration and base shroud was successfully tested in the Ames 40- by 80-Foot Wind Tunnel (ref. 25).

A schematic of a possible deployable base shroud mechanism is shown in figure 23. A telescoping tube, inflation gas supply and base shroud are stowed behind the rocket engines. The shroud is deployed with the tube between the rocket engines and a portion of the fuselage shell simultaneously translates aft. When the shroud is inflated the fuselage extensions provide the necessary circumferential seal and the shroud seals the base. The deployable shroud is a technology item which requires development, but it appears to be technically feasible.

The cryogenic rocket engines shown in the figure represent the main engines now under construction for the NASA Space Shuttle. The engine, shown in figure 24, is about 14 ft (4.27 m) long, 8 ft (2.44 m) in diam, and weighs about 6,000 lb (2,722 kg). The engine has a sea-level thrust of 417,300 lb (1.856×10^6 N), vacuum thrust of 512,300 (2.279×10^6 N), and emergency thrust of 530,000 lb (2.358×10^6 N). The vacuum specific impulse provided by the LOX/H_2 has a value of 456 sec. The engine can be reused up to 7.5 hr with maintenance performed between flights using jet engine techniques similar to those employed by the airlines to lower the cost per flight. The engine has regenerative cooling similar to the F-1 and J-2 engines. A digital computer monitors engine parameters, such as pressure and temperature, and automatically adjusts the engine to operate at the required thrust and mixture ratio. The thrust requirement for the vehicles with UDMH fuel are essentially the same as for the cryogenic vehicles. Therefore, development of a new UDMH rocket engine with geometric characteristics similar to the Space Shuttle engine would be required if storable fuels were necessary.

Procedures to maintain cryogenically fueled vehicles on ground alert are more complicated than for storable liquids. Figure 25 shows a schematic of one potential cryogenic ground handling procedure. The boiloff from the insulated cryogenic tank is recirculated through a ground based recirculation system back into the tank aboard the aircraft. A ground based air circulation system circulates warm gas between the insulated tank and fuselage inner shell to prevent ice buildup. Quick disconnects for the circulation systems similar to those used on space vehicles are needed. Cryogenically fueled space vehicles have been held for periods exceeding 9 hr with no apparent difficulties encountered. These vehicles did not have warm air circulation systems and no attempt was made to prevent ice buildup. The dash on warning concept will be on ground alert for periods far greater than 9 hr. This is a technology item which must be studied in greater detail, but such a proposed procedure appears to be feasible at the present time.

Modified Space Shuttle

The modified Space Shuttle Vehicle, shown in figure 26, was studied to determine the capability of this vehicle which will soon be operational. The components of the basic Shuttle which were changed are underlined in the group weight statement shown in figure 27.

The heat shielding, reaction control system and orbital maneuvering system were removed since these are required for out-of-atmosphere flight. The payload provision and growth allowance were removed. The tanks for the boost propellent are located beneath the missile cargo bay. A deployable base shroud was added to reduce cruise drag and the deployment mechanism is the same as that proposed for the unstaged rocket. Two wing-mounted high-bypass-ratio turbofan engines were added for the endurance mission. To provide clearance for missile launch, the single vertical tail was changed to a canted twin-vertical tail arrangement. These modifications increased the empty weight about 30 percent above the current Space Shuttle. The gross weight of the modified Space Shuttle was 600,000 lb (272,155 kg), compared to the orbital design gross weight of 245,000 lb (111,130 kg).

It should be noted that this modified version of the Shuttle would require missile launch through the top of the fuselage. Feasibility of this maneuver has not been investigated in detail in the present study.

Weights and Sensitivities

Weight comparisons for the concepts shown in figure 4 are presented in figure 28 for the nominal mission of a supersonic dash of 50 n. mi. in 3 min, 6-hr subsonic endurance, and a payload of two 100,000 lb (45,359 kg) missiles. All staged and unstaged rocket configurations have gross weights in excess of one million lb (453,592 kg). Gross weights of the unstaged rockets are lighter than the staged rockets, reflecting the lower energy content of the staged solid-propellent fuel. The storable liquid propellent vehicles are slightly heavier than the corresponding cryogenic vehicles for a similar reason. Although the storable liquid propellent is a less energetic fuel than the cryogenic, it has a density about four times the cryogenic propellent. This permits smaller rocket propellent tankage and results in a somewhat smaller fuselage.

The modified Space Shuttle had a fixed gross weight of 600,000 lb (272,155 kg). This vehicle satisfied the dash requirement but could carry only one missile for 2 hr in the endurance mode. The HTO conventional variable-sweep wing using the cryogenic propellent for boost was about 70 percent heavier than the corresponding VTO configuration. The increased weight for horizontal takeoff is primarily a result of the wing and landing gear being designed to support the boost system fuel during takeoff. The all airbreathing HTO aircraft was the heaviest vehicle studied, weighing about two-million lb (907,185 kg). To satisfy the dash requirement, 10 duct-burning, afterburning engines each with 200,000 lb (889,644 N) of thrust were required. In addition, a dynamic pressure of 1,100 lb/ft^2 (52,668 N/m^2) was required to satisfy the dash requirement. Because the Space Shuttle did not meet the payload/endurance requirements and the HTO configurations were about twice the weight of the VTO concepts, they were rejected from further consideration.

The endurance weight of the aircraft is the weight at the end of the dash. In contrast to the gross weight comparison, the unstaged rocket vehicles are heavier at endurance than the staged rockets. This converse behavior reflects the increased weight of the structure and cruise fuel required to carry the rocket engines and tankage throughout the entire mission profile. The UDMH vehicles are essentially the same weight at endurance as the cryogenic vehicles. It may be noted that these endurance weights are comparable to current wide body subsonic jet transports. The airframe can be made from aluminum and existing CF-6 or JT-9 high-bypass-ratio turbofan engines can be used for cruise.

The vehicle empty weights are also comparable to wide body subsonic jet transports. The unstaged rocket concepts vary from about 1.5 to 2 times the weight of the staged rockets. Although the unstaged rocket empty weights are heavier than the staged rocket, the effect of costs have yet to be considered. Therefore, the unstaged rockets were retained as candidate configurations.

The weights shown in figure 28 are for the nominal mission profile. The variation of vehicle gross weight with changes in payload for the unstaged rockets using cryogenic propellent are shown in figure 29. The gross weight divided by the nominal gross weight (the weight given in fig. 28) is shown as a function of the payload divided by the nominal payload [two 100,000-lb (45,359 kg) missiles]. On these nondimensionalized scales a payload ratio of 0.8 represents two 80,000-lb (36,287 kg) missiles; a value of 1.6 represents four 80,000-lb (36,287 kg) missiles. As indicated by the curves, variable geometry aircraft are more sensitive to changes in payload than fixed-wing aircraft. Another measure of sensitivity is the ratio of the percentage change in gross weight for a 1-percent change in payload, evaluated at the nominal. That is, the normalized curve slope at the nominal. For example, a 1-percent change in payload changes the gross weight of the fixed-wing aircraft by 0.4 percent, evaluated at the nominal, and by about 0.6 percent for the variable geometry aircraft. Numerical nondimensional sensitivity values permit a rapid relative assessment of the effect of changes in parameters other than payload. Therefore, direct comparisons and ranking of the various parameters can then be made.

In figure 30 the normalized sensitivity to changes in payload, endurance, boost dynamic pressure and airframe material technology are shown for the staged rocket and unstaged rocket with cryogenic propellent. The range of payloads and endurance studied are indicated in the section "Requirements." The range of boost dynamic pressures considered were from 500 to 1,300 psf (23,940 to 62,244 N/m^2). The material technology factors considered aircraft with airframes (except for landing gear) made from all-composite materials to all-aluminum conventional airframe material. Higher numbers for sensitivity indicate high sensitivity and are therefore the less desirable. For example, a 10-percent change in payload causes a 5-percent increase in gross weight for the SR-2P configuration and a 2.1-percent increase for the SR-FW configuration. The sensitivity study indicated that all vehicles were most sensitive to changes in payload and least sensitive to changes in material technology. In view of the high cost factors associated with composite structures, it would appear unlikely that the technology risks of such a structure would be accepted for so little relative gain in reduced weight. Sensitivity to increasing boost dynamic pressure is favorable for the two-position wing configurations. Increasing boost dynamic pressure reduces the weight of these configurations and increases the weight for the other configurations. The explanation for this favorable effect has been previously discussed. The sensitivities indicate that the staged rockets are the least sensitive design because there is no dead-weight at endurance associated with the boost system.

A table of the detailed characteristics for the nominal endurance configurations are given in Appendix A. Typical graphical views of the UR-FW-UDMH vehicle as represented in the ACSYNT program, aerodynamic and propulsion characteristics are shown. Group weight statements for the nominal configurations are given, followed by tabulated boost fuel fractions and thrust-to-weight ratios. Tabulated gross weight statements for the endurance aircraft with changes in mission parameters are given in Appendix B.

Economics

The nominal requirement for the economic study was to maintain 200 missiles airborne during an attack. For an assumed launch probability of 90 percent, the purchase of a fleet of 112 aircraft is required to satisfy dash on warning system requirements. Partial cost elements used in this study were development and acquisition costs to purchase the fleet and fuel costs for 10 years of operation as a function of the number of fleet launches. An aggragate learning curve of 80 percent was used on acquisition costs, comparable to current experience trends in the aerospace industry. In particular, this learning rate is typical of that encountered in the design of subsonic jet transport aircraft. It has been shown that the empty weights of dash on warning aircraft are comparable to current big subsonic jets and they employ similar airframe and cruise engine technology.

In addition to airframe costs are the additional costs associated with boost propulsion acquisition. For the solid rocket booster this cost was $6 million <u>per launch per aircraft</u>. The booster was considered expendable, although the Space Shuttle booster is recoverable. However, the Space Shuttle booster is designed for water recovery, not land recovery. It is generally felt that impact velocities of the present system prohibit land recovery and they would have to be redesigned if land recovery is to be considered. The refurbishment cost for the Space Shuttle solid rocket boosters is about $4.7 million per booster, about 80 percent of the acquisition cost.

The cost of the Space Shuttle cryogenic rocket engine is estimated to be $5 million each. Four rocket engines are required for the unstaged rocket systems, resulting in a boost propulsion cost of $20 million <u>per aircraft</u>. This is a nonrecurring cost since these reusable engines remain with the vehicle throughout the entire mission profile. The UDMH rocket engines are about the same size and thrust class as the cryogenic engines. Therefore, it was assumed they would also cost $20 million <u>per aircraft</u>. In addition to the acquisition cost, the UDMH engine would require a development cost of approximately $800 million which is the development cost of the shuttle engine. If this cost is amortized over 112 operational aircraft, the total cost of UDMH boost engines is $27 million <u>per aircraft</u>, $7 million more per aircraft than the cryogenic rocket engines. The cruise engine cost is estimated to be $1 million per engine; the current acquisition cost for CF-6, JT-9 or TF-39 engines which power the DC-10, 747 and C-5A, respectively.

Fuel costs used in this study were 2¢ per lb (4.4¢ per kg) for LOX and 50¢ per lb ($1.10 per kg) for H_2. For the mixture ratios of LOX to H_2 this results in a net price of 10¢ per lb (22¢ per kg) for the propellent combination. The cost for the storable propellent components was 14¢ per lb (31¢ per kg) for nitrogen tetroxide, 50¢ per lb ($1.10 per kg) for UDMH and $4.00 per lb ($8.80 per kg) for hydrazine. For the fuel to oxidizer ratios required the combined propellent cost is $1.00 per lb ($2.20 per kg). The cruise engine JP-4 fuel cost was 30¢ per gal (66¢ per kg). The cost of solid propellent fuel for the staged rocket is included in the $6 million-acquisition cost.

A comparison of the development and acquisition cost, in billions of dollars, for the various concepts is shown in figure 31. Development, acquisition and initial boost system costs are presented. Independent of wing geometry, the staged rocket development and acquisition cost is about $4 billion. The unstaged cryogenic concepts have higher development and acquisition costs, primarily reflecting their heavier empty weights. The initial cost of the unstaged rocket boost system is also larger than the staged rocket concepts. Again, independent of wing geometry, cryogenic unstaged rocket development and acquisition cost are about $7 billion. The storable liquid propellent concepts are somewhat more costly than the cryogenic concepts. This primarily reflects the development cost of a new UDMH rocket engine. The all airbreathing HTO concept was the most costly, with a partial cost of about $11 billion. This reflects the heavy empty weight of the aircraft and the development and acquisition costs associated with advanced airbreathing engines in the 200,000 lb (889,644 N) thrust class. The costs shown for the variable geometry configurations did not consider the increased complexity due to wing pivots. The cost sensitivity as a function of complexity is shown in figure 32.

The complexity factor (CF) is defined as the ratio of labor, engineering and tooling costs for the complete variable geometry airframe divided by labor, engineering and tooling costs for a fixed-wing aircraft. The costs shown do not include the boost propulsion system costs. These costs are for the unstaged rocket UDMH vehicle because it had the highest ratio of wing weight to endurance weight. The normalized sensitivity indicates that a 10-percent change in complexity factor will increase the vehicle cost by 5.7 percent. As noted above, a complexity factor of one was used throughout this study. Figure 32 is presented to provide information on the costs of variable geometry aircraft if a penalty is warranted. Of course, a small penalty is included for variable geometry by the 15-percent increase in wing weight that was included in the weight estimates (costs are partially based on weight).

The cost sensitivity to missiles airborne is shown in figure 33. When system reliability is included, a fleet of 56 aircraft are required to maintain 100 missiles airborne; 223 are required to maintain 400 missiles airborne. Independent of wing geometry, the staged rockets exhibit the same sensitivity to number of missiles airborne. For the unstaged rockets the differences between wing geometries is due to aircraft empty weight. The UDMH concepts are slightly more costly because of the development cost for a new UDMH rocket engine. Development and acquisition costs are not the entire economic story. A complete economic picture must also include the fuel cost for the fleet. Vehicle maintenance and operation costs were outside the present study scope; these were to be determined by USAF-SAMSO under guidelines for making economic comparisons among all concepts being considered in the M-X program. However, development, acquisition and fuel costs were computed due to the impact of fuel costs on system costs.

Figure 34 shows the partial cost as a function of alerts (or training flights) per year. Partial cost is defined here as development and acquisition costs for the fleet and fuel costs for 10 years. The aircraft are assumed to be airborne 6 hr per alert. Four alerts per year represent a total of 40 fleet alerts over the 10 years. Only the fixed-wing configurations are presented, but they require the greatest boost propellent due to their higher configuration drag.

From an initial cost of $4 billion, the staged rocket costs rise rapidly with number of alerts per year. Each fleet alert requires the purchase of a new $6 million booster for each aircraft. The net boost cost per alert is $600 million for replacement of the expendable solid rockets. At four alerts per year, the partial cost for staged rocket system is about $28 billion. The cryogenic unstaged rocket is initially more costly than a staged rocket, but even at four alerts per year there is only a slight rise in cost. The only costs which accrue to this system at each launch are boost and cruise fuels, since the rocket engines and tanks are reusable. At four alerts per year, the unstaged rocket UDMH cost is about $3 billion more than the cryogenic. This reflects the higher cost of the UDMH propellent.

Figure 35 shows the yearly JP-4 endurance fuel requirements for a fleet of aircraft. For this computation, the method for maintaining the fleet on air alert differs from that discussed above. The fuel shown is for one 14-day alert per year. To perform this mission, 134 aircraft are required, 22 more than the previous model. For a launch probability of 90 percent, to maintain 100 aircraft on air alert for extended periods, requires that one-sixth of the fleet be cycled hourly for refueling. The reference values for the number of gallons in each category are for 1974. Unstaged rocket configurations require more fuel than staged systems, reflecting the dead weight of the boost propulsion system which must be carried throughout the mission profile. Staged rockets require about 1.5 percent of the current utilization of military aircraft fuel; unstaged rockets about 2 percent.

Cost sensitivity studies for the UR-FW-UDMH vehicle were made for the 320,000 lb (145,250 kg) payload and for 10-percent changes in both payload and endurance. The economic results and group weight statements are presented in Appendix C. An itemization of the development and acquisition costs for the nominal configurations are also included in Appendix C.

CONCLUDING REMARKS

All the new concepts studied satisfied the mission profile of a 50 n. mi. dash in 3 min, 6-hr endurance, and 200,000 lb (90,718 kg) of payload. One of the most significant findings is that the supersonic dash can be achieved at a dynamic pressure of 500 psf (23,940 N/m^2). This is about the same dynamic pressure encountered by current subsonic jet transports and suggests that conventional large subsonic jet structure and material technology can be used for the airframe. The airframe can be made from conventional aluminum structure and the cruise engines used for endurance flight are in operation today. Either the CF-6 or JT-9 will satisfy the endurance cruise and conventional takeoff and landing requirements. The cryogenic unstaged rocket concepts utilize the current Space Shuttle rocket engine design.

All candidate configurations weighed more than one million lb (453,592 kg) at launch. There is a negligible weight difference among the three wing geometries considered and between the cryogenic and storable liquid boost propellents. At launch, unstaged rockets are about 20 percent lighter than staged rockets because they use a more energetic boost propellent. Conversely, during endurance flight the staged rockets are about 40 percent lighter than unstaged rockets because they have no dead weight associated with the boost. The empty weight and endurance flight weight are similar to the big subsonic jet transports.

The horizontal takeoff vehicles are about 50 percent heavier than vertical takeoff configurations primarily due to the wing and landing gear being designed to support the boost system during takeoff. The all airbreather was the heaviest concept considered, approximately 70 percent greater than the corresponding variable-sweep wing aircraft using a cryogenic propellent. In addition to the increased weight resulting from horizontal takeoff, the all airbreather concept required a dynamic pressure in excess of 1,100 psf (52,668 N/m^2) to satisfy the dash requirement. Ten duct burning, afterburning engines each with 200,000 lb (889,644 N) of thrust were required to satisfy the time constraint.

The modified Space Shuttle satisfied the dash requirement but could carry only one 100,000-lb (45,359 kg) missile for two hr. The gross weight of the modified Shuttle was 600,000 lb (272,155 kg), compared to the orbital design weight of 245,000 lb (111,130 kg).

The development, acquisition and boost propulsion costs to maintain 200 missiles on air alert for 6 hr will be about $4 billion for staged rockets and about $7 billion for unstaged rockets. Staged rocket costs are highly sensitive to the number of alerts or training flights per year because they require an expendable booster. The cost will be nearly $600 million for each fleet alert. Therefore the unstaged rockets appear to be the lowest cost configuration if even a few fleet training flights or alerts are planned. For these aircraft the boost propulsion system is reusable and therefore only fuel costs are incurred at each alert.

The dash-on-warning concept will require advanced technology in some areas. Technology advancement is required for vehicles which have gross weights in excess of one million lb (453,592 kg), although a large portion of this weight is in boost fuel. An advanced development program is required for a deployable base shroud for the unstaged rocket vehicles. There is a wing design compromise requiring further investigation since dash-on-warning aircraft requires supersonic flight during the dash and subsonic flight during cruise. Further detailed study is required to determine the characteristics of subsonic-like airfoils flying at supersonic speeds.

Another advanced technology area involves an all-weather vertical-takeoff with large aircraft, especially in high ground wind. Although the study indicated no superiority of one wing geometry over another, all-weather launch may favor variable geometry aircraft and makes the two-position wing most attractive. The two-position wing will present the lowest profile to ground winds while on the launch pad and will probably be least affected during launch in bad weather.

There is need for a ground based cryogenic recirculation system, if a cryogenic propellant boost system is to be used. Alternately, a new rocket engine development costing approximately $800 million will be required if a storable liquid propellant is selected.

APPENDIX A

NOMINAL ENDURANCE VEHICLE CHARACTERISTICS

Characteristics of the endurance aircraft are presented. The values for body length given in the table of aircraft geometric characteristics does not include the deployable aft shroud on the unstaged rocket configurations. The shroud length is determined by using a fineness ratio (shroud-length/body-diam) of 1.5. The thrust-per-engine is the sea-level static thrust for one cruise engine. All concepts required four cruise engines.

The views of the UR-FW-UDMH aircraft are the configurations analyzed by the ACSYNT program.

Notations used within this Appendix are given below:

ACCOM	Crew accommodations, lb (kg)
ADV WEAPONS 1	Payload support, lb (kg)
ADV WEAPONS 2	Boost engines and tankage, lb (kg)
AIR COND	Air conditioning, lb (kg)
ALT	Mission altitude, ft (m)
ALPHA	Angle of attack, deg
AUX	Auxiliary equipment, lb (kg)
BODY	Body (same as fuselage), lb (kg)
CD	Total drag coefficient
CDO	Minimum drag coefficient
CL	Lift coefficient
DE-ICE	De-icing equipment, lb (kg)
EQUIP	Equipment, lb (kg)
FRICT	Friction drag coefficient
HTAIL	Horizontal tail, lb (kg)
HYD	Hydraulics, lb (kg)
INT	Interference drag coefficient

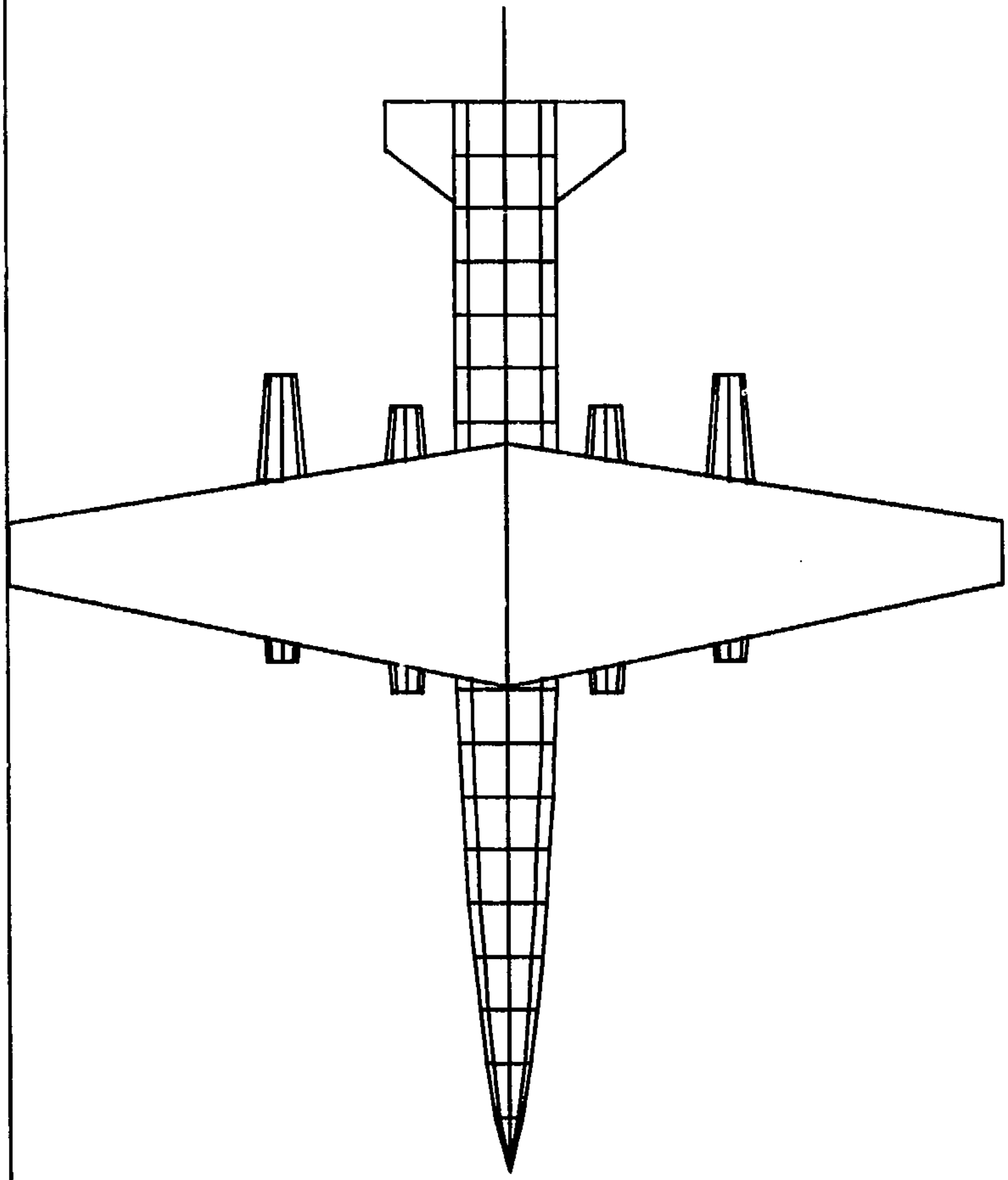
L/D	Lift-drag ratio
LG	Landing gear (same as alighting gear), lb (kg)
MACH	Mach number
NACL	Nacelles for cruise engines, lb (kg)
PNEU	Pneumatics, lb (kg)
PROP	Propulsion (cruise engines and fuel system), lb (kg)
SFC	Cruise engine specific fuel consumption, lb/fuel/lb-thrust/hr
TAILS	Horizontal plus vertical tail, lb (kg)
THRUST	Cruise engine thrust, lb (N)
VTAIL	Vertical tail, lb (kg)
WGTO	Weight at start of endurance (end of dash), lb (kg)

Configuration Notation

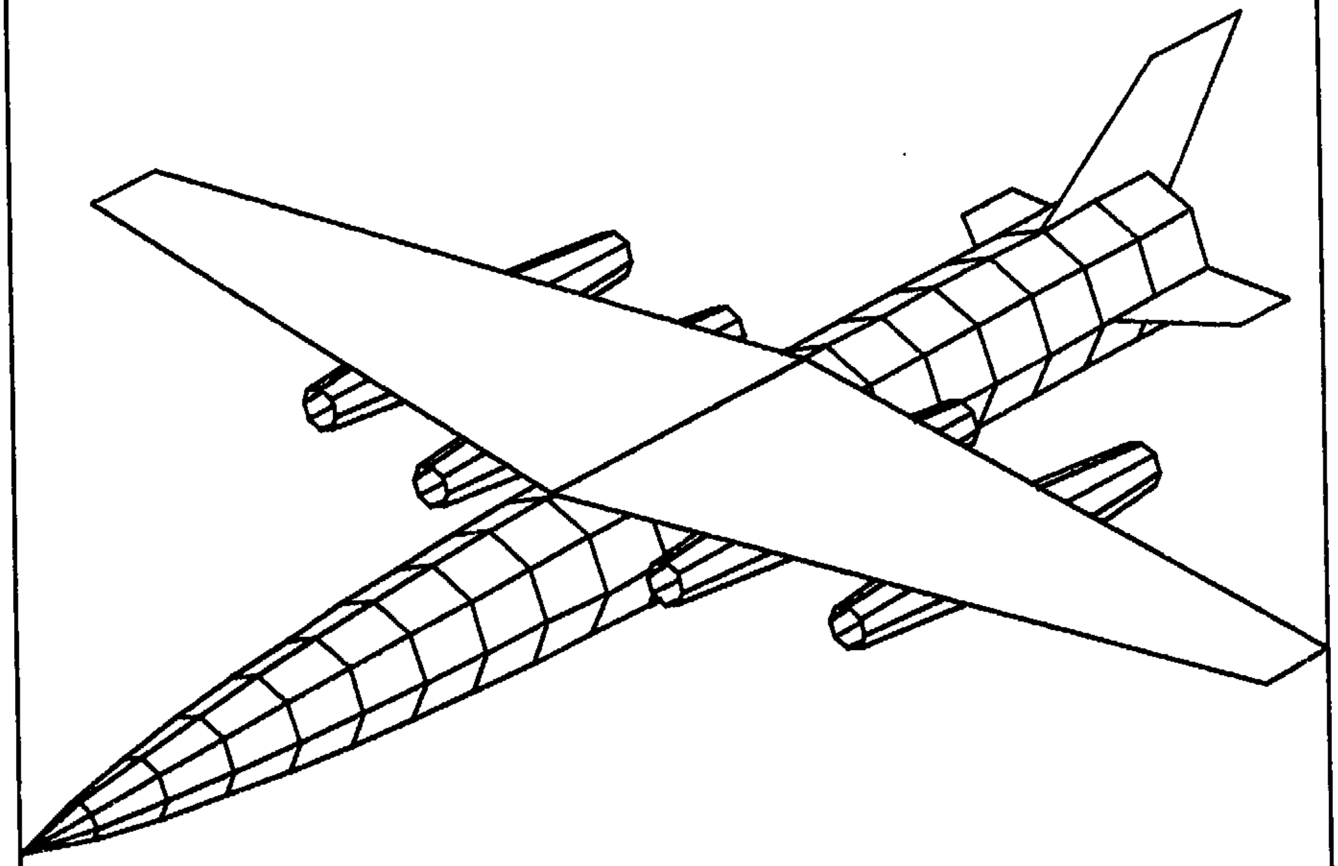
UR	Unstaged rocket
SR	Staged rocket
2P	Two-position wing
VS	Conventional variable-sweep wing
FW	Fixed-wing
LOX	Liquid oxygen
H_2	Liquid hydrogen
UDMH	Unsymmetrical dymethal hydrazine

AIRCRAFT GEOMETRIC CHARACTERISTICS

Concept	Wing aspect ratio	Wing span ft (m)	Wing area ft^2 (m^2)	Wing sweep at 1/4 chord, deg	Wing thickness ratio	Body length ft (m)	Body diam ft (m)	Thrust per engine, lb (N)
SR-2P-SOLID	5.1	148 (45.11)	4300 (399)	8	0.10/0.06	162 (49.38)	15 (4.57)	31,400 (139,674)
-VS-	6.7	163 (49.68)	3900 (362)	7	0.10/0.06	148 (45.11)	15 (4.57)	31,000 (137,894)
-FW-	7.5	175 (53.34)	4100 (381)	6	0.10/0.06	148 (45.11)	15 (4.57)	30,700 (136,560)
UR-2P-LOX/H_2	5.1	184 (56.08)	6600 (613)	11	0.10/0.06	198 (60.35)	20 (6.10)	48,600 (216,182)
-VS-	6.0	194 (59.13)	6200 (576)	10	0.10/0.06	196 (59.74)	20 (6.10)	43,700 (194,387)
-FW-	6.1	186 (56.69)	5700 (530)	11	0.10/0.06	201 (61.26)	20 (6.10)	41,700 (185,491)
-2P-UDMH	5.7	174 (53.04)	5300 (492)	6	0.10/0.06	188 (57.30)	18 (5.49)	44,700 (198,835)
-FW-	6.6	180 (54.86)	4900 (455)	6	0.10/0.06	194 (59.13)	19 (5.79)	38,900 (173,036)



UNSTAGED ROCKET FIXED WING UDMH 03/04/75



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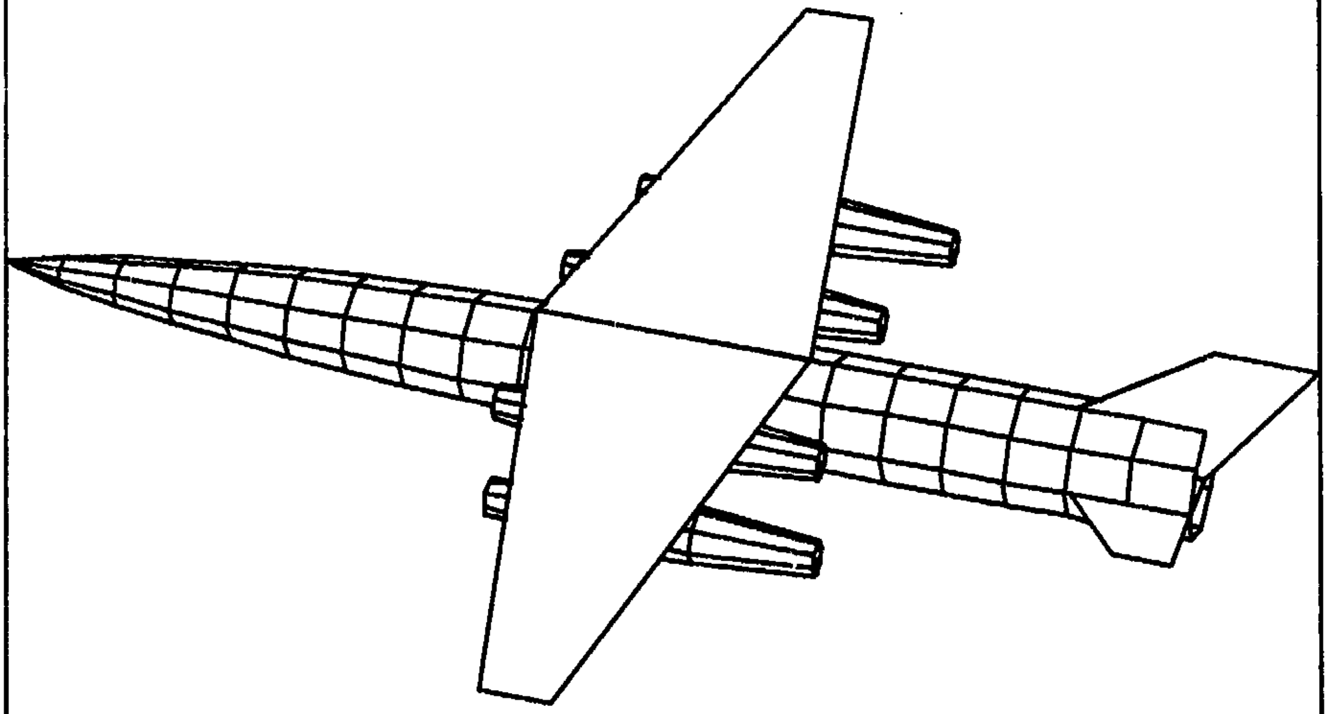

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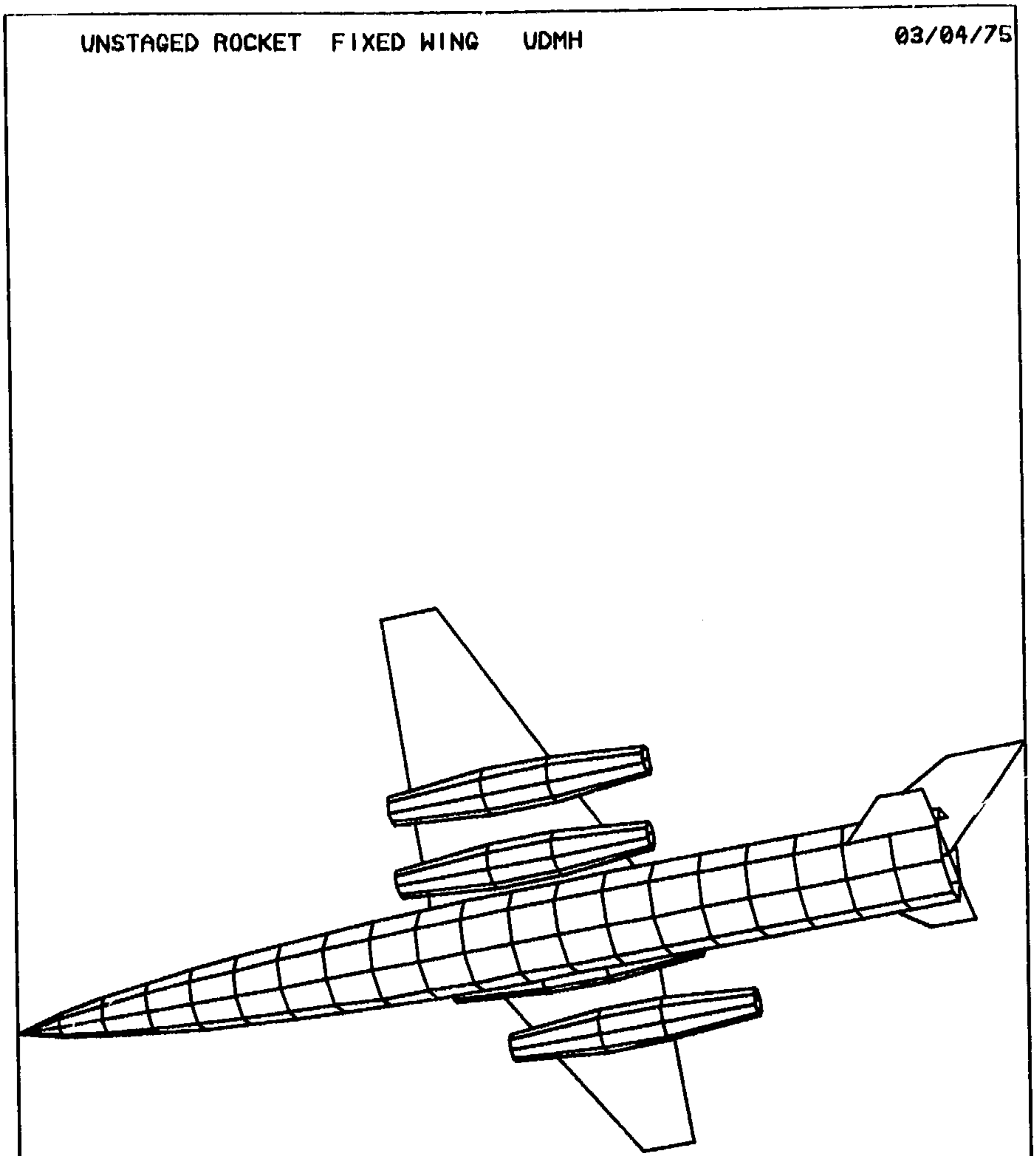
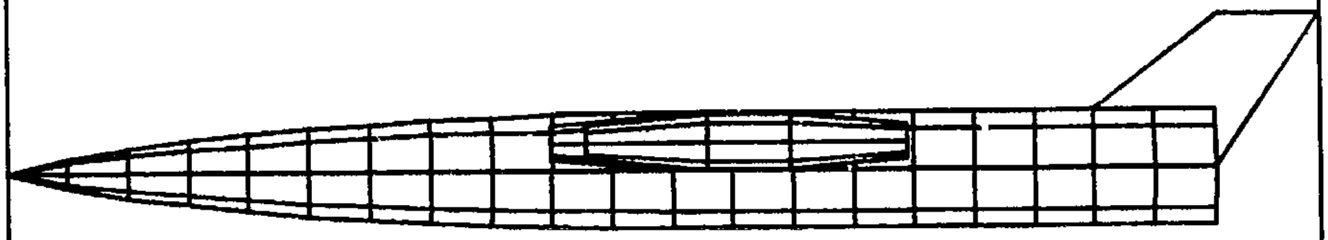
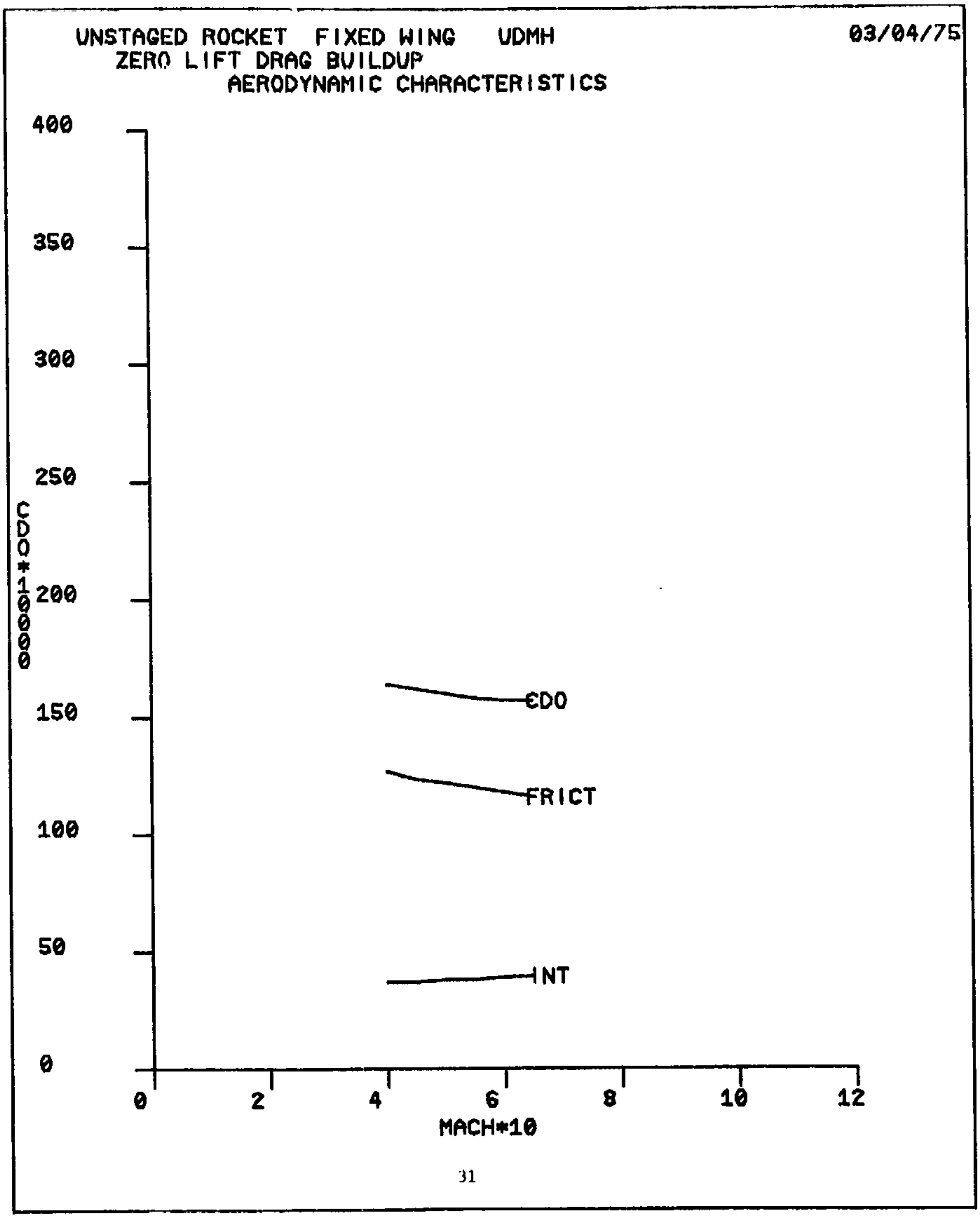
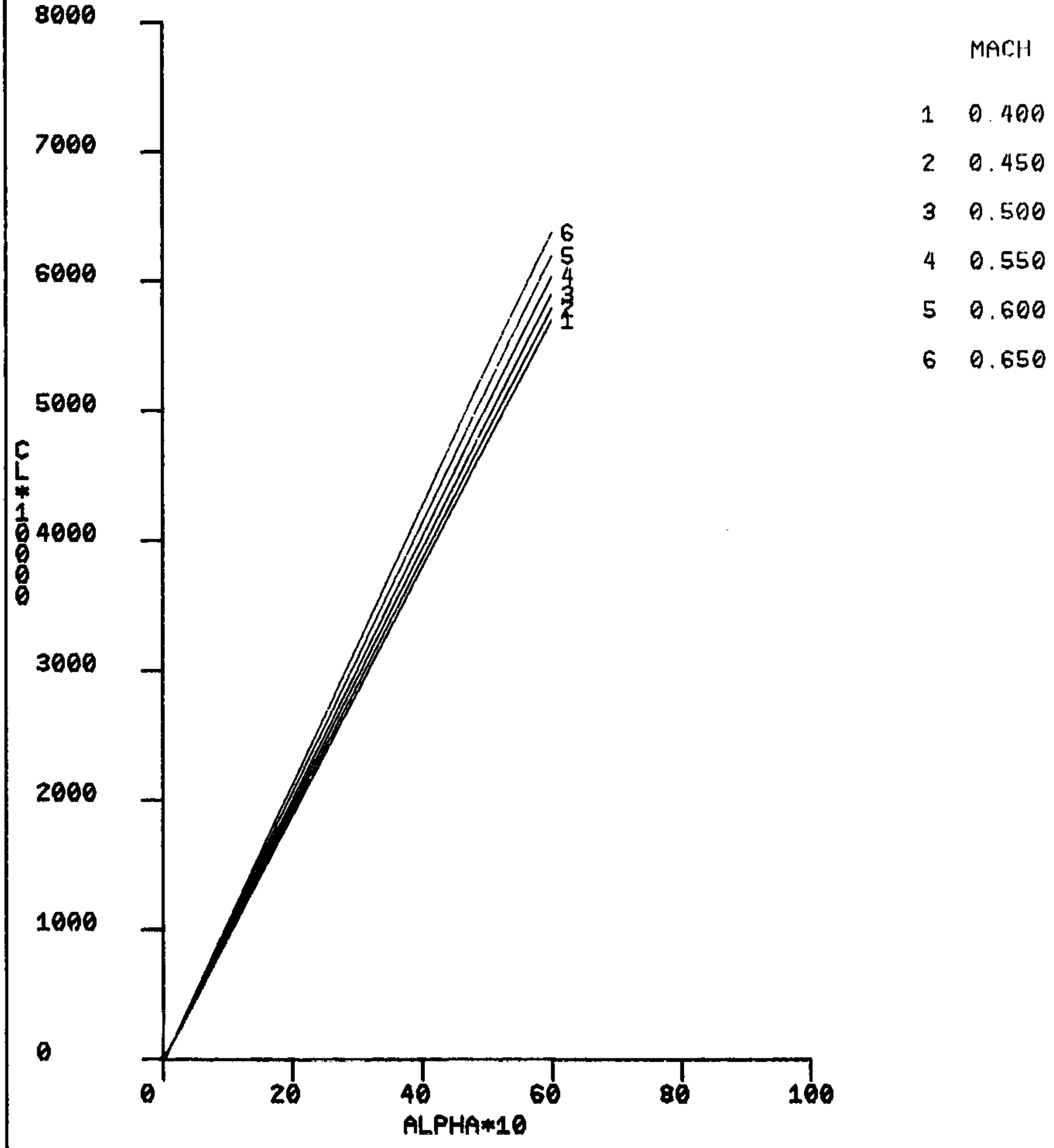

UNSTAGED ROCKET FIXED WING UDMH
03/04/75

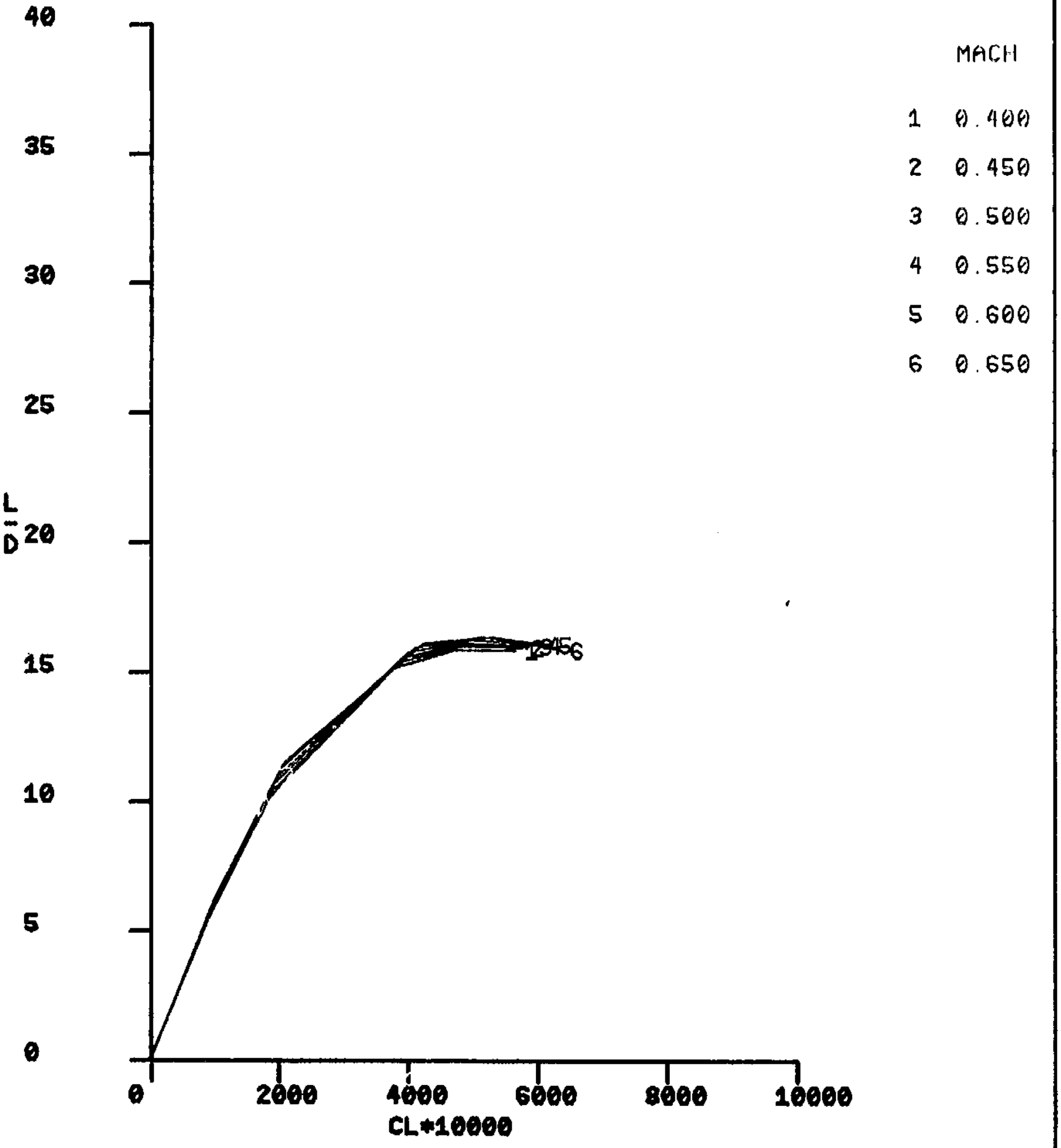
UNSTAGED ROCKET   FIXED WING   UDMH   03/04/75




UNSTAGED ROCKET FIXED WING UDMH
03/04/75
ZERO LIFT DRAG BUILDUP
AERODYNAMIC CHARACTERISTICS
400
350
300
250
200
150
100
50
0
CDO*10000
CDO
FRICT
INT
0
2
4
6
8
10
12
MACH*10

UNSTAGED ROCKET FIXED WING UDMH 03/04/75
LIFT CURVES
AERODYNAMIC CHARACTERISTICS



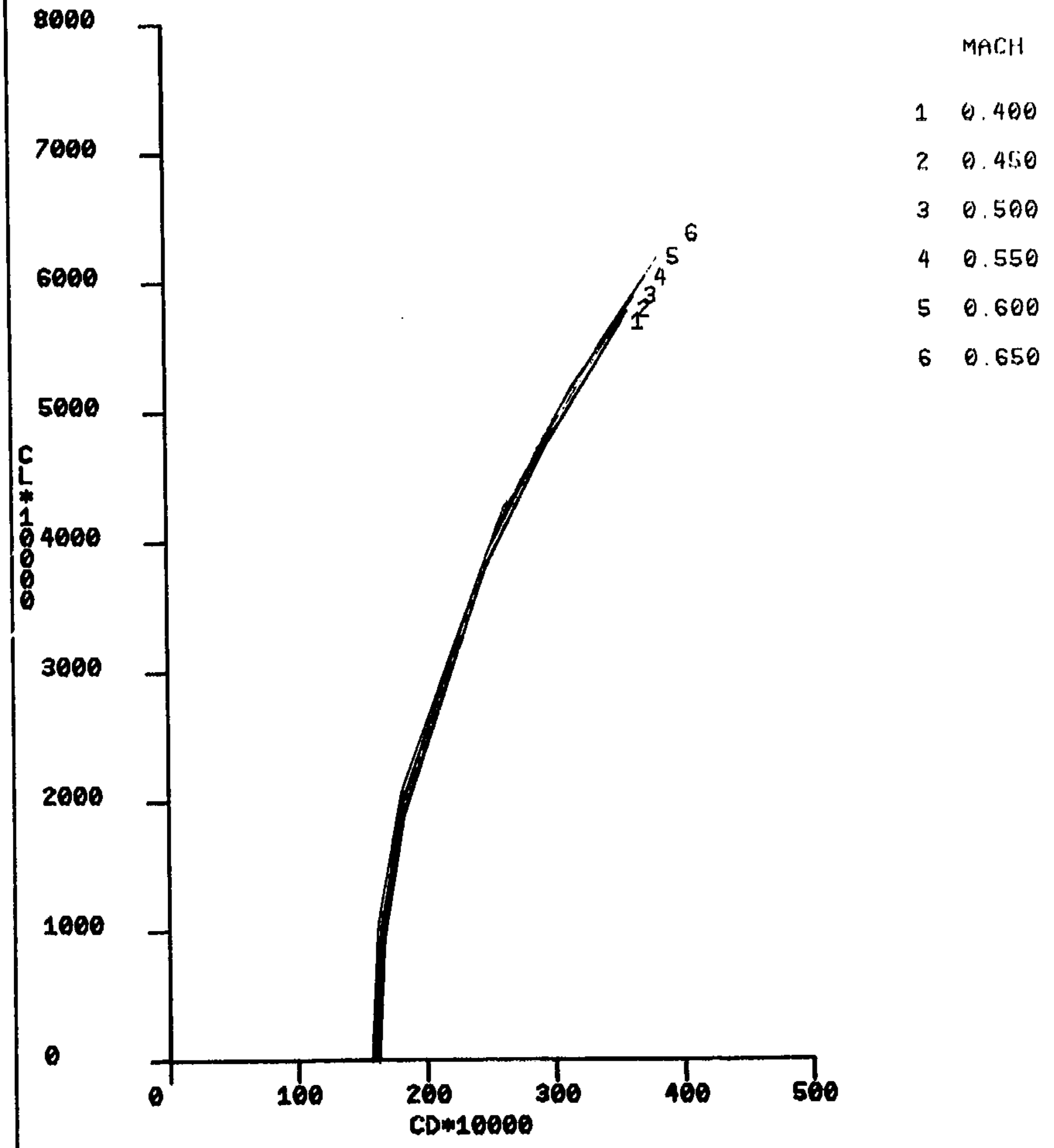


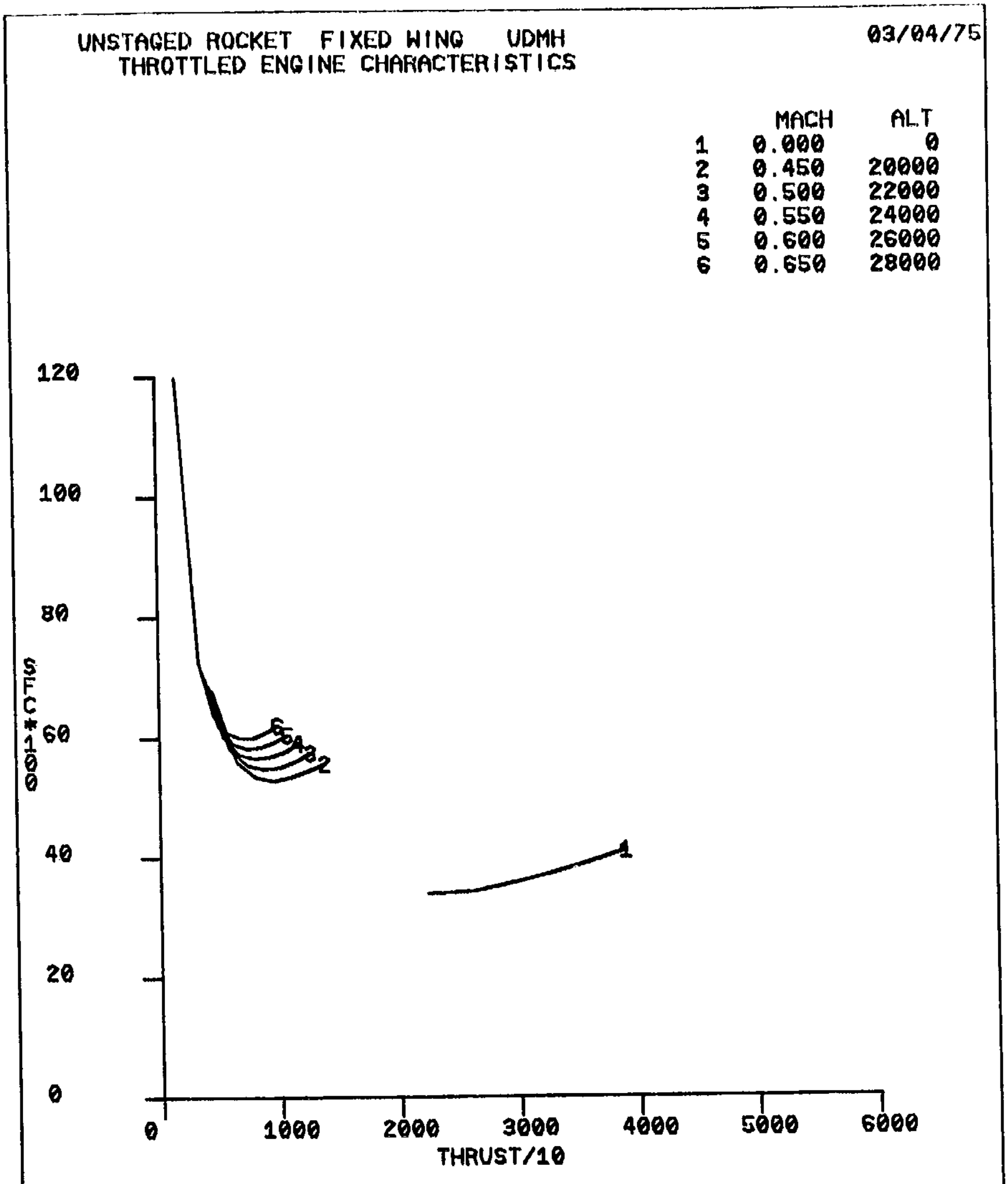
UNSTAGED ROCKET FIXED WING UDMH 03/04/75

LIFT/DRAG

AERODYNAMIC CHARACTERISTICS

UNSTAGED ROCKET FIXED WING UDMH 03/04/75
DRAG POLARS
AERODYNAMIC CHARACTERISTICS



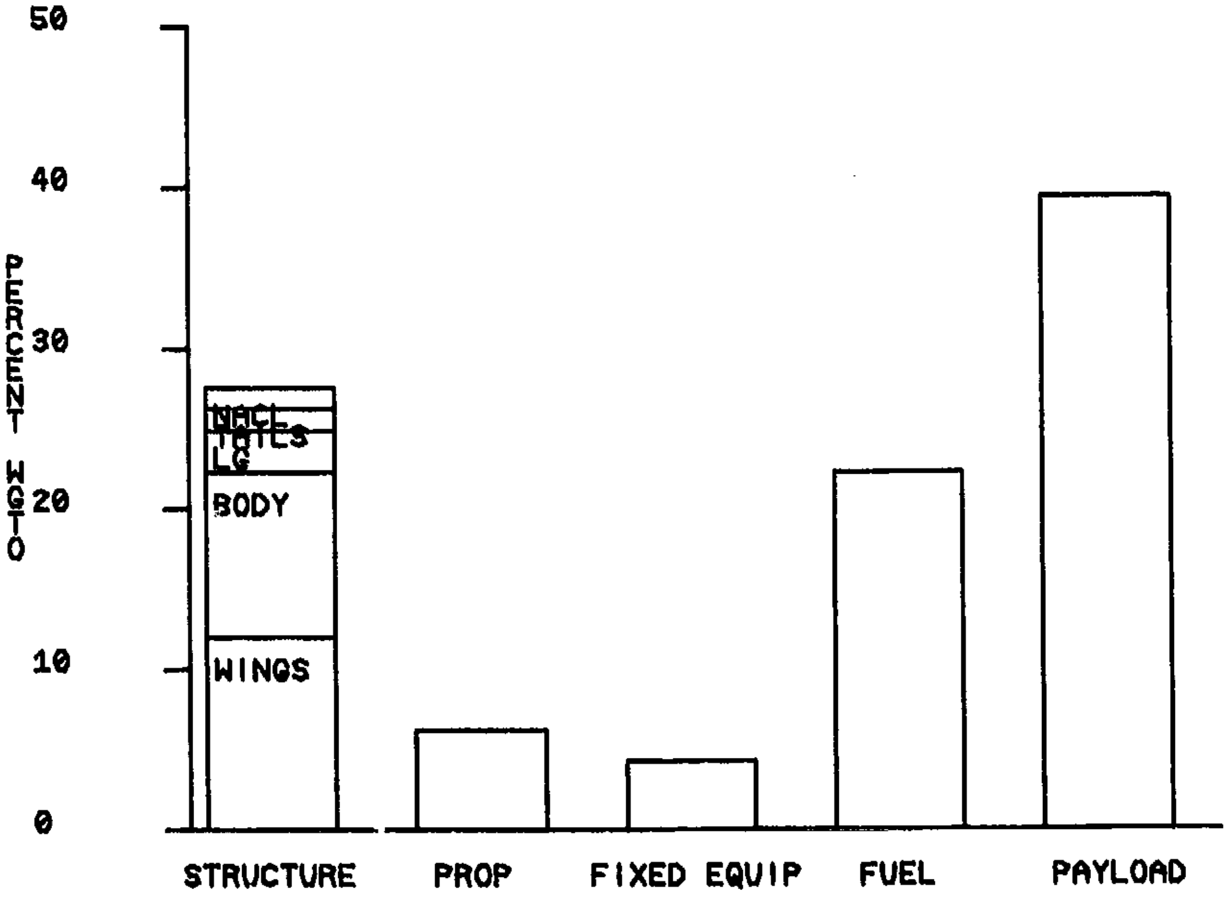


UNSTAGED ROCKET FIXED WING UDMH
THROTTLED ENGINE CHARACTERISTICS

03/04/75

UNSTAGED ROCKET FIXED WING UDMH 03/04/75

AIRCRAFT MASS DISTRIBUTION



UNSTAGED ROCKET — FIXED WING UDMH

Component	Weight (lb)	Weight (kg)
Airframe Structure	179,192	81,279
Wing	78,351	35,539
Fuselage	66,503	30,165
HTail	1,629	739
VTail	7,355	3,336
Nacelles	8,149	3,696
Alighting gear	17,205	7,804
Propulsion	40,239	18,252
Engines	36,074	16,363
Fuel system	4,165	1,889
Fixed Equipment	28,481	12,920
Hyd. & Pneu.	4,091	1,856
Electrical	6,892	3,126
Avionics	5,000	2,268
Instruments	2,653	1,203
De-ice/air cond.	3,149	1,428
Aux. gear	2,182	990
Crew accom.	1,395	633
Flight controls	3,121	1,416
Fuel	145,041	65,789
Payload	255,720	115,992
Crew	720	327
Armament	0	0
Ammunition	0	0
Missiles	200,000	90,718
Bombs	0	0
External tanks	0	0
Adv. weapons 1	15,000	6,803
Adv. weapons 2	40,000	18,144
TOTAL:	648,674	294,232

STAGED ROCKET — TWO-POSITION WING

Component	Weight (lb)	Weight (kg)
Airframe Structure	122,719	55,664
Wing	55,685	25,258
Fuselage	38,709	17,558
HTail	1,581	717
VTail	6,173	2,800
Nacelles	7,783	3,530
Alighting gear	12,789	5,801
Propulsion	38,430	17,432
Engines	34,433	15,618
Fuel system	3,997	1,814
Fixed Equipment	23,153	10,502
Hyd. & Pneu.	3,041	1,379
Electrical	5,123	2,324
Avionics	5,000	2,268
Instruments	1,972	894
De-ice/air cond.	2,340	1,061
Aux. gear	1,622	736
Crew accom.	1,395	633
Flight controls	2,660	1,207
Fuel	123,395	55,971
Payload	215,720	97,849
Crew	720	327
Armament	0	0
Ammunition	0	0
Missiles	200,000	90,718
Bombs	0	0
External tanks	0	0
Adv. weapons 1	15,000	6,804
Adv. weapons 2	0	0
TOTAL:	523,418	237,418

STAGED ROCKET — VARIABLE SWEEP

Component	Weight (lb)	Weight (kg)
Airframe Structure	129,415	58,703
Wing	68,584	31,109
Fuselage	35,699	16,193
HTail	1,439	653
VTail	2,801	1,271
Nacelles	7,647	3,469
Alighting gear	13,245	6,008
Propulsion	37,758	17,127
Engines	33,849	15,354
Fuel system	3,908	1,773
Fixed Equipment	23,665	10,734
Hyd. & Pneu.	3,149	1,428
Electrical	5,305	2,406
Avionics	5,000	2,268
Instruments	2,042	926
De-ice/air cond.	2,424	1,100
Aux. gear	1,679	762
Crew accom.	1,395	633
Flight controls	2,670	1,211
Fuel	110,189	49,981
Payload	215,720	97,849
Crew	720	327
Armament	0	0
Ammunition	0	0
Missiles	200,000	90,718
Bombs	0	0
External tanks	0	0
Adv. weapons 1	15,000	6,804
Adv. weapons 2	0	0
TOTAL:	516,747	234,394

STAGED ROCKET — FIXED WING

Component	Weight (lb)	Weight (kg)
Airframe Structure	126,997	57,605
Wing	66,622	30,219
Fuselage	35,383	16,049
HTail	1,459	662
VTail	2,895	1,313
Nacelles	7,576	3,436
Alighting gear	13,042	5,916
Propulsion	37,409	16,968
Engines	33,537	15,212
Fuel system	3,872	1,756
Fixed Equipment	23,527	10,673
Hyd. & Pneu.	3,101	1,407
Electrical	5,224	2,370
Avionics	5,000	2,268
Instruments	2,011	912
De-ice/air cond.	2,387	1,083
Aux. gear	1,654	750
Crew accom.	1,395	633
Flight controls	2,755	1,250
Fuel	100,323	45,506
Payload	215,720	97,849
Crew	720	327
Armament	0	0
Ammunition	0	0
Missiles	200,000	90,718
Bombs	0	0
External tanks	0	0
Adv. weapons 1	15,000	6,804
Adv. weapons 2	0	0
TOTAL:	503,976	228,601

UNSTAGED ROCKET — TWO-POSITION WING

Component	Weight (lb)	Weight (kg)
Airframe Structure	218,119	98,936
Wing	96,044	43,565
Fuselage	75,389	34,195
HTail	2,308	1,047
VTail	10,451	4,740
Nacelles	12,264	5,563
Alighting gear	21,663	9,826
Propulsion	60,559	27,469
Engines	54,290	24,626
Fuel system	6,268	2,843
Fixed Equipment	33,456	15,175
Hyd. & Pneu.	5,151	2,336
Electrical	8,678	3,936
Avionics	5,000	2,268
Instruments	3,340	1,515
De-ice/air cond.	3,964	1,798
Aux. gear	2,747	1,246
Crew accom.	1,395	633
Flight controls	3,181	1,443
Fuel	184,209	83,556
Payload	265,720	120,529
Crew	720	327
Armament	0	0
Ammunition	0	0
Missiles	200,000	90,718
Bombs	0	0
External tanks	0	0
Adv. weapons 1	15,000	6,804
Adv. weapons 2	50,000	22,680
TOTAL:	762,063	345,666

UNSTAGED ROCKET — VARIABLE SWEEP

Component	Weight (lb)	Weight (kg)
Airframe Structure	214,273	97,193
Wing	104,258	47,291
Fuselage	71,120	32,259
HTail	2,184	991
VTail	4,845	2,198
Nacelles	10,963	4,973
Alighting gear	20,903	9,481
Propulsion	54,131	24,553
Engines	48,528	22,012
Fuel system	5,603	2,541
Fixed Equipment	32,666	14,817
Hyd. & Pneu.	4,970	2,254
Electrical	8,373	3,798
Avionics	5,000	2,268
Instruments	3,223	1,462
De-ice/air cond.	3,825	1,735
Aux. gear	2,650	1,202
Crew accom.	1,395	633
Flight controls	3,230	1,465
Fuel	160,771	72,924
Payload	265,720	120,529
Crew	720	327
Armament	0	0
Ammunition	0	0
Missiles	200,000	90,718
Bombs	0	0
External tanks	0	0
Adv. weapons 1	15,000	6,804
Adv. weapons 2	50,000	22,680
TOTAL:	727,561	330,016

UNSTAGED ROCKET — FIXED WING

Component	Weight (lb)	Weight (kg)
Airframe Structure	192,205	87,183
Wing	84,600	38,374
Fuselage	71,838	32,585
HTail	1,924	873
VTail	4,323	1,961
Nacelles	10,468	4,748
Alighting gear	19,052	8,642
Propulsion	51,688	23,446
Engines	46,338	21,019
Fuel system	5,350	2,427
Fixed Equipment	30,611	13,886
Hyd. & Pneu.	4,530	2,055
Electrical	7,632	3,462
Avionics	5,000	2,268
Instruments	2,937	1,332
De-ice/air cond.	3,487	1,582
Aux. gear	2,416	1,096
Crew accom.	1,395	633
Flight controls	3,214	1,458
Fuel	154,417	70,042
Payload	265,720	120,529
Crew	720	327
Armament	0	0
Ammunition	0	0
Missiles	200,000	90,718
Bombs	0	0
External tanks	0	0
Adv. weapons 1	15,000	6,804
Adv. weapons 2	50,000	22,680
TOTAL:	694,641	315,086

UNSTAGED ROCKET, UDMH — TWO-POSITION WING

Component	Weight (lb)	Weight (kg)
Airframe Structure	182,294	82,688
Wing	82,831	37,572
Fuselage	62,320	28,268
HTail	1,872	849
VTail	7,962	3,612
Nacelles	9,412	4,269
Alighting gear	17,897	8,118
Propulsion	46,474	21,080
Engines	41,663	18,898
Fuel system	4,811	2,182
Fixed Equipment	29,153	13,223
Hyd. & Pneu.	4,255	1,930
Electrical	7,169	3,251
Avionics	5,000	2,268
Instruments	2,759	1,251
De-ice/air cond.	3,275	1,486
Aux. gear	2,269	1,029
Crew accom.	1,395	633
Flight controls	3,031	1,375
Fuel	157,289	71,345
Payload	247,720	112,364
Crew	720	327
Armament	0	0
Ammunition	0	0
Missiles	200,000	90,718
Bombs	0	0
External tanks	0	0
Adv. weapons 1	15,000	6,804
Adv. weapons 2	32,000	14,515
TOTAL:	662,930	300,700

THRUST-TO-WEIGHT RATIO AND BOOST FUEL FRACTION (NOMINAL CONFIGURATIONS)

Boost Dynamic Pressure = 500 psf (23,940 N/m^2)

Concept	Thrust-to-Weight	Boost Fuel Fraction
SR-FW	2.31	0.643
SR-VS	2.60	0.598
SR-2P	2.64	0.578
UR-FW-LOX/H_2	1.85	0.395
UR-VS-LOX/H_2	1.95	0.331
UR-2P-LOX/H_2	1.82	0.347
UR-FW-UDMH	1.65	0.495
UR-2P-UDMH	1.77	0.448

Propulsion System	Maximum Vacuum Thrust Million lb (10^6 N)
Solid	3.6 (16.014)
LOX/H_2	2.12 (9.43) - emergency power
UDMH	2.12 (9.43)

NOTE: For the SR configurations, the boost fuel fraction shown includes the strap-on casing weight (11 percent of boost fuel).

APPENDIX B

GROUP WEIGHT STATEMENTS OF THE ENDURANCE AIRCRAFT WITH CHANGES IN PAYLOAD, ENDURANCE, DYNAMIC PRESSURE AND AIRFRAME MATERIALS TECHNOLOGY

Group weight statements for the endurance aircraft are presented for configurations other than the nominal. The weight statements presented are for changes in payload, endurance, dynamic pressure and airframe materials technology. Included are the boost fuel fraction to determine vehicle gross takeoff weight and sea-level static thrust per cruise engine. For the staged rocket systems, the boost fuel fraction includes the strap-on casing weight (11 percent of boost fuel). The configuration notation is given in Appendix A.

To determine vehicle gross takeoff weight from these tables, use the weight indicated by "TOTAL," the boost fuel fraction indicated and substitute into the following relation:

$$\text{WGTO} = \frac{\text{TOTAL}}{1. - \text{Boost Fuel Fraction}}$$

where

WGTO = Gross Takeoff Weight (weight at launch)

GROUP WEIGHT STATEMENT

CONFIGURATION: SR-2P

Payload	2 - 80K M-X (36,287 kg)		4 - 80K M-X (36,287 kg)	
	Weight		Weight	
Component	(lb)	(kg)	(lb)	(kg)
Airframe Structure	113,692	51,570	166,179	75,377
Wing	52,507	23,817	70,283	31,879
Fuselage	36,425	16,522	45,834	20,790
H. Tail	1,272	577	3,746	1,699
V. Tail	5,342	2,423	13,654	6,193
Nacelles	6,505	2,951	14,209	6,445
Alighting gear	11,641	5,280	18,453	8,370
Propulsion	32,120	14,569	70,163	31,825
Engines (4)	28,795	13,061	62,900	28,531
Fuel system	3,325	1,508	7,263	3,294
Fixed Equipment	21,895	9,931	29,473	13,367
Hyd. & Pneu	2,768	1,256	4,387	1,990
Electrical	4,663	2,115	7,392	3,352
Avionics	5,000	2,268	5,000	2,268
Instruments	1,795	814	2,845	1,290
De-ice/air cond.	2,130	966	3,377	1,532
Auxiliary gears	1,476	670	2,340	1,061
Furnish & equip.	1,395	633	1,395	633
Flight controls	2,668	1,210	2,737	1,241
Cruise Fuel	97,532	44,240	240,749	109,202
Payload	175,720	79,705	335,720	152,280
Crew (3)	720	327	720	327
Missiles	160,000	72,575	320,000	145,150
Payload support	15,000	6,803	15,000	6,803
Boost engines & tanks	0	0	0	0
TOTAL:	440,959	200,015	842,284	382,051
Boost Fuel Fraction	.627		.532	
$(T/EN)_{SLS}$	26,500	117,878 N	56,000	249,100 N

GROUP WEIGHT STATEMENT

CONFIGURATION: SR-2P

Endurance	8 hr		10 hr	
	Weight		Weight	
Component	(lb)	(kg)	(lb)	(kg)
Airframe Structure	142,800	64,772	161,896	73,434
Wing	67,184	30,474	68,772	31,194
Fuselage	41,095	18,640	45,545	20,659
H. Tail	2,175	987	3,740	1,696
V. Tail	8,192	3,716	13,818	6,268
Nacelles	9,269	4,204	12,518	5,678
Alighting gear	14,885	6,751	17,503	7,939
Propulsion	45,770	20,761	61,810	28,036
Engines (4)	41,032	18,612	55,412	25,134
Fuel system	4,738	2,149	6,398	2,902
Fixed Equipment	25,517	11,575	28,423	12,893
Hyd. & Pneu.	3,532	1,602	4,161	1,887
Electrical	5,951	2,699	7,011	3,180
Avionics	5,000	2,268	5,000	2,268
Instruments	2,290	1,039	2,699	1,224
De-ice/air cond.	2,718	1,233	3,203	1,453
Auxiliary gears	1,884	855	2,219	1,007
Furnish & equip.	1,395	633	1,395	633
Flight controls	2,747	1,246	2,735	1,241
Cruise Fuel	189,657	86,027	359,561	163,094
Payload	215,720	97,849	215,720	97,849
Crew (3)	720	327	720	327
Missiles	200,000	90,718	200,000	90,718
Payload support	15,000	6,804	15,000	6,804
Boost engines & tanks	0	0	0	0
TOTAL:	619,464	280,984	827,410	375,306
Boost Fuel Fraction	.555		.532	
$(T/EN)_{SLS}$	37,200	165,474 N	49,700	221,077 N

GROUP WEIGHT STATEMENT

CONFIGURATION: SR-2P

Dynamic Pressure	1,000 psf (47,880 N/m^2)		1,300 psf (62,244 N/m^2)	
	Weight		Weight	
Component	(lb)	(kg)	(lb)	(kg)
Airframe Structure	124,820	56,617	125,516	56,933
Wing	55,685	25,258	55,685	25,258
Fuselage	38,709	17,558	38,709	17,558
H. Tail	1,950	885	2,451	1,112
V. Tail	7,616	3,455	7,645	3,468
Nacelles	7,783	3,530	7,783	3,530
Alighting gear	13,077	5,932	13,243	6,007
Propulsion	38,430	17,432	38,430	17,432
Engines (4)	34,452	15,627	34,452	15,627
Fuel system	3,978	1,804	3,978	1,804
Fixed Equipment	23,453	10,638	23,696	10,748
Hyd. & Pneu.	3,041	1,379	3,041	1,379
Electrical	5,123	2,324	5,123	2,324
Avionics	5,000	2,268	5,000	2,268
Instruments	1,972	894	1,972	894
De-ice/air cond.	2,340	1,061	2,340	1,061
Auxiliary gears	1,622	736	1,622	736
Furnish & equip.	1,395	633	1,395	633
Flight controls	2,960	1,343	3,203	1,453
Cruise Fuel	127,081	57,643	134,454	60,987
Payload	215,720	97,849	215,720	97,849
Crew (3)	720	327	720	327
Missiles	200,000	90,718	200,000	90,718
Payload support	15,000	6,804	15,000	6,804
Boost engines & tanks	0	0	0	0
TOTAL:	529,504	240,179	537,816	243,949
Boost Fuel Fraction	.493		.488	
$(T/EN)_{SLS}$	31,400	139,674 N	31,400	139,674 N

GROUP WEIGHT STATEMENT

CONFIGURATION: SR-2P

Airframe Material Technology Composite

Components	Weight (lb)	(kg)
Airframe Structure	84,332	38,252
Wing	38,150	17,305
Fuselage	25,741	11,676
H. Tail	1,166	529
V. Tail	5,087	2,307
Nacelles	4,683	2,124
Alighting gear	9,505	4,311
Propulsion	33,032	14,983
Engines (4)	29,613	13,432
Fuel system	3,419	1,551
Fixed Equipment	19,597	8,889
Hyd. & Pneu.	2,260	1,025
Electrical	3,808	1,727
Avionics	5,000	2,268
Instruments	1,465	665
De-ice/air cond.	1,739	789
Auxiliary gears	1,205	547
Furnish & equip.	1,395	633
Flight controls	2,725	1,236
Cruise Fuel	100,261	45,478
Payload	215,720	97,849
Crew (3)	720	327
Missiles	200,000	90,718
Payload support	15,000	6,804
Boost engines & tanks	0	0
TOTAL:	452,942	205,451
Boost Fuel Fraction	.618	
$(T/EN)_{SLS}$	27,200	120,992 N

GROUP WEIGHT STATEMENT

CONFIGURATION: SR-VS

Payload	2 - 80K M-X (36,287 kg)		4 - 80K M-X (36,287 kg)	
	Weight		Weight	
Component	(lb)	(kg)	(lb)	(kg)
Airframe Structure	105,875	48,024	163,389	74,112
Wing	52,057	23,613	85,762	38,901
Fuselage	33,311	15,110	40,980	18,588
H. Tail	1,058	480	2,837	1,287
V. Tail	2,236	1,014	5,030	2,282
Nacelles	6,261	2,840	11,535	5,232
Alighting gear	10,952	4,968	17,245	7,822
Propulsion	30,916	14,203	56,959	25,836
Engines (4)	27,716	12,572	51,063	23,162
Fuel system	3,200	1,451	5,896	2,674
Fixed Equipment	21,022	9,535	28,154	12,770
Hyd. & Pneu.	2,604	1,181	4,100	1,860
Electrical	4,387	1,990	6,109	2,771
Avionics	5,000	2,268	5,000	2,268
Instruments	1,689	766	2,659	1,206
De-ice/air cond.	2,004	909	3,156	1,432
Auxiliary gears	1,389	630	2,187	992
Furnish & equip.	1,395	633	1,395	633
Flight controls	2,554	1,158	2,748	1,246
Cruise Fuel	91,661	41,577	177,973	80,727
Payload	175,720	79,706	335,720	152,281
Crew (3)	720	327	720	327
Missiles	160,000	72,575	320,000	145,150
Payload support	15,000	6,804	15,000	6,804
Boost engines & tanks	0	0	0	0
TOTAL:	425,194	192,865	762,195	345,726
Boost Fuel Fraction	.658		.556	
$(T/EN)_{SLS}$	25,500	113,430 N	45,800	203,729 N

GROUP WEIGHT STATEMENT

CONFIGURATION: SR-VS

Endurance	8 hr		10 hr	
	Weight		Weight	
Component	(lb)	(kg)	(lb)	(kg)
Airframe Structure	163,614	74,214	190,236	86,290
Wing	94,947	43,067	113,685	51,567
Fuselage	37,726	17,112	39,913	18,104
H. Tail	1,942	881	2,514	1,140
V. Tail	3,630	1,647	4,521	2,051
Nacelles	9,031	4,096	10,649	4,830
Alighting gear	16,338	7,411	18,954	8,597
Propulsion	44,592	20,227	52,582	23,851
Engines (4)	39,976	18,133	47,139	21,382
Fuel system	4,616	2,094	5,443	2,469
Fixed Equipment	27,264	12,367	30,244	13,718
Hyd. & Pneu.	3,884	1,762	4,506	2,044
Electrical	6,545	2,968	7,593	3,444
Avionics	5,000	2,268	5,000	2,268
Instruments	2,519	1,143	2,922	1,325
De-ice/air cond.	2,990	1,356	3,469	1,574
Auxiliary gears	2,072	940	2,403	1,090
Furnish & equip.	1,395	633	1,395	633
Flight controls	2,859	1,297	2,956	1,341
Cruise Fuel	152,592	69,215	218,763	99,229
Payload	215,720	97,849	215,720	97,849
Crew (3)	720	327	720	327
Missiles	200,000	90,718	200,000	90,718
Payload support	15,000	6,804	15,000	6,804
Boost engines & tanks	0	0	0	0
TOTAL:	603,782	273,872	707,545	320,937
Boost Fuel Fraction	.574		.562	
$(T/EN)_{SLS}$	36,200	161,026 N	42,500	189,049 N

GROUP WEIGHT STATEMENT

CONFIGURATION: SR-VS

Dynamic Pressure	1,000 psf (47,880 N/m^2)		1,300 psf (62,244 N/m^2)	
	Weight		Weight	
Component	(lb)	(kg)	(lb)	(kg)
Airframe Structure	173,583	78,736	203,936	92,504
Wing	95,029	43,104	119,656	54,275
Fuselage	40,148	18,211	41,266	18,718
H. Tail	3,109	1,410	3,309	1,501
V. Tail	6,727	3,051	7,589	3,442
Nacelles	10,810	4,903	11,722	5,317
Alighting gear	17,760	8,056	20,394	9,251
Propulsion	53,375	24,210	57,879	26,253
Engines (4)	47,850	21,704	51,888	23,536
Fuel system	5,525	2,506	5,991	2,717
Fixed Equipment	28,964	13,138	32,049	14,537
Hyd. & Pneu.	4,223	1,916	4,849	2,199
Electrical	7,114	3,226	8,169	3,705
Avionics	5,000	2,268	5,000	2,268
Instruments	2,738	1,242	3,144	1,426
De-ice/air cond.	3,250	1,474	3,732	1,693
Auxiliary gears	2,252	1,021	2,586	1,173
Furnish & equip.	1,395	633	1,395	633
Flight controls	2,992	1,357	3,174	1,440
Cruise Fuel	247,766	112,385	267,688	121,421
Payload	215,720	97,849	215,720	97,849
Crew	720	327	720	327
Missiles	200,000	90,718	200,000	90,718
Payload support	15,000	6,804	15,000	6,804
Boost engines & tanks	0	0	0	0
TOTAL:	719,408	326,318	777,272	352,565
Boost Fuel Fraction	.499		.494	
$(T/EN)_{SLS}$	43,200	192,163 N	46,700	207,732 N

GROUP WEIGHT STATEMENT

CONFIGURATION: SR-VS

Airframe Material Technology Composite

Components	Weight (lb)	(kg)
Airframe Structure	89,611	40,646
Wing	49,091	22,267
Fuselage	23,666	10,734
H. Tail	798	362
V. Tail	1,657	752
Nacelles	4,563	2,070
Alighting gear	9,836	4,462
Propulsion	32,186	14,599
Engines (4)	28,854	13,088
Fuel system	3,332	1,511
Fixed Equipment	19,953	9,051
Hyd. & Pneu.	2,338	1,060
Electrical	3,940	1,787
Avionics	5,000	2,268
Instruments	1,516	688
De-ice/air cond.	1,800	816
Auxiliary gears	1,247	566
Furnish & equip.	1,395	633
Flight controls	2,717	1,232
Cruise Fuel	85,887	38,958
Payload	215,720	97,849
Crew (3)	720	327
Missiles	200,000	90,718
Payload support	15,000	6,804
Boost engines & tanks	0	0
TOTAL:	443,357	201,103
Boost Fuel Fraction	.642	
$(T/EN)_{SLS}$	26,600	118,323 N

GROUP WEIGHT STATEMENT

CONFIGURATION: SR-FW

Payload	2 - 80K M-X (36,287 kg)		4 - 80K M-X (36,287 kg)	
	Weight		Weight	
Component	(lb)	(kg)	(lb)	(kg)
Airframe Structure	97,715	44,323	154,291	69,985
Wing	45,360	20,575	78,978	35,824
Fuselage	32,887	14,917	40,470	18,356
H. Tail	1,011	459	2,637	1,196
V. Tail	2,174	986	4,679	2,122
Nacelles	6,029	2,735	11,117	5,043
Alighting gear	10,254	4,651	16,410	7,443
Propulsion	29,771	13,504	54,895	24,900
Engines (4)	26,689	12,106	49,213	22,323
Fuel system	3,082	1,398	5,682	2,577
Fixed Equipment	20,261	9,190	27,271	12,370
Hyd. & Pneu.	2,438	1,106	3,901	1,769
Electrical	4,107	1,863	6,573	2,981
Avionics	5,000	2,268	5,000	2,268
Instruments	1,581	717	2,530	1,148
De-ice/air cond.	1,876	851	3,003	1,362
Auxiliary gears	1,300	590	2,081	944
Furnish & equip.	1,395	633	1,395	633
Flight controls	2,564		2,788	1,265
Cruise Fuel	86,653	39,305	163,607	74,210
Payload	175,720	79,706	335,720	152,281
Crew (3)	720	327	720	327
Missiles	160,000	72,575	320,000	145,150
Payload support	15,000	6,804	15,000	6,804
Boost engines & tanks	0	0	0	0
TOTAL:	410,120	186,028	735,784	333,746
Boost Fuel Fraction	.707		.599	
$(T/EN)_{SLS}$	24,600	109,426 N	44,200	196,611 N

GROUP WEIGHT STATEMENT

CONFIGURATION: SR-FW

Endurance	8 hr		8 hr	
	Weight		Weight	
Component	(lb)	(kg)	(lb)	(kg)
Airframe Structure	144,166	65,392	163,213	77,032
Wing	79,021	35,843	91,776	41,629
Fuselage	36,960	16,765	38,850	17,622
H. Tail	1,726	783	2,170	984
V. Tail	3,264	1,481	3,944	1,789
Nacelles	8,507	3,859	9,855	4,470
Alighting gear	14,688	6,662	16,618	7,538
Propulsion	42,007	19,054	48,662	22,073
Engines (4)	37,659	17,081	43,625	19,788
Fuel system	4,348	1,972	5,037	2,285
Fixed Equipment	25,420	11,530	27,623	12,530
Hyd. & Pneu.	3,492	1,584	3,951	1,792
Electrical	5,884	2,669	6,657	3,020
Avionics	5,000	2,268	5,000	2,268
Instruments	2,265	1,027	2,562	1,162
De-ice/air cond.	2,688	1,219	3,041	1,379
Auxiliary gears	1,862	845	2,107	956
Furnish & equip.	1,395	633	1,395	633
Flight controls	2,834	1,285	2,910	1,320
Cruise Fuel	142,462	64,620	200,601	90,991
Payload	215,720	97,849	215,720	97,849
Crew (3)	720	327	720	327
Missiles	200,000	90,718	200,000	90,718
Payload support	15,000	6,804	15,000	6,804
Boost engines & tanks	0	0	0	0
TOTAL:	569,775	258,446	655,819	297,474
Boost Fuel Fraction	.620		.610	
$(T/EN)_{SLS}$	34,200	152,129 N	39,400	175,260 N

GROUP WEIGHT STATEMENT

CONFIGURATION: SR-FW

Dynamic Pressure	1,000 psf (47,880 N/m^2)		1,300 psf (62,244 N/m^2)	
	Weight		Weight	
Component	(lb)	(kg)	(lb)	(kg)
Airframe structure	159,162	72,195	184,819	83,833
Wing	81,489	36,963	103,373	46,889
Fuselage	39,704	18,009	40,583	18,408
H. Tail	3,334	1,512	3,256	1,477
V. Tail	7,616	3,455	7,698	3,492
Nacelles	10,465	4,747	11,159	5,062
Alighting gear	16,554	7,509	18,750	8,505
Propulsion	51,672	23,438	55,100	24,993
Engines (4)	46,323	21,012	49,397	22,406
Fuel system	5,349	2,426	5,703	2,587
Fixed Equipment	27,663	12,548	30,258	13,725
Hyd. & Pneu.	3,936	1,785	4,458	2,022
Electrical	6,631	3,008	7,511	3,407
Avionics	5,000	2,268	5,000	2,268
Instruments	2,552	1,158	2,891	1,311
De-ice/air cond.	3,029	1,374	3,431	1,556
Auxiliary gears	2,099	952	2,378	1,079
Furnish & equip.	1,395	633	1,395	633
Flight controls	3,021	1,370	3,194	1,449
Cruise Fuel	242,973	110,211	255,685	115,977
Payload	215,720	97,849	215,720	97,849
Crew (3)	720	327	720	327
Missiles	200,000	90,718	200,000	90,718
Payload support	15,000	6,804	15,000	6,804
Boost engines & tanks	0	0	0	0
TOTAL:	697,190	316,241	741,582	336,377
Boost Fuel Fraction	.521		.516	
$(T/EN)_{SLS}$	41,800	185,936 N	44,500	197,946 N

GROUP WEIGHT STATEMENT

CONFIGURATION: SR-FW

Airframe Material Technology Composite

Component	Weight (lb)	Weight (kg)
Airframe Structure	105,791	47,986
Wing	61,668	27,972
Fuselage	24,291	11,018
H. Tail	1,023	464
V. Tail	2,105	955
Nacelles	5,273	2,392
Alighting gear	11,431	5,185
Propulsion	37,195	16,871
Engines (4)	33,345	15,125
Fuel system	3,850	1,746
Fixed Equipment	21,729	9,856
Hyd. & Pneu.	2,718	1,233
Electrical	4,579	2,077
Avionics	5,000	2,268
Instruments	1,762	799
De-ice/air cond.	2,092	949
Auxiliary gears	1,449	657
Furnish & equip.	1,395	633
Flight controls	2,734	1,240
Cruise Fuel	96,664	43,846
Payload	215,720	97,849
Crew (3)	720	327
Missiles	200,000	90,718
Payload support	15,000	6,804
Boost engines & tanks	0	0
TOTAL:	477,099	216,408
Boost Fuel Fraction	.657	
$(T/EN)_{SLS}$	30,600	136,116 N

GROUP WEIGHT STATEMENT

CONFIGURATION: UR-2P (LOX/H_2)

	2 - 80K M-X (36,287 kg)		4 - 80K M-X (36,287 kg)	
	Weight		Weight	
Component	(lb)	(kg)	(lb)	(kg)
Airframe Structure	188,335	85,428	344,771	156,385
Wing	79,472	36,048	161,385	73,203
Fuselage	71,150	32,273	92,283	41,859
H. Tail	1,629	739	4,065	1,844
V. Tail	7,885	3,577	14,088	6,390
Nacelles	9,724	4,411	33,778	15,321
Alighting gear	18,475	8,380	39,172	17,768
Propulsion	48,015	21,779	166,788	75,654
Engines (4)	43,045	19,525	149,524	67,823
Fuel system	4,970	2,254	17,264	7,831
Fixed Equipment	29,837	13,535	52,909	23,999
Hyd. & Pneu.	4,393	1,993	9,313	4,224
Electrical	7,401	3,357	15,691	7,117
Avionics	5,000	2,268	5,000	2,268
Instruments	2,849	1,292	6,039	2,739
De-ice/air cond.	3,381	1,534	7,168	3,251
Auxiliary gears	2,343	1,063	4,967	2,253
Furnish & equip.	1,395	633	1,395	633
Flight controls	3,075	1,395	3,336	1,513
Cruise Fuel	155,508	70,537	396,817	179,993
Payload	225,720	102,385	385,720	174,960
Crew (3)	720	327	720	327
Missiles	160,000	72,575	320,000	145,150
Payload support	15,000	6,804	15,000	6,804
Boost engines & tanks	50,000	22,680	50,000	22,680
TOTAL:	647,415	293,664	1,347,005	610,991
Boost Fuel Fraction	.378		.316	
$(T/EN)_{SLS}$	38,900	173,036 N	128,000	569,372 N

GROUP WEIGHT STATEMENT

CONFIGURATION: HR-2P (LOX/H_2)

Endurance	8 hr		10 hr
	Weight		
Component	(lb)	(kg)	Weight
Airframe Structure	271,548	123,172	
Wing	135,520	61,471	
Fuselage	80,421	36,478	
H. Tail	2,820	1,279	
V. Tail	11,737	5,324	NO CONVERGED AIRCRAFT
Nacelles	14,522	6,587	
Alighting gear	26,528	12,033	
Propulsion	71,709	32,527	
Engines (4)	64,286	29,160	
Fuel system	7,423	3,367	
Fixed Equipment	38,996	17,688	
Hyd. & Pneu.	6,307	2,861	
Electrical	10,627	4,820	
Avionics	5,000	2,268	
Instruments	4,090	1,855	
De-ice/air cond.	4,855	2,202	
Auxiliary gears	3,364	1,526	
Furnish & equip.	1,395	633	
Flight controls	3,358	1,523	
Cruise Fuel	266,236	120,763	
Payload	265,720	120,529	
Crew (3)	720	327	
Missiles	200,000	90,718	
Payload support	15,000	6,804	
Boost engines & tanks	50,000	22,680	
TOTAL:	914,209	414,679	
Boost Fuel Fraction	.333		
$(T/EN)_{SLS}$	57,100	253,993 N	

GROUP WEIGHT STATEMENT

CONFIGURATION: UR-2P (LOX/H_2)

Component	Dynamic Pressure 1,000 psf (47,880 N/m^2) Weight (lb)	(kg)	1,300 psf (62,244 N/m^2) Weight (lb)	(kg)
Airframe Structure	220,348	99,948	222,680	101,007
Wing	96,044	43,565	96,044	43,565
Fuselage	75,389	34,196	75,389	34,196
H. Tail	2,847	1,291	3,578	1,623
V. Tail	11,791	5,348	12,943	5,871
Nacelles	12,264	5,563	12,264	5,563
Alighting gear	22,013	9,985	22,462	10,189
Propulsion	60,559	27,469	60,558	27,469
Engines (4)	54,290	24,626	54,290	24,626
Fuel system	6,268	2,843	6,268	2,843
Fixed Equipment	33,815	15,339	34,105	15,469
Hyd. & Pneu.	5,151	2,336	5,151	2,336
Electrical	8,678	3,936	8,678	3,936
Avionics	5,000	2,268	5,000	2,268
Instruments	3,340	1,515	3,340	1,515
De-ice/air cond.	3,964	1,798	3,964	1,798
Auxiliary gears	2,747	1,246	2,747	1,246
Furnish & equip.	1,395	633	1,395	633
Flight controls	3,540	1,737	3,830	1,737
Cruise Fuel	185,313	84,057	196,433	89,101
Payload	265,720	120,529	265,720	120,529
Crew (3)	720	327	720	327
Missiles	200,000	90,718	200,000	90,718
Payload support	15,000	6,804	15,000	6,804
Boost engines & tanks	50,000	22,680	50,000	22,680
TOTAL:	765,755	347,342	779,496	353,575
Boost Fuel Fraction	.293		.291	
$(T/EN)_{SLS}$	48,600	216,183 N	48,600	216,183 N

GROUP WEIGHT STATEMENT

CONFIGURATION: UR-2P (LOX/H_2)

Airframe Material Technology Composite

Component	Weight (lb)	Weight (kg)
Airframe Structure	131,818	59,792
Wing	55,152	25,017
Fuselage	49,063	22,255
H. Tail	1,061	481
V. Tail	5,247	2,380
Nacelles	6,976	3,164
Alighting gear	14,319	6,495
Propulsion	49,207	22,320
Engines (4)	44,114	20,010
Fuel system	5,093	2,310
Fixed Equipment	25,257	11,456
Hyd. & Pneu.	3,404	1,544
Electrical	5,736	2,602
Avionics	5,000	2,268
Instruments	2,208	1,002
De-ice/air cond.	2,620	1,188
Auxiliary gears	1,816	824
Furnish & equip.	1,395	633
Flight controls	3,078	1,396
Cruise Fuel	148,591	67,400
Payload	265,720	120,529
Crew (3)	720	327
Missiles	200,000	90,718
Payload support	15,000	6,804
Boost engines & tanks	50,000	22,680
TOTAL:	620,593	281,496
Boost Fuel Fraction	.389	
$(T/EN)_{SLS}$	39,800	177,039 N

GROUP WEIGHT STATEMENT

CONFIGURATION: UR-VS (LOX/H_2)

	2 - 80K M-X (36,287 kg)		4 - 80K M-X (36,287 kg)	
	Weight		Weight	
Components	(lb)	(kg)	(lb)	(kg)
Airframe Structure	179,248	81,306	332,749	150,932
Wing	79,786	36,190	165,183	74,926
Fuselage	67,337	30,544	86,729	39,340
H. Tail	1,526	692	4,280	1,941
V. Tail	3,592	1,629	7,544	3,422
Nacelles	9,353	4,242	31,567	14,319
Alighting gear	17,654	8,008	37,446	16,985
Propulsion	46,185	20,949	155,872	70,702
Engines (4)	41,404	18,781	139,738	63,384
Fuel system	4,781	2,169	16,134	7,318
Fixed Equipment	28,927	13,121	51,042	23,152
Hyd. & Pneu.	4,197	1,904	8,903	4,038
Electrical	7,072	3,208	15,000	6,804
Avionics	5,000	2,268	5,000	2,268
Instruments	2,722	1,235	5,773	2,619
De-ice/air cond.	3,231	1,466	6,853	3,108
Auxiliary gears	2,239	1,016	4,748	2,154
Furnish & equip.	1,395	633	1,395	633
Flight controls	3,071	1,393	3,370	1,529
Cruise Fuel	143,748	65,203	347,297	157,531
Payload	225,720	102,385	385,720	174,960
Crew (3)	720	327	720	327
Missiles	160,000	72,575	320,000	145,150
Payload support	15,000	6,804	15,000	6,804
Boost engines & tanks	50,000	22,680	50,000	22,680
TOTAL:	623,828	282,964	1,272,680	577,278
Boost Fuel Fraction	.356		.303	
$(T/EN)_{SLS}$	37,400	166,363 N	120,000	533,787 N

GROUP WEIGHT STATEMENT

CONFIGURATION: HR-VS (LOX/H_2)

Endurance	8 hr		10 hr	
	Weight		Weight	
Component	(lb)	(kg)	(lb)	(kg)
Airframe Structure	260,781	118,288	318,779	144,596
Wing	136,738	62,023	179,448	81,396
Fuselage	75,504	34,248	81,117	36,794
H. Tail	3,246	1,472	3,855	1,749
V. Tail	6,987	3,169	7,544	3,421
Nacelles	13,108	5,946	16,128	7,316
Alighting gear	25,198	11,430	30,687	13,919
Propulsion	64,724	29,358	79,635	36,122
Engines (4)	58,024	26,319	71,392	32,383
Fuel system	6,700	3,039	8,243	3,739
Fixed Equipment	37,603	17,056	43,778	19,857
Hyd. & Pneu.	5,991	2,717	7,296	3,309
Electrical	10,094	4,579	12,292	5,576
Avionics	5,000	2,268	5,000	2,268
Instruments	3,885	1,762	4,731	2,146
De-ice/air cond.	4,611	2,092	5,616	2,547
Auxiliary gears	3,195	1,449	3,891	1,765
Furnish & equip.	1,395	633	1,395	633
Flight controls	3,432	1,557	3,557	1,613
Cruise Fuel	232,425	105,426	346,118	156,996
Payload	265,720	120,529	265,720	120,529
Crew (3)	720	327	720	327
Missiles	200,000	90,718	200,000	90,718
Payload support	15,000	6,804	15,000	6,804
Boost engines & tanks	50,000	22,680	50,000	22,680
TOTAL:	861,253	390,658	1,054,030	478,100
Boost Fuel Fraction	.317		.309	
$(T/EN)_{SLS}$	51,700	229,973 N	63,200	281,128 N

GROUP WEIGHT STATEMENT

CONFIGURATION: UR-VS (LOX/H_2)

Dynamic Pressure	1,000 psf (47,880 N/m^2)		1,300 psf (62,244 N/m^2)	
	Weight		Weight	
Component	(lb)	(kg)	(lb)	(kg)
Airframe Structure	283,163	128,441	354,826	160,946
Wing	147,497	66,904	206,142	93,504
Fuselage	80,071	36,320	83,653	37,944
H. Tail	3,777	1,713	4,045	1,835
V. Tail	8,512	3,861	9,343	4,238
Nacelles	15,519	7,039	17,656	8,009
Alighting gear	27,787	12,604	33,987	15,416
Propulsion	76,629	34,758	87,182	39,545
Engines (4)	68,697	31,160	78,158	35,452
Fuel system	7,932	3,598	9,024	4,093
Fixed Equipment	40,590	18,411	47,725	21,648
Hyd. & Pneu.	6,606	2,996	8,080	3,665
Electrical	11,131	5,048	13,614	6,175
Avionics	5,000	2,268	5,000	2,268
Instruments	4,284	1,943	5,240	2,377
De-ice/air cond.	5,085	2,307	6,220	2,821
Auxiliary gears	3,523	1,598	4,310	1,955
Furnish & equip.	1,395	633	1,395	633
Flight controls	3,566	1,618	3,866	1,754
Cruise Fuel	350,098	158,802	394,042	178,734
Payload	265,720	120,529	265,720	120,529
Crew (3)	720	327	720	327
Missiles	200,000	90,718	200,000	90,718
Payload support	15,000	6,804	15,000	6,804
Boost engines & tanks	50,000	22,680	50,000	22,680
TOTAL:	1,016,200	460,941	1,149,495	521,402
Boost Fuel Fraction	.276		.270	
$(T/EN)_{SLS}$	61,000	271,342 N	69,000	306,927 N

GROUP WEIGHT STATEMENT

CONFIGURATION: UR-VS (LOX/H_2)

Air Frame Material Technology Composite

Component	Weight (lb)	Weight (kg)
Airframe Structure	129,057	58,538
Wing	59,433	26,958
Fuselage	46,276	20,990
H. Tail	1,006	456
V. Tail	2,436	1,105
Nacelles	6,201	2,813
Alighting gear	13,705	6,216
Propulsion	43,744	19,842
Engines (4)	39,216	17,788
Fuel system	4,528	2,054
Fixed Equipment	24,628	11,168
Hyd. & Pneu.	3,258	1,477
Electrical	5,490	2,490
Avionics	5,000	2,268
Instruments	2,113	958
De-ice/air cond.	2,508	1,136
Auxiliary gears	1,738	788
Furnish & equip.	1,395	633
Flight controls	3,126	1,418
Cruise Fuel	129,120	58,568
Payload	265,720	120,529
Crew (3)	720	327
Missiles	200,000	90,718
Payload support	15,000	6,804
Boost engines & tanks	50,000	22,680
TOTAL:	592,269	268,645
Boost Fuel Fraction	.366	
$(T/EN)_{SLS}$	35,600	158,357 N

GROUP WEIGHT STATEMENT

CONFIGURATION: UR-FW (LOX/H_2)

Payload	2 - 80K M-X (36,287 kg)		4 - 80K M-X (36,287 kg)	
	Weight		Weight	
Component	(lb)	(kg)	(lb)	(kg)
Airframe Structure	183,555	83,259	267,277	121,235
Wing	80,518	36,522	135,014	61,241
Fuselage	69,429	31,492	80,784	36,643
H. Tail	1,510	685	3,439	1,559
V. Tail	3,531	1,602	6,931	3,144
Nacelles	10,249	4,649	14,792	6,710
Alighting gear	18,318	8,309	26,317	11,937
Propulsion	50,607	22,954	73,038	33,129
Engines (4)	45,369	20,579	65,478	29,700
Fuel system	5,238	2,375	7,560	3,429
Fixed Equipment	29,779	13,508	38,912	17,650
Hyd. & Pneu.	4,355	1,975	6,257	2,838
Electrical	7,338	3,328	10,542	4,782
Avionics	5,000	2,268	5,000	2,268
Instruments	2,824	1,281	4,058	1,841
De-ice/air cond.	3,352	1,520	4,816	2,185
Auxiliary gears	2,323	1,054	3,337	1,514
Furnish & equip.	1,395	633	1,395	633
Flight controls	3,192	1,448	3,507	1,591
Cruise Fuel	141,362	64,121	201,938	91,598
Payload	225,720	102,385	385,720	174,960
Crew (3)	720	327	720	327
Missiles	160,000	72,575	320,000	145,150
Payload support	15,000	6,804	15,000	6,804
Boost engines & tanks	50,000	22,680	50,000	22,680
TOTAL:	631,023	286,227	966,885	438,572
Boost Fuel Fraction	.413		.371	
$(T/EN)_{SLS}$	41,000	182,377 N	58,000	257,997 N

GROUP WEIGHT STATEMENT

CONFIGURATION: UR-FW (LOX/H_2)

Endurance	8 hr		10 hr	
	Weight		Weight	
Component	(lb)	(kg)	(lb)	(kg)
Airframe Structure	230,695	104,641	260,737	118,268
Wing	112,781	51,156	130,917	59,383
Fuselage	75,937	34,444	80,469	36,500
H. Tail	2,277	1,033	3,019	1,369
V. Tail	4,741	2,150	5,941	2,695
Nacelles	12,318	5,587	14,628	6,635
Alighting gear	22,641	10,270	25,763	11,686
Propulsion	60,823	27,589	72,231	32,763
Engines (4)	54,527	24,733	64,754	29,372
Fuel system	6,296	2,856	7,477	3,391
Fixed Equipment	34,725	15,751	38,241	17,346
Hyd. & Pneu.	5,383	2,442	6,125	2,778
Electrical	9,069	4,114	10,320	4,681
Avionics	5,000	2,268	5,000	2,268
Instruments	3,491	1,583	3,972	1,802
De-ice/air cond.	4,143	1,879	4,715	2,139
Auxiliary gears	2,871	1,302	3,267	1,482
Furnish & equip.	1,395	633	1,395	633
Flight controls	3,373	1,530	3,447	1,564
Cruise Fuel	220,272	99,914	319,353	144,856
Payload	265,720	120,529	265,720	120,529
Crew (3)	720	327	720	327
Missiles	200,000	90,718	200,000	90,718
Payload support	15,000	6,804	15,000	6,804
Boost engines & tanks	50,000	22,680	50,000	22,680
TOTAL:	812,235	368,424	956,282	433,762
Boost Fuel Fraction	.379		.371	
$(T/EN)_{SLS}$	48,700	216,628 N	57,400	255,327 N

GROUP WEIGHT STATEMENT

CONFIGURATION: UR-FW (LOX/H_2)

Dynamic Pressure	1,000 psf (47,880 N/m^2)		1,300 psf (62,244 N/m^2)	
	Weight		Weight	
Component	(lb)	(kg)	(lb)	(kg)
Airframe Structure	224,059	101,631	237,559	107,755
Wing	96,153	43,614	105,992	48,077
Fuselage	79,202	35,925	80,211	36,383
H. Tail	3,562	1,616	3,634	1,648
V. Tail	8,512	3,861	9,343	4,238
Nacelles	13,896	6,303	14,425	6,543
Alighting gear	22,734	10,312	23,954	10,865
Propulsion	68,617	31,124	71,227	32,308
Engines (4)	61,514	27,902	63,854	28,964
Fuel system	7,103	3,222	7,373	3,344
Fixed Equipment	34,904	15,832	36,388	16,505
Hyd. & Pneu.	5,405	2,452	5,695	2,583
Electrical	9,107	4,131	9,596	4,353
Avionics	5,000	2,268	5,000	2,268
Instruments	3,505	1,590	3,693	1,675
De-ice/air cond.	4,160	1,887	4,384	1,989
Auxiliary gears	2,883	1,308	3,037	1,378
Furnish & equip.	1,395	633	1,395	633
Flight controls	3,449	1,564	3,588	1,627
Cruise Fuel	321,163	145,677	336,786	152,764
Payload	265,720	120,529	265,720	120,529
Crew (3)	720	327	720	327
Missiles	200,000	90,718	200,000	90,718
Payload support	15,000	6,804	15,000	6,804
Boost engines & tanks	50,000	22,680	50,000	22,680
TOTAL:	914,463	414,793	947,680	429,860
Boost Fuel Fraction	.322		.321	
$(T/EN)_{SLS}$	54,900	244,207 N	56,900	253,104 N

GROUP WEIGHT STATEMENT

CONFIGURATION: UR-FW (LOX/H_2)

Airframe Material Technology Composite

Component	Weight (lb)	Weight (kg)
Airframe Structure	123,860	56,182
Wing	54,178	24,575
Fuselage	47,138	21,381
H. Tail	942	427
V. Tail	2,308	1,047
Nacelles	6,055	2,747
Alighting gear	13,239	6,005
Propulsion	42,714	19,375
Engines (4)	38,293	17,369
Fuel system	4,421	2,006
Fixed Equipment	24,183	10,969
Hyd. & Pneu.	3,148	1,428
Electrical	5,303	2,405
Avionics	5,000	2,268
Instruments	2,041	926
De-ice/air cond.	2,423	1,099
Auxiliary gears	1,679	762
Furnish & equip.	1,395	633
Flight controls	3,194	1,449
Cruise Fuel	122,515	55,572
Payload	265,720	120,529
Crew (3)	720	327
Missiles	200,000	90,718
Payload support	15,000	6,804
Boost engines & tanks	50,000	22,680
TOTAL:	578,992	262,626
Boost Fuel Fraction	.431	
$(T/EN)_{SLS}$	34,800	154,798 N

APPENDIX C

DEVELOPMENT AND ACQUISITION COST DETAILS

Development and acquisition costs are presented as a function of fleet size. No cruise engine development costs were associated with any of the concepts since existing CF-6 or JT-9 engines were used. Each aircraft required four cruise engines. The costs for the engines and boost propulsion include an additional five aircraft for test purposes. Cost sensitivity to changes in complexity factor are tabulated. Included are group weight statements for the UR-FW-UDMH configuration for 320,000 lb (145,150 kg) of payload and for 10 percent changes in both payload and endurance. These weights were used to obtain cost sensitivity information for changes in these two parameters. The configuration notation is given in Appendix A.

DEVELOPMENT AND ACQUISITION COST

CONFIGURATION: SR-2P

(All costs in millions of dollars)

	Develop.	Acquisition			
		Number of Aircraft			
		56	112	167	223
Airframe	528	803	1,263	1,631	1,960
Propulsion	0	244	468	688	912
Avionics	63	47	85	118	151
Support	209	409	676	902	1,112
Facilities	0	220	220	220	220
Boost System	0	366	702	1,032	1,368
TOTAL:	800	2,089	3,414	4,591	5,723

No. Aircraft	Total Dev. & Acq. Cost
56	2,889
112	4,214
167	5,391
223	6,523

DEVELOPMENT AND ACQUISITION COST

CONFIGURATION: SR-VS

(All costs in millions of dollars)

	Develop.	Acquisition Number of Aircraft			
		56	112	167	223
Airframe	547	825	1,297	1,675	2,013
Propulsion	0	244	468	688	912
Avionics	63	47	85	118	151
Support	212	414	684	912	1,124
Facilities	0	220	220	220	220
Boost System	0	366	702	1,032	1,368
TOTAL:	822	2,116	3,456	4,645	5,788

No. Aircraft	Total Dev. & Acq. Cost
56	2,938
112	4,278
167	5,467
223	6,610

DEVELOPMENT AND ACQUISITION COST

CONFIGURATION: SR-FW

(All costs in millions of dollars)

		Acquisition			
		Number of Aircraft			
	Develop.	56	112	167	223
Airframe	540	817	1,285	1,660	1,994
Propulsion	0	244	468	688	912
Avionics	63	47	85	118	151
Support	210	411	679	906	1,116
Facilities	0	220	220	220	220
Boost System	0	336	702	1,032	1,368
TOTAL:	813	2,105	3,439	4,624	5,761

No. Aircraft	Total Dev. & Acq. Cost
56	2,918
112	4,252
167	5,437
223	6,574

DEVELOPMENT AND ACQUISITION COST

CONFIGURATION: UR-2P (LOX/H_2)

(All costs in millions of dollars)

	Develop.	Acquisition			
		Number of Aircraft			
		56	112	167	223
Airframe	788	1,086	1,702	2,194	2,635
Propulsion	0	244	468	688	912
Avionics	63	47	85	118	151
Support	286	539	888	1,183	1,457
Facilities	0	220	220	220	220
Boost Systems	0	1,220	2,340	3,440	4,560
TOTAL:	1,137	3,356	5,703	7,843	9,935

No. Aircraft	Total Dev. & Acq. Cost
56	4,493
112	6,840
167	8,980
223	11,072

DEVELOPMENT AND ACQUISITION COST

CONFIGURATION: UR-VS (LOX/H_2)

(All costs in millions of dollars)

	Develop.	Acquisition			
		Number of Aircraft			
		56	112	167	223
Airframe	778	1,076	1,686	2,174	2,610
Propulsion	0	244	468	688	912
Avionics	63	47	85	118	151
Support	277	524	862	1,147	1,411
Facilities	0	220	220	220	220
Boost System	0	1,220	2,340	3,440	4,560
TOTAL:	1,118	3,331	5,661	7,787	9,864

No. Aircraft	Total Dev. & Acq. Cost
56	4,449
112	6,779
167	8,905
223	10,982

DEVELOPMENT AND ACQUISITION COST

CONFIGURATION: UR-FW (LOX/H_2)

(All costs in millions of dollars)

	Develop.	Acquisition Number of Aircraft 56	112	167	223
Airframe	721	1,015	1,592	2,054	2,467
Propulsion	0	244	468	688	912
Avionics	63	47	85	118	151
Support	263	501	825	1,098	1,352
Facilities	0	220	220	220	220
Boost System	0	1,220	2,340	3,440	4,560
TOTAL:	1,047	3,247	5,530	7,618	9,662

No. Aircraft	Total Dev. & Acq. Cost
56	4,294
112	6,577
167	8,665
223	10,709

DEVELOPMENT AND ACQUISITION COST

CONFIGURATION: UR-2P (UDMH)

(All costs in millions of dollars)

	Develop.	Acquisition Number of Aircraft			
		56	112	167	223
Airframe	694	987	1,548	1,997	2,399
Propulsion	0	244	468	688	912
Avionics	63	47	85	118	151
Support	262	500	825	1,100	1,355
Facilities	0	220	220	220	220
Boost System	800	1,220	2,340	3,440	4,560
TOTAL:	1,819	3,218	5,486	7,563	9,597

No. Aircraft	Total Dev. & Acq. Cost
56	5,037
112	7,305
167	9,382
223	11,416

DEVELOPMENT AND ACQUISITION COST

CONFIGURATION: UR-FW (UDMH)

(All costs in millions of dollars)

		Acquisition Number of Aircraft			
	Develop.	56	112	167	223
Airframe	685	978	1,534	1,979	2,377
Propulsion	0	244	468	688	912
Avionics	63	47	85	118	151
Support	252	482	794	1,058	1,302
Facilities	0	220	220	220	220
Boost System	800	1,220	2,340	3,440	4,560
TOTAL:	1,800	3,191	5,441	7,503	9,522

No. Aircraft	Total Dev. & Acq. Cost
56	4,991
112	7,241
167	9,303
223	11,322

DEVELOPMENT AND ACQUISITION COST

CONFIGURATION: UR-FW (UDMH)

5% increase in (labor + engineering + tooling) hours

(All costs in millions of dollars)

	Develop.	Acquisition Number of Aircraft 56	112	167	223
Airframe	724	1,029	1,612	2,078	2,494
Propulsion	0	244	468	688	912
Avionics	63	47	85	118	151
Support	268	512	844	1,124	1,384
Facilities	0	220	220	220	220
Boost System	800	1,220	2,340	3,440	4,560
TOTAL:	1,855	3,272	5,569	7,668	9,721

No. Aircraft	Total Dev. & Acq. Cost
56	5,127
112	7,424
167	9,523
223	11,576

DEVELOPMENT AND ACQUISITION COST

CONFIGURATION: UR-FW (UDMH)

10% increase in (labor + engineering + tooling) hours

(All costs in millions of dollars)

		Acquisition			
		Number of Aircraft			
	Develop.	56	112	167	223
Airframe	751	1,066	1,668	2,149	2,578
Propulsion	0	244	468	688	912
Avionics	63	47	85	118	151
Support	273	524	861	1,146	1,409
Facilities	0	220	220	220	220
Boost System	800	1,220	2,340	3,440	4,560
TOTAL:	1,887	3,321	5,642	7,761	9,830

No. Aircraft	Total Dev. & Acq. Cost
56	5,208
112	7,529
167	9,648
223	11,717

GROUP WEIGHT STATEMENT

CONFIGURATION: UR-FW (UDMH)

10% endurance and payload change for economic study

Payload = 220,000 lb (99,790 kg)   Endurance = 6.6 hr

Component	Weight (lb)	Weight (kg)	Weight (lb)	Weight (kg)
Airframe Structure	187,904	85,231	182,134	82,615
Wing	89,815	40,739	87,839	39,843
Fuselage	63,503	28,804	62,252	28,237
H. Tail	2,352	1,067	1,836	833
V. Tail	5,141	2,332	3,901	1,769
Nacelles	8,934	4,052	8,678	3,936
Alighting gear	18,159	8,237	17,628	7,996
Propulsion	44,114	20,010	42,852	19,437
Engines (4)	39,548	17,939	38,416	17,425
Fuel system	4,566	2,071	4,436	2,012
Fixed Equipment	29,644	13,446	28,986	13,148
Hyd. & Pneu.	4,317	1,958	4,191	1,901
Electrical	7,274	3,299	7,061	3,203
Avionics	5,000	2,268	5,000	2,268
Instruments	2,800	1,270	2,718	1,233
De-ice/air cond.	3,323	1,507	3,226	1,463
Auxiliary gears	2,303	1,045	2,235	1,014
Furnish & equip.	1,395	633	1,395	633
Flight controls	3,232	1,466	3,160	1,433
Cruise Fuel	140,068	63,534	151,132	68,552
Payload	275,720	125,064	255,720	115,993
Crew (3)	720	327	720	327
Missiles	220,000	99,790	200,000	90,718
Payload support	15,000	6,804	15,000	6,804
Boost engines & tanks	40,000	18,144	40,000	18,144
TOTAL:	677,450	307,286	660,824	299,745
Boost Fuel Fraction	.488		.491	
$(T/EN)_{SLS}$	42,400	188,605 N	41,300	183,712 N

DEVELOPMENT AND ACQUISITION COST

CONFIGURATION: UR-FW (UDMH)

Payload = 220,000 lb (99,790 kg)

(All costs in millions of dollars)

		Acquisition			
		Number of Aircraft			
	Develop.	56	112	167	223
Airframe	709	1,003	1,573	2,030	2,438
Propulsion	0	244	468	688	912
Avionics	63	47	85	118	151
Support	261	499	822	1,095	1,349
Facilities	0	220	220	220	220
Boost System	800	1,220	2,340	3,440	4,560
TOTAL:	1,833	3,233	5,508	7,591	9,630

No. Aircraft	Total Dev. & Acq. Cost
56	5,066
112	7,341
167	9,424
223	11,463

DEVELOPMENT AND ACQUISITION COST

CONFIGURATION: UR-FW (UDMH)

Endurance = 6.6 hours

(All costs in millions of dollars)

		Acquisition			
		Number of Aircraft			
	Develop.	56	112	167	223
Airframe	693	987	1,547	1,997	2,399
Propulsion	0	244	468	688	912
Avionics	63	47	85	118	151
Support	257	491	809	1,079	1,329
Facilities	0	220	220	220	220
Boost System	800	1,220	2,340	3,440	4,560
TOTAL:	1,813	3,209	5,469	7,542	9,571

No. Aircraft	Total Dev. & Acq. Cost
56	5,022
112	7,282
167	9,355
223	11,384

GROUP WEIGHT STATEMENT

CONFIGURATION: UR-FW-UDMB

Component	Weight (lb)	Weight (kg)
	Payload 320,000 lb (145,150 kg)	
Airframe Structure	233,747	106,026
Wing	103,485	46,940
Fuselage	80,824	36,661
H. Tail	3,198	1,451
V. Tail	6,766	3,069
Nacelles	5,832	2,645
Alighting gear	33,642	15,260
Propulsion	57,597	26,126
Engines (4)	51,635	23,421
Fuel system	5,962	2,705
Fixed Equipment	40,919	18,560
Hyd. & Pneu.	4,446	2,017
Electrical	13,475	6,112
Avionics	5,000	2,268
Instruments	3,300	1,497
De-ice/air cond.	7,333	3,326
Auxiliary gears	3,208	1,455
Furnish & equip.	1,395	633
Flight controls	2,762	1,253
Cruise Fuel	205,696	93,302
Payload	375,720	170,424
Crew (3)	720	327
Missiles	320,000	145,150
Payload support	15,000	6,804
Boost engines & tanks	40,000	18,144
TOTAL:	913,679	414,438
Boost Fuel Fraction	.455	
$(T/EN)_{SLS}$	55,300	245,987 N

DEVELOPMENT AND ACQUISITION COST

CONFIGURATION: UR-FW-UDMH

Payload 320,000 lb (145,150 kg) (4 - 80K M-X)

(All costs in millions of dollars)

	Develop.	Acquisition Number of Aircraft 28	56	84	112	223
Airframe	840	716	1,140	1,488	1,784	2,762
Propulsion	0	132	244	356	468	912
Avionics	63	26	47	66	85	151
Support	305	344	571	767	941	1,545
Facilities	0	220	220	220	220	220
Boost System	800	660	1,220	1,780	2,340	4,560
TOTAL:	2,008	2,098	3,442	4,677	5,838	10,150

No. Aircraft	Total Dev. & Acq. Cost
28	4,106
56	5,450
84	6,685
112	7,846
223	12,158

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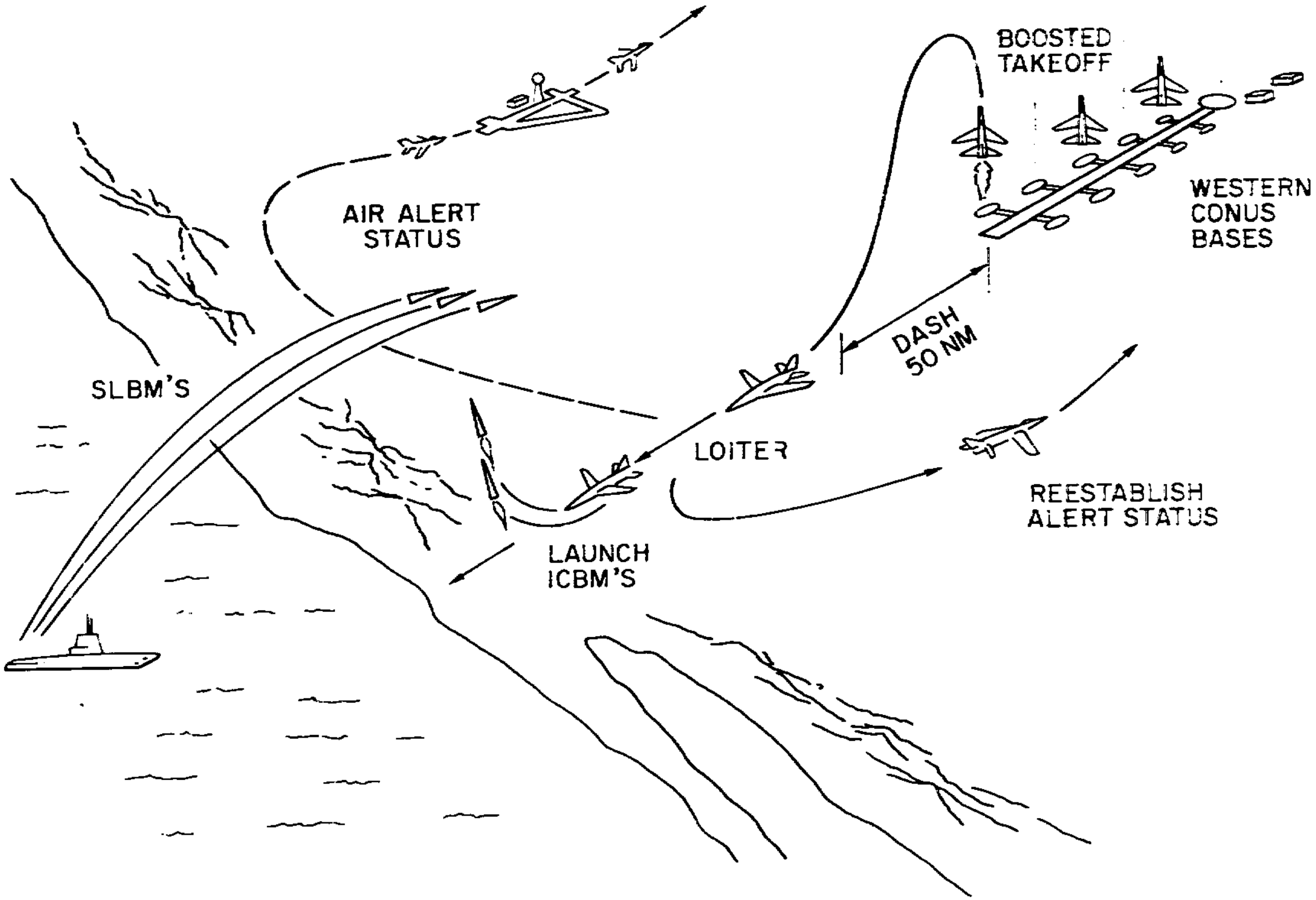


Figure 1.- Concept of high performance dash on warning.

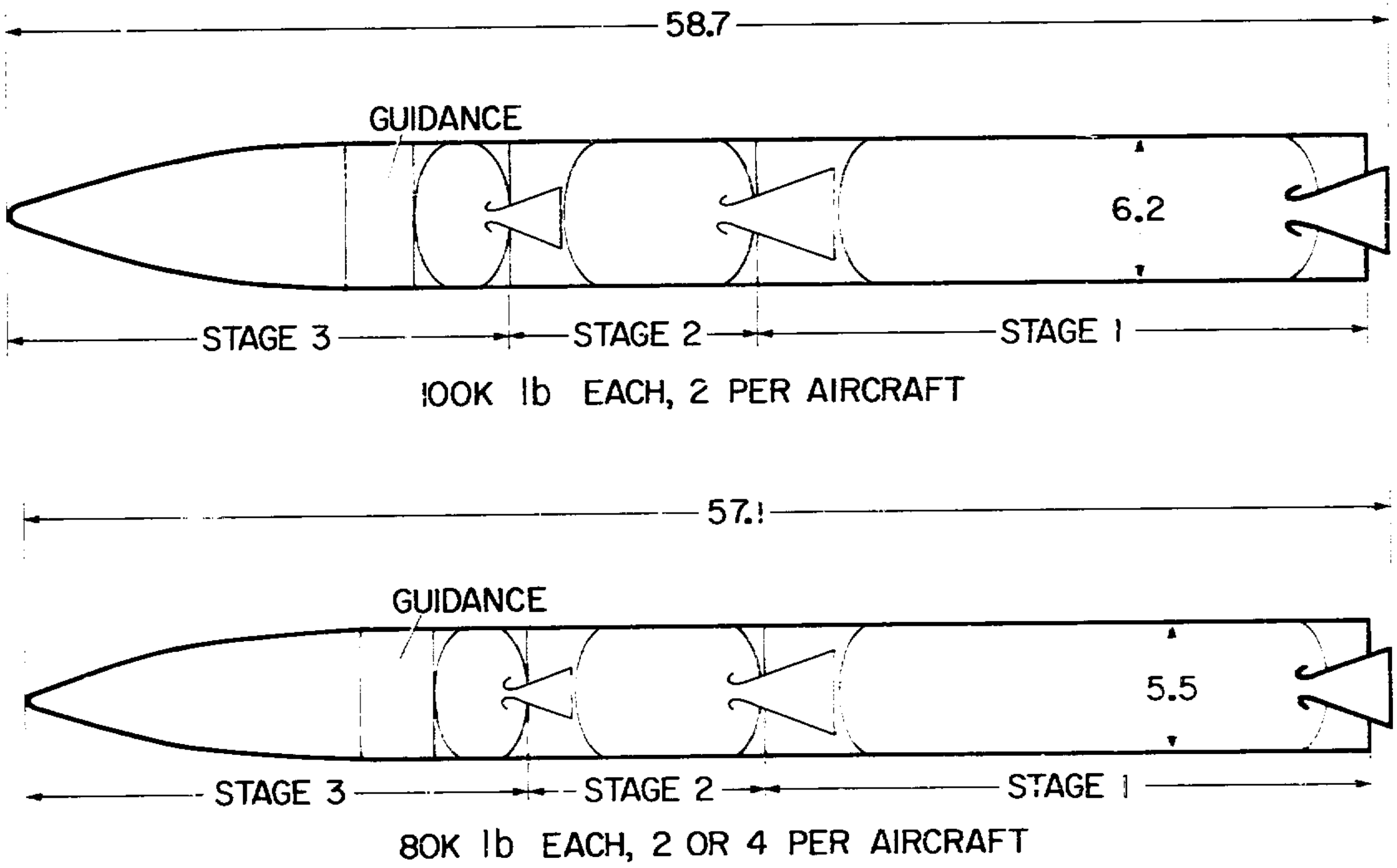
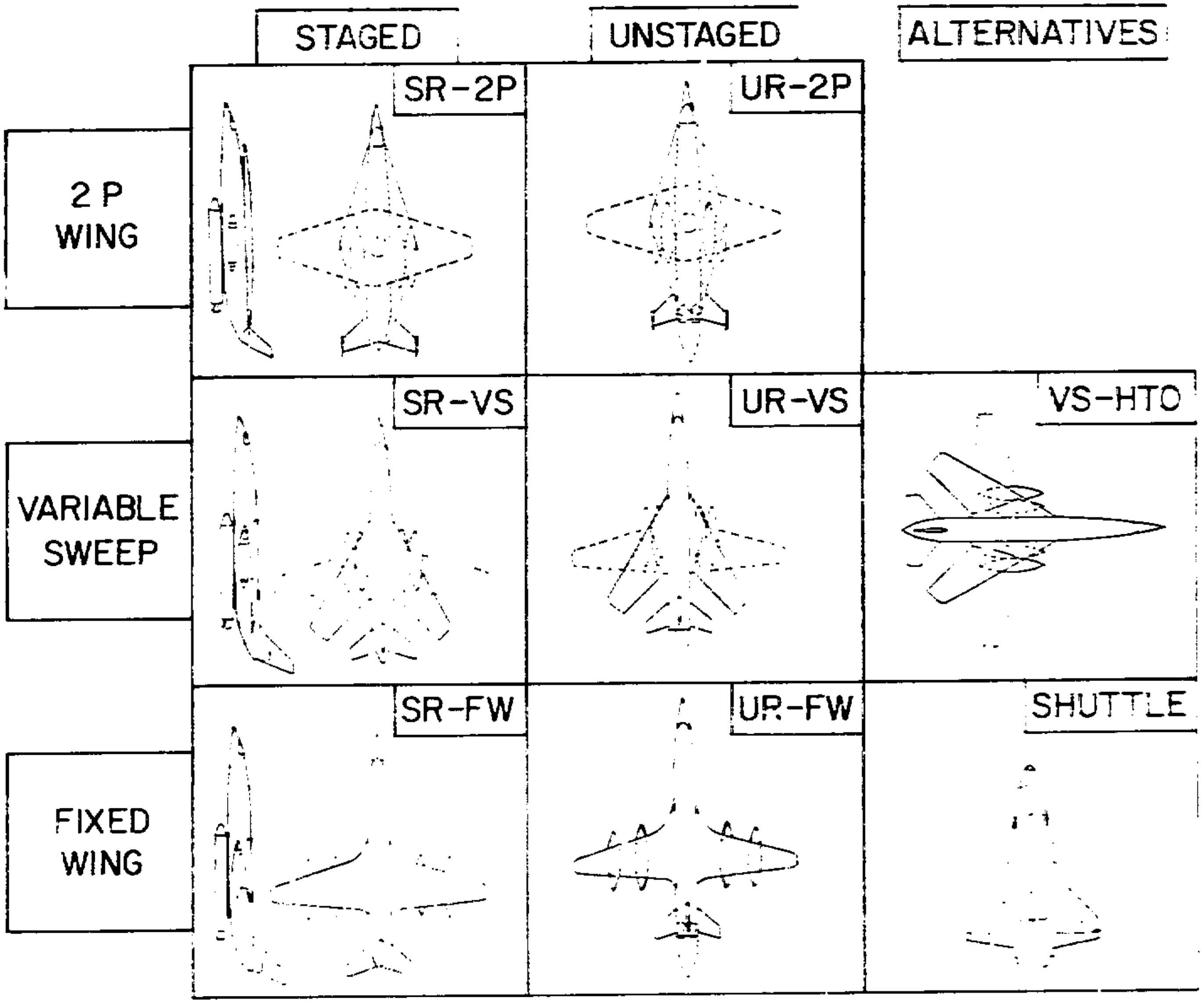
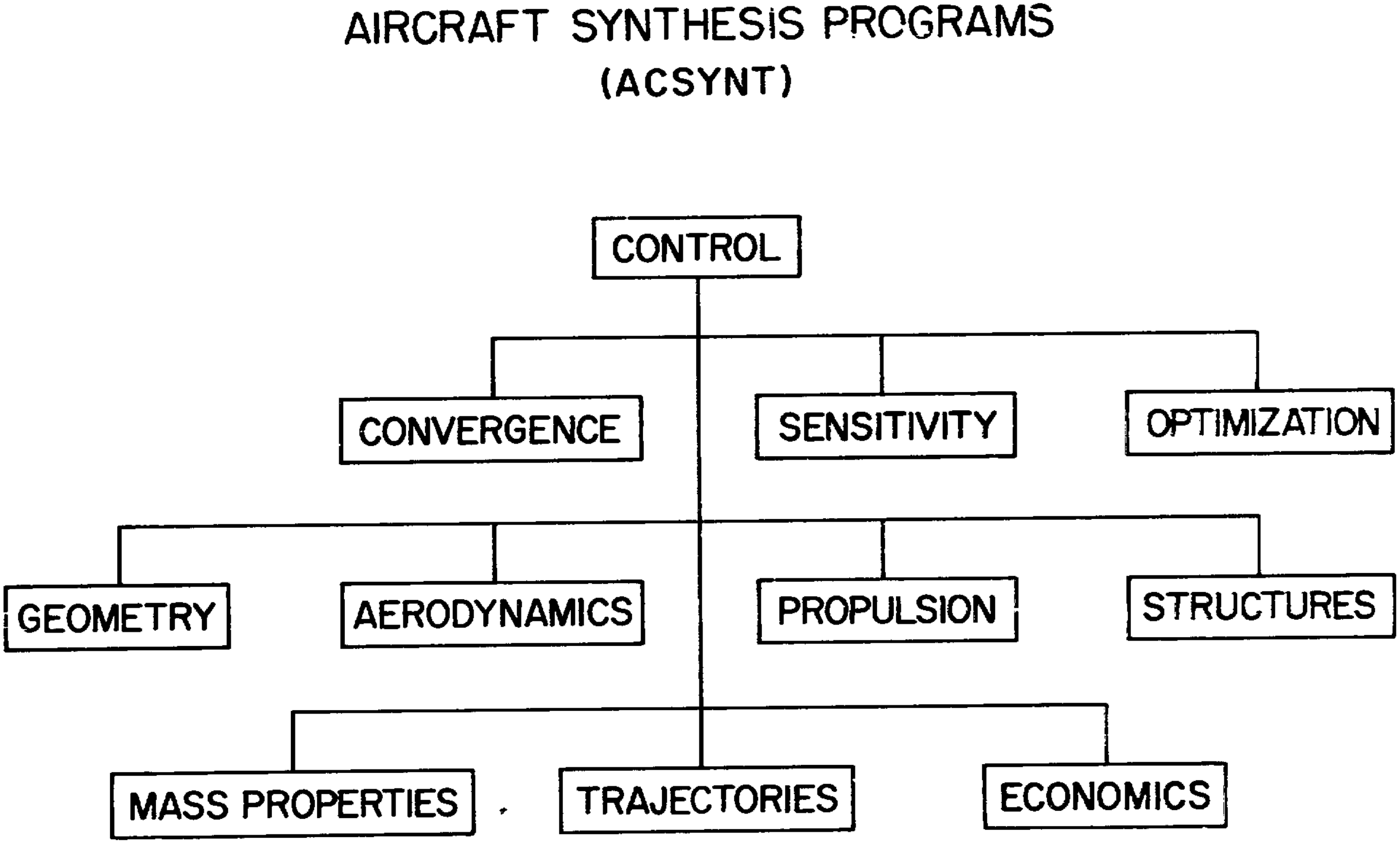


Figure 2.- Missile designs.


STAGED
UNSTAGED
ALTERNATIVES
2 P WING
VARIABLE SWEEP
FIXED WING
SR-2P
UR-2P
SR-VS
UR-VS
VS-HTO
SR-FW
UR-FW
SHUTTLE

[illegible]



AIRCRAFT SYNTHESIS PROGRAMS
(ACSYNT)

Figure 4.- Synthesis program block diagram.

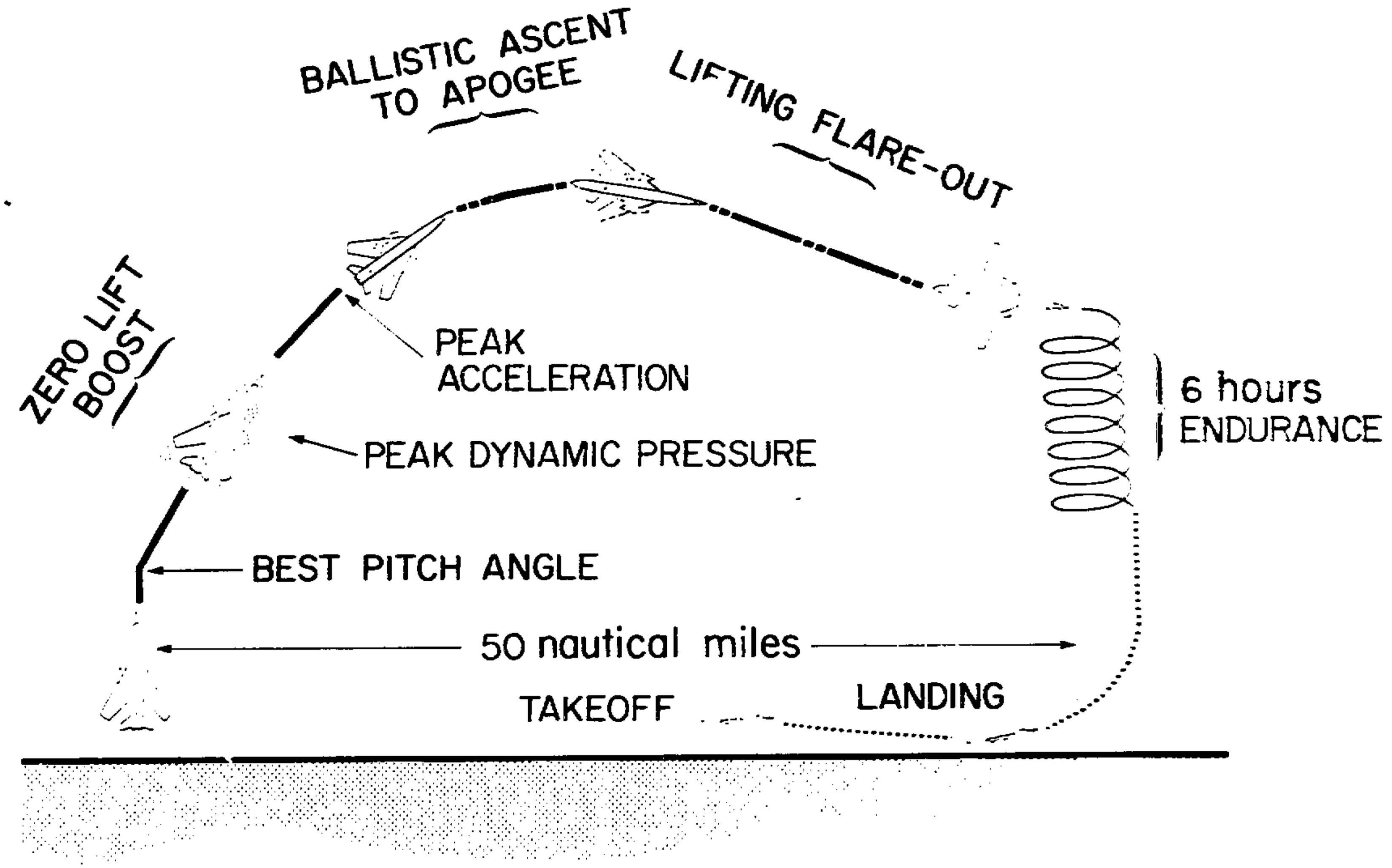


Figure 5.- Ballistic mission profile.

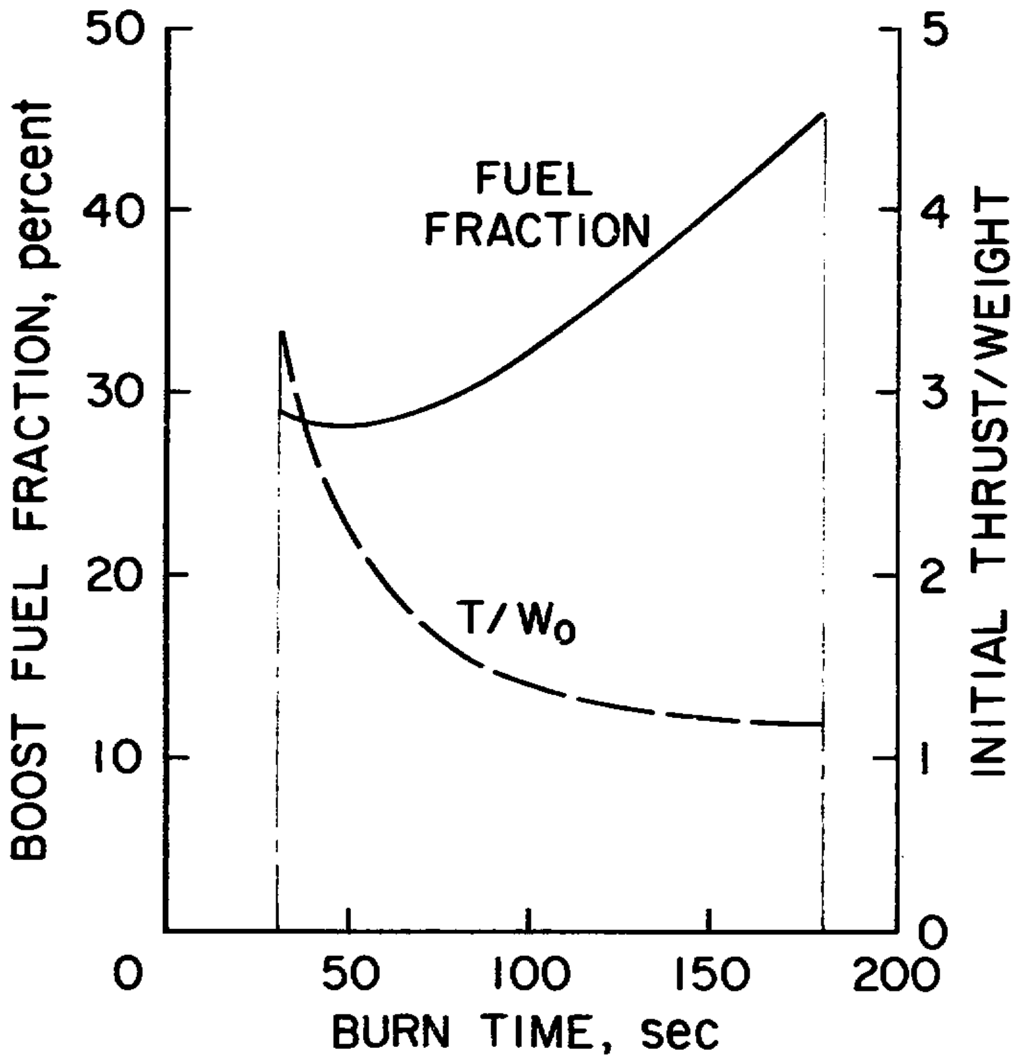


Figure 6.- Boost fuel fraction and thrust-to-weight ratio; ballistic profile; LOX/H_2.

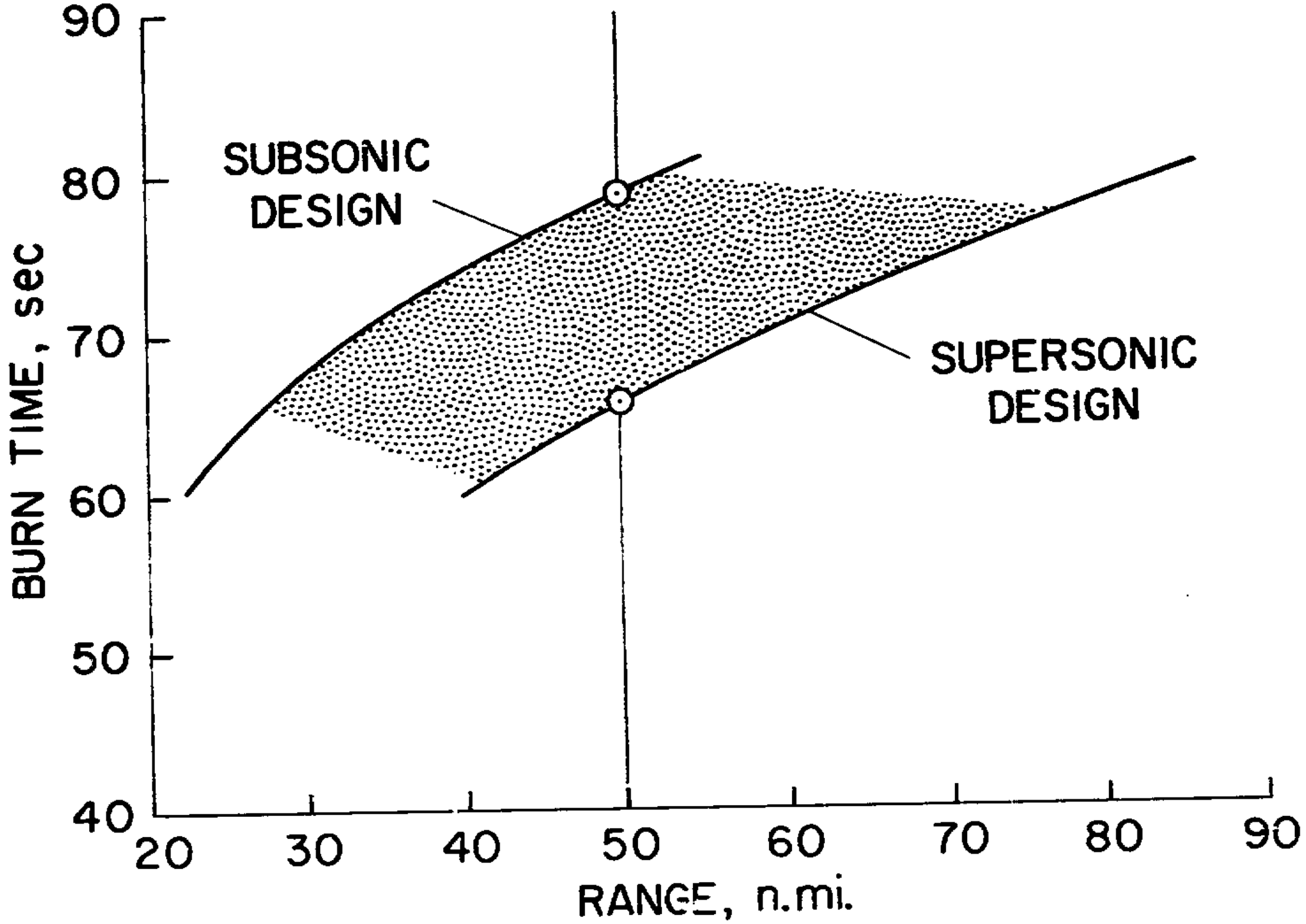


Figure 7.- Effect of aircraft design on boost fuel requirement.

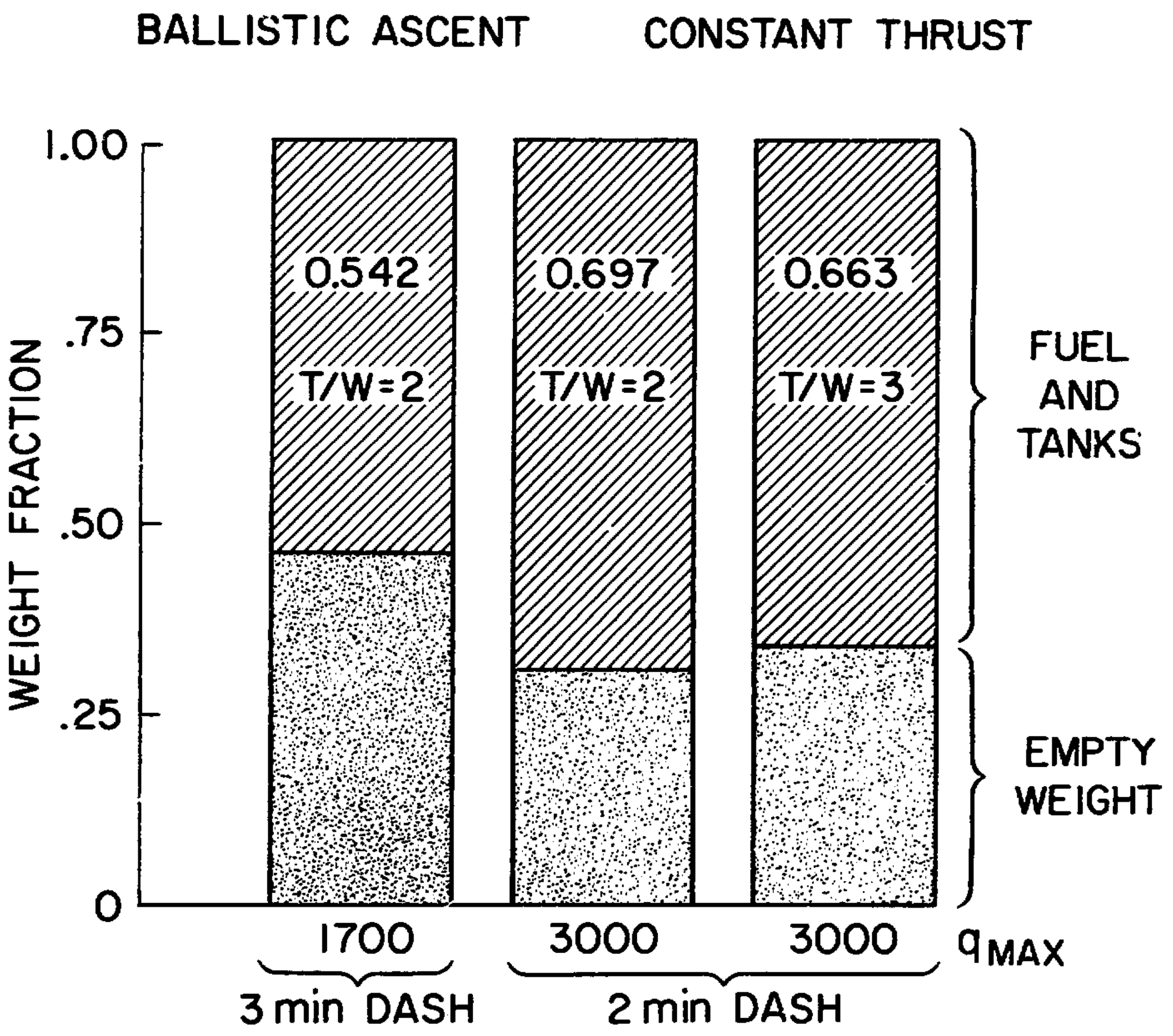


Figure 8.- Effect of dash time on boost fuel fraction.

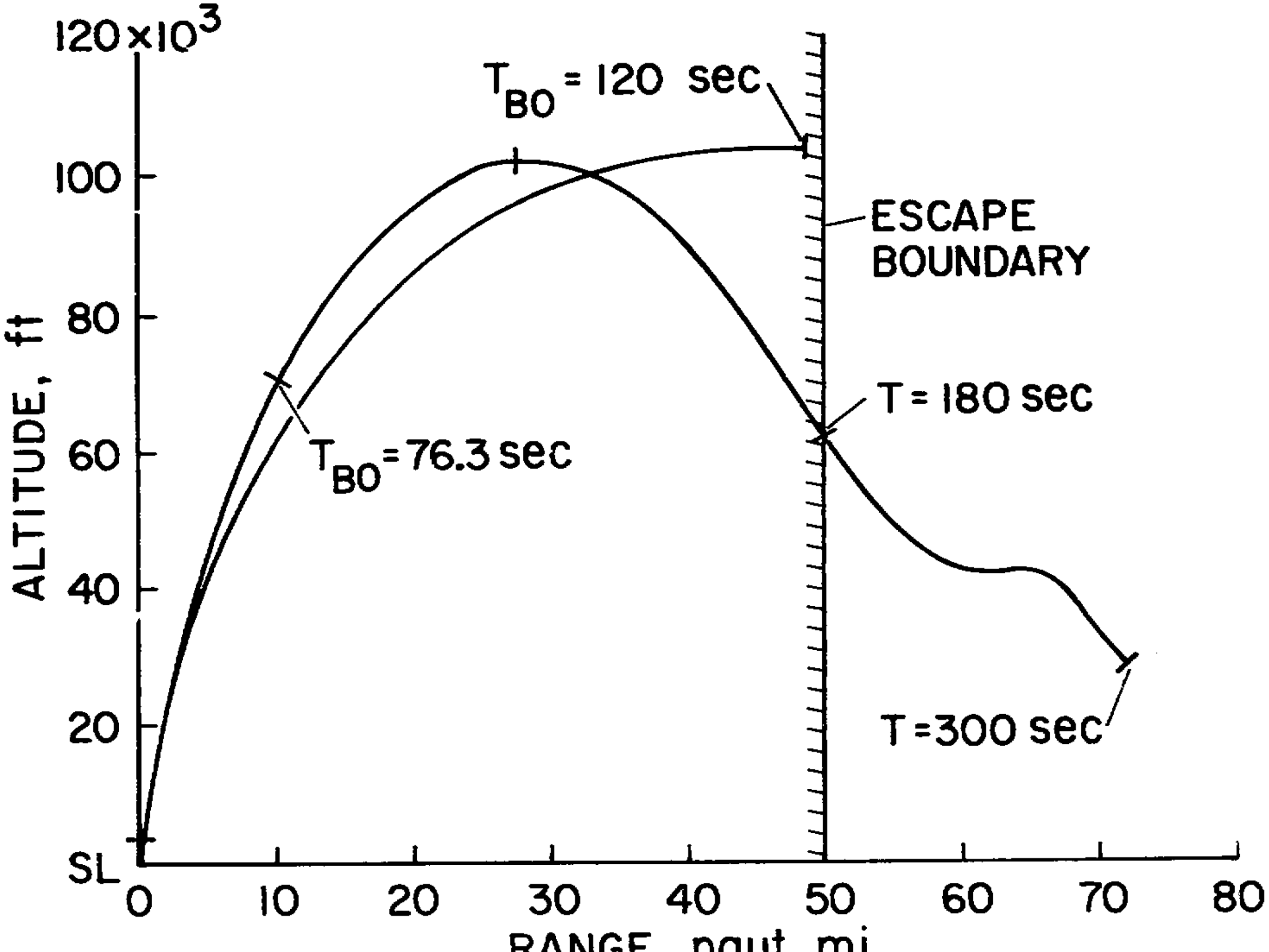


Figure 9.- Typical VTO range-altitude flight profiles.

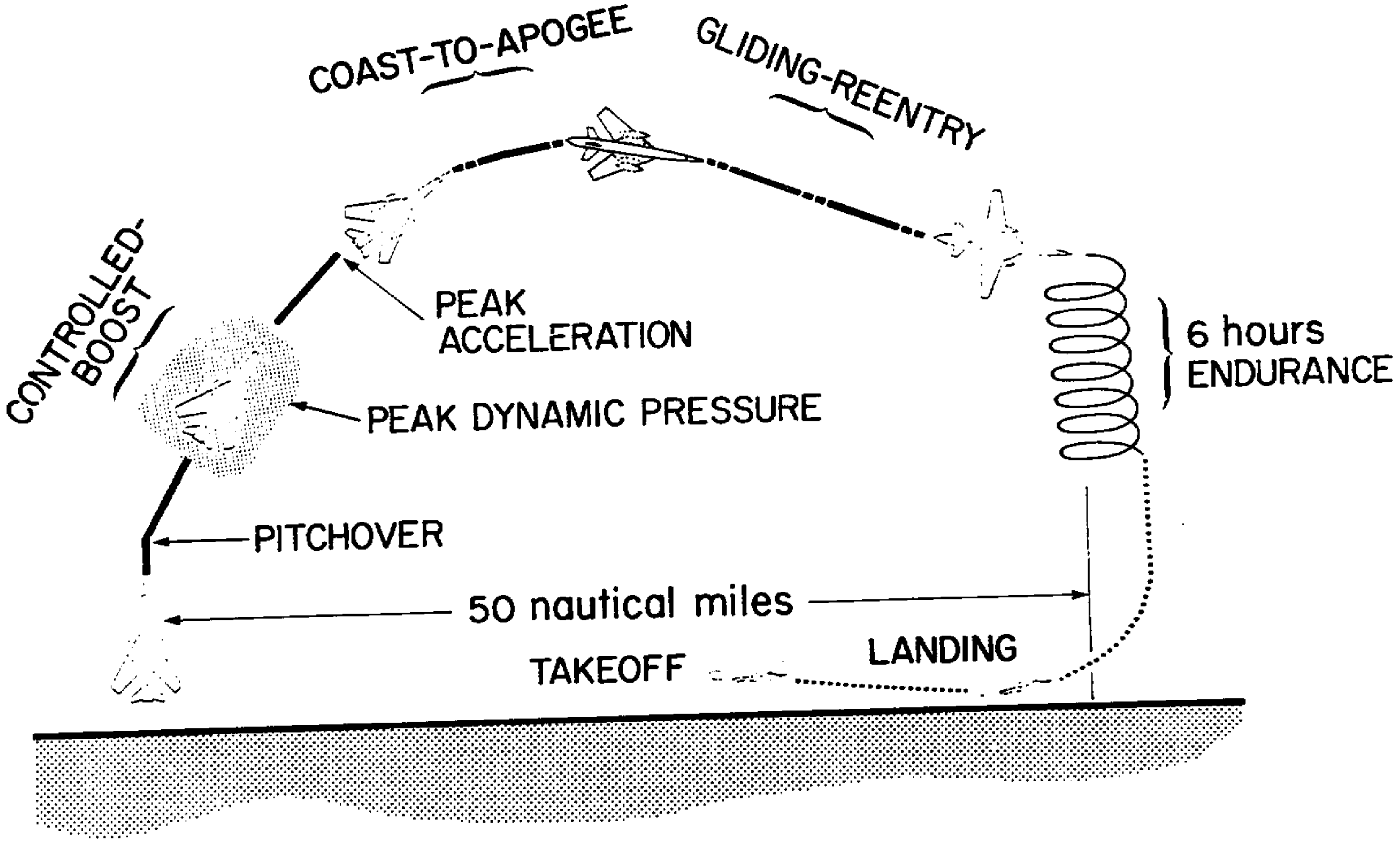


Figure 10.- Throttle and angle-of-attack controlled mission profile.

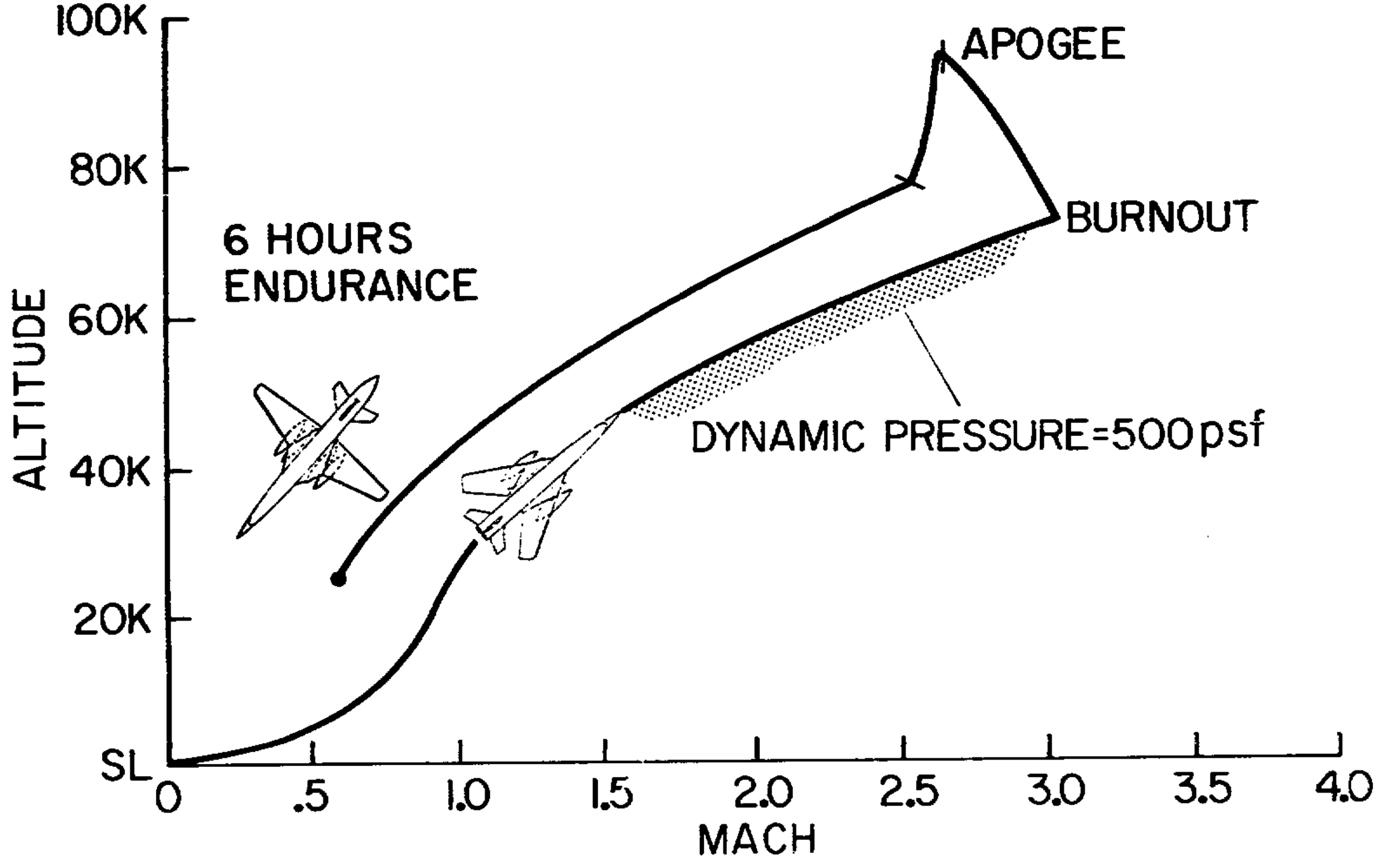


Figure 11.- Typical trajectory; throttle and angle-of-attack profile.

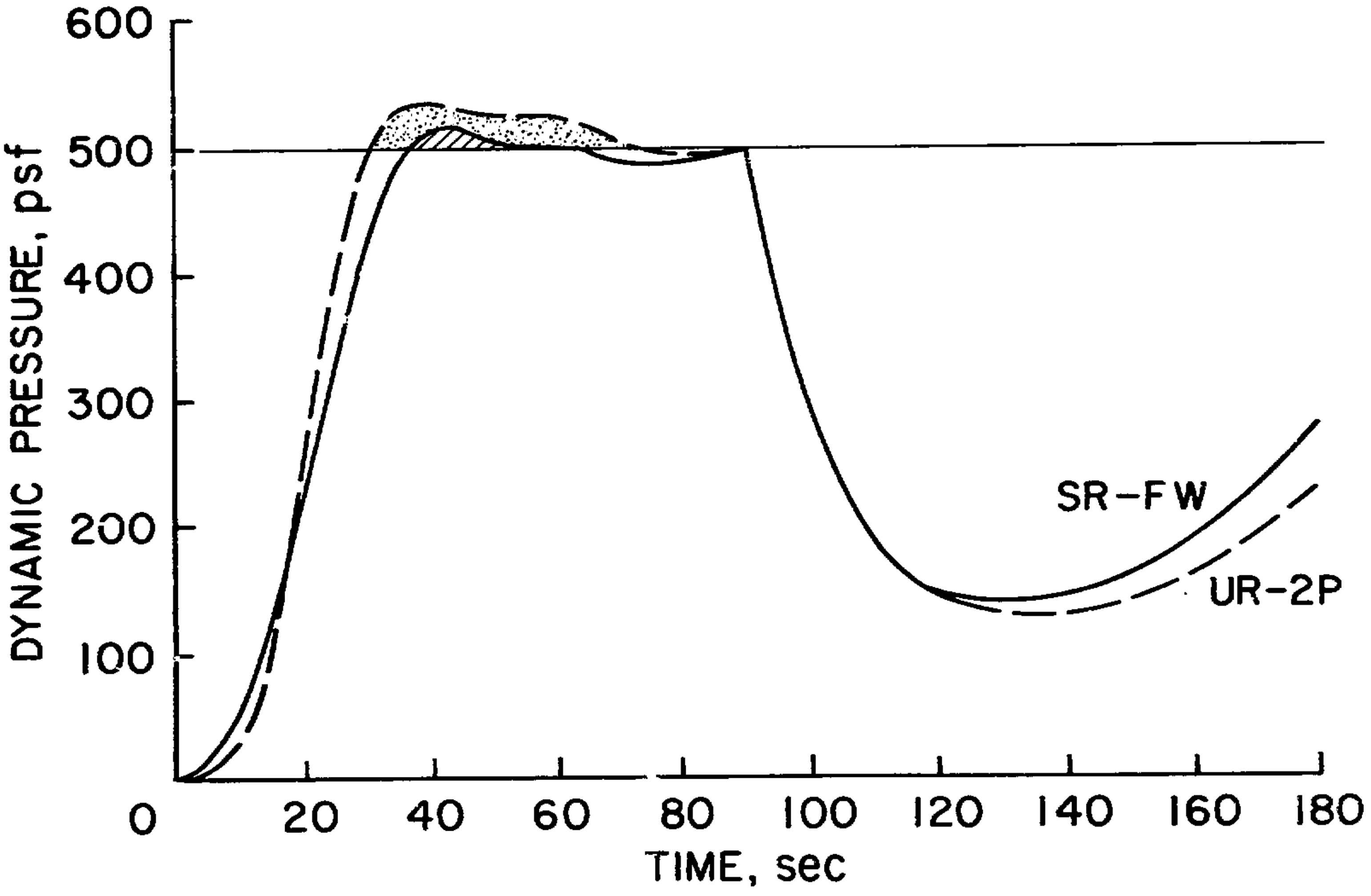


Figure 12.- Typical dynamic pressure time histories; throttle and angle-of-attack profile.

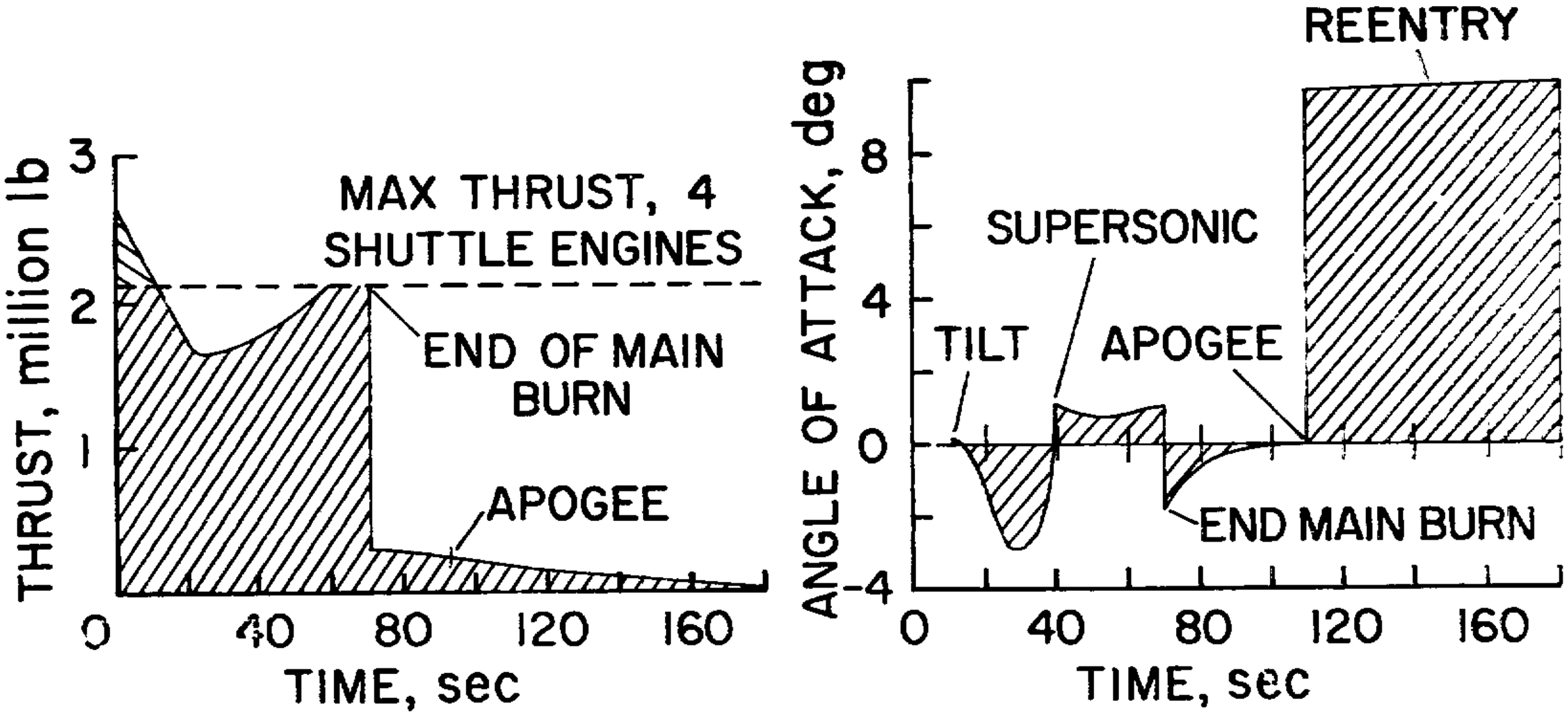


Figure 13.- Typical control histories for throttle and angle-of-attack profile.

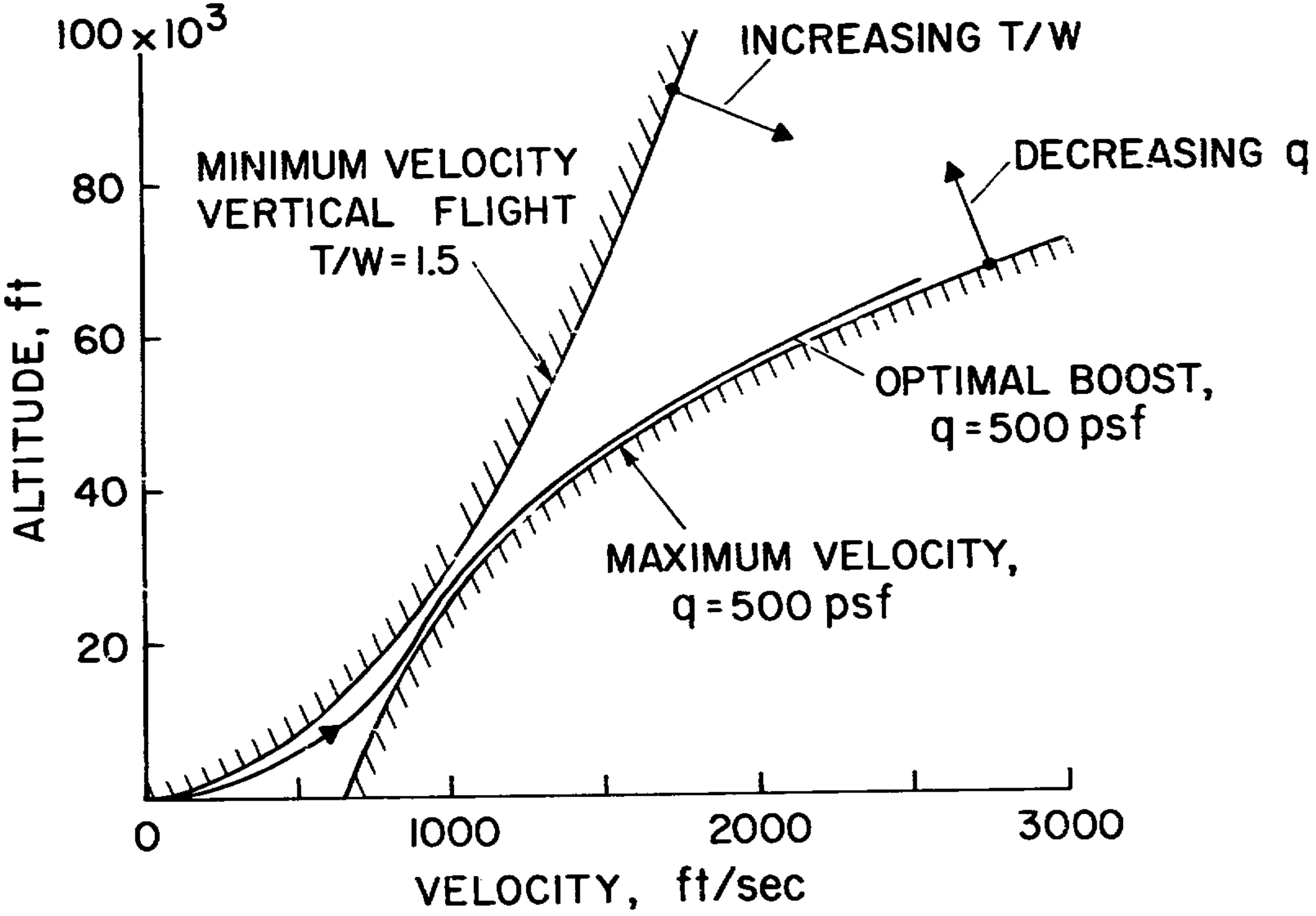


Figure 14.- Optimal boost corridor; dynamic pressure = 500 psf.

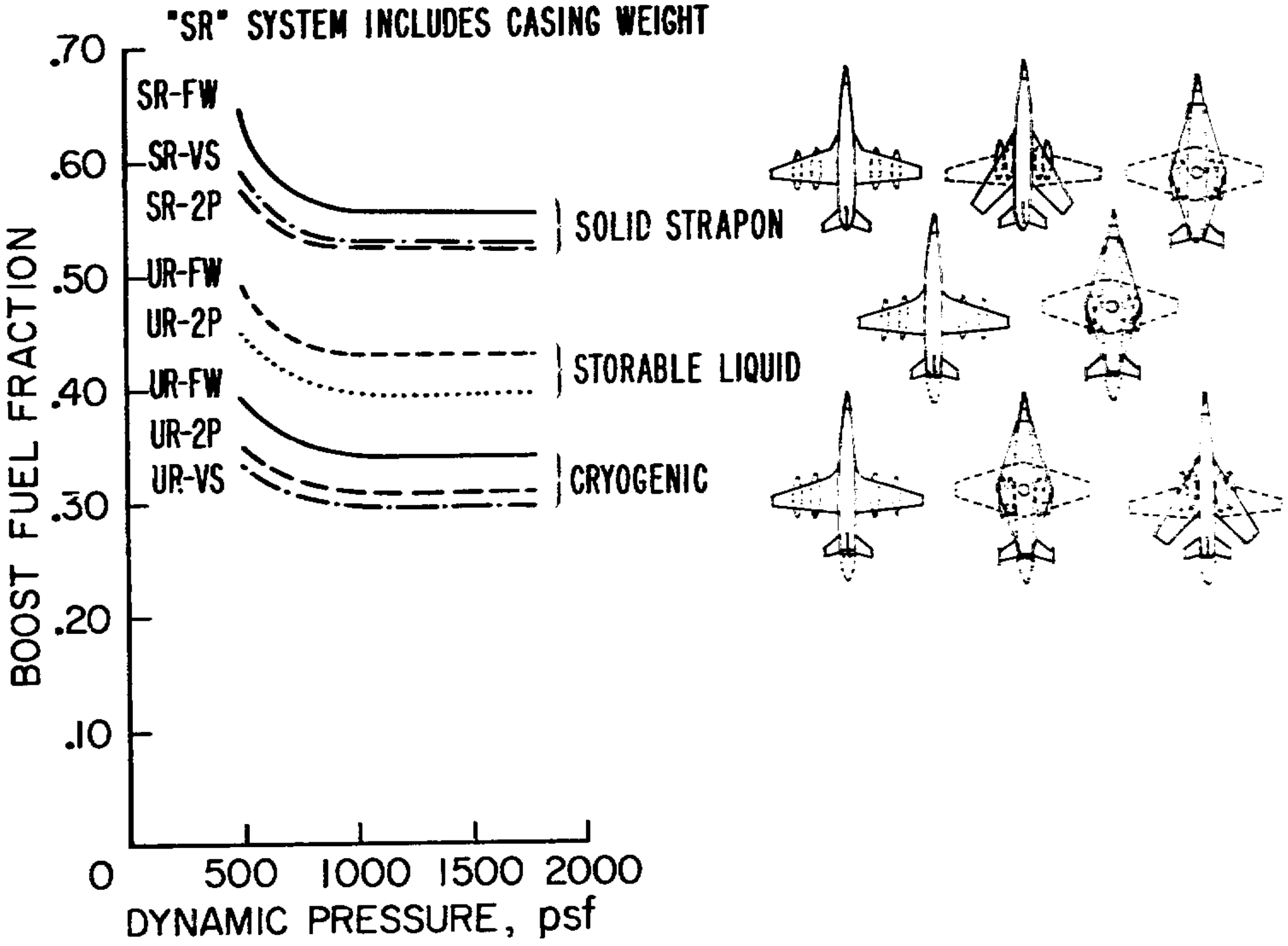


Figure 15.- Variation of boost fuel fraction with boost dynamic pressure.

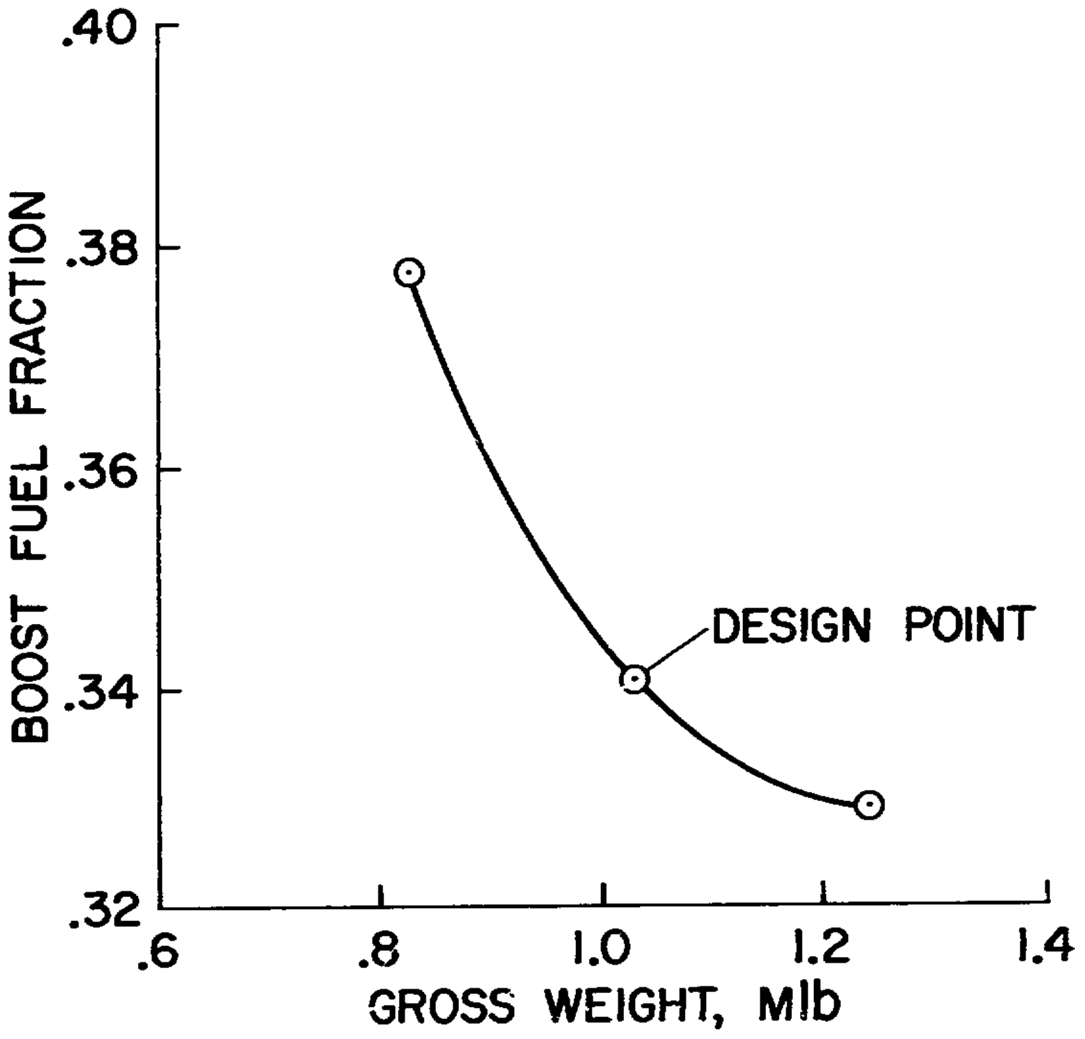


Figure 16.- Effect of vehicle weight on boost fuel fraction.

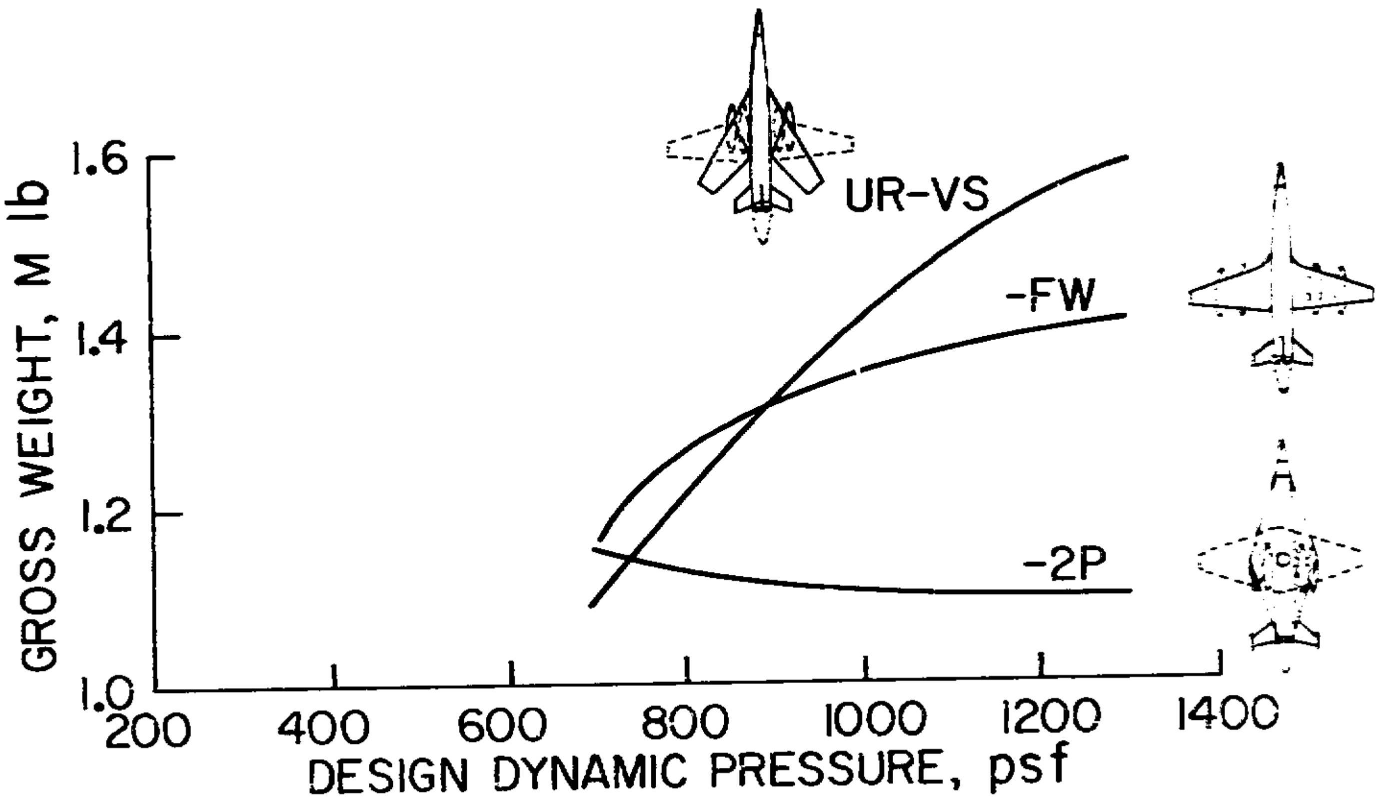


Figure 17.- Variation of gross weight with design dynamic pressure.

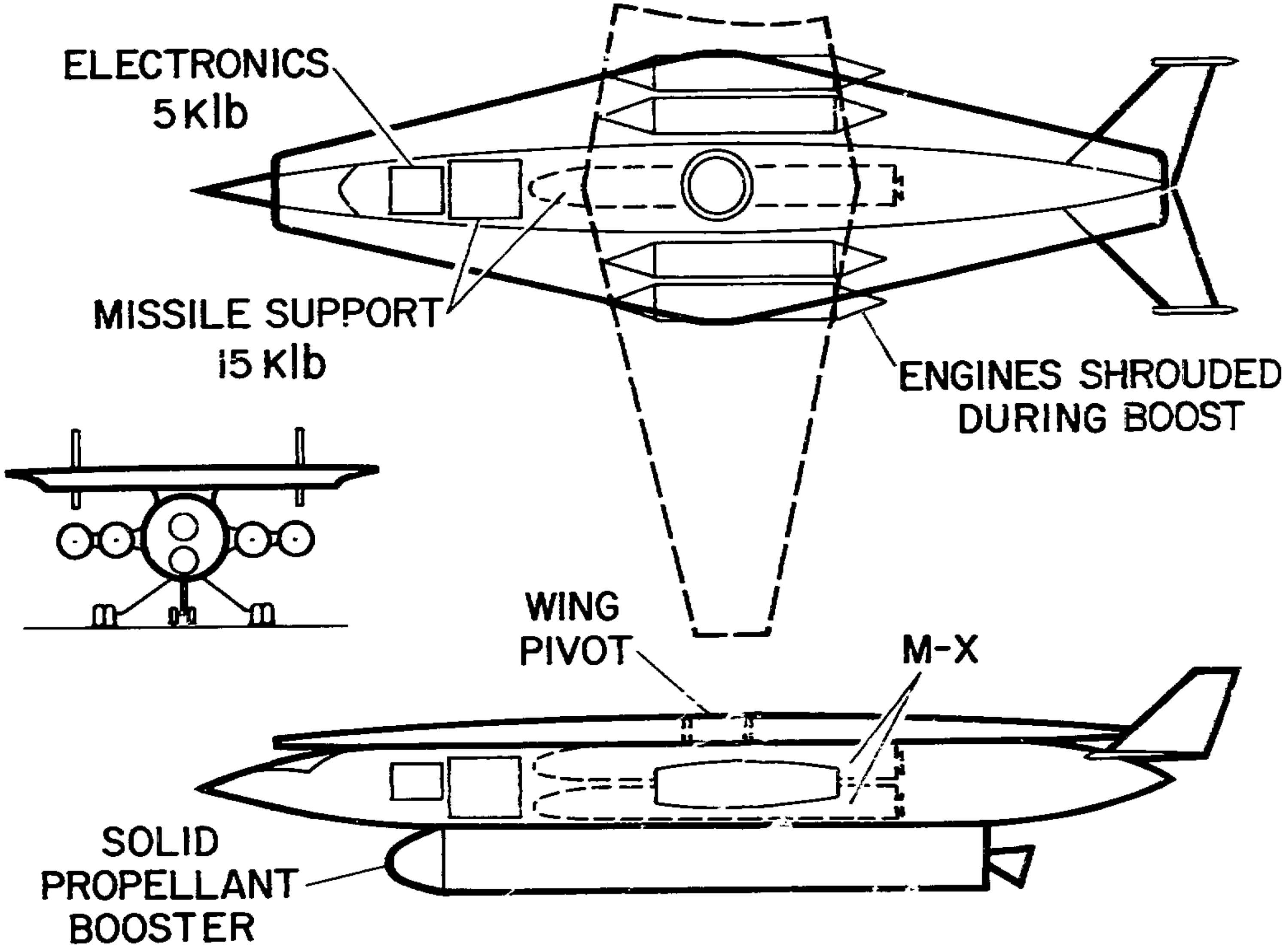


Figure 18.- Staged rocket, two-position wing configuration; body length = [illegible] ft; wing span = [illegible] ft.

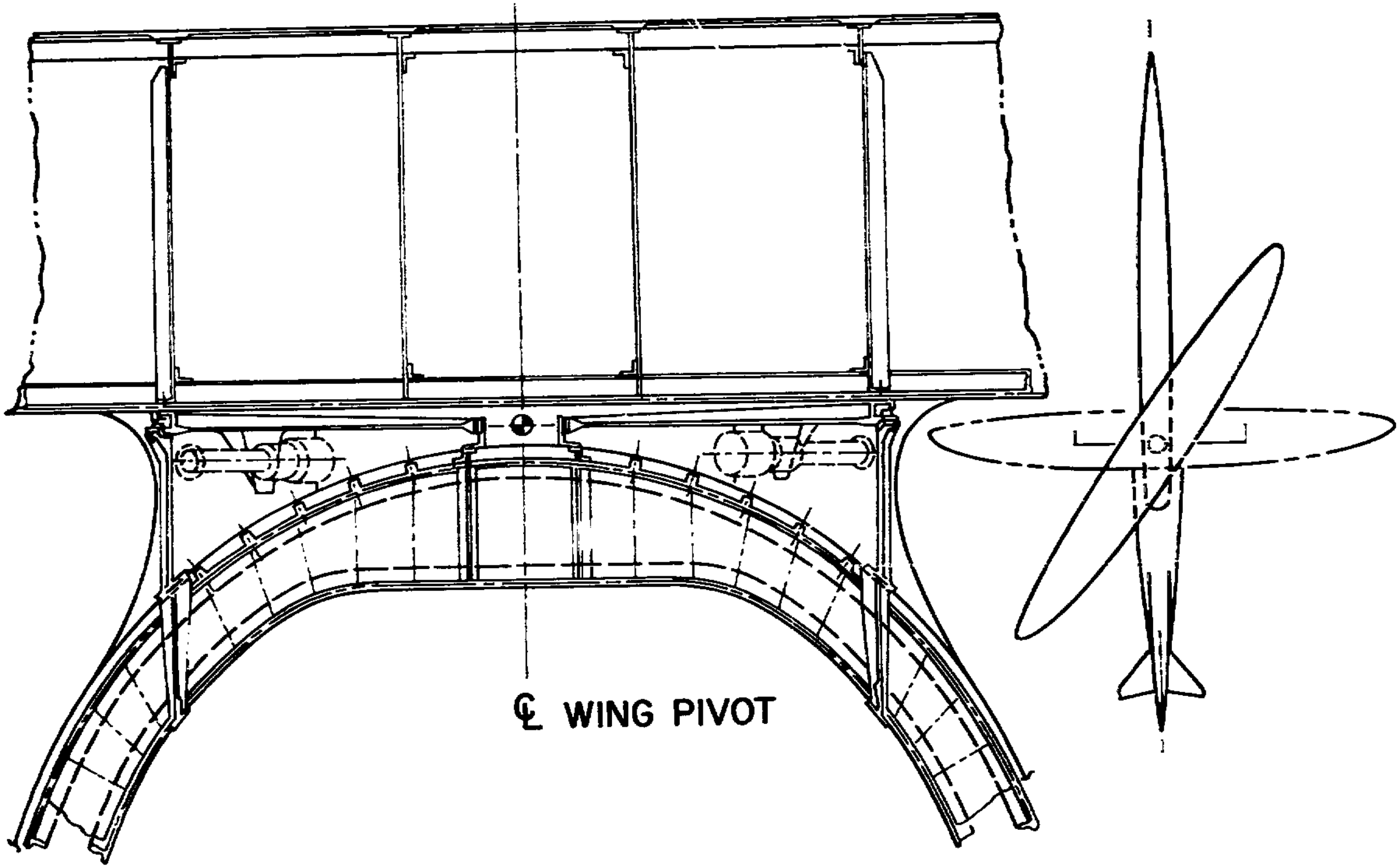


Figure 19.- Two-positon wing-pivot structural arrangement.

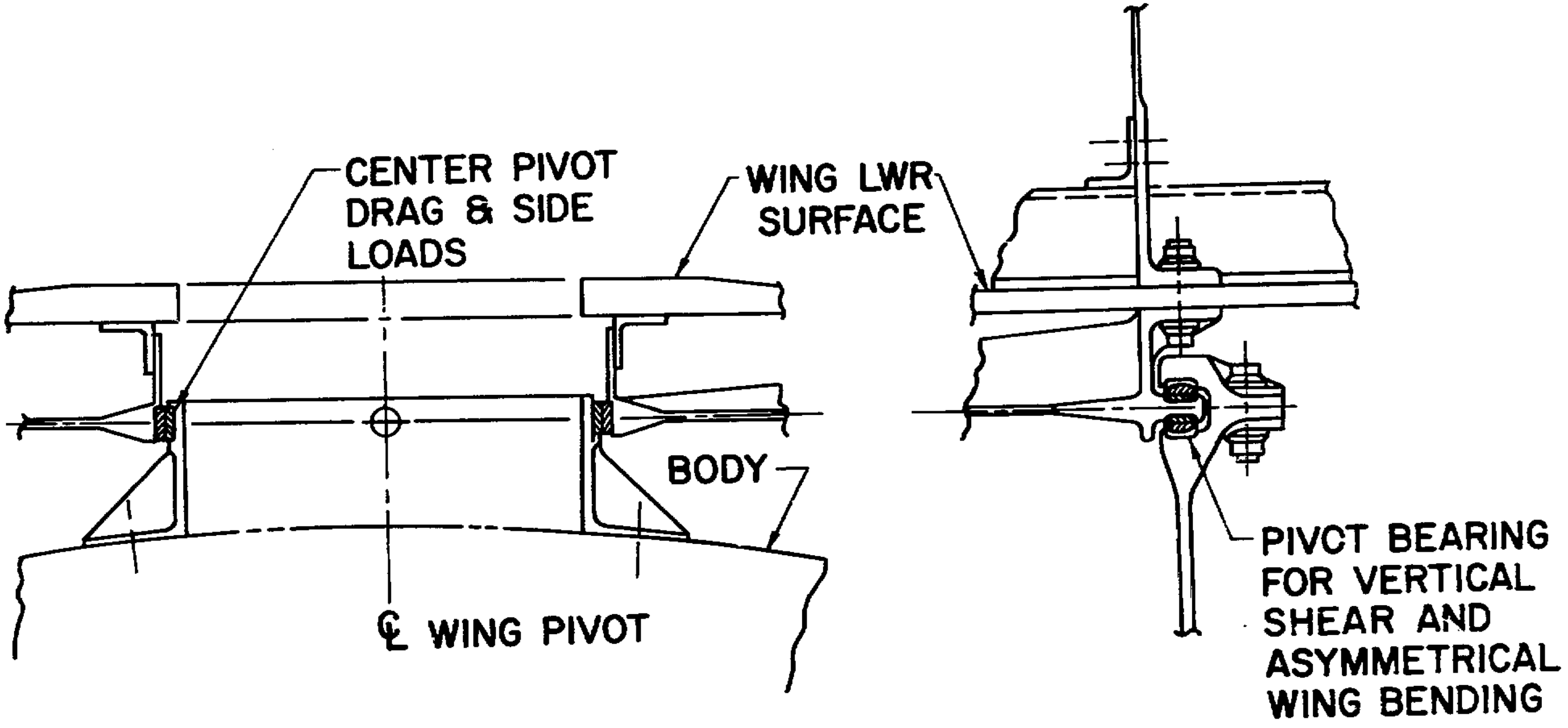


Figure 20.- Wing pivot details.

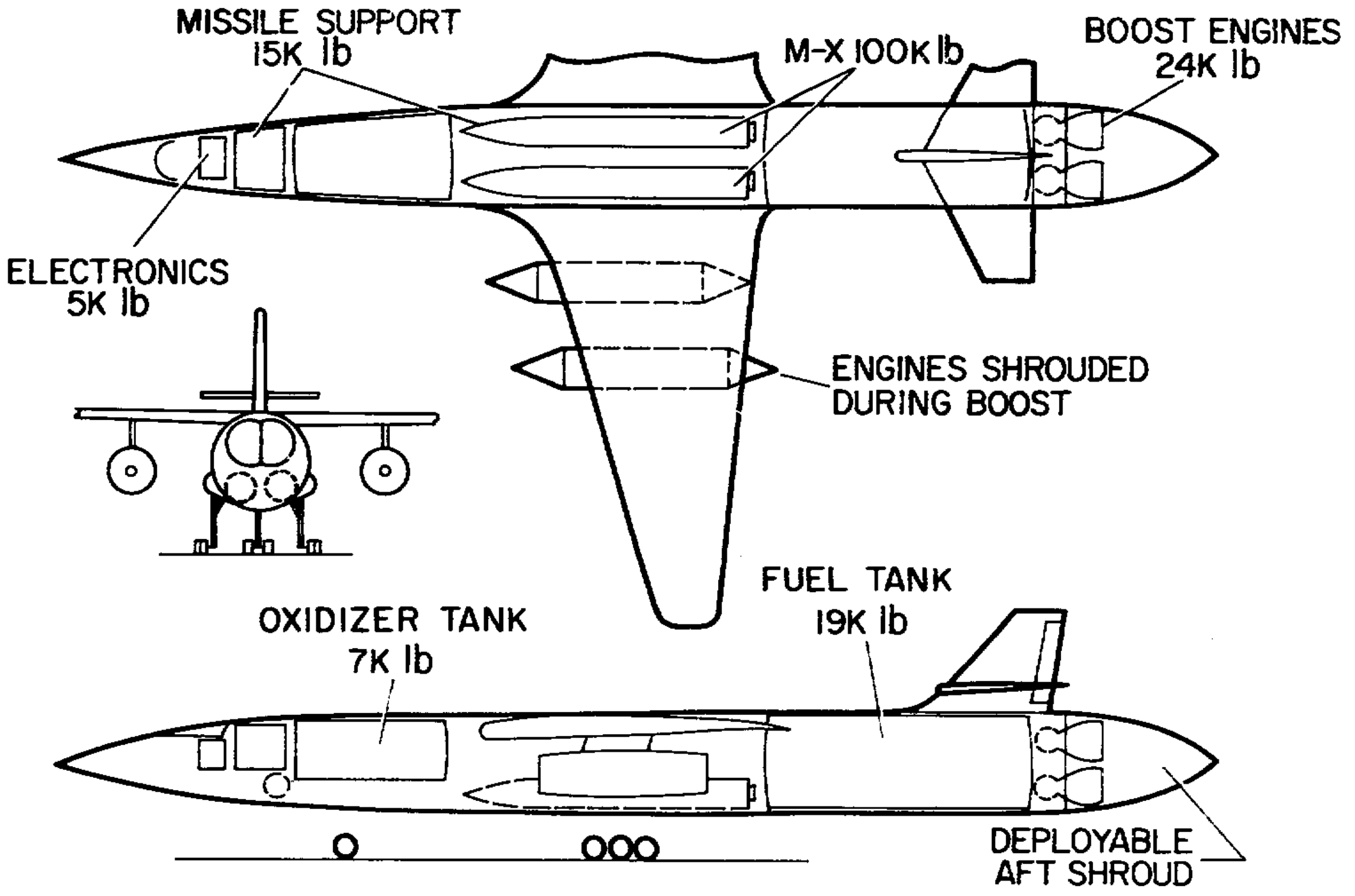


Figure 21.- Unstaged rocket, fixed-wing configuration; body length = 2[illegible] ft; wing span = 18[illegible] ft.

AFTERBODY ATTACHED TO FOREBODY

MODEL ASSEMBLED WITH CONTROLS

Figure 22.- Deployable base shroud on the M1-L lifting body.

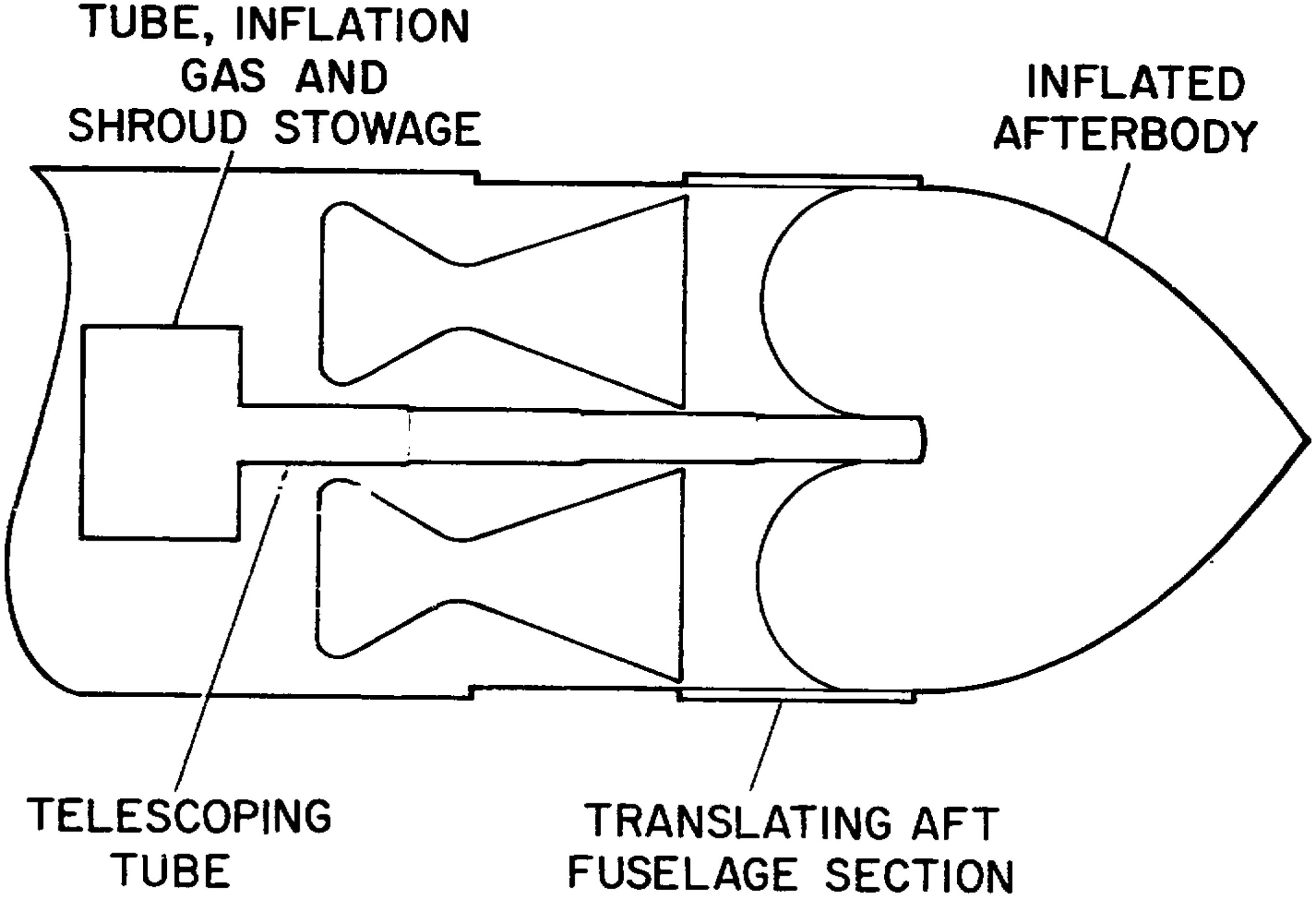


Figure 21.- Deployable base shroud schematic; unstaged rocket.

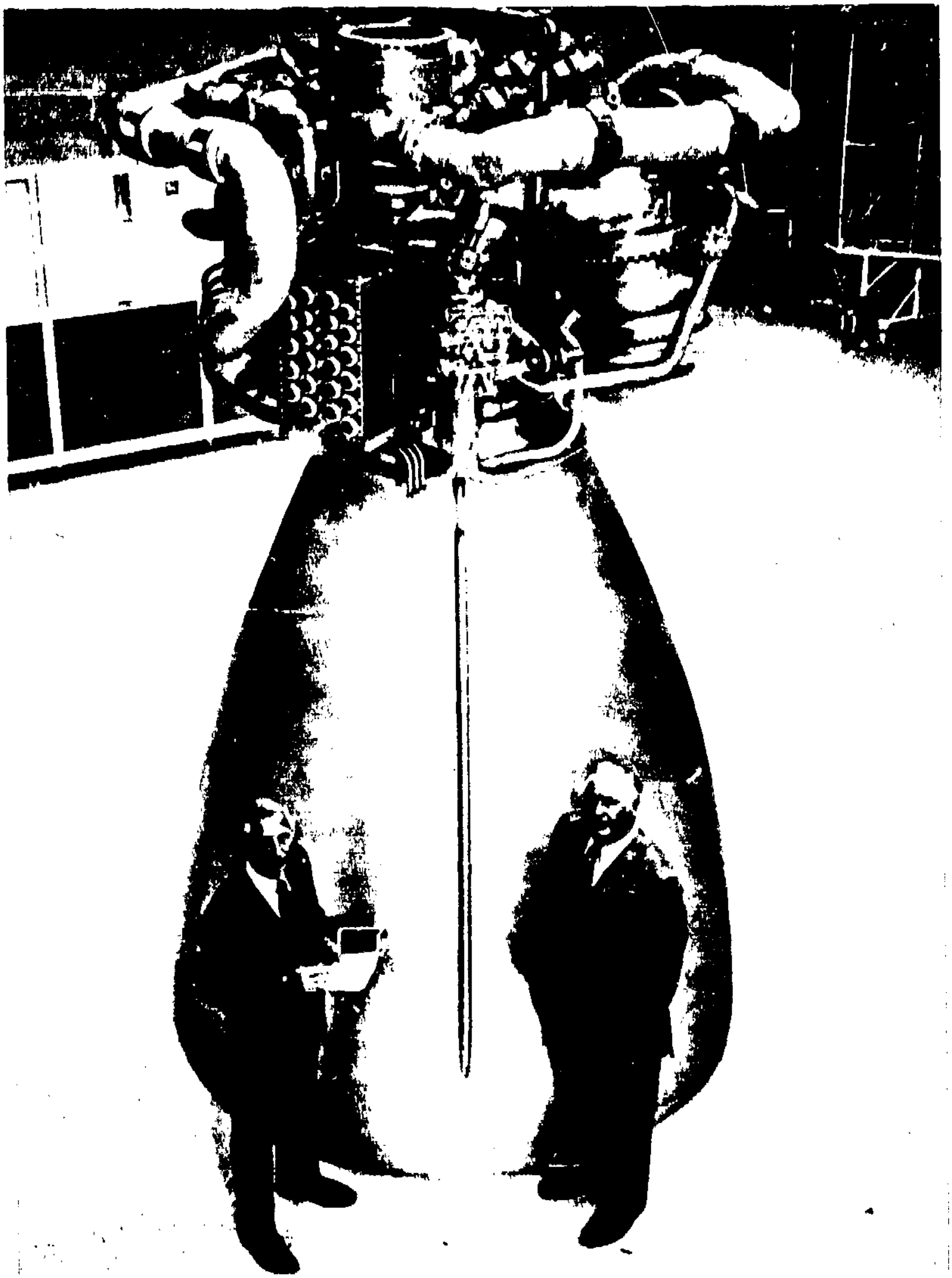


Figure 24.- Space Shuttle main LOX/H_2 rocket engine.

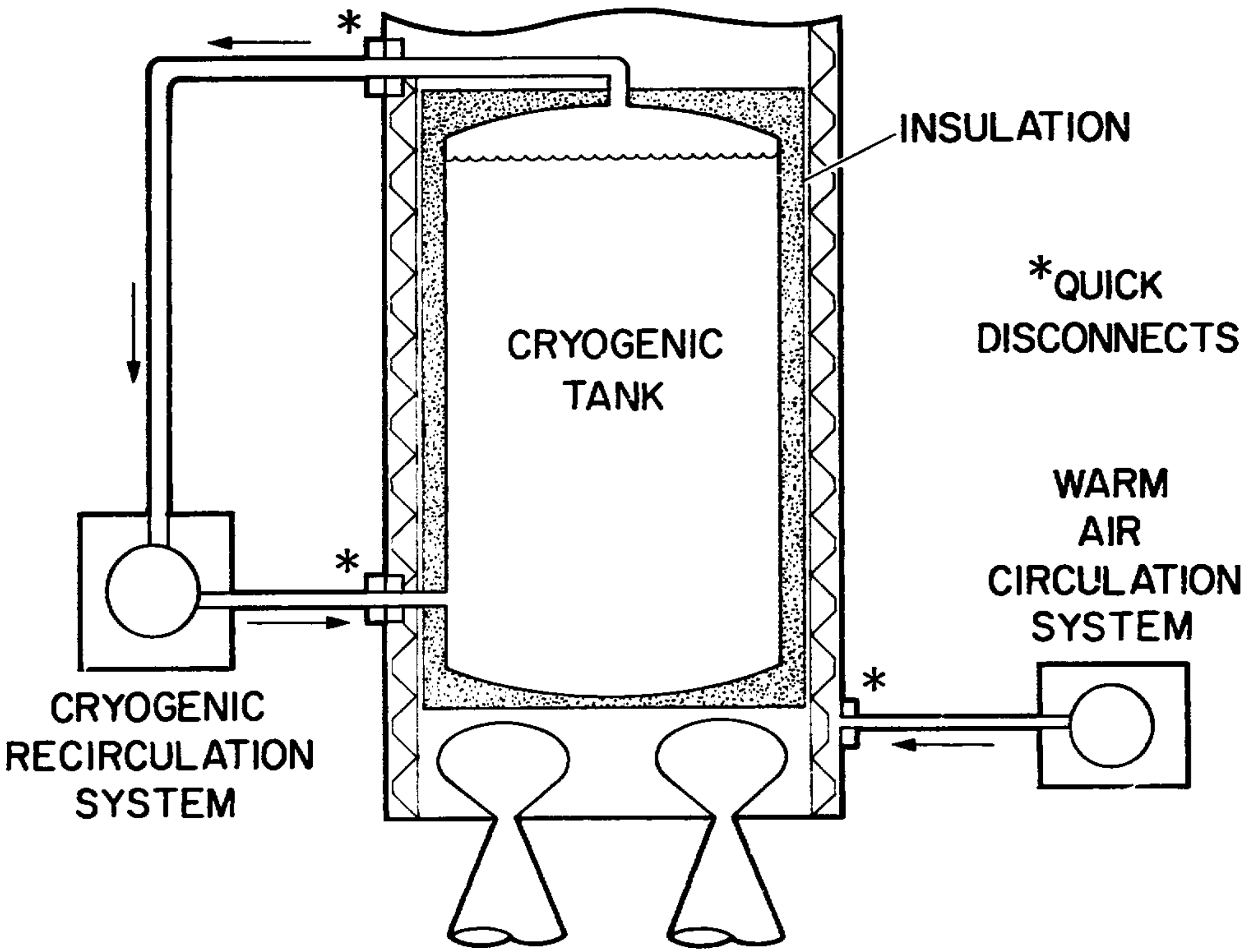


Figure 2[illegible].- Cryogenic ground handling scheme [illegible]b.

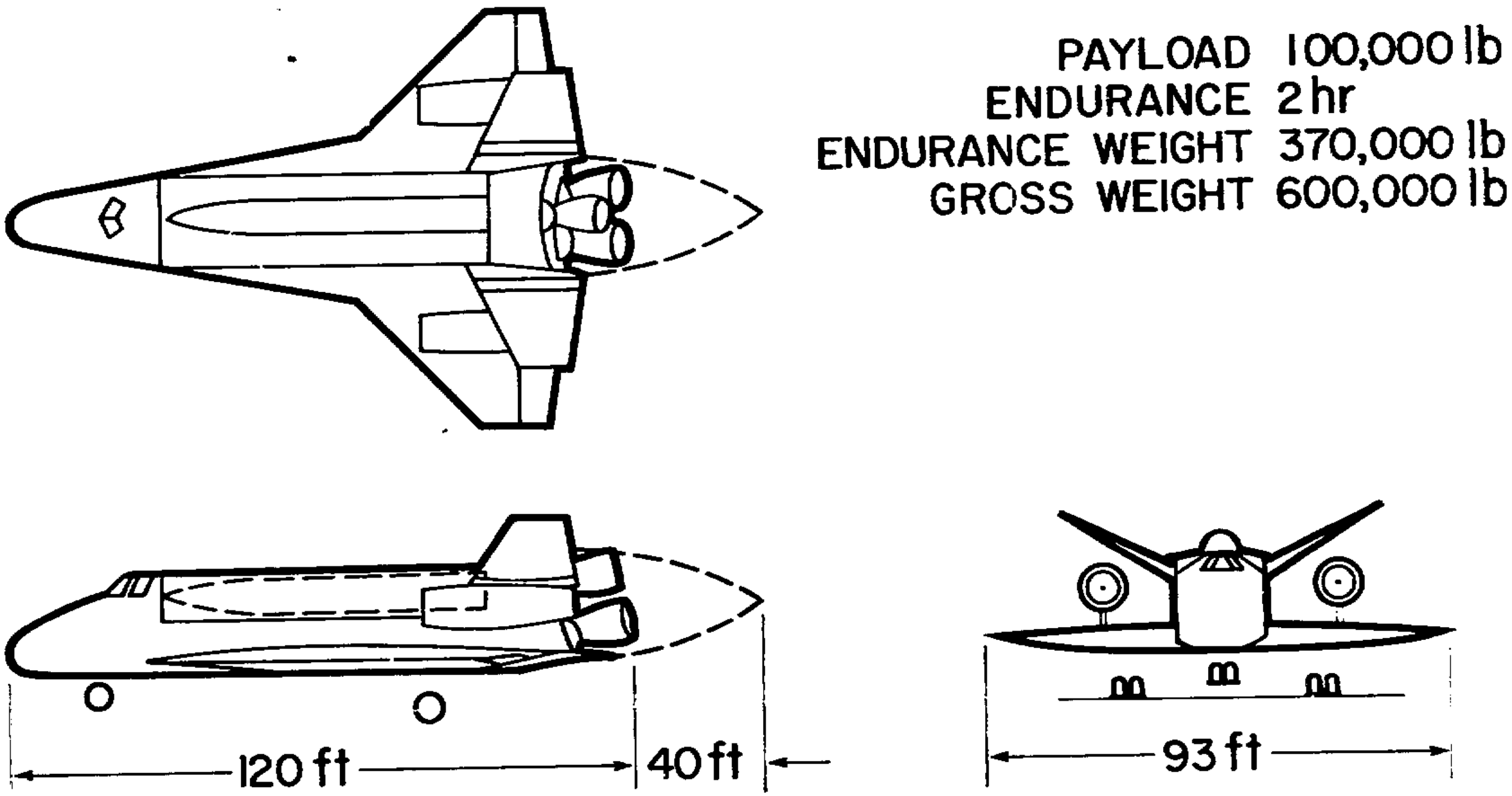


Figure 26.- Details of modified Space Shuttle.

ITEM	BASIC ORBITER	MODIFIED ORBITER
WING GROUP	12,495	12,495
TAIL GROUP	3,016	3,216
BODY GROUP	42,616	42,616
INDUCED ENVIR. PROTECT.	25,017	0
LANDING, DOCKING	8,104	11,415
PROPULSION, ASCENT	27,651	27,651
PROPULSION, RCS	2,353	0
PROPULSION, OMS	2,768	0
PRIME POWER	3,019	3,019
ELECT. CONV. & DIST.	5,269	5,269
HYDRAULIC CONV. & DIST.	1,371	1,371
SURFACE CONTROLS	2,280	2,280
AVIONICS	5,687	5,687
ENVIRON. CONTROL	4,189	4,189
PERSONNEL PROVISION	1,069	1,069
PAYLOAD PROVISION	135	0
GROWTH	2,961	0
BOOST TANKAGE	0	10,514
ENDURANCE TANKAGE	0	5,643
AIRBREATHING ENGINES	0	48,866
NACELLES	0	7,359
	150,000	192,659

Figure 27.- Modified Space Shuttle group weight statement.

	CONCEPT	GROSS WEIGHT, million lb	ENDURANCE WEIGHT, million lb	EMPTY WEIGHT, million lb
STAGED	2P-SOLID-VTO	1.10	.52	.20
	VS-	1.29	.52	.21
	FW-	1.41	.50	.20
UNSTAGED	2P-LOX/H_2-VTO	1.10	.76	.38
	VS-	1.09	.73	.37
	FW-	1.15	.69	.34
	2P-UDMH-VTO	1.10	.66	.31
	FW-	1.28	.65	.30
ALTERNATE	*SHUTTLE-LOX/H_2-	.60	.37	.19
	VS-LOX/H_2-HTO	1.78	1.27	.75
	VS-AIRBREATHER	1.93	1.54	.68

* REDUCED PAYLOAD AND TIME

Figure 28.- Weight comparison of aircraft concepts.

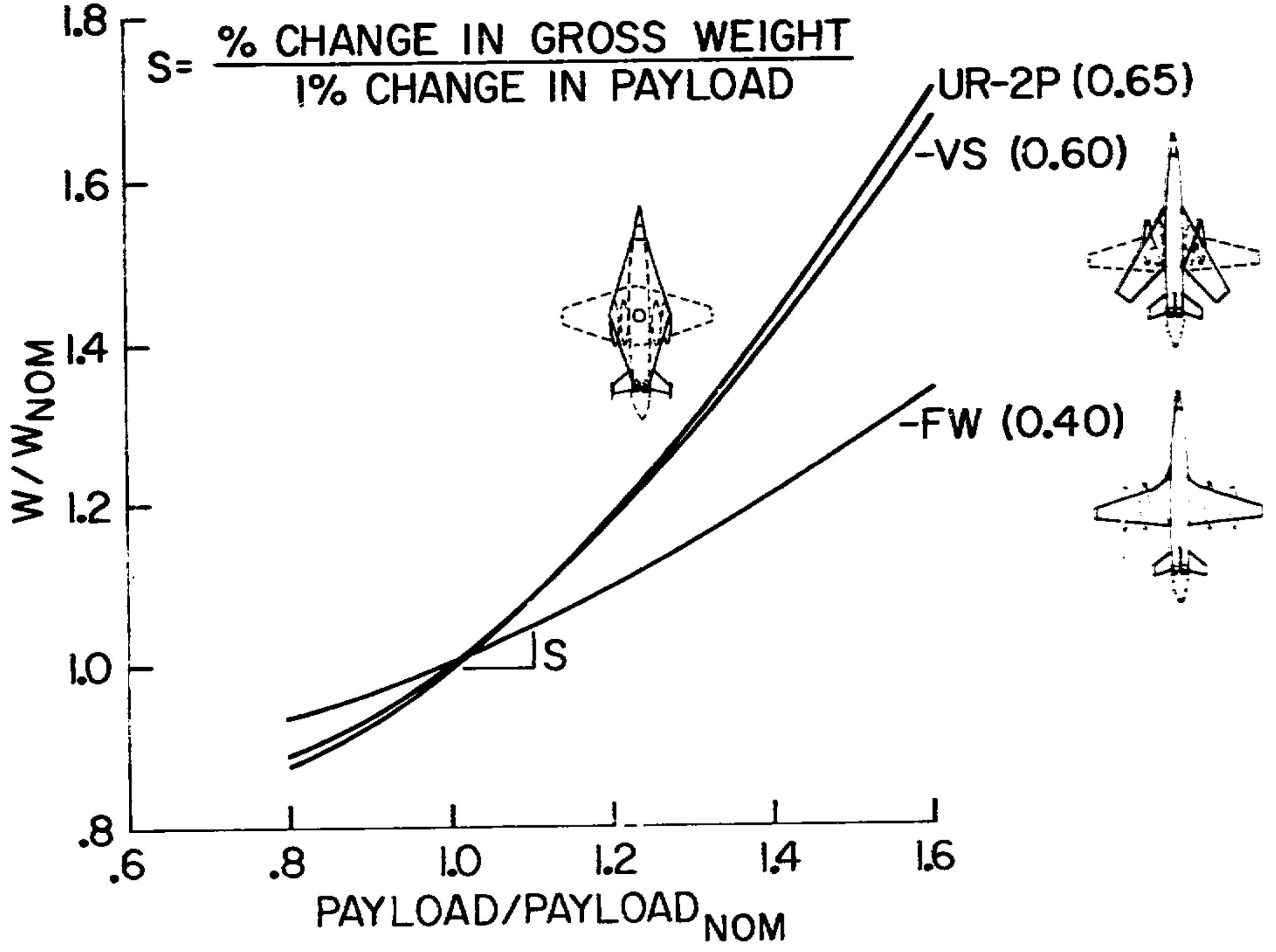


Figure 39.- Gross weight sensitivity to changes in payload.

$$S = \frac{\text{PERCENT CHANGE IN GROSS WEIGHT}}{1\ \text{PERCENT CHANGE IN PARAMETER}}$$

CONCEPT	PARAMETER			
	PAYLOAD	ENDURANCE	BOOST DYNAMIC PRESSURE	MATERIAL TECHNOLOGY
SR-2P	0.50	0.41	-0.35	0.05
-VS	.34	.31	.27	.13
-FW	.21	.19	.10	.05
UR-2P	.65	.52	- .14	.43
-VS	.60	.48	.68	.47
-FW	.40	.42	.41	.38

Figure 30.- Normalized sensitivities.

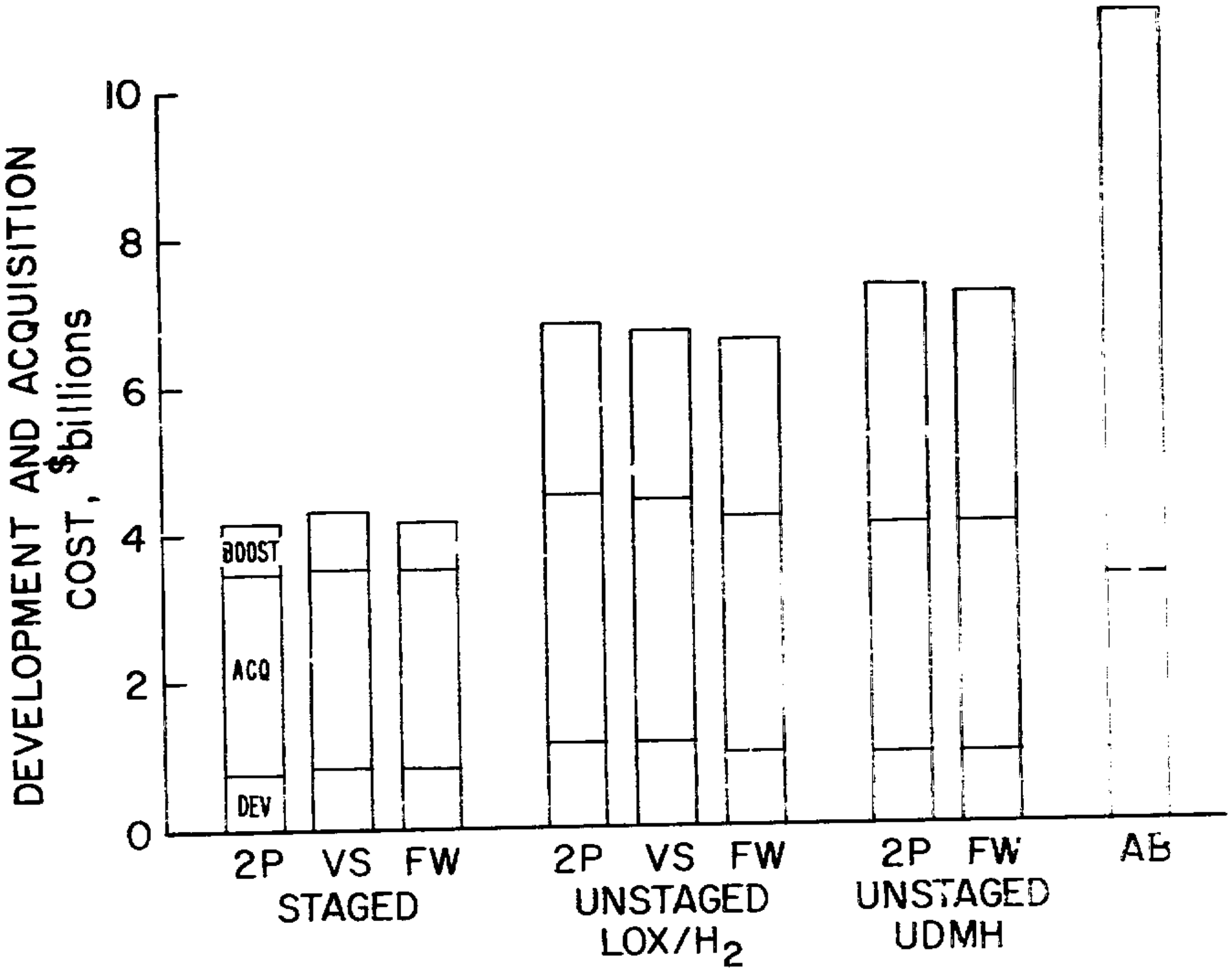


Figure [illegible].- Development and acquisition cost comparison; [illegible] missile [illegible], [illegible].

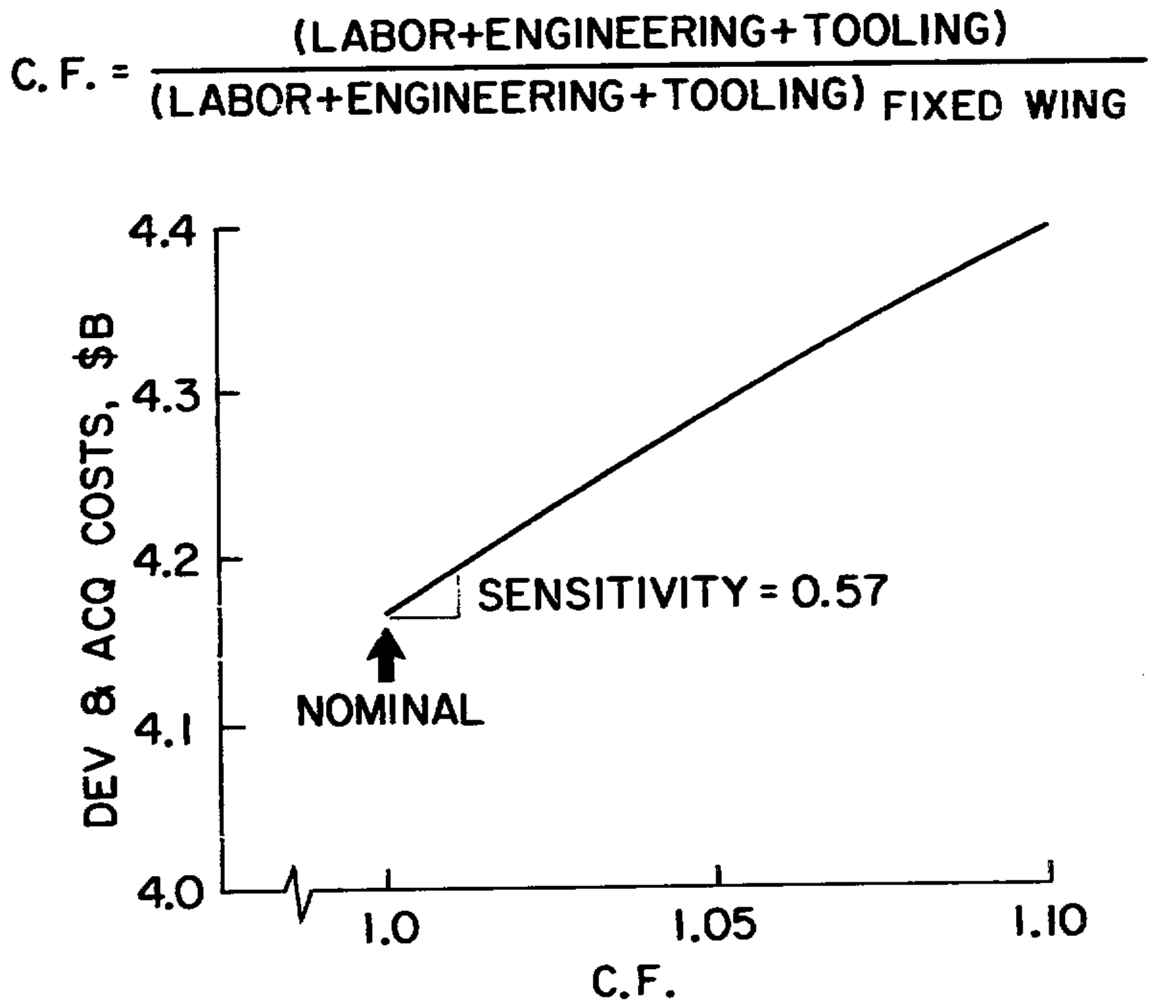


Figure 32.- Cost variation with aircraft complexity.

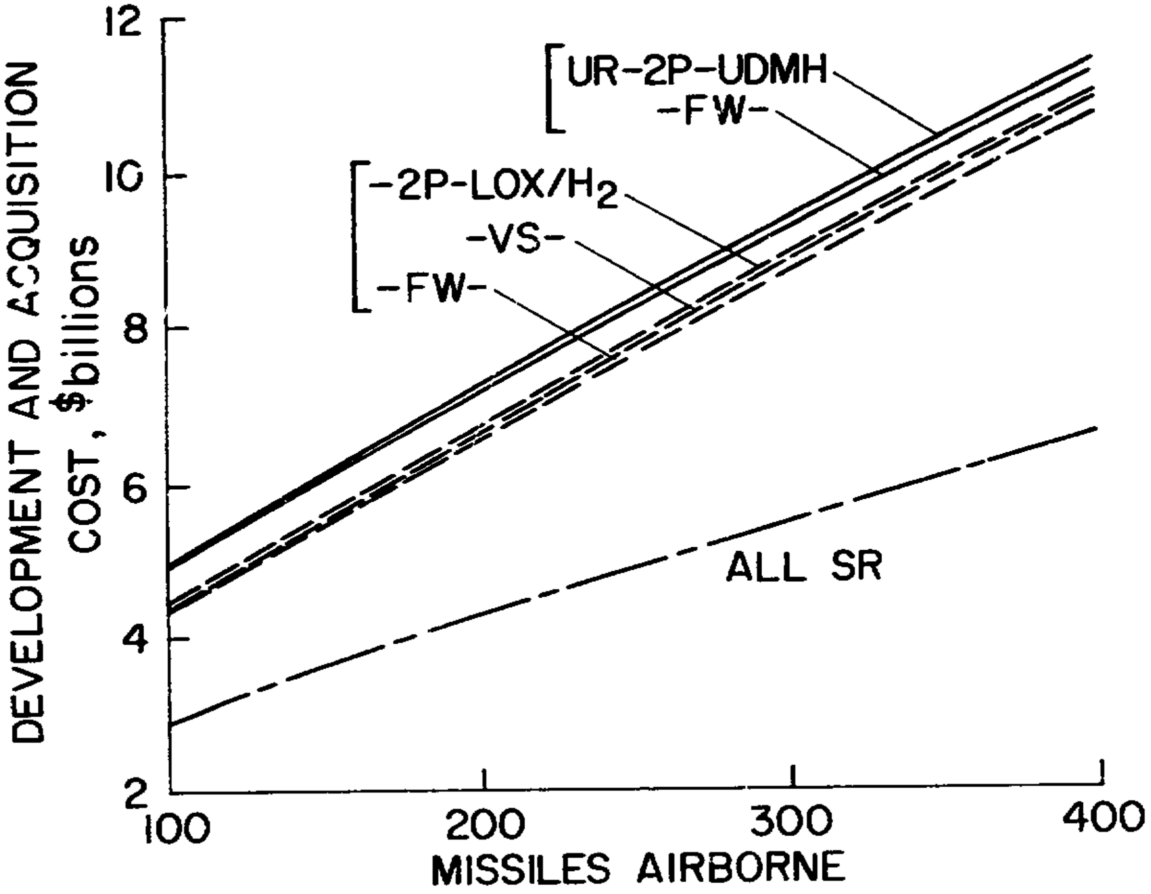


Figure 33.- Development and acquisition cost sensitivity to number of missiles airborne; 2-100K lb. missiles per aircraft.

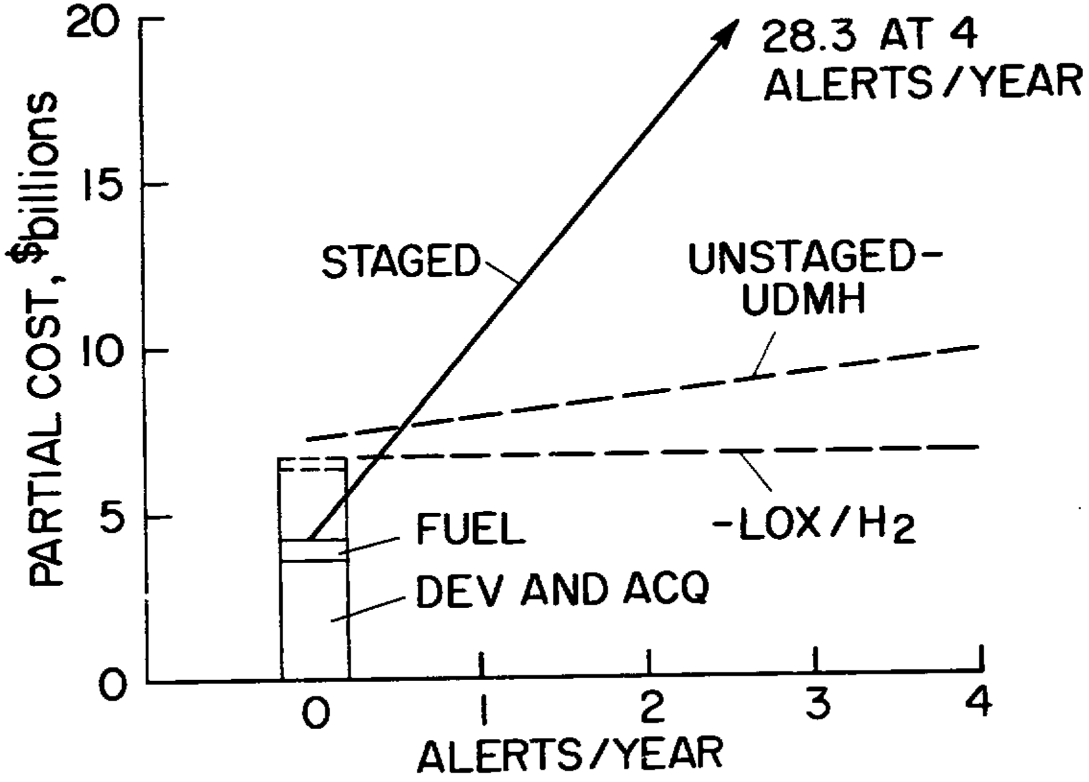


Figure 34.- Development, acquisition and fuel cost variation with number of fleet alerts; 10 years, 6 hours/alert, 200 missiles airborne.

CONFIGURATION	% U.S. DEMAND (300×10^9)	% U.S. PROD (170×10^9)	% CIVIL AVIA (17×10^9)	% MIL A/C (7×10^9)
* SR-2P	.04	.06	.6	1.5
-VS	.03	.06	.6	1.3
-FW	.03	.05	.5	1.2
* UR-2P	.05	.09	.9	2.2
-VS	.05	.08	.8	2.0
-FW	.04	.08	.8	1.9

* ONE 14 DAY ALERT PER YEAR

Figure 35.- Yearly relative loiter fuel consumption comparison; one-14 day alert/year loiter.