NASA Contractor Report 159018

A Turbojet-Boosted Two-Stage-to-Orbit Space Transportation System Design Study

A. K. Hepler, H. Zeck, W. Walker, and W. Scharf

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P.O. Box 3999
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Contract NAS1-15204
April 1979

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Langley Research Center
Hampton, Virginia 23665
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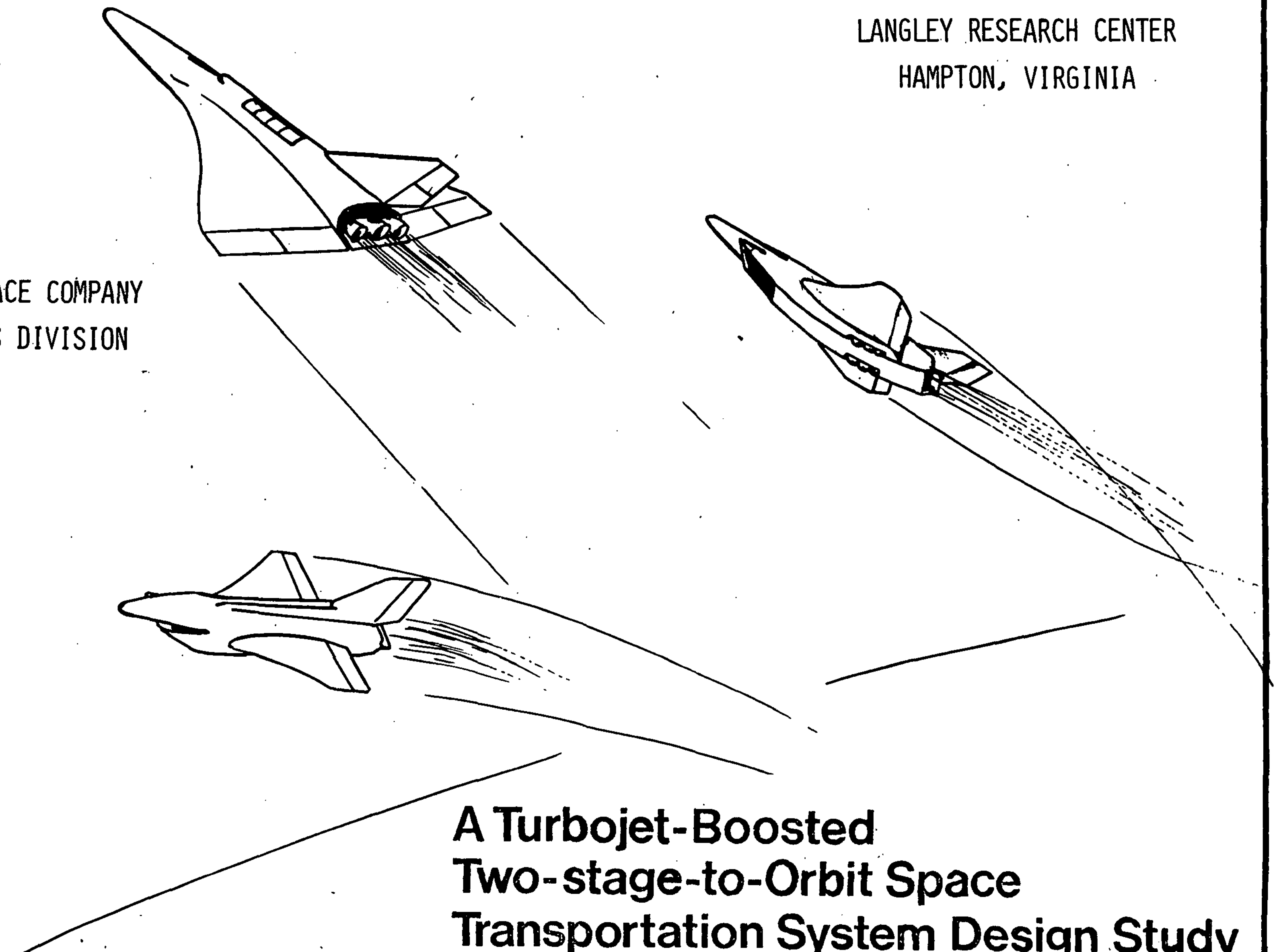


A Turbojet-Boosted Two-stage-to-Orbit Space Transportation System Design Study

FOREWORD

A Turbojet-Boosted Two Stage to Orbit Space Transportation System Design Study was conducted by Boeing Aerospace Company; Kent, Washington from January 1978 through December 1978. The study was sponsored by NASA/Langley Research Center under Contract NAS1-15204.

Principal investigator was Mr. Howard Zeck under the administration of study manager Mr. A. K. Hepler. Boeing Aerospace major contributors were:

George A. Dishman	Documentation
Andrew K. Hepler	Structures
William H. Scharf	Propulsion
William H. Walker	Design and Subsystems
Howard Zeck	Aerodynamics and Performance

Acknowledgement is expressed to the following NASA/Langley Research Center personnel for their helpful guidance and technical assistance during the course of the study:

J. A. Martin	Performance
L. R. Jackson	Vehicle Definition
W. J. Small	Aerodynamics
J. D. Watts	(Study Monitor)

CONTENTS

Summary

The next generation of advanced earth orbital transportation systems have recently been studied by NASA to assess their potential payoff in terms of cost, performance and utility. Most of these studies have only considered all rocket propulsion systems. An alternative approach proposed by NASA Langley has considered air breathing engines for the first boost stage. Their novel concept proposed to use twin turbo-powered boosters for acceleration to supersonic staging speed followed by an all rocket powered orbiter stage. This effort is a follow-on design study of such a concept with performance objective of placing a 29483 kg (65000 lb) payload into a 92.6 X 195.3 km (50 X 100 n.mi.) orbit for an eastern launch from Cape Kennedy. The study was performed in terms of analysis and trade studies, conceptual design, utility and economic analysis, and technology assessment.

Design features of the final configuration include:

Strakes and area rule for improved take-off and low transonic drag, variable area inlets, exits and turbine, and low profile fixed landing gear for turbojet booster stage. To inject a 29483 kg (65000 lb) payload in orbit required an estimated GLOW of 1.27 X 10^6 kg (2.8 X 10^6 lb). Each twin booster required (8) afterburning turbojet engines each with a static sea level thrust rating

of 444,800 N (100,000 lb). Life cycle costs for this concept were comparable to a SSTO/SLED concept except for increased development cost due to the turbojet engine propulsion system.

Technologies in need of development for the turbojet booster concept include: advanced aerodynamics, orbiter structure and thermal design, and booster propulsion integration.

Future studies of this approach should also consider subsonic staging with both single vehicle boosters and twin boosters.

INTRODUCTION

Recent studies of fully reusable advanced space transportation systems (Ref. 1) have utilized all rocket propulsion engines. An alternative approach has been proposed (Ref. 2) which utilizes twin turbojet powered boosters for acceleration to Mach 3.5. This concept illustrated in Figure 1 offers take-off from conventional runways and potential advantages of offset orbit insertion, self-ferry and intact-abort. This 7-month study is a follow-on of NASA's prelininary findings of the twin-turbojet powered booster systems. The present study explores the technical considerations, the vehicle definition, subsystems, and the life cycle costing. The initial configuration of the orbiter rocket powered stage was generic to that developed during the NASA funded studies. The study objectives were divided into the following tasks: Task I - Analysis and Trade Studies, Task II - Conceptual Design, including identification of unique problems, development of solutions, and incorporation into a vehicle design; Task III - Utility Economic Analysis; and Task IV - Technology Assessment.

Study Guidelines

- Twin Boosters
- Takeoff Speed = 121.9 m/sec (400 FPS)
- Design Payload = 29483 kg (65,000 lb)
- ΔV in orbit = 1981 m/sec (650 FPS)
- Injection Orbit = 92.6 X 185.3 km (50 X 100 n.mi.)
- Entry Cross Range = 2038 km (1100 n.mi.)
- Staging Mach = 2.7
- ΔV RCS = 30.5 m/sec (100 FPS)

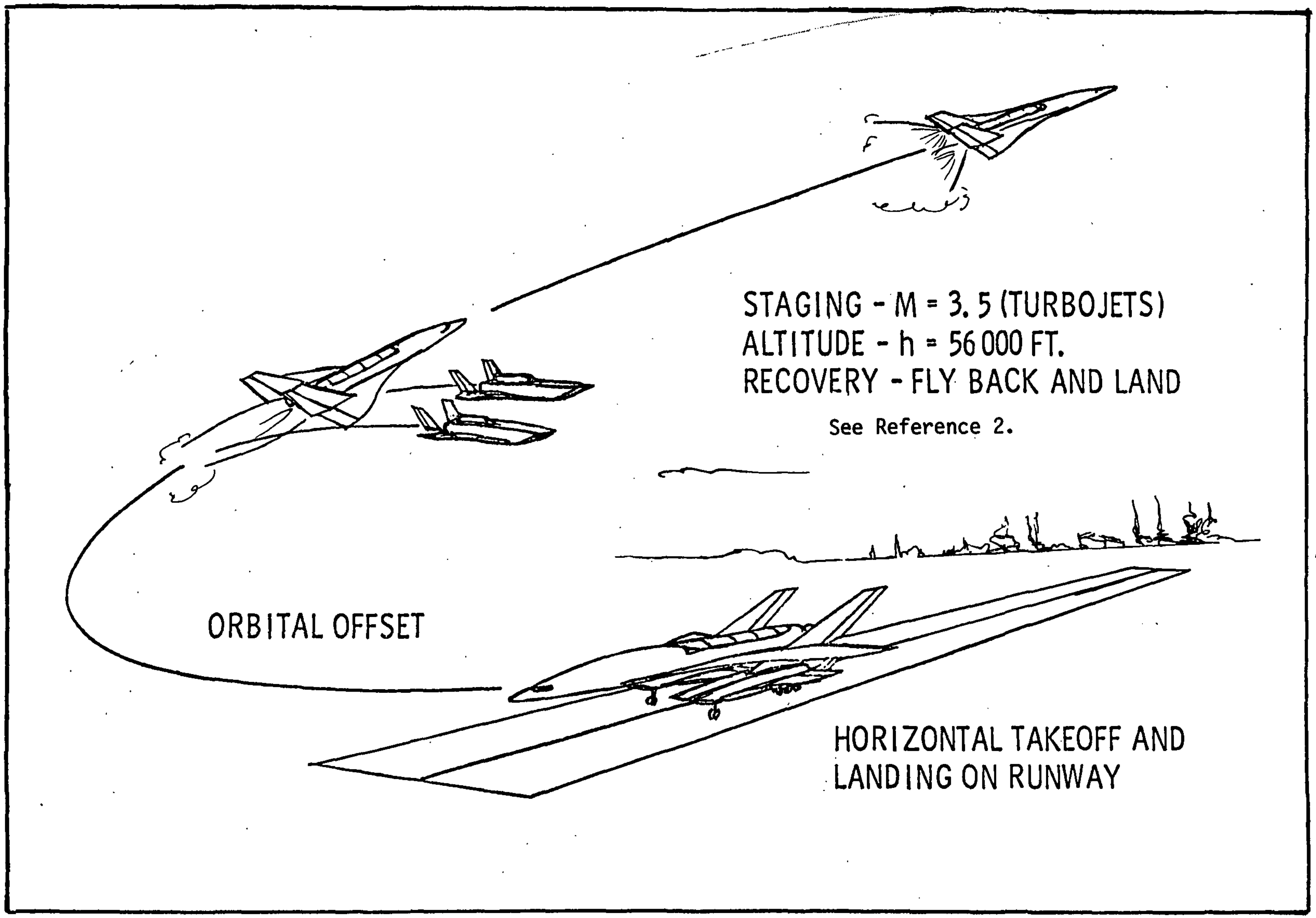


Figure 1 Advanced Space Transport Concept

LIST OF SYMBOLS

A_c	Inlet Capture Area Turbojet Engine
A.C.	Aerodynamic Center
C_D	Drag Coefficient
C_{D_0}	Minimum Drag Coefficient
CL	Lift Coefficient
CL_α	Lift Curve Slope
C_m	Pitching Moment Coefficient
C_N	Normal Force Coefficient
CT	Thrust Coefficient ($\approx T/qA_c$) Turbojet Engine.
D	Drag
GLOW	Gross Liftoff Weight
L_B	Orbiter Reference Length
L	Lift
LCC	Life Cycle Cost
M	Free Stream Mach Number
q	Free Stream Dynamic Pressure
S_b	Booster Reference Area
SF	Scale Factor Turbojet Engine
S_{REF}	Orbiter Wing Area, Reference for Aerodynamic Coefficients
SFC	Specific Fuel Consumption Turbojet Engine
T	Net Thrust per Turbojet Engine
W	Weight
α	Angle of Attack
\$/kg(lb)	Dollars per kg (lb)
δ_e	Elevon Deflection Angle

Analyses Logic

The approach used to accomplish the task objectives is shown in the analyses logic diagram of Figure 2. The subtasks were conducted by the various technical disciplines (propulsion, etc.) leading to the development of baseline configurations. A series of iterations were required to arrive at the finalized configuration. The mid-term briefing at NASA resulted in a major reconfiguration to incorporate area rule and vortex lift features. This required a major reallocation of manpower effort. Much assistance was supplied by NASA for this updated configuration. The final configuration for which detailed inboard profiles were drawn and analysed did not meet the 29483 kg (65,000 lb) payload requirement. However, it was performance-scaled to this payload for its GLOW and life cycle costing. Since the iterated configuration development overran the planned effort, it was decided to reduce the times spent on Task III (Utility and Economic Analysis) and Task IV (Technology Assessment).

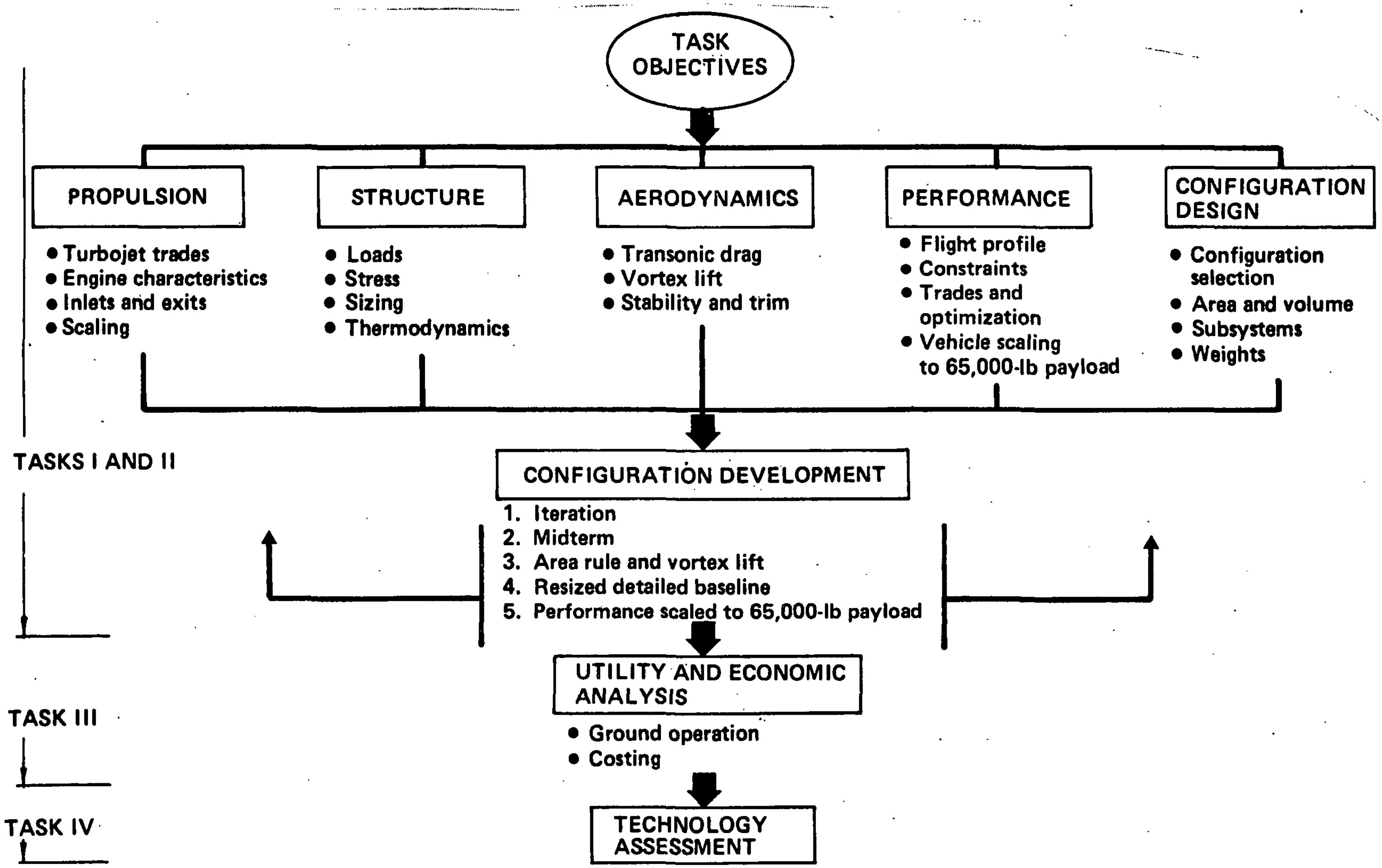


Figure 2 Analyses Logic

Aerodynamics

The mid-term configuration did not use area variation design techniques and most confidence in the aerodynamic characteristics were for the orbiter (isolated) since wind tunnel tests data is available for a similar configuration (See Ref. 3) except for a thinner wing profile (t/c from 0.105 to 0.09) and slightly finer body. For the twin boosters, past test data of large clustered Nacelles and engines have shown drag interference factors from 1.2 to 3.0. Thus, with an average affect of about 25 percent increase in the minimum drag over the isolated stages, it became very desirable to employ area variation techniques to reduce the transonic drag of the mated configuration. With the cooperation of NASA using the Harris wave drag computer program (Ref. 6), estimates were made for the final mated configuration shown in Figure 3 . The minimum drag and subsonic lift characteristics are presented in Figure 4 .

Another feature of the final configuration was the inclusion of full vortex lift at high angles of attack and subsonic take-off speeds ($M \approx 0.36$). Vortex lift effects were based on John Lamar's (NASA/Langley) theoretical techniques (See Ref. 4) which predicted a 30 percent increase in take-off lift. Without the benefit of wind tunnel tests of the mated configuration, it is anticipated that these aerodynamic characteristics have an uncertainity from 10 to 20 percent. Further details of the aerodynamic characteristics are given in Appendix I.

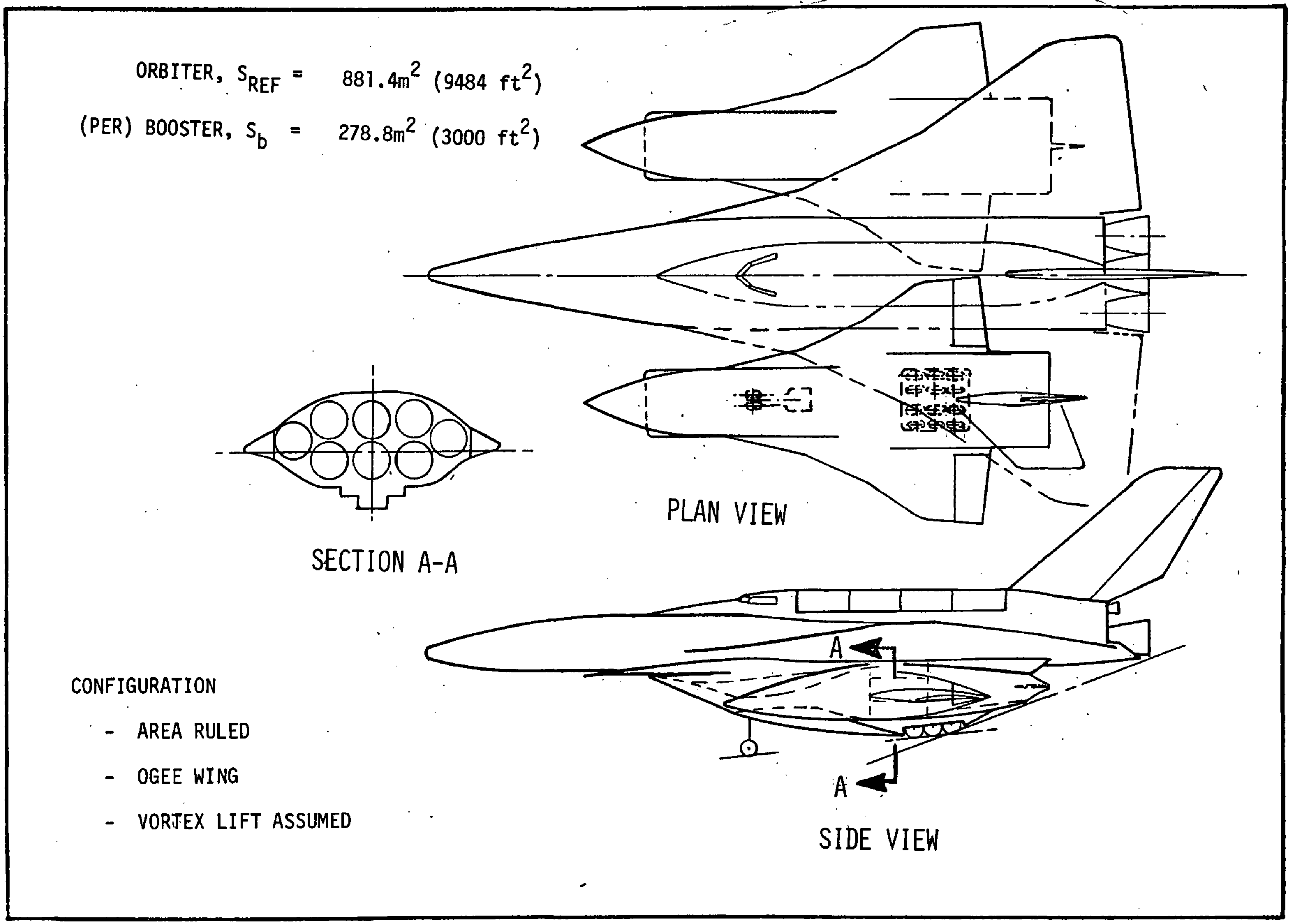


Figure 3 Turbojet Boosted System Sixteen Turbojets

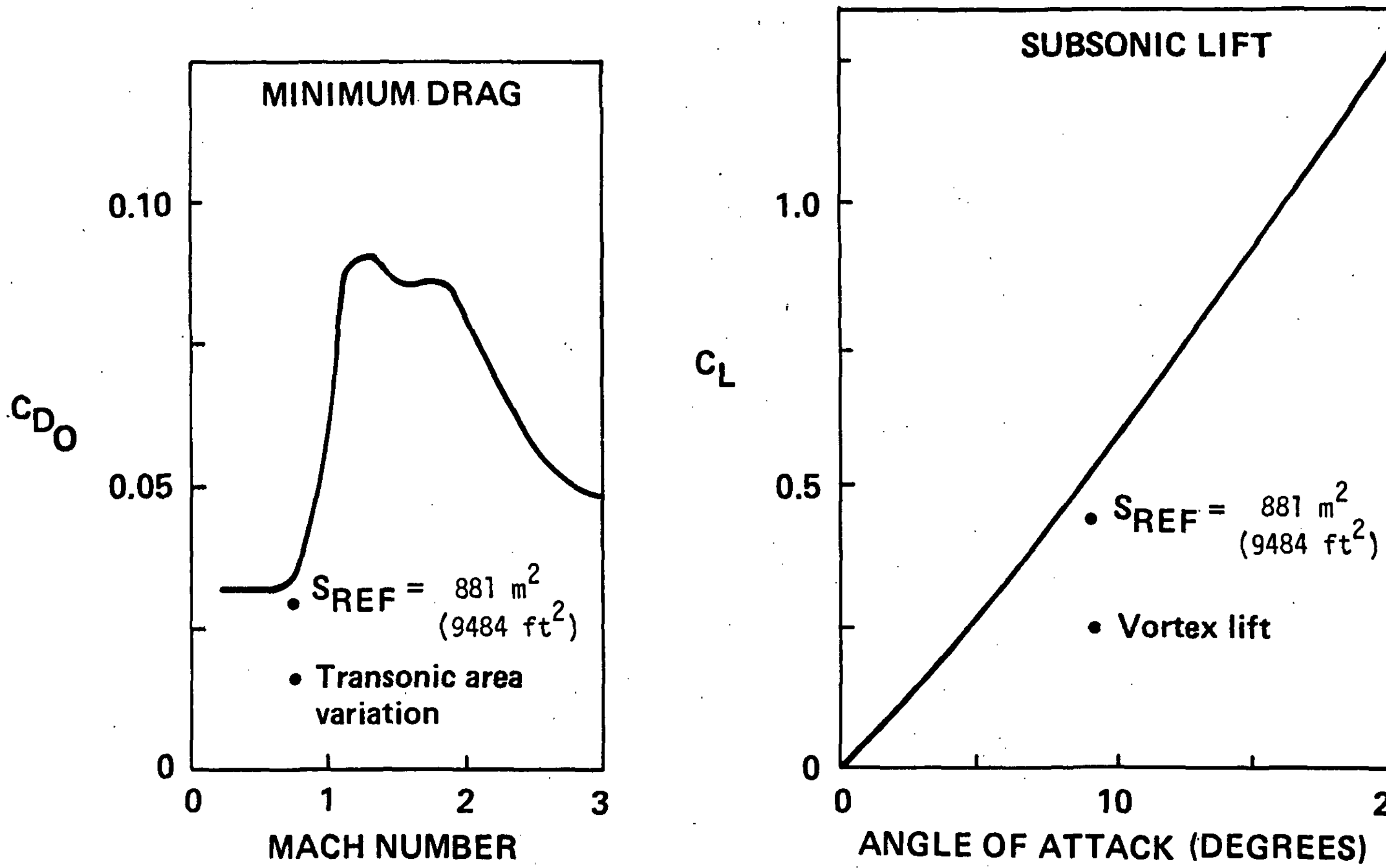


Figure 4 Lift and Drag Mated Two-Stage Turbojet Booster

Takeoff Speed (Mated Vehicles)

Takeoff performance is based upon the lift coefficient characteristics shown in Figure 5. The angle of attack required to not exceed the takeoff speed design goal (400 fps) is 18.6 degrees. For a 20 degree angle of attack at this design speed, the excess vertical force is about 8 percent of the weight of the mated vehicles. The takeoff phase is followed by pull-up phase from the runway in which the normal load factor, $\left(\frac{D \sin\alpha + L \cos\alpha}{W}\right)$, is set to not exceed 1.25 until the desired initial climbout flight path angle is reached (see Figure 14 for detailed trajectory characteristics). The effects of turbojet thrust are included in the take-off speed estimates.

Subsonic Stability

Longitudinal static stability was estimated in terms of the aerodynamic center of both isolated and mated orbiter. For the isolated orbiter, the main factor is the wing planform with the body contributing only secondary effects. For the mated configuration, the uncertainty of interference effects could considerably alter the values shown in Figure 6. The estimates indicate an unstable configuration in pitch over most of the anticipated C.G. range. Wind tunnel tests would be required to substantiate the estimated values of stability and trim for the mated configuration.

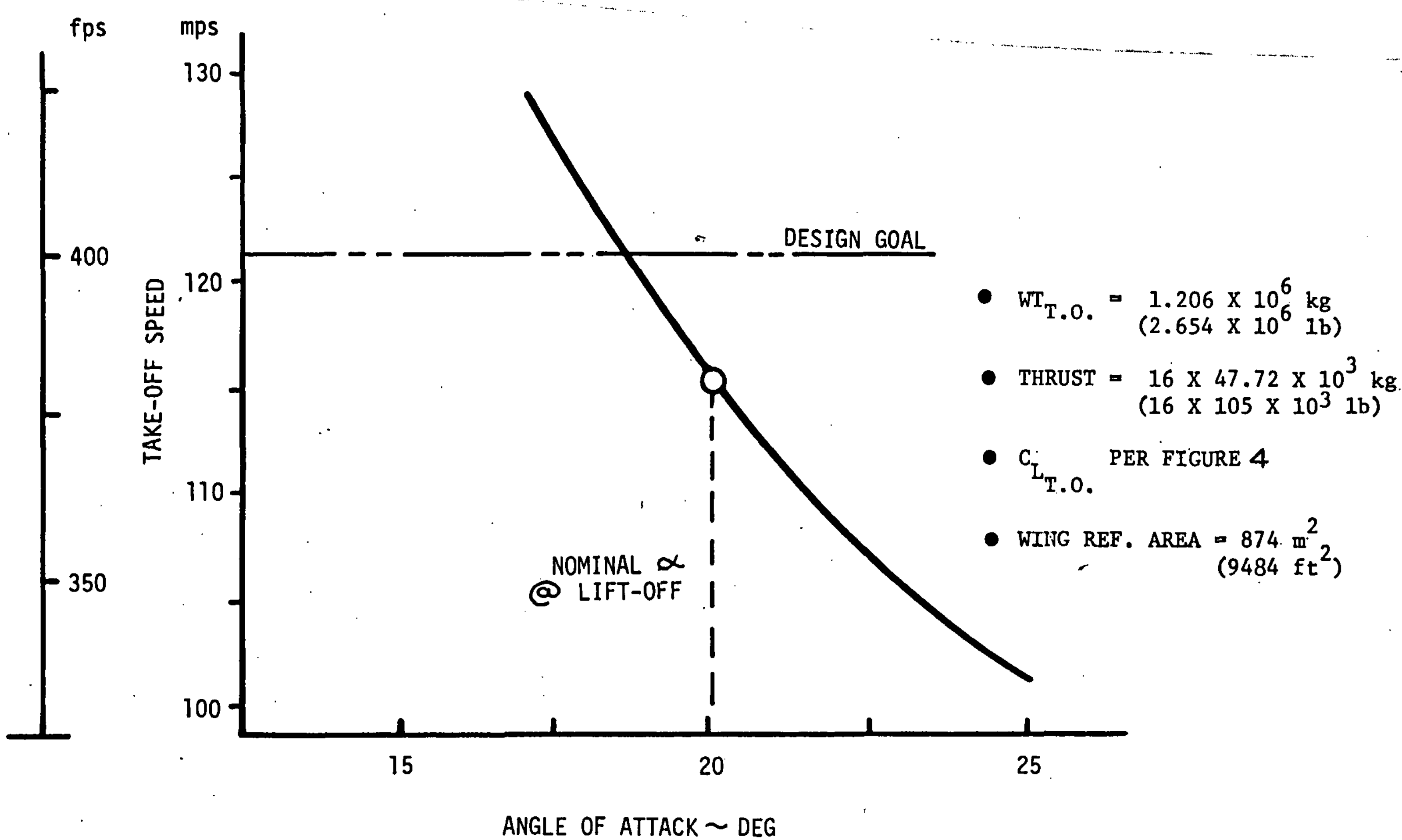


Figure 5 Take-Off Performance - Mated Vehicles

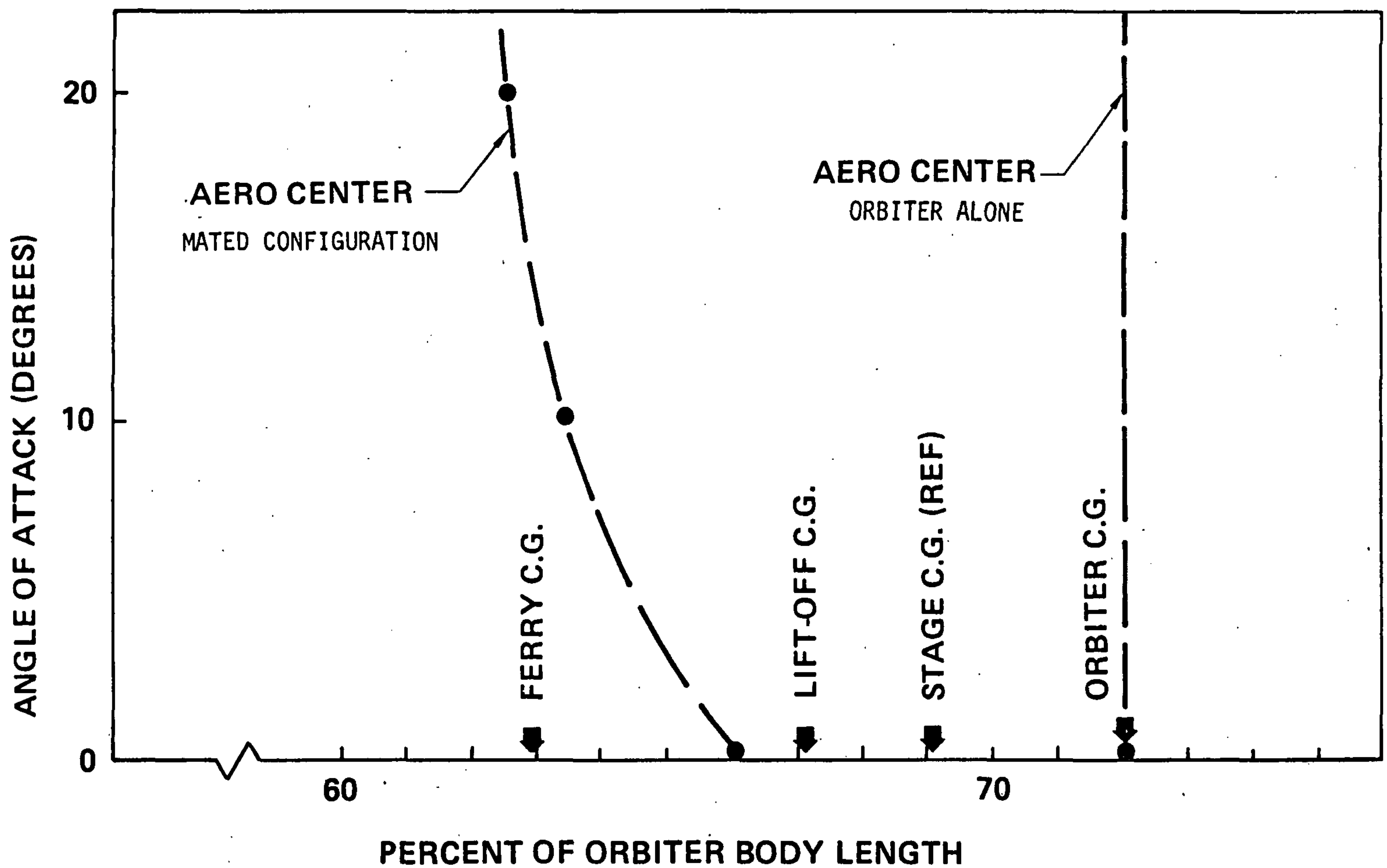


Figure 6 Subsonic Stability

A. C. Travel (Booster Only)

The travel of the Aerodynamic Center (A.C.) of the booster alone with Mach number is presented in Figure 7. Except for subsonic speeds, the booster is neutrally stable (or slightly unstable) for a C.G. position of 65 percent of booster body length. At subsonic speeds, the booster is about 8 percent unstable. A 2 to 3 percent unstable margin is considered acceptable to the authors. This instability can be negated by increasing T.E. wing sweep or by an aft movement of the wing relative to the body.

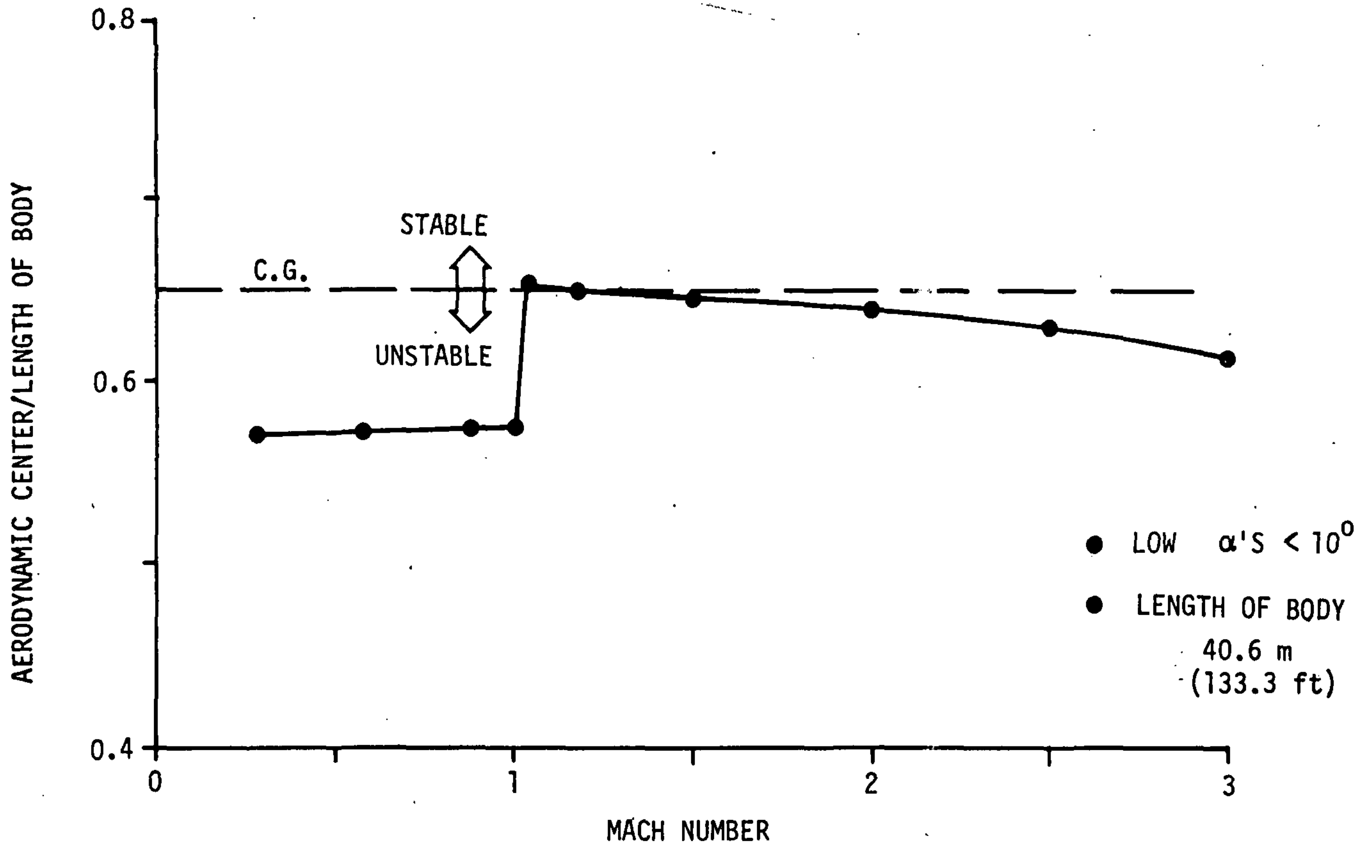


Figure 7 Aerodynamic Center Travel - Booster Only

Orbiter Stability

Compared to the booster stage, the orbiter is very stable. At subsonic speeds, see Figure 8, the orbiter is very slightly unstable and at transonic speed it is about 10 percent stable for a C.G. position of 0.72 of body length. With increasing speed the A.C. moves slowly forward. This high degree of pitch stability may cause some trim problems with up elevons.

The very stable orbiter configuration at supersonic speeds carries over to the hypersonic speeds as indicated in Figure 9. The neutral point is aft of 0.74 L_B at entry angles of attack (25 to 50 degrees). For an entry C.G. of 0.72 L_B, up elevons to -20 degrees are required for trim even with the body flap up -10 degrees. To improve these characteristics requires a small forward shift of the wing relative to the body or removal of some of the planform area near the wing trailing edges. This is not considered to be a serious problem area.

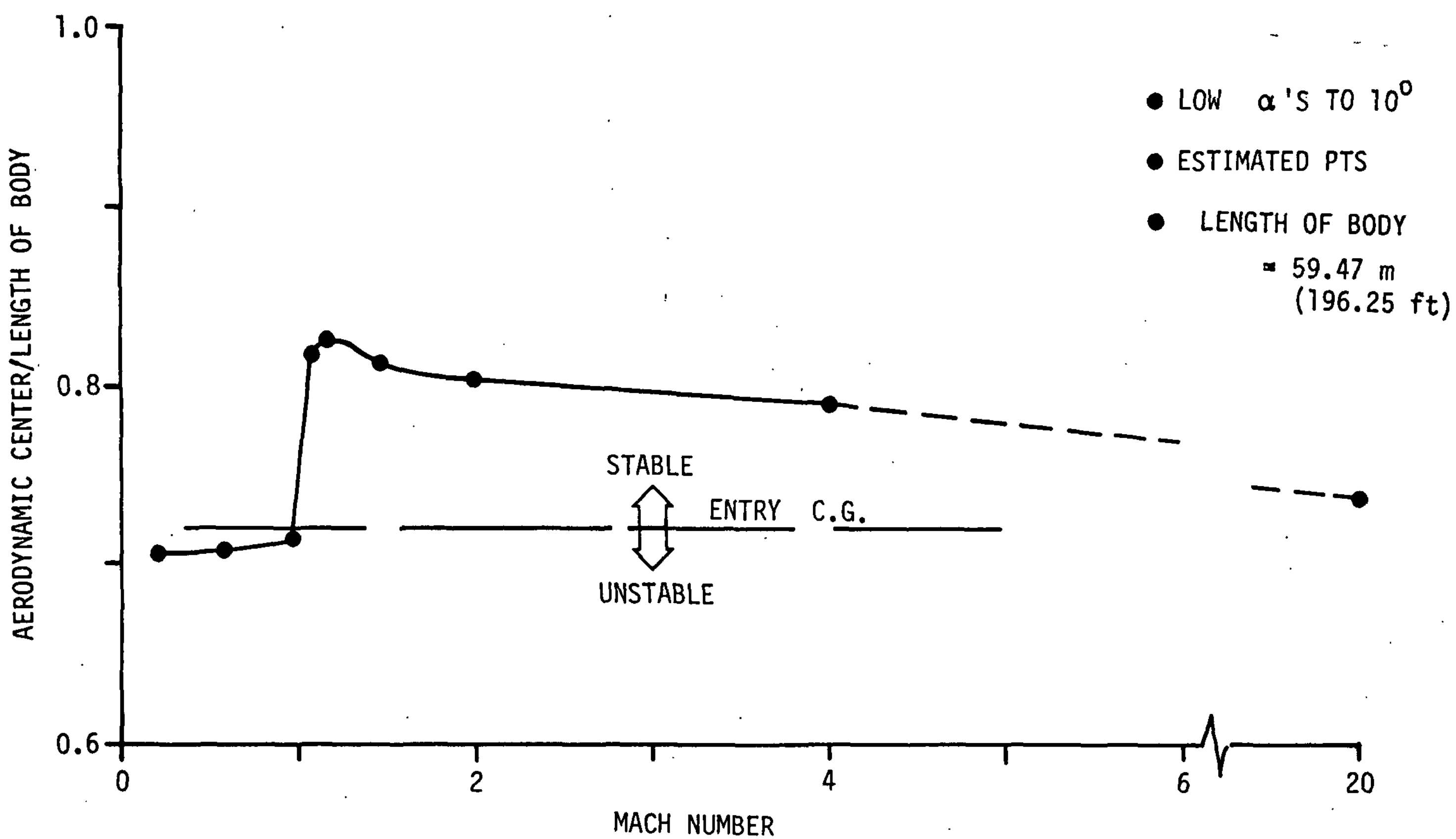


Figure 8 Aerodynamic Center Travel - Orbiter

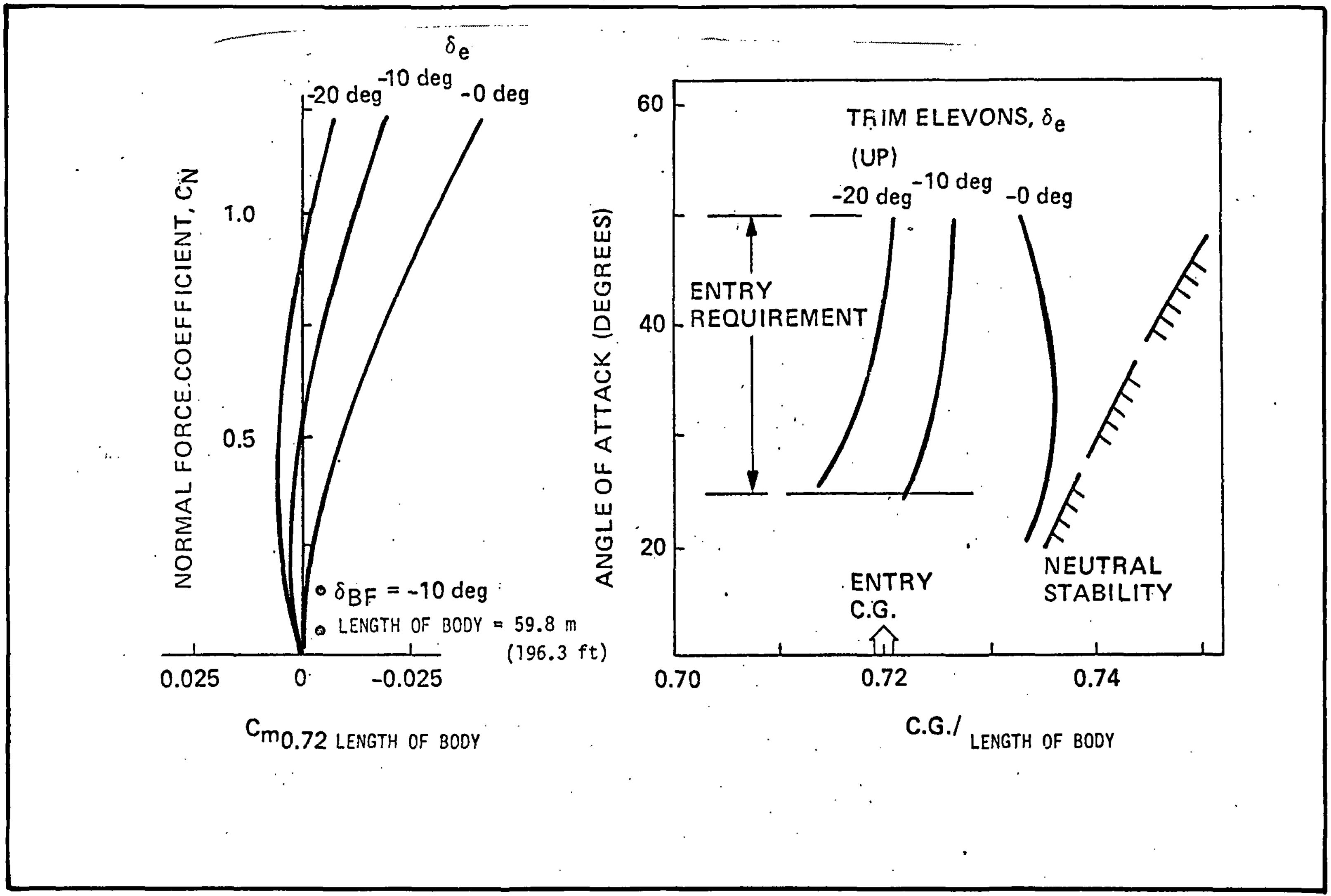


Figure 9 Orbiter Hypersonic Stability and Trim

Orbiter Landing Speed

Due to the low wing loading the orbiter has no difficulty in not exceeding a design landing speed of 85 m/sec (165 knots) at an angle of attack of 15 degrees. For an orbiter landing weight 133397 kg (250,000 lb), the required angle of attack is 8 degrees at the design landing speed (see Figure 10).

The booster stage was also designed to not exceed the same design landing speed and the objective was met by proper selection of wing loading with the maximum lift coefficient characteristics.

Turbojet Propulsion

Trades and selection for the turbojets are outlined in Figure 11. Preliminary parametric trades verified the selection of a design with the following characteristics:

After burner Thrust Augmentation No Fan Bypass (i.e. BPR=0)

Low to Medium Compressor Pressure Ratios (CPR = 13)

Variable Area Turbine (VAT for Controlling Airflow)

Large Size Engines 445,000 Newtons (100,000 lb of thrust)

Common 2-D inlet and nozzle

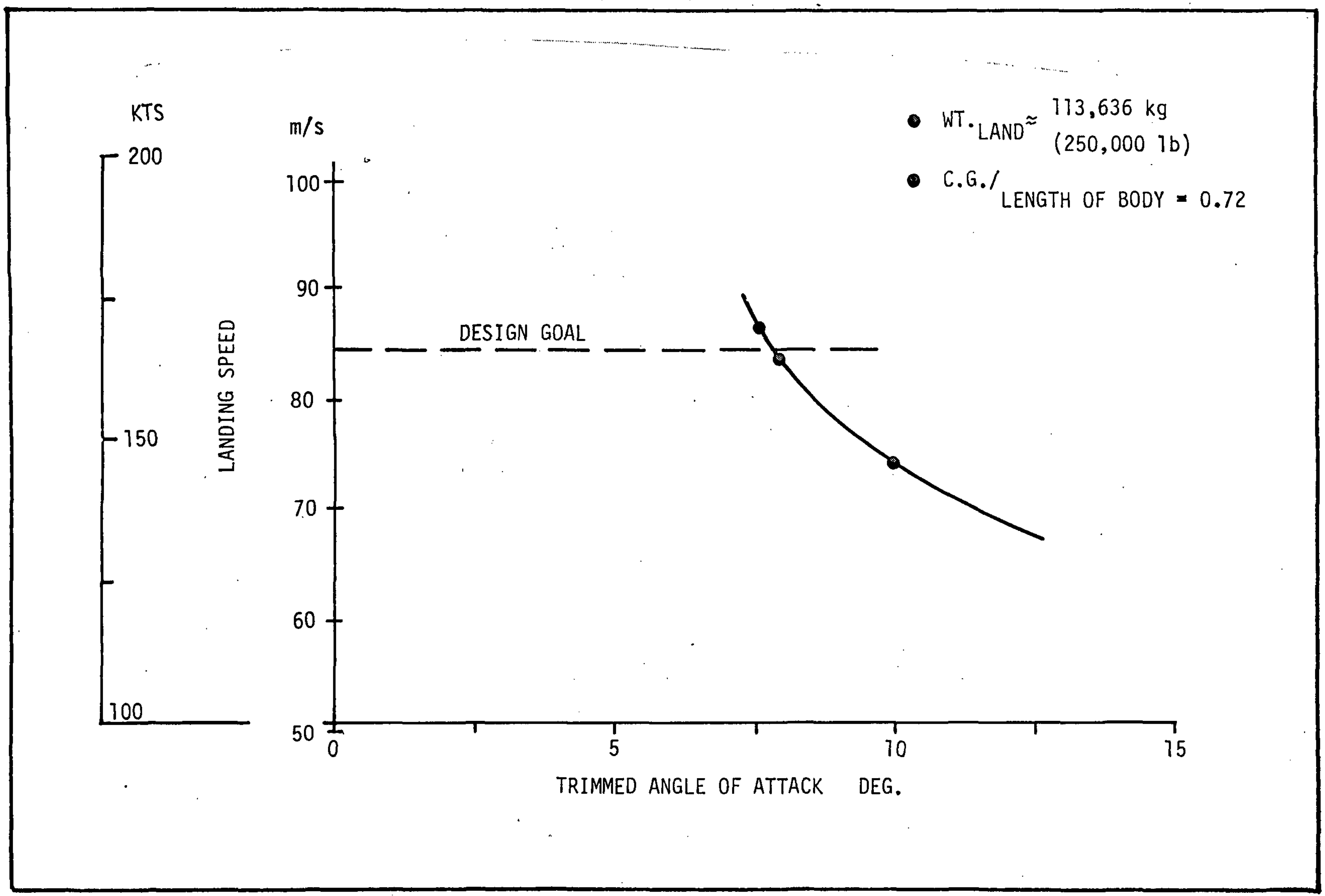


Figure 10 Landing Speed - Orbiter

INLET

INLET SELECTION BASED UPON:

- FLIGHT TRAJECTORY MAXIMUM MACH NUMBER
  - 2.5 EXTERNAL COMPRESSION
  - 3.0 MIXED COMPRESSION
- LOW DRAG
- HIGH TOTAL PRESSURE RECOVERY

ENGINE

ENGINE CYCLE TRADES

- COMPRESSOR PRESSURE RATIO
- BYPASS RATIO
- VARIABLE ENGINE AIRFLOW SCHEDULING
- AUGMENTED VS NON AUGMENTED CONFIGURATIONS

EXHAUST SYSTEM

VARIABLE AREA CONVERGENT-DIVERGENT NOZZLE SELECTED

- AXISYMMETRIC C-D NOZZLE
  - LIGHTER WEIGHT THAN 2 DIMENSIONAL NOZZLE
  - BETTER INTERNAL PERFORMANCE
- TWO DIMENSIONAL C-D NOZZLE
  - TWICE AS HEAVY AS AXISYMMETRIC NOZZLE
  - BETTER INTEGRATED INTO VEHICLE AFT END
  - CAPABILITY FOR THRUST VECTOR CONTROL

Figure 11 Propulsion System Selection Rationale

At mid-term of the study, the engine chosen was designed as MK-35. The final selected version was designated MK-15 and detailed comparisons are presented in Figure 12. The T/q and D/q are compared at a fixed sea level static thrust of 444820 N (100,000 lbs) which has the effect of relatively changing the required engine capture area. Further details of capture area engine drag components and scaling are given in Appendix III. These characteristics were generated by a Pratt and Whitney Advanced Technology Parametric Engine Cycle Computer program along the design trajectories. Since the turbojet booster accelerated the vehicle to Mach numbers in excess of 2.5, a mixed compression inlet was used for maximum efficiency. The refinement in engine airflow scheduling from the mid-term engine, MK-35, to the final selected engine, MK-15, resulted in a lower internal drag as shown in Figure 13 in terms of drag over dynamic pressure, D/q. Also compared are the C_T, T/q and SFC versus Mach number. The refined airflow scheduling for MK-15 resulted in an increase in net thrust available at transonic speeds for a constant sea level static thrust rating. The net thrust increase of 4.5 percent was accompanied by a reduction in inlet capture area of 17 percent. These improvements are due mostly to the reduction in transonic spillage drag. For Mach numbers above 1.5, the net thrust or T/q is reduced along with the reduced airflow scheduling. However, specific fuel consumption, SFC, continues to be favorably reduced.

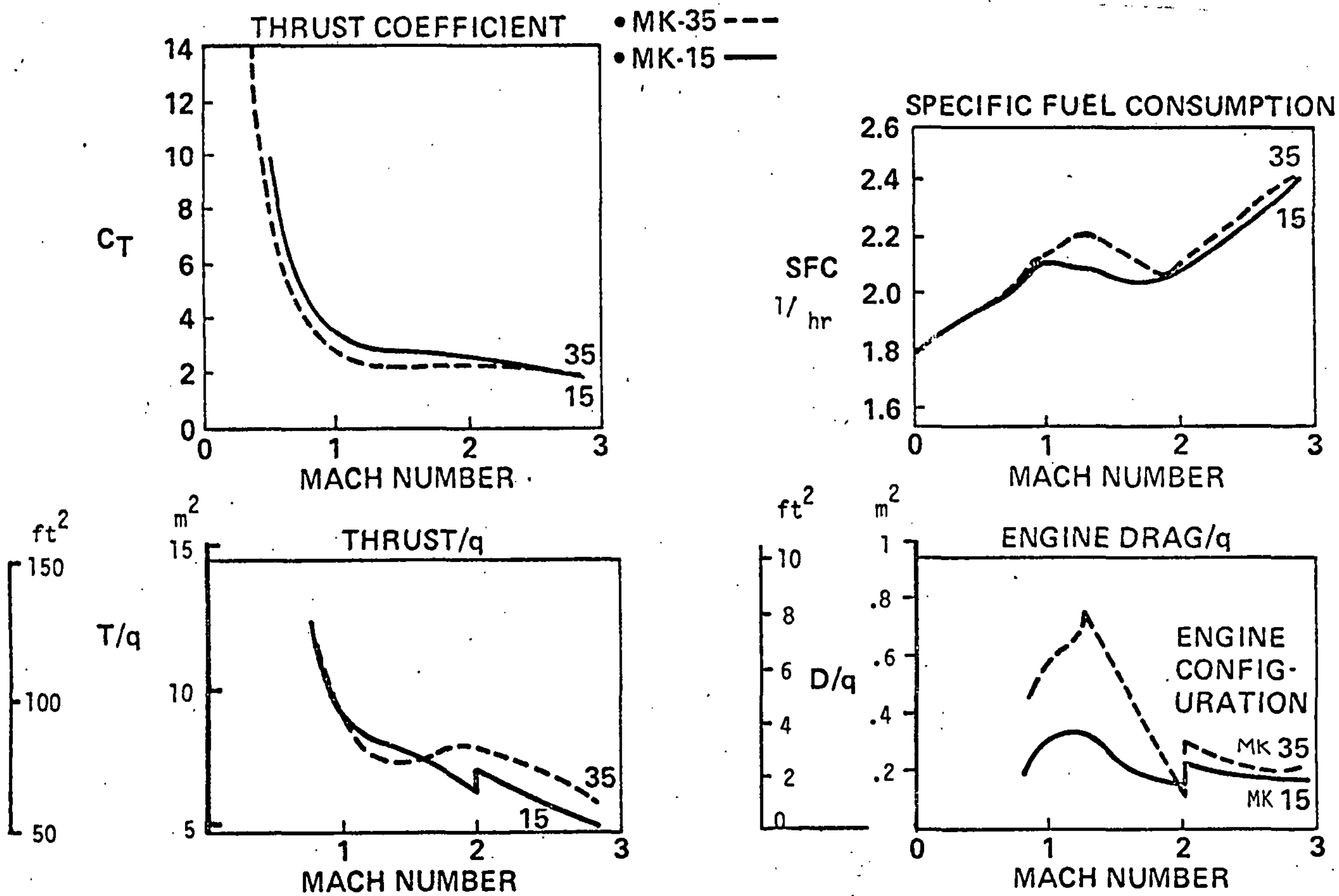


Figure 12 Comparison of Turbojet Characteristics

Variable - Geometry Turbine After Burning Turbojet

The basic engine is sized at sea level static conditions at an airflow of 181 kg/sec (400 lb/sec). The installed static thrust, weight and dimensions are presented in Figure 13. The engine size, weight and performance may be scaled using the scale factors presented. A schematic of the engine is presented to illustrate the dimensional nomenclature. The nozzle depicted is axi-symmetric, however, and would be replaced by a two-dimensional nozzle for this booster configuration. By choosing (8) engines per booster thrust rating of 467,000 Newtons (105,000 lb) optimized payload. This resulted in net thrust minus drag values during ascent acceleration of the Turbojet Booster Vehicle of about 25 percent. Further details of the Turbojet Propulsion System are given in Appendix III.

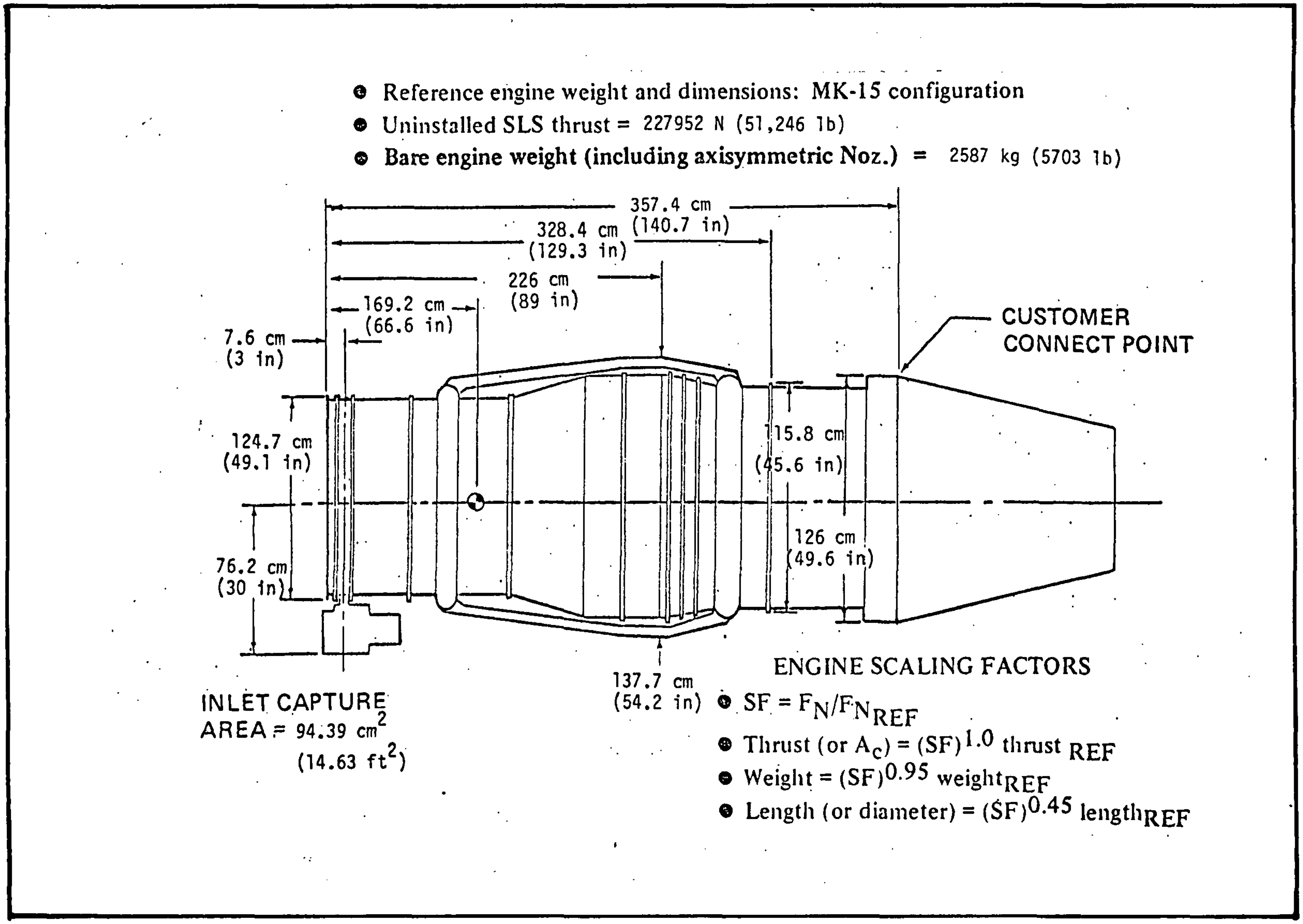


Figure 13 Variable - Geometry Turbine Afterburning Turbojet

Performance

Trajectory

Ascent heating constraints on the orbiter hot structure played a very significant role in shaping the ascent trajectory. To avoid exceeding these limits, the staging Mach number had to be limited to about 2.7 at an altitude of 19.5 km (64,000 ft). Along with these conditions, maximum dynamic pressure, q, and $q\alpha$ are important parameters. These maximum values were:

$$Q = 69426 \text{ Pascals } (1450 \text{ PSF})$$

$$Q\alpha = 397{,}404 \text{ Pascals Deg. } (8300 \text{ PSF Deg})$$

The final tailored trajectory is presented in Figure 14 and represents the results of many trajectory runs to obtain near optimum payload performance. Just prior to staging a pull up maneuver (α increasing from 3.5 to 8 deg) is initiated to avoid exceeding the heating limits for the particular hot structure design used in this study. Other structural approaches could allow increased staging velocity at higher dynamic pressure with a resulting performance improvement. For more details of finalized trajectory, see Table 17 of Appendix I.

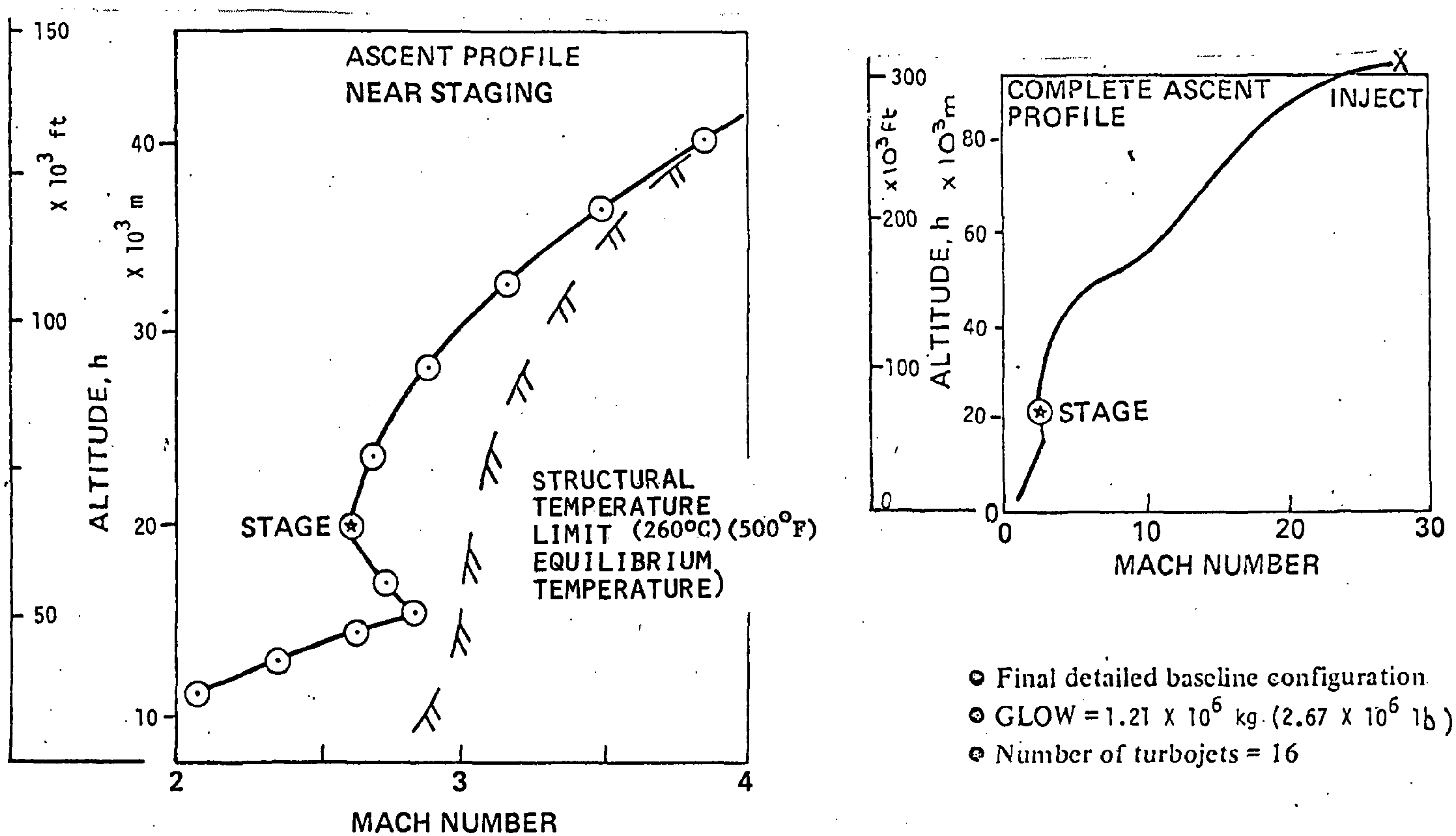


Figure 14 Ascent Trajectory

Performance Trade - Number of Turbojets

The effect of varying the number of turbojets for the first stage on payload is shown in Figure 15, for three fixed values of GLOW. For a GLOW of 1.211 X 10^6 kg (2.67 million lb), the final baseline had (16) turbojets with a resulting payload of about 24494 kg (54,000 lb). Adding (2) turbojets to (18) slightly increased payload. Subtracting (2) turbojets reduced the payload to 21319 kg (47,000 lb). These engine trades indicated that the excess thrust margin over drag at transonic/supersonic speeds should be at least 25 percent. As expected, the higher GLOWS required the number of turbojets to increase.

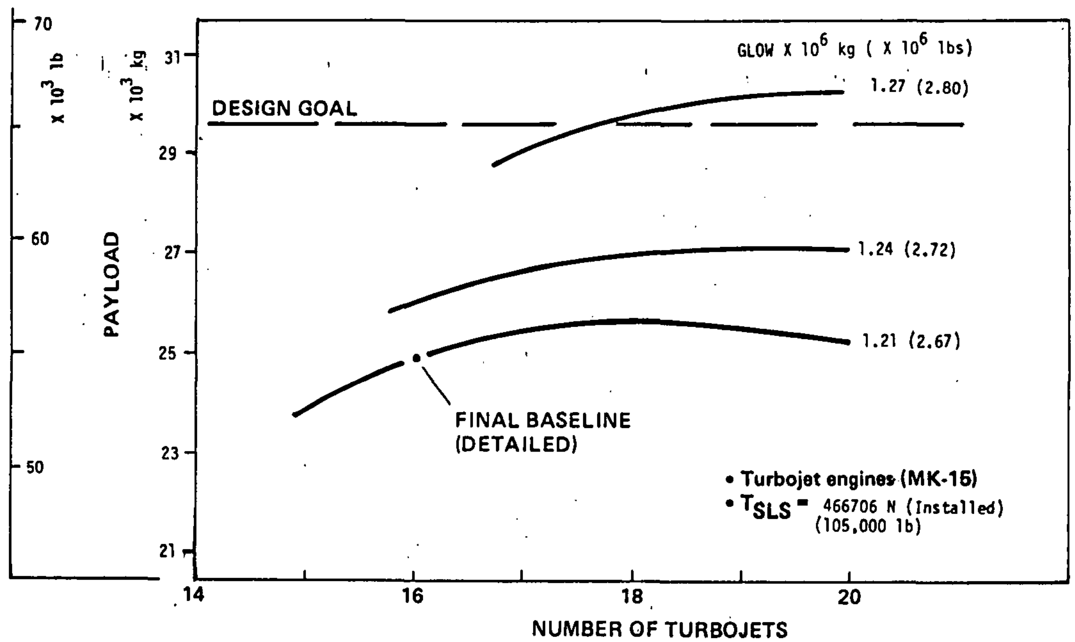


Figure 15 Performance Trade - Number of Turbojets

Performance Trade - Payload/GLOW

For a GLOW of 1.211 X 10^6 kg (2.67 million lb), a detailed weight statement for the final baseline was determined. Using this information, parametric weight relationships were established in order to scale the size of the vehicle to a 29483 kg (65,000 lb) payload. This trend of payload with GLOW is shown in Figure 16, for (16) and (18) turbojets. To meet the design payload, the vehicle was increased to a GLOW of 1.302 X 10^6 kg (2.80 million lb). These performance trades were verified by ascent trajectory runs.

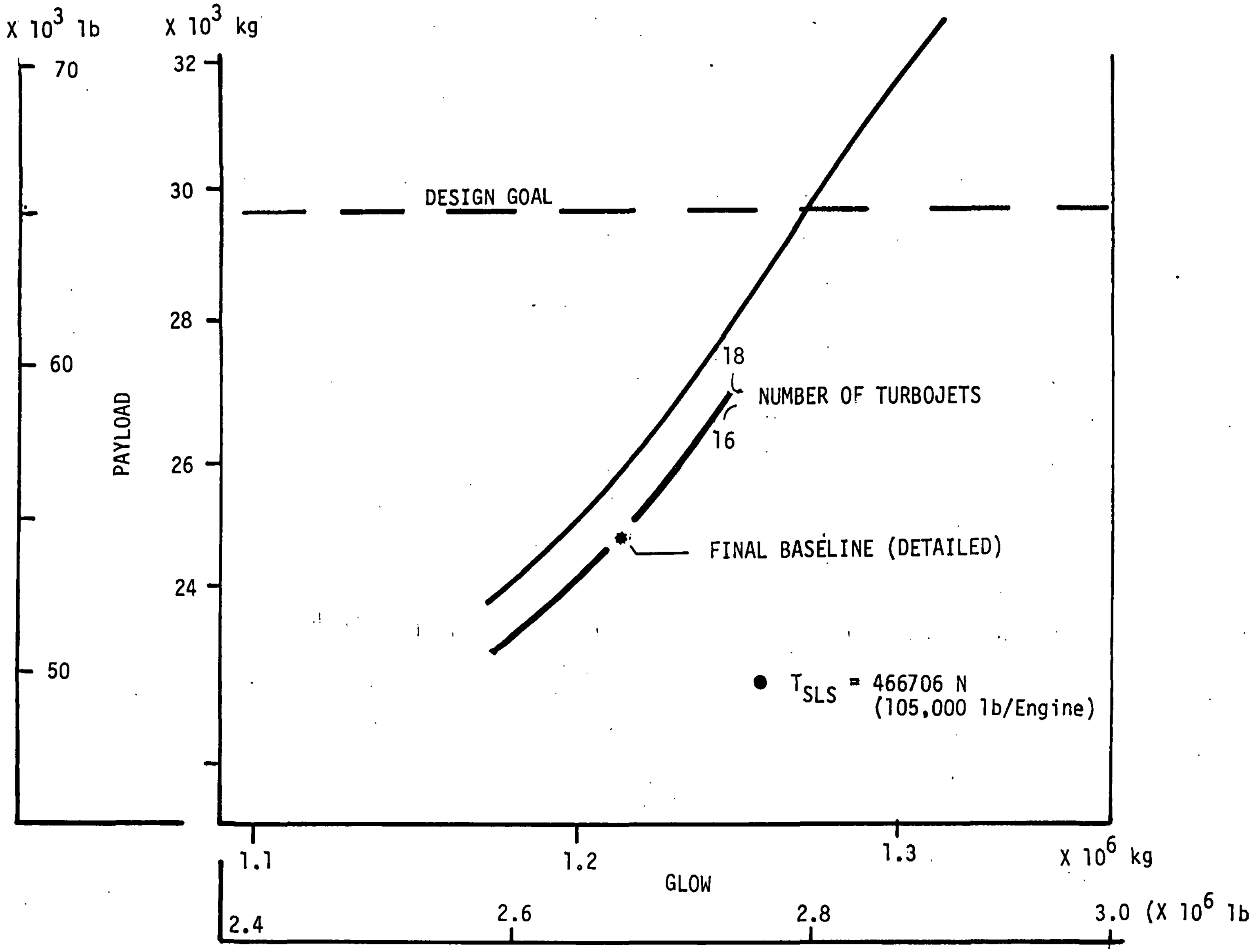


Figure 16 Performance trade - Payload/GLOW

Performance Sensitivity - Drag

Since there is not an existing aerodynamic data bank for mated configurations of the type used for this study, it is important that the sensitivity of payload to drag be established. By using a drag ratio relative to the estimated minimum drag and running a series of ascent trajectories, the sensitivites were determined. Both minimum-drag and drag-due-to-lift (dCD/dCL^2) sensitivites were established as shown in Figure 17. The number of Turbojets was held constant at (18). For large increases in drag, it would be better to also increase the number of Turbojets as the excess thrust margin dropped below about 20 percent. This also has the effect of reducing the slope of the payload sensitivity to drag increases. Therefore, the number of turbojets should be reoptimized for each drag level. Because of its cascading effect on performance, drag reduction for this class of vehicle could result in significant performance gains.

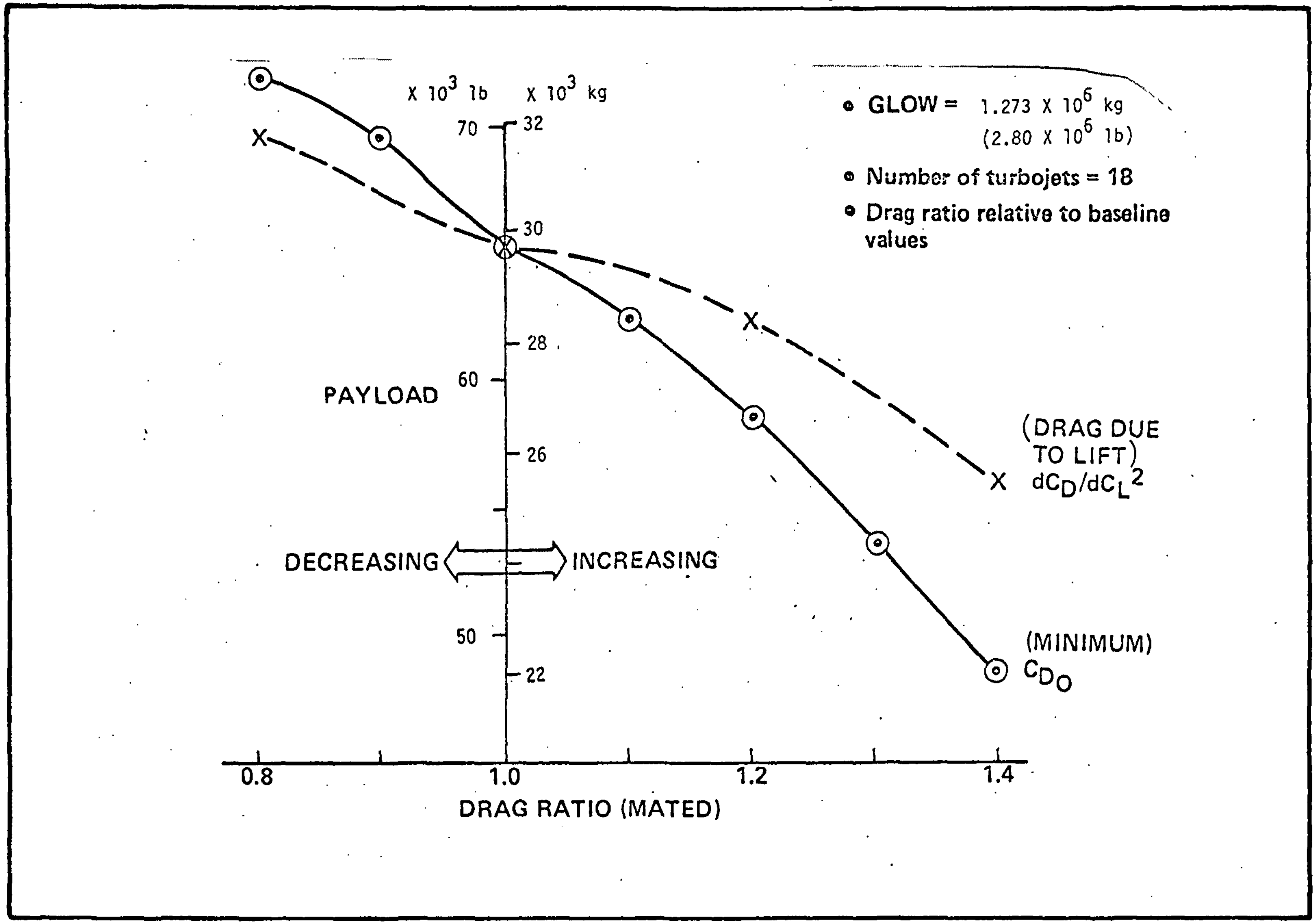


Figure 17 Performance Sensitivity - Drag

Vehicle Design and Subsystems

The study was initiated under the precept that the maximum effort would be expended on the booster vehicle(s) to provide a complete detailed definition of the vehicle(s) such that concept feasibility could be established. To facilitate this approach, the ALRS 205 configuration was selected for the orbiter. To accommodate the reduced propellant volume, the body height and length were reduced, and the wing thickness reduced maintaining the planform area. The body width was reduced compatible with the reduction of the number of SSME engines from four to three.

The booster configuration selected was the configuration with the twin boosters symmetrically located under the orbiter wing with eight 355857 N. (80000 lb) thrust SST type engines located in each booster (Fig.18). The basic booster concept could be summarized as a multi-engine pod with adequate wing area for fly back and landing and a landing gear suitable for taxi and takeoff of the loaded configuration. Subsystems were to be minimal compatible with operational requirements. The engine pods were to be located under the wing of the orbiter similar to the usual turbojet engine installation.

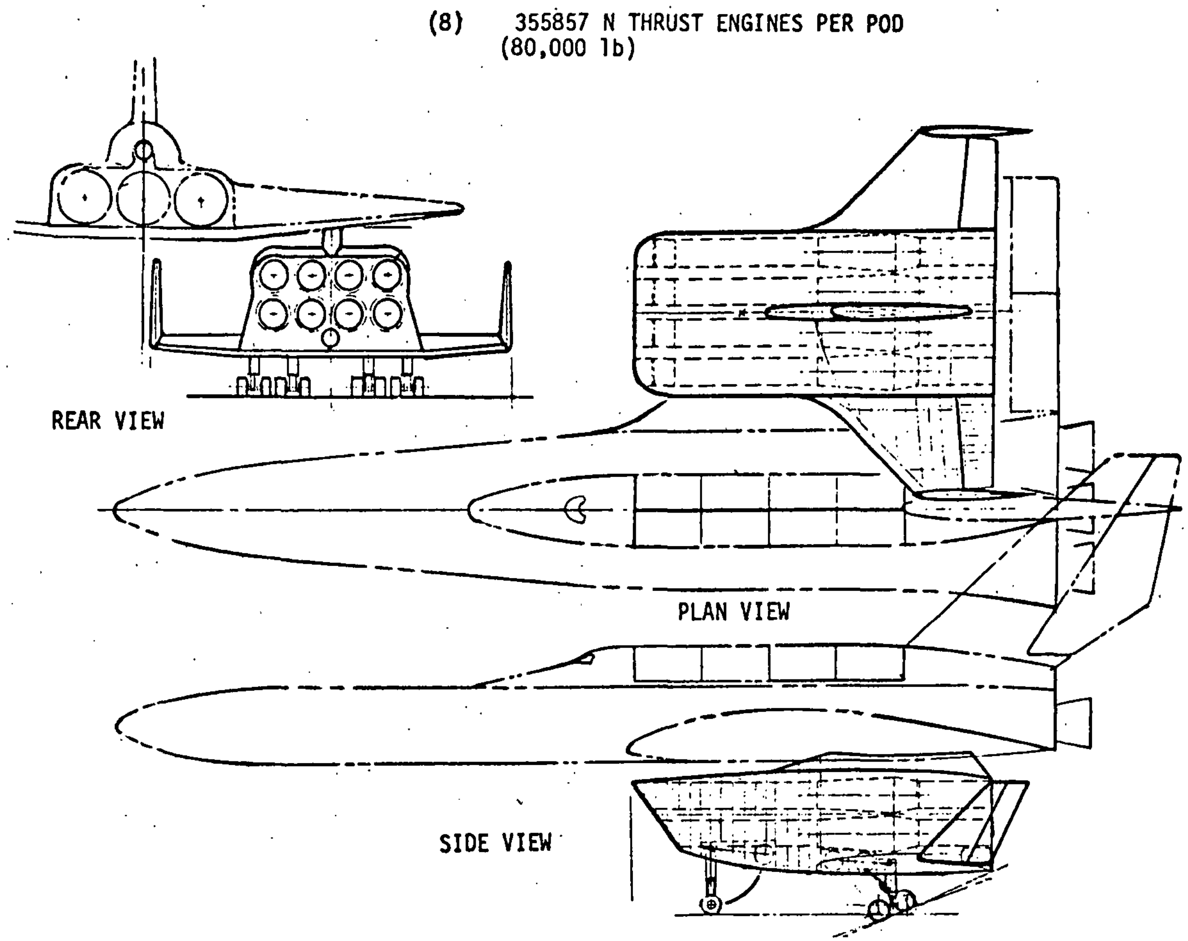


Figure 18 Turbojet Boosted System Sixteen Engines FIRST CONFIGURATION

A number of problem areas were revealed as the configuration evolved requiring effort to develop solutions which would least adversely impact the system. These are discussed as follows:

- Booster engine nozzle plane - The orbiter lower wing surface and trailing edge surfaces would require additional structure and heat shielding to withstand the plume acoustics and thermal environment. As shown on Figure 19 the acoustic environment is in excess of the normal maximum of 160 db within 7.62 m (25 feet) side line of the plane of the exhaust. However, the inherent feature of honeycomb construction of a stiff light structure lends additional acoustic dynamic resistance. Consequently, no weight penalty was encountered.

- Thrust Line Offset - The high thrust to weight relative to usual turbojet applications became evident as the combined thrust line of the boosters was displaced below the vehicle such that the necessity for thrust vectoring for control at takeoff was indicated. Significant design and development effort has occurred in the area of two dimensional vectoring nozzles over several years and configurations have been developed for thrust deflection which have been wind tunnel tested for deflections as high as 26^{o}.

- Orbiter Support Impacts - As configured the orbiter is supported symmetrically by attachments under each outboard wing. These attachments must carry vertical support loads as well as thrust loads, and torsional loads as a consequence of yaw, pitch, and roll. These loads increase the orbiter wing weight as much as 6804 kg (15, 000 lb) over the ALRS 205 baseline. This was reduced to about 5130 kg (11,400 lb) by moving the attachments inboard. A further orbiter wing weight

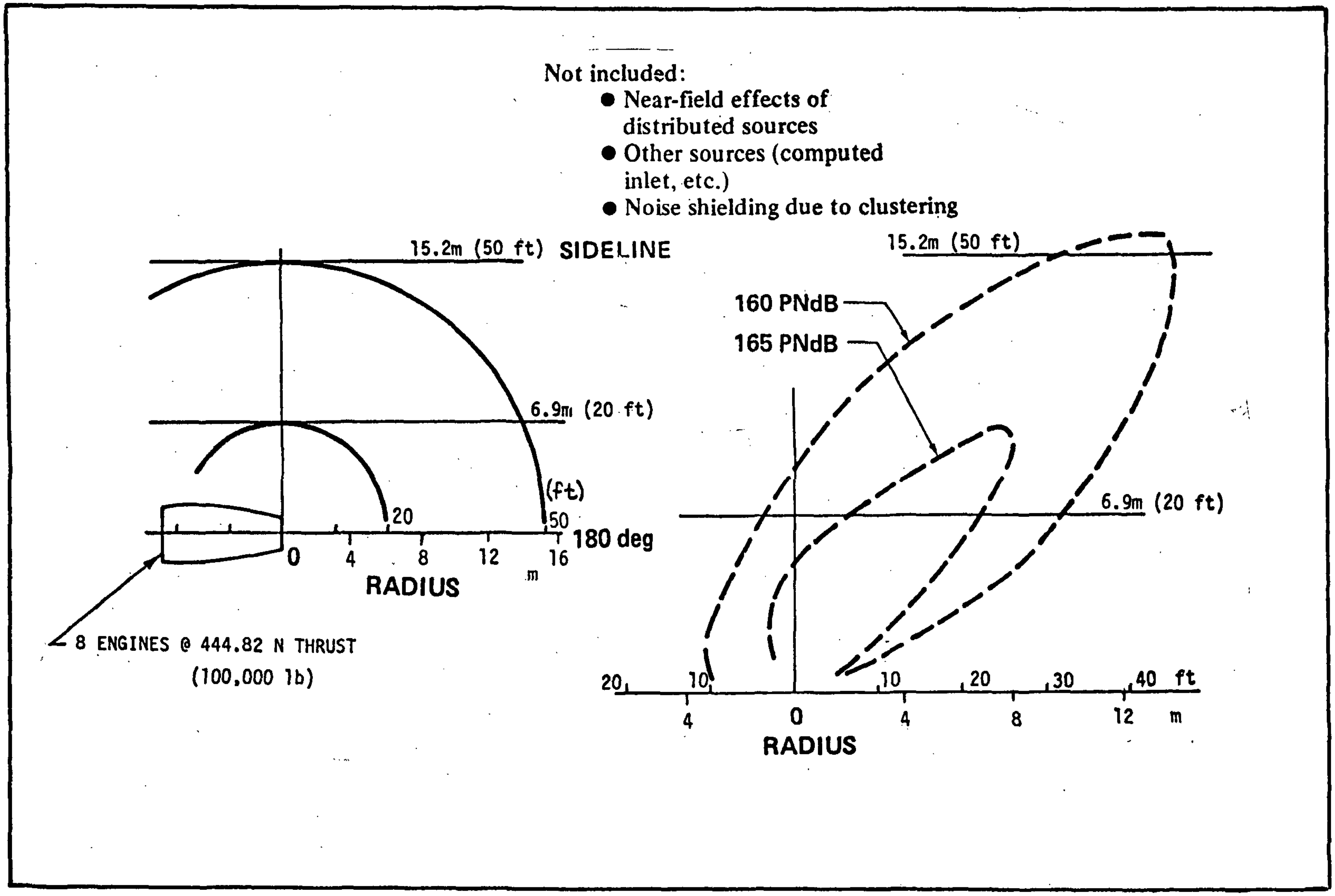


Figure 19 Turbojet Booster Nozzle Acoustic Environment

reduction is possible if the booster wing span could be reduced, allowing a further inboard movement of the attachments. In addition, a runway bump load criterion should be established for vehicles of this weight class. The 2 "g" load used in this study may be too high.

- Takeoff Gear - The takeoff gear to support the gross weight of 1.179 X 10^6 kg (2.6 million lb) and the speed of 122 m/sec (400 feet per second) designed to the usual aircraft standards weighed in excess of 32658 kg (72,000 lb) per booster, or approximately 5.4% of takeoff gross weight. The combination of high load and high speed severely impacted this element of the design. This was significantly reduced by utilizing a fixed gear for takeoff utilizing the multiple tires for small surface irregularity shock absorbing. This reduced the weight of the takeoff gear by approximately 72%, to about 9,000 kg (20,000 lb) per booster.

- Supersonic engine inlets - The configuration selected initially was for a cluster of individual inlets for each engine of the external compression configuration. This inlet was suitable up to approximately M = 2.5. The common inlet selected, although longer, was shown to be lighter due to reduced inlet wetted area. Higher speeds than M = 2.5 necessitated utilization of a mixed compression inlet with an increase in complexity, weight and cost. In addition, concern for the shock from the orbiter nose crossing the inlet at the higher Mach numbers indicated a forward placement of the inlet.

- Transonic Drag - The baseline configuration was not area ruled and as a consequence more and larger turbojets were required in an effort to achieve the desired payload. This in turn required more cross section area compounding the problem for a very small gain. Through area ruling the maximum drag coefficient was reduced approximately 20%. An optimum area distribution has yet to be defined.

- Increased GLOW Effects - The vehicle growth to achieve the payload goal of 29483 kg (65,000 lb) required a scale up of approximately 20%. This in turn could have required a wing reference area increase of approximately 185.8 m^2 (2000 ft^2) for an estimated weight penalty of approximately 5897 kg (13,000 lb) as a result of the 122 m/sec (400 FPS) takeoff speed. However, with vortex lift, the lift coefficient increased approximately 20% thereby eliminating the wing size and weight increase. The Ogee wing planform was incorporated for both the orbiter and the boosters to produce the lift coefficients desired. This had the beneficial effect of relocating the aero-center aft such that vehicle stability was much easier to achieve.

- Aero Interference Effects - This problem area was one which remained unresolved. While the location, magnitude, penalty, etc. were undefined, this problem area was one which was pointed to by numerous reviewers. It appears that this area can only be resolved by wind tunnel testing to establish the impact of such effects and the penalty, if any, of these effects. These tests should explore the benefits of geometrical arrangement to minimize the penalties.

- Second Configuration - The second configuration developed to respond to the problems noted on the first configuration is shown on Figure 2.0 The engine size was increased to 507097 N (114,000 lbT). To minimize the penalty on the orbiter, the attachments were located at B. L. 336 and 605, with B. L. 336 the primary support. To reduce booster frontal area, the main load carrying gear was arranged in tandem and retracted into a pod arranged along side of the engines. The wing carry through was centrally located with the engines located above and below providing good engine access for maintenance. The engine inlets were bifurcated horizontally with four engines per inlet. The exhaust nozzles were individually arranged 2-dimensional nozzles with thrust vectoring with the exit plane located at the trailing edge of the orbiter to minimize acoustic thermal effects. Subsystems were arranged in the forward section of the asymmetric booster with fuel in the wings and center section. An outboard tip gear retracted into the wing. Although this booster configuration did respond to the problems of the preliminary configuration, the design required development of two different booster vehicles and this was considered to be too great a penalty on system development costs.

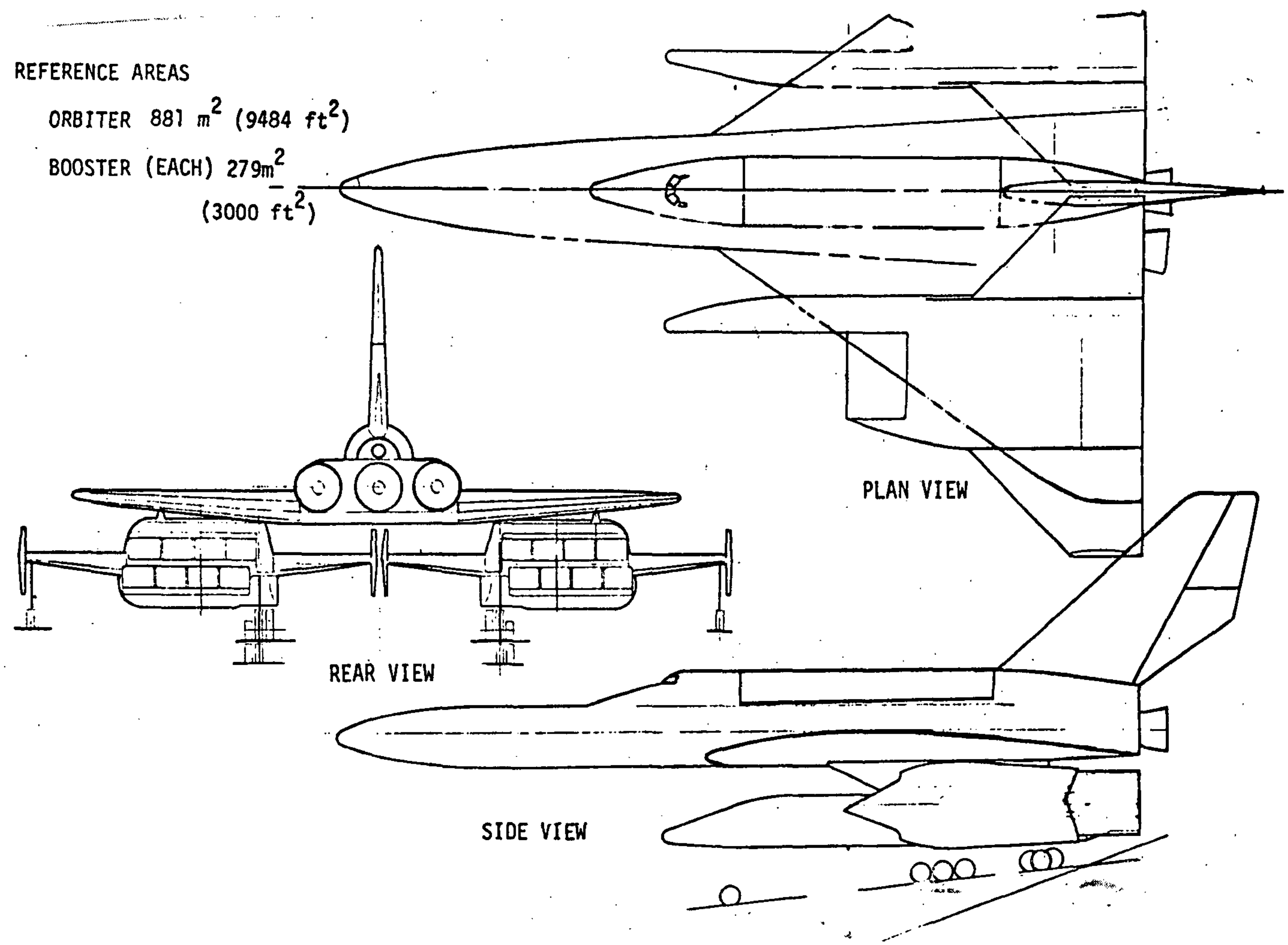


Figure 20 Turbojet Boosted System Sixteen Engines Second Configuration

- Mid-Term Configuration - The mid-term configuration was the evolution of the second configuration revised to provide symmetrical boosters and is shown on Figure 21. The weights are given in Table 1. This configuration was developed in detail. However, symmetry required attachment to the orbiter at BL 496 which did impose a weight penalty on the orbiter wing. This configuration exceeded the booster target weights by 123377 kg (272,000 lb) and the orbiter target weights by 24947 kg (55,000 lb). Thus this configuration had essentially no payload. Configuration problems were compounded by high drag, excess weight, and low lift coefficients which increased fuel consumption and reduced performance.

The secondary power requirements were very high, compounded by landing gear retraction, engine starting system (Figure 22), and fuel boost pump power requirements of the fuel system (Figure 23). This in turn added to the weight problem. The aft location of the boosters to avoid plume impingement problems created an aft c.g. problem of the combined configuration which preliminary analysis indicated would be difficult to control for takeoff rotation as well as subsequent flight path control.

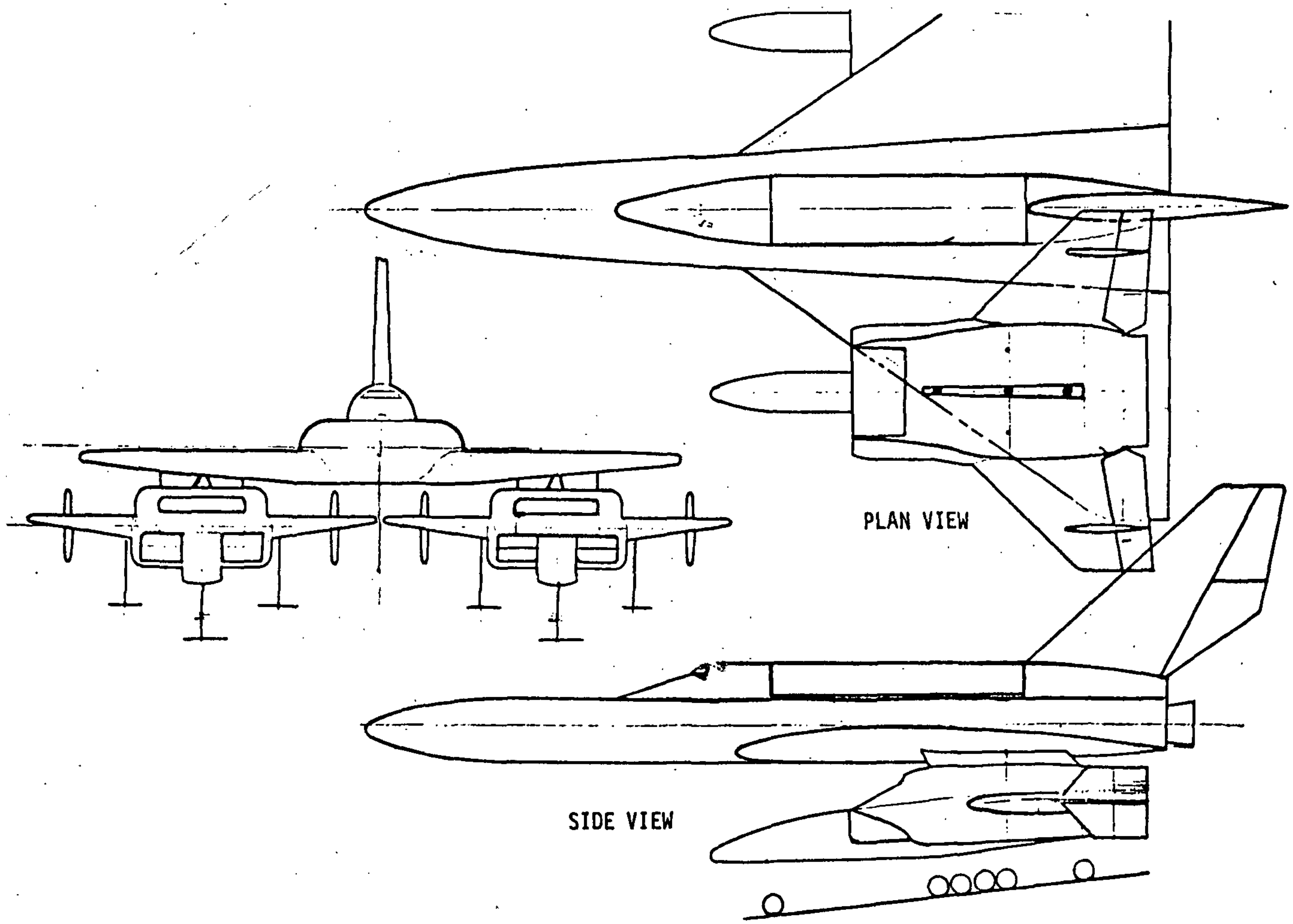


Figure 21 Turbojet Boosted System Sixteen Engines Mid Term Configuration

Table 1 Air Breather Booster

MASS PROPERTIES	kg		lb	
STRUCTURE		69049		152227
WING	12076		26622	
VERTICAL TAIL	1474		3250	
BODY	10711		23613	
MAIN NOSE AND WING LANDING GEAR	32848		72418	
NACELLE AND COWLINGS AND MOUNTS	9037		19924	
ORBITER SUPPORT PYLON AND MECH. (3000)	2903		6400	
PROPULSION		5996		132203
ENGINE (13492) X 8	48959		107936	
ENGINE CONTROLS AND ACCESSORIES .04 X ENGINE WT.	1958		4317	
STARTING SYSTEM	456		1006	
FUEL SYSTEM	3723		8208	
THRUST VECTOR 1342 X 8	4870		10736	
FIXED EQUIPMENT		9030		19922
SURFACE CONTROLS	711		1567	
HYDRAULICS SYSTEM (2075 HP)	4988		10997	
ELECTRICAL (200 HP)	762		1680	
ELECTRONICS	1270		2800	
EMERGENCY EQUIPMENT	276		608	
ECS	77		170	
APU	953		2100	
10% WT GROWTH		13805		30435
		151856		334787

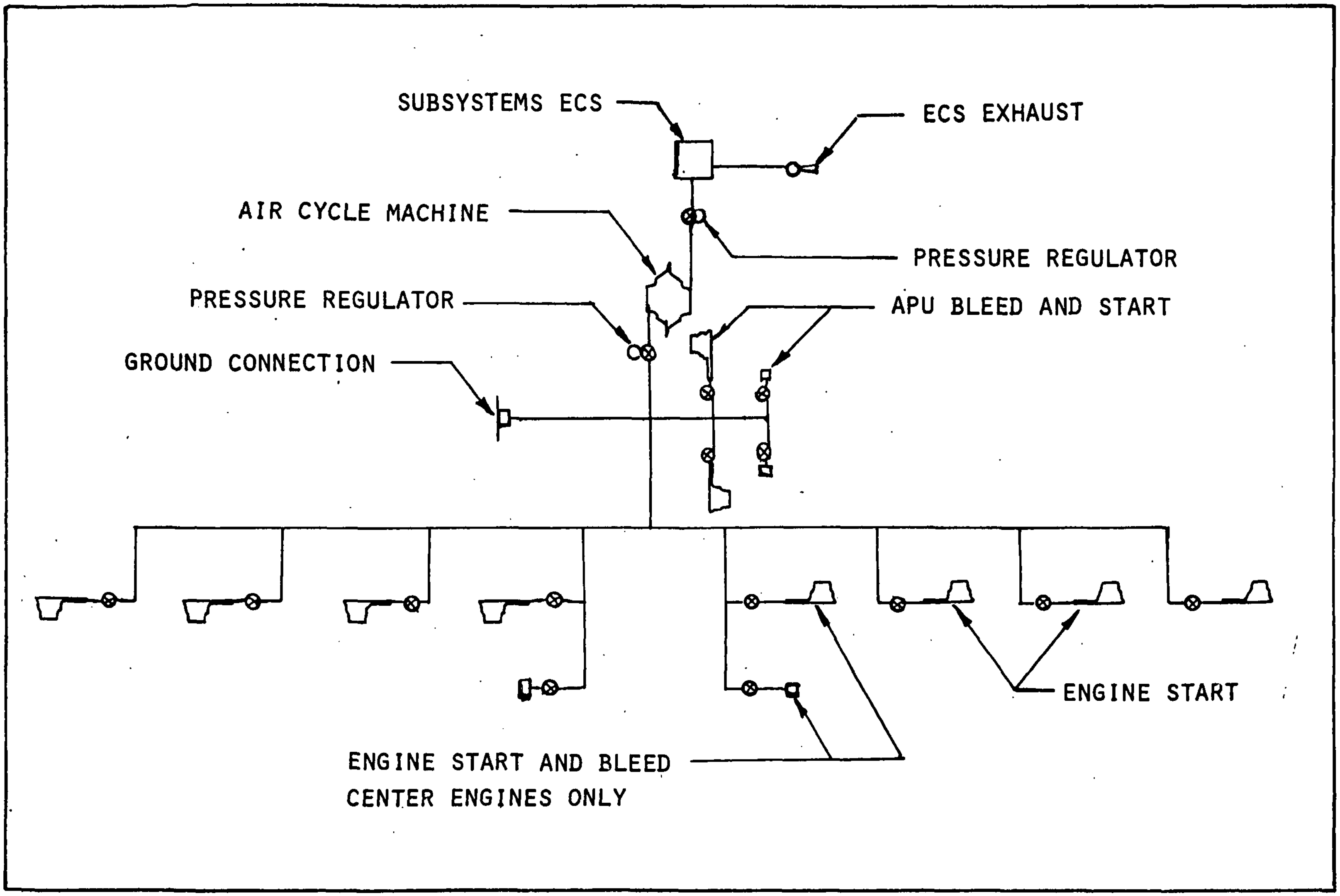


Figure 22 Air Breather Booster Pneumatic System

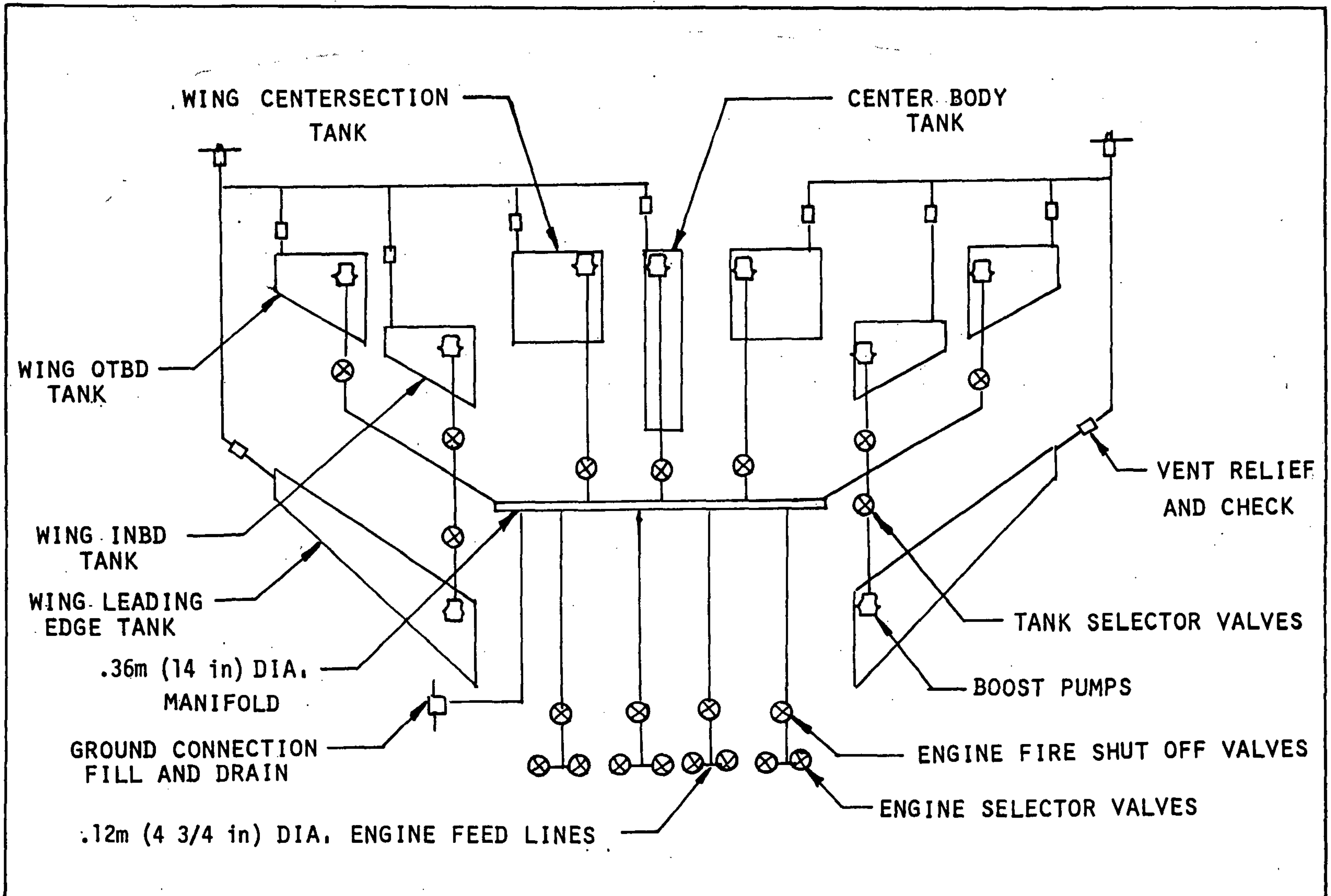


Figure 23 Air Breather Booster Fuel System

- Initial Area Ruled Configuration - Several approaches were utilized to attempt to overcome the problems of the mid-term configuration. These included a higher velocity staging which required booster flight up to M = 3. This necessitated a change to a mixed compression inlet configuration. The number of engines per booster was reduced to six to aid in reducing maximum cross sectional area of the overall configuration. The orbiter body was area ruled as much as feasible and the base area was redesigned to reduce the base area from 41.8 m^2 (450 ft^2) to 29.7 m^2 (320 ft^2). The booster areas were then nested and adjusted to provide the minimum cross section area at M = 1. This forced the boosters forward in the configuration necessitating a longer exhaust duct. To minimize the weight penalty, the exhausts were combined leading aft to the combined two dimensional nozzle in which area control was provided by flaps deflecting toward the centerline. Pitch thrust vectoring was provided by a vane located on the horizontal centerline of the nozzle. The main load carrying gear was fixed with the tires used to accommodate surface irregularities. This configuration is shown in Figures 24 and 25. The results of these efforts were that drag was reduced and the configuration showed a payload of approximately 9072 kg (20,000 lb). The c.g. of the configuration was far enough forward to indicate that control was feasible. Although the payload goals had not been achieved, positive payload to orbit was shown with 75% of the thrust of the mid-term configuration. Section EE Figure 24 illustrates the engine stacking arrangement to provide structural paths below the engines for wing carry through structure and between the center

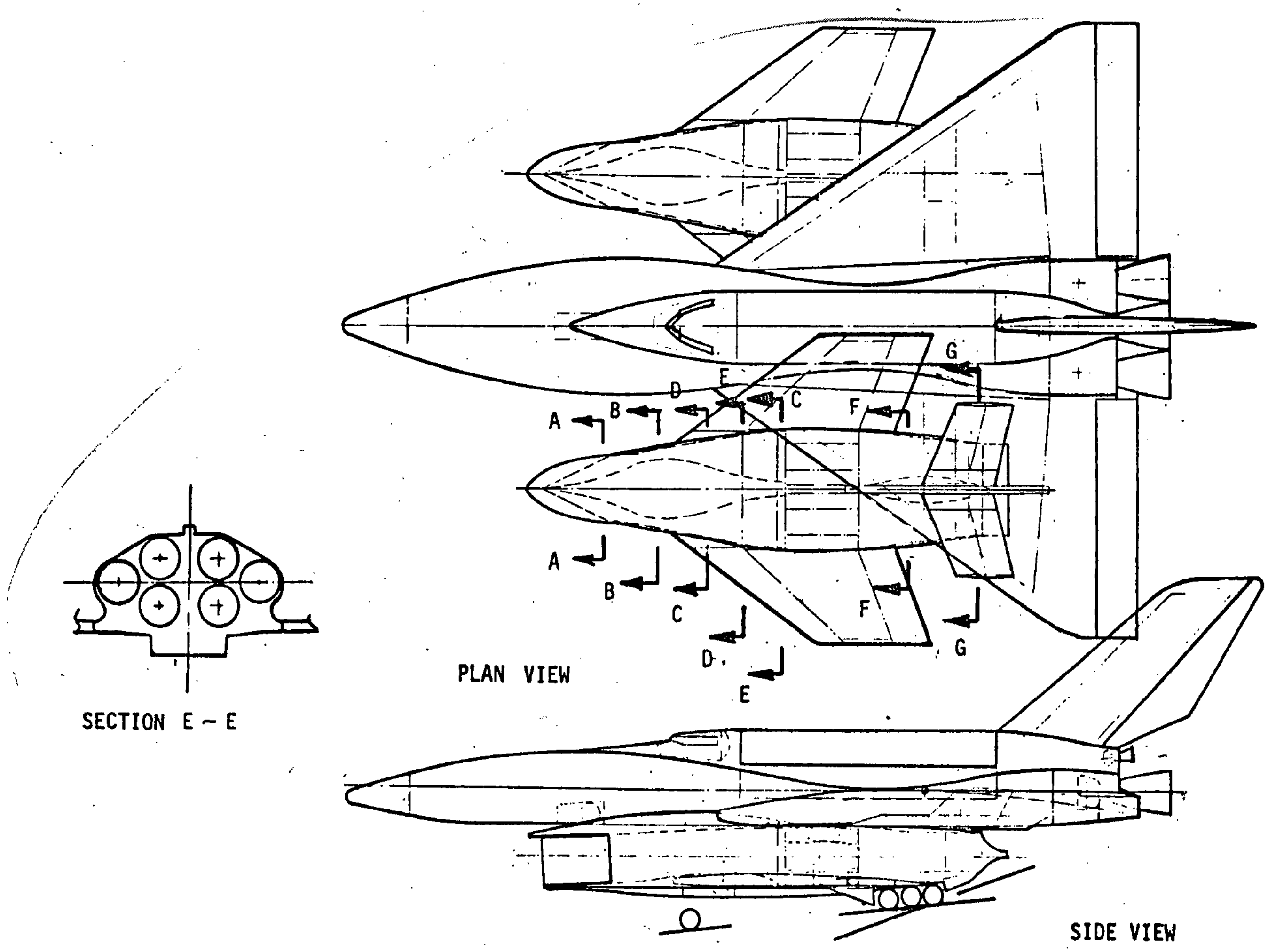


Figure 24 Turbojet Boosted System - Twelve Engines Area Ruled Configuration

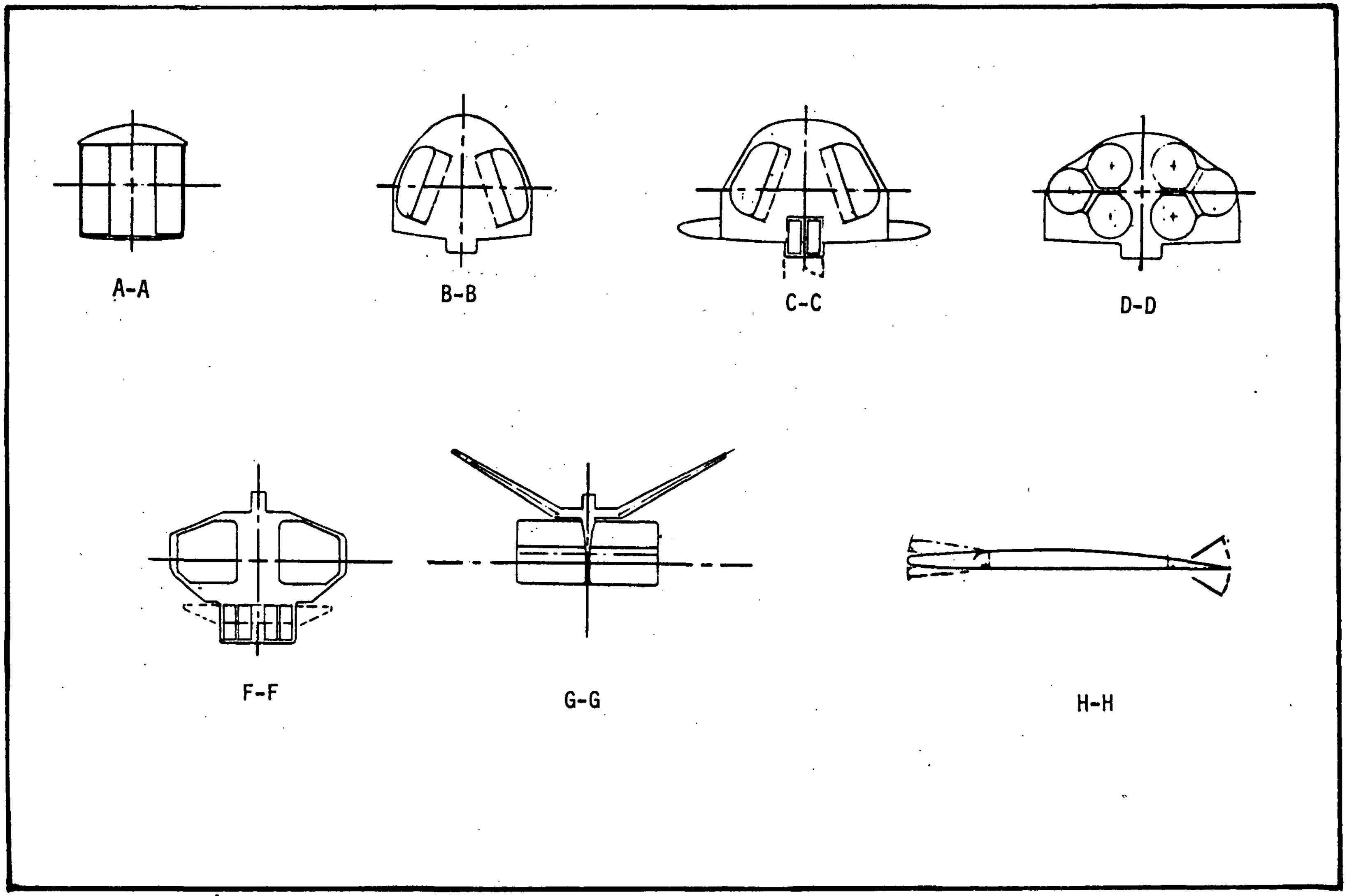


Figure 25 Turbojet Booster Six Engine Configuration

engines for orbiter support structure. Sections A-A, B-B, and C-C Figure 25 illustrate the inlet arrangement and ramp for supersonic shock control. Section D-D illustrates the one inlet diameter length separation provided for each engine inlet to avoid adverse inter-engine inlet affects. Section F-F shows the location of the fixed main gear, the closure door configuration and the structural load path between exhausts for the orbiter to main gear loads. The folding ruddervators are shown in the deployed position in Section G-G as well as the thrust vectoring vane in the center of each exhaust nozzle. The problem of controlling booster lift during takeoff, climb, and staging was attacked by the use of active leading and trailing edges to effectively vary wing camber from plus to minus. This is shown in Section H.H. Control studies of this nature are under development for high maneuverability vehicles.

Final Detailed Configuration

- The final detailed configuration was derived from the initial area ruled configuration. The configuration was parametrically scaled up to accommodate the specified payload to orbit. This required eight engines per booster. This indicated an increase in take-off lift of approximately 20% was needed to maintain the 122 MPS (400 FPS) takeoff speed at the increased gross weight. To avoid increasing wing area and the associated weight penalty, the wing planform was revised to take advantage of the benefits of vortex lift. This appeared to improve the lift coefficient by approximately 20% to 25%, sufficient to accommodate the increase in weight without an increase in wing area.

The vehicle was area ruled with the help of NASA Langley personnel. The configuration is shown on Figures 3 and 26 through 31. Figure 26 illustrates through selected sections the structural arrangement of the orbiter which features mold line tankage with internal truss bracing. The booster configuration is illustrated on figures 27, and 28. The Ogee wing planform is shown on Figure 27. The folding vertical fin is shown in the deployed position. The radome extends forward of the inlet to provide an additional plate to prevent inlet stall during the staging pitch up maneuver. Fuel is stowed behind the radome above the inlet, behind the nose gear below the inlet and in the wings and wing leading edges. The collected nozzle and deflector is shown on Figure 28. Flaps close toward the center flap from the top and bottom for nozzle area control. Afterburner flame holders are located immediately forward of the center deflector. The center engines have their own inlet and exhaust for improved flyback operations. Figure 29 illustrates the main gear. The forward set of three wheels is retractable and is a servo controlled actuator loaded trailing swing arm gear which is the landing gear and during takeoff carries its proportional share of the load. Closure doors for the wheels are shown on Figure 28.

Section A-A illustrates the axle assembly. Brakes are provided on the outboard wheels only. The main load carrying take-off gear is the two aft sets of three wheels each. The center wheel has two tires mounted on it with sufficient clearance for sidewall deflection and cooling. The tires illustrated are advanced design low aspect ratio utilizing advanced cord.

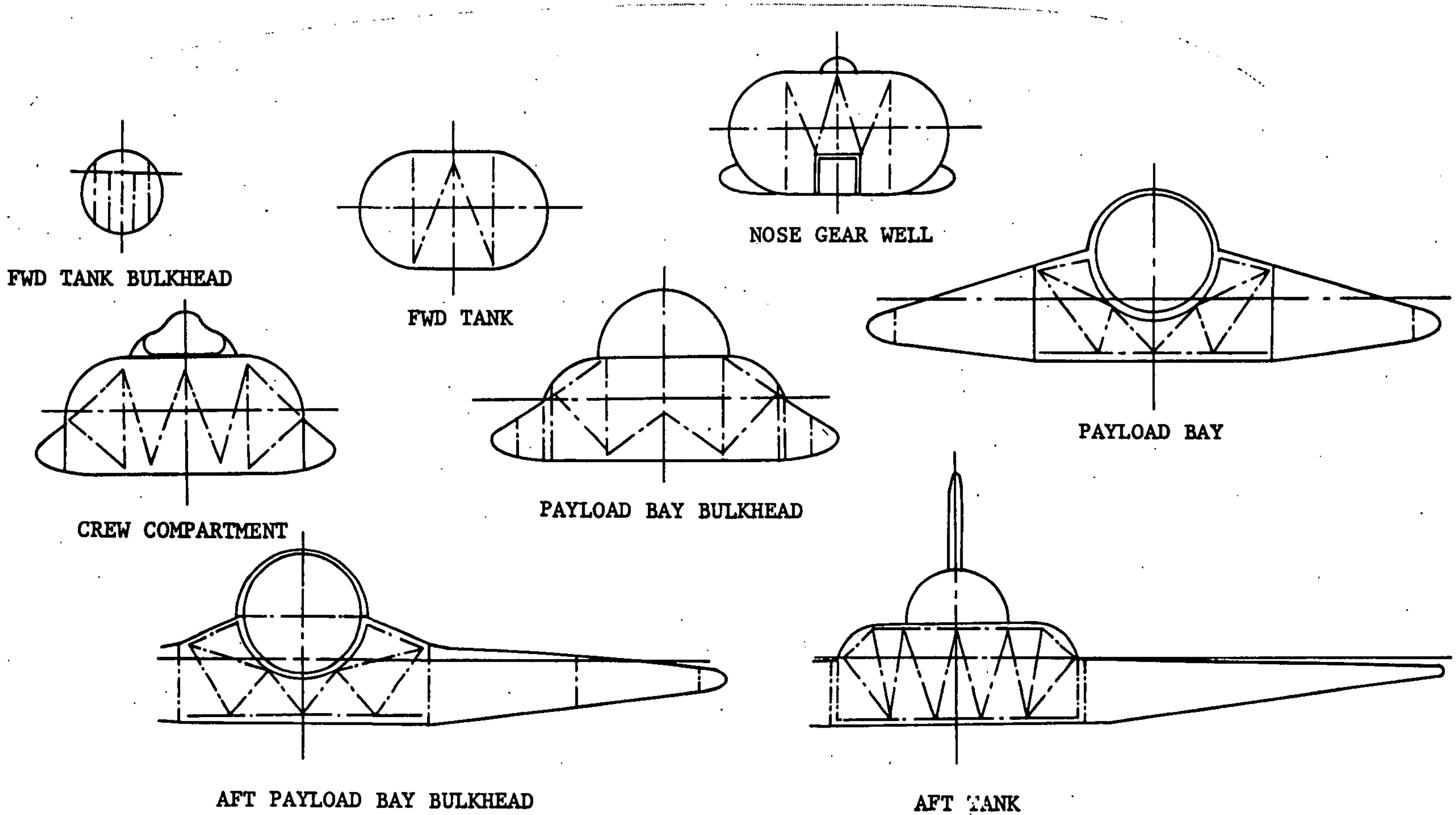
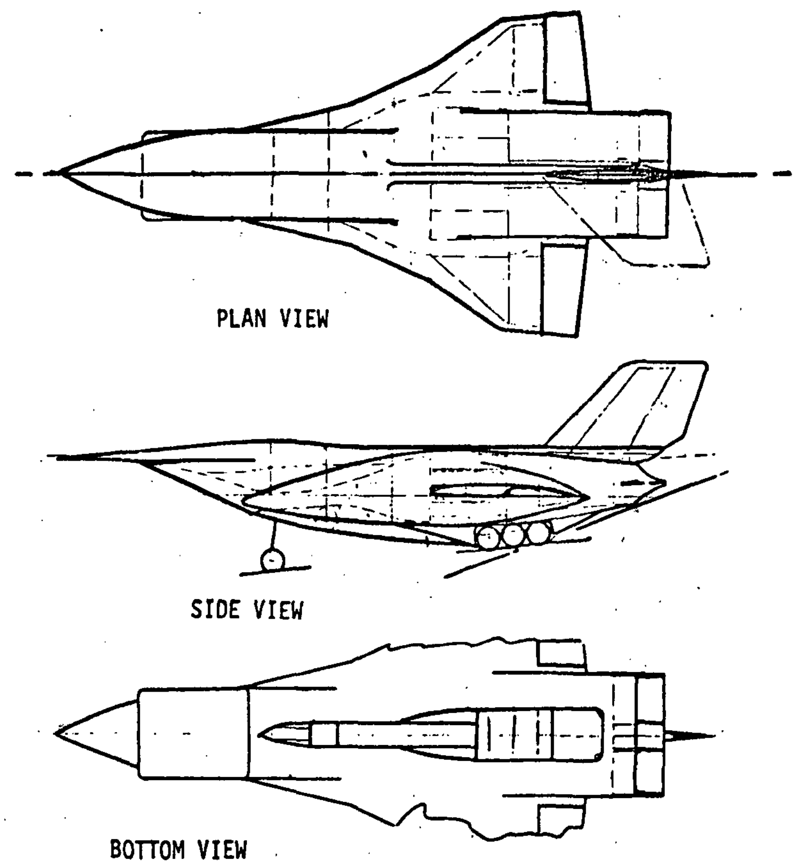


Figure 26 Turbojet Boosted Orbiter Final Detailed Configuration

SPAN	21.0m (69.0 ft)
LENGTH	40.7 m (133.6 ft)
HEIGHT	8.5 m (27.9 ft)
EMPTY WEIGHT	114197 kg (251762 lb)
THRUST	8 X 467063N (105000 lb)
FUEL JP-4	111155 kg (245055 lb) *
C.G. % B.L.	
EMPTY	67.3
FULL	60.6



* Performance section shows improved results achieved at the conclusion of the study.

Figure 27 Turbojet Booster Eight Engine Configuration

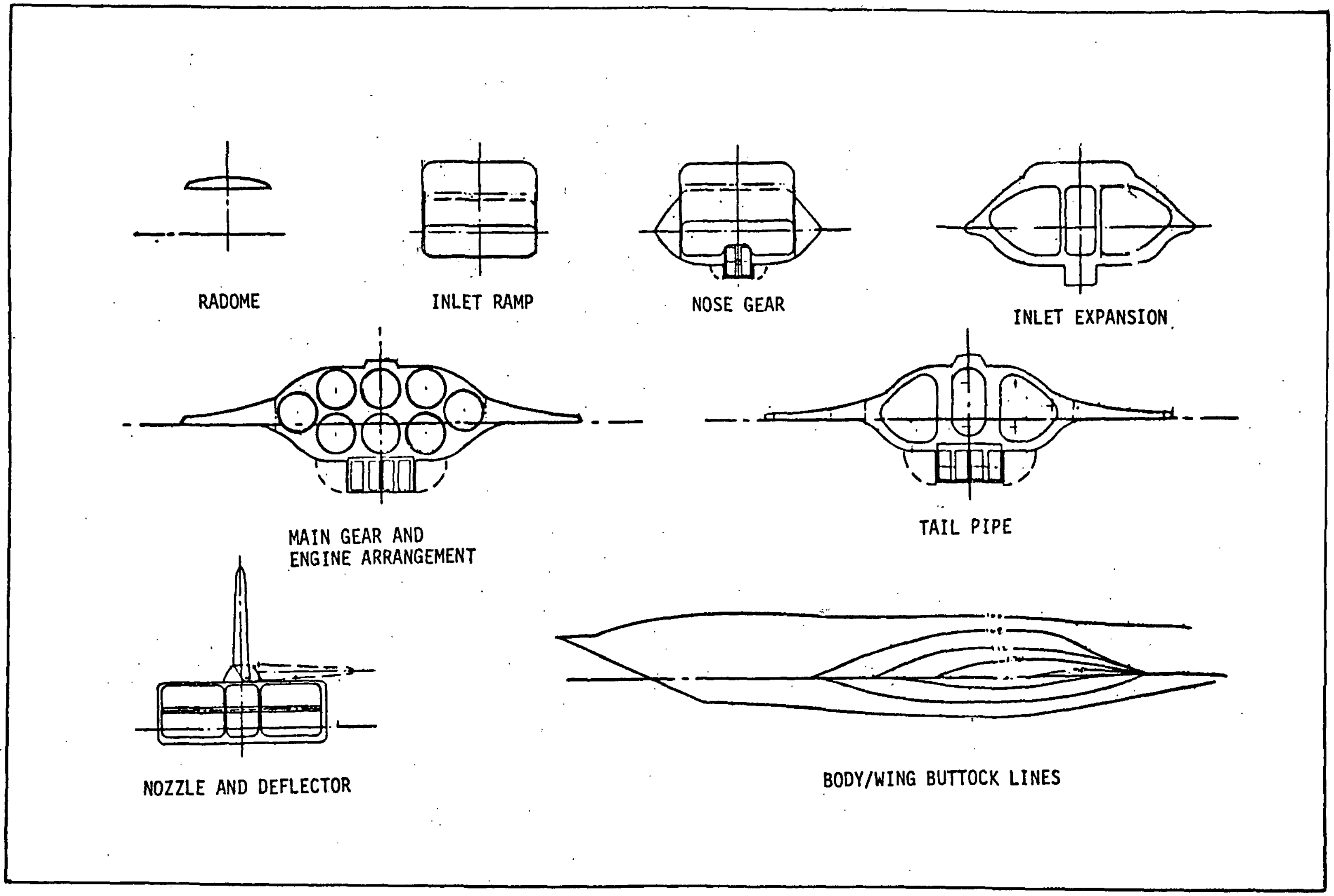


Figure 28 Turbojet Booster Eight Engine Configuration

TIRES

56 X 24 -40 PLY

AR .5

PRESSURE 2.89 X 10^6 Pa (420 psi)

MAX DEFL. 17%

WT. 167 kg (368 lb)

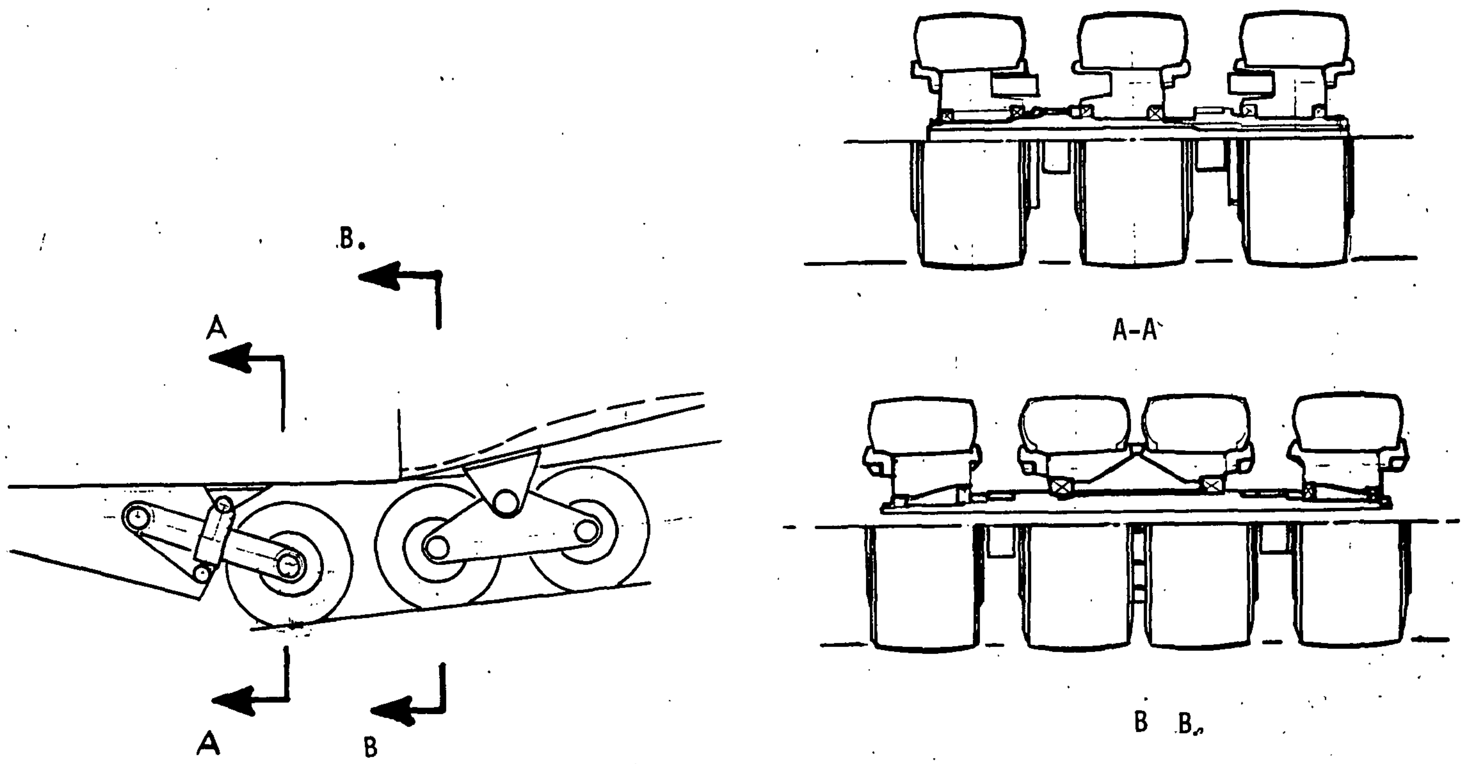


Figure 29 Turbojet Booster, Landing Gear - Fixed

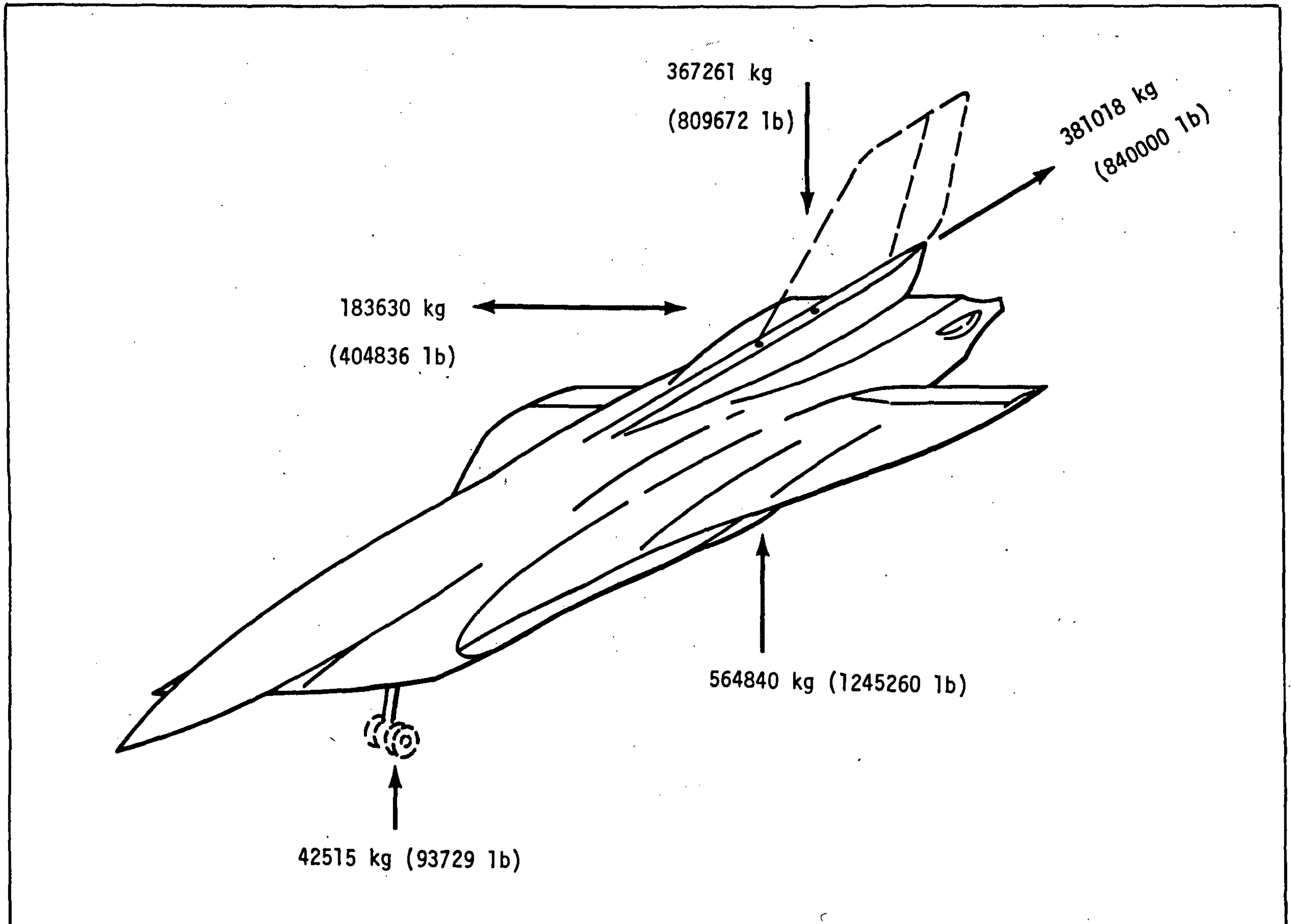


Figure 30 Turbojet Booster Loads

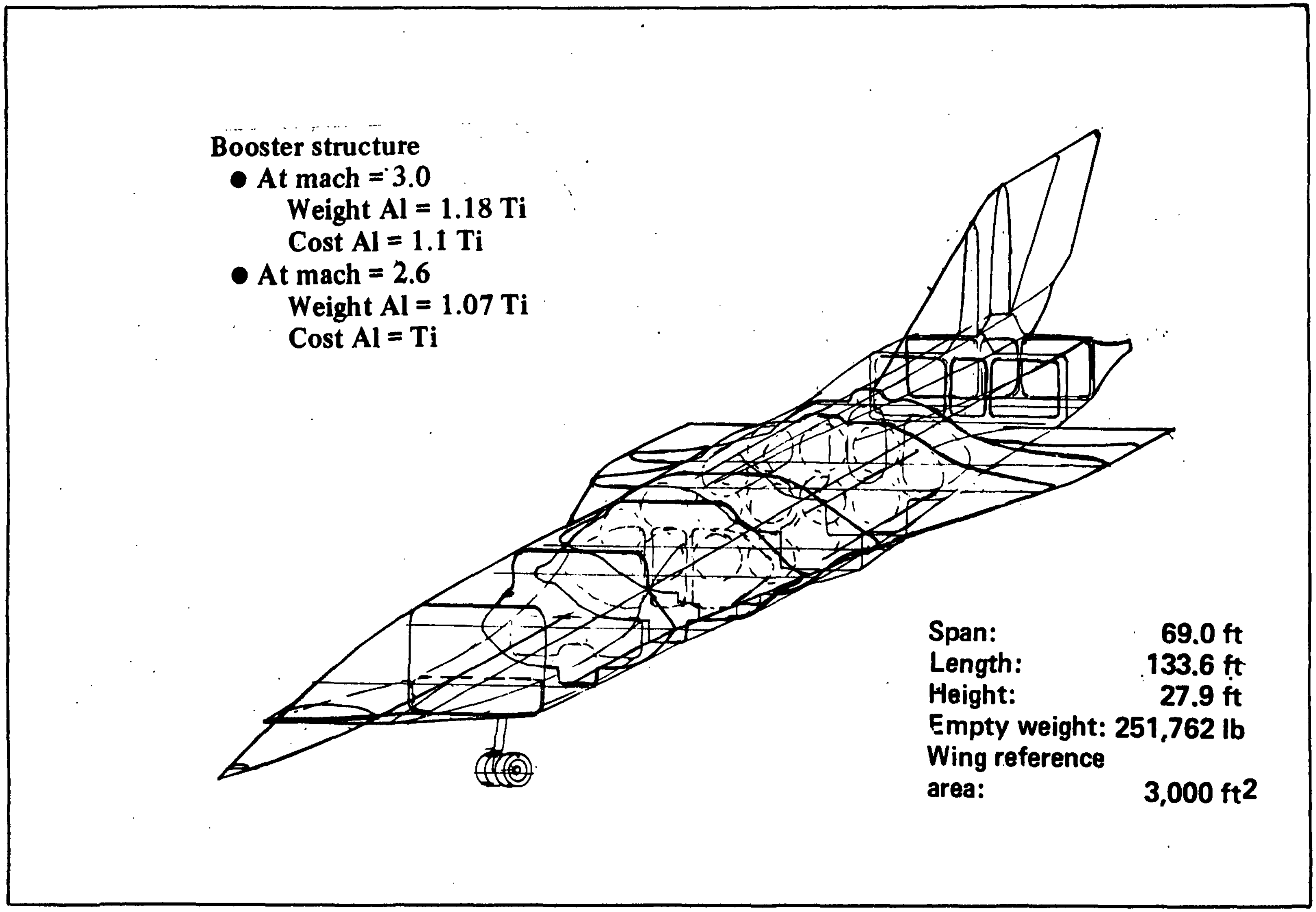


Figure 31 Turbojet Booster Structure

material for the plys to permit the high loading. Tread depth is minimum to avoid tread separation problems. The forward axle is spaced slightly further from the center pivot than the aft axle. This compensates for the rotation associated with rolling resistance which would tend to increase the load on the forward wheel set. Structural mountings are a high durometer elastomer to provide some additional shock absorbtion and to permit low frequency deflections for turns and tracking. A small centering actuator positions these gear after takeoff for door closure. The nose gear is a steerable dual wheel configuration which folds aft for stowage. The landing gear is center line mounted without outboard or tip gear. However, the wheel spacing is such that the outboard gear is considered unnecessary for the booster alone and the tip gear appears to be undesirable for the mated configuration.

Figure 30 shows the principal loads imposed on the vehicle and Figure 31 is a montage of section cuts to illustrate the structural arrangement. The vehicle is configured about the center box section containing the engines, inlets, orbiter support pylons, wing attachments, and main landing gear attachments. The concept is planned to minimize tooling for the limited production run.

One aspect of the configuration which was initially ignored and which became dominant as the study progressed was the necessity for area ruling of the combined vehicle to reduce transonic drag. The mid-term configuration highlighted this aspect. The drag coefficients imposed the requirement for still larger engines which in turn increased the cross-section area further increasing the thrust problem. Through area ruling the drag coefficient was reduced by approximately 20% making a configuration possible. Figure 32 illustrates the changes in area distribution optimized for Mach 1.0 as the configuration evolved. These changes are subtle with the exception of the mid-term configuration which demonstrates possible problems if area distribution is not considered. The initial area distribution configuration was designed to utilize 75% of the thrust of the mid-term predicated on a reduction in drag of 25%. This initial configuration approached this goal and the iterated configuration achieved the desired results. From this the final configuration was developed. The mass properties of the final detailed configuration as well as the elements of the orbiter and boosters are shown on Tables 2 through 4. The final configuration achieved a payload to orbit of 23133 kg (51000 lb) with a GLOW of 1.217 X 10^6 kg (2.68 X 10^6 lb). It is noted that subsequent to the completion of the study, the performance data has been iterated with significantly improved payload to orbit values. These data are shown in the performance section.

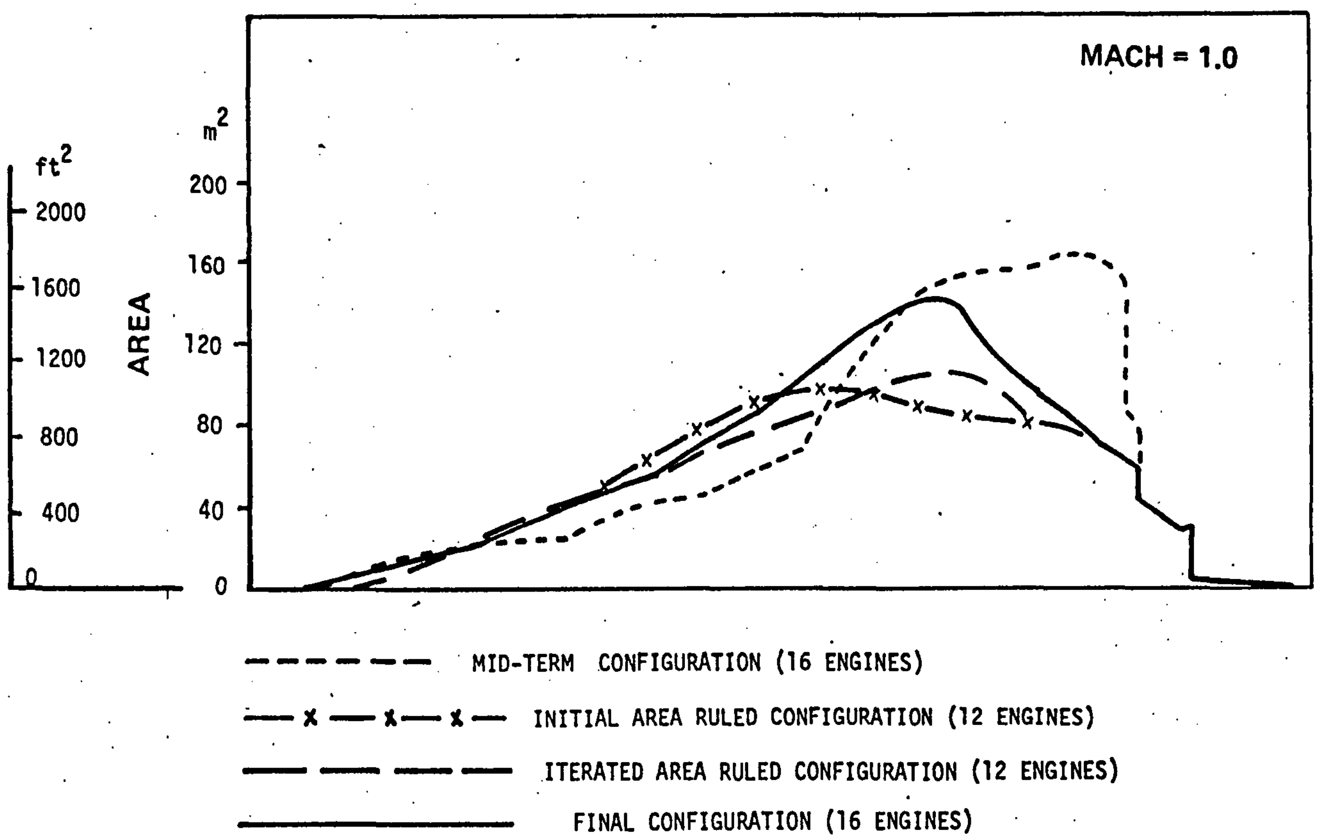


Figure 32 Turbojet-Boosted System Area Plot

Table 2 Mass Properties Turbojet Boosted System 16 Turbojet Final Detailed Configuration

	kg	(lb)	STA.	ACTUAL WEIGHTS kg	(lb)	STA	TARGET WEIGHTS
BOOSTERS				450705	(993634)	1519.4	456314 (1,006,000)
BOOSTER (EA)	114197	(251762)	1629 (70.5%)				
JP 4	111155	(245055)	1406.8				
ORBITER				743138	(1638300)	1752.7	737088 (1,625,000)
EMPTY	112800	(248700)	1805 (72%)				
PROPELLANT	630493	(1,390,000)	1743.2				
PAYLOAD				23133	(51,700)	1655	29483 (65,000)
GLOW				1217276	(2,683,634)	1664 (67%)	1222885 (2,696,000)
STAGE				1013053	(2,233,400)	1716 (69%)	
FERRY				551005	(1,214,759)	1568 (63%)	

Table 3 Mass Properties Turbojet Booster Final Detailed Configuration

	kg	lb	STA	kg	lb	STA.
STRUCTURE				19270	(42484)	1647.4
BODY	8587	18931	1347.5			
VERT. FIN.	2692	5936	2080			
WING	5088	11217	1752			
ORBITER SUPPORT & ATTACH.	2902	6400	1950			
PROPULSION				70294	(154971)	1636
ENGINE (8)	40341	88936	1632			
EXHAUST	9064	19982	1920			
INLET	7476	16482	1320			
MOUNTS COWLS FRAMES	7620	16800	1632			
ACCESSORIES AND CONT.	1613	3557	1632			
START SYSTEM	456	1006	1632			
FUEL SYSTEM	3723	8208	1632			
SUBSYSTEMS				14252	(31420)	1570.4
CONTROLS	575	1267	1800			
HYDRAULICS 559 kW (750 HP)	1803	3975	1650			
ELECTRICAL 149kW (200 HP)	762	1680	1600			
AVIONICS	1270	2800	800			
EMERG. EQUIP.	276	608	1600			
ECS	77	170	800			
APU 969 kW (1300 HP)	486	1071	1600			
LANDING GEAR	9003	19849	1650			
10% GROWTH				10381	(22887)	
				114197	(251762)	1629

Table 4 Orbiter Mass Properties

	kg	(lb)	STA	kg	lb	C.G. LOC. STA
STRUCTURE				74300	(163800)	1742
BODY	30450	67100	1496			
PAYLOAD DOOR	2098	4626	1610			
CREW COMPARTMENT	2440	5380	1140			
HEAT SHIELD	204	450	2250			
WING	35834	79000	1827			
TAIL	3766	7200	2335			
SUBSYSTEMS				23881	(52649)	1920
PERSONNEL				263	(580)	900
FLUIDS				14361	(31660)	1957
FLT. PERF. RES	1823	4020	1220			
RCS	1089	2400	2190			
OMS	4309	9500	2270			
RES. & UNUSEABLES	5579	12300	1920			
SUBSYST. FLUIDS	1560	3440	1920			
			INJECTED	112800	(248700)	1805
			RE-ENTRY	100545	(221625)	1787.3

NOTE: ALL WEIGHTS INCLUDE 10% GROWTH

Orbiter Weight

The orbital vehicle ALRS 254-22108 used in this study is generic tothe ALRS 205 of reference 1 . The orbital vehicle utilizes an airframe structural concept and subsystems identical to the ALRS-205. Both vehicles have the same wing reference area. Prime difference is in the size of the forward body, change in engine size and wing thickness. This similarity was used as an aid to establish weight for the orbital vehicle. The ALRS 205 weights are given by subsystem in reference (1). Weight changes from the ALRS 205 are calculated for the study orbital vehicle.

The ALRS 254-22108 weights are summarized in Table 5. The center of gravity location for each major system is given in distance from the nose of the orbiter. The weights include a 10% growth for all non-off-the-shelf items. The resulting weight 113101 kg (249,345 pounds) represents an increase of 6360 kg (14,000 pounds) over the weight targeted for this vehicle. (Ref. Table 2.).

Orbiter subsystem weights are shown in Tables 5, 7 and 8 for each of the major subsystems. The base for the subsystem weights, the ALRS-205 subsystem weights are shown. Under "Comments" the general rationale for establishing the orbiter weight is shown. The major change is in the weight of the rocket engines, reflecting the reduced thrust requirements for the turbojet boosted system.

Table 5 Orbiter System Weights

COMPONENTS

ITEM	WT ALRS 205 kg	(lb)	△ WT FOR 2 STAGE kg	(lb)	☆ 2ND STAGE kg (lb) ▲ (c.g. LOC. m IN.)		COMMENTS
PAYLOAD DOOR	2098	(4626)	0	(0)	☆ 2098 ▲ 39.88	(4626) (1570)	SAME DOORS
CREW COMPT.	2440	(5380)	0	(0)	☆ 2440 ▲ 27.94	(5380) (1100)	SAME CREW CMPT.
VERTICAL TAIL	3270	(7210)	0	(0)	☆ 3270 ▲ 59.31	(7210) (2335)	SAME AREA AS ALRS 205
LAUNCH SUPT.	680	(1500)	0	(0)	☆ 680 ▲ 47.75	(1500) (1880)	(EST. BASED ON TWO RIBS @ q_s = 7200 #/IN)
HEAT SHIELD	272	(600)	-68	(-150)	☆ 204 ▲ 56.13	(450) (2210)	REDUCED BASE AREA
					☆ 8709	(19200)	

▲ CENTER OF GRAVITY - DISTANCE FROM NOSE

Table 6 Orbiter System Weights

FLUIDS

ITEM	WT ALRS 205 kg	(lb)	WT 2ND STAGE kg	(lb)	COMMENTS
FLT. PERF RESERVE	2218	(4890)	1823	(4020)	RATIO OF FUEL WTS
REACTION CONT. PROP.	1253	(2763)	1089	(2400)	RATIO OF INJECTED WTS.
ORBIT MANU. SYS.	5114	(11275)	4309	(9500)	RATIO OF INJECTED WTS
RESIDUALS/UNUSABLE	6158	(13576)	5579	(12300)	RATIO OF INJECTED WTS
SUBSYS. FLUIDS	1562	(3443)	1562	(3443)	SIMILAR POWER REQ'S
	16305	(35947)	14362	(31663)	

Table 7 Orbiter Subsystem Weights

ITEM	WT. ALRS 205 kg	WT. ALRS 205 (lb)	△ WT. FOR 2 STAGE kg	△ WT. FOR 2 STAGE (lb)	☆ kg ▲ m	SECOND STAGE WT. (lb) C.G. LOC. IN.	COMMENT
SURFACE CONT.	998	(2200)	136	(300)	☆ 1134 ▲ 52.83	(2500) (2080)	15% INCREASE SURFACES AND HINGE MOMENTS
LANDING GEAR	3342	(7368)	-194	(-428)	☆ 3284 ▲ 17.65 ▲ 43.94	(7240) (695)F (1730)A	2.67% LDG. WT.
ROCKET ENG.	13458	(29670)	-3706	(-8170)	☆ 9752 ▲ 56.39	(21500) (2220)	3 ENGINES - NO NOZZLE EXTENSIONS (250#/ENG.)
PROPELLANT FEED	984	(2169)	-131	(-289)	☆ 853 ▲ 55.37	(1880) (2180)	3/4 VOL. FLOW RATIO
PRESSURIZATION	725	(1600)	-218	(-480)	☆ 507 ▲ 21.34	(1120) (840)	(ALRS 205) - FUEL TANK RATIO
RCS SYS.	782	(1724)	-79	(-174)	☆ 703 ▲ 1.14 ▲ 56.64	(1550) (45) F (2230)A	RATIO OF ENTRY WTS.
OMS SYS.	718	(1583)	-118	(-260)	☆ 599 ▲ 57.15	(1320) (2250)	RATIO OF INJECTED WT.
AVIONICS	1306	(2880)	0	(0)	☆ 1306 ▲ 26.42	(2880) (1040)	SAME FUNCTIONS AS ALRS 205

CONTD ON TABLE 8

Table 8 Orbiter Subsystem Weights (Cont)

CONTD FROM TABLE 7

ITEM	WT ALRS 205 kg	(lb)	△ WT. FOR 2 STAGE kg	(lb)	☆ SECOND STAGE WT. kg (lb) ▲ C.G. LOC. m (IN.)	COMMENT
PRIME POWER	358	(790)	0	(0)	☆ 358 (790) ▲ 54.10 (2130)	SAME CONTROL AND SUBSYSTEM FUNCTIONS
ELEC. CONV. AND DIST.	1619	(3570)	0	(0)	☆ 1619 (3570) ▲ 37.08 (1460)	"
HYD. CONV. AND DIST.	985	(2173)	0	(0)	☆ 986 (2173) ▲ 5156 (2030)	"
ENVIRON CONT.	1134	(2500)	-91	(-200)	☆ 1043 (2300) ▲ 29.46 (1160)	SMALLER LANDING GEAR WELLS
PERSONNEL PROV.	362	(797)	0	(0)	☆ 362 (797) ▲ 26.80 (1055)	
GROWTH	1349	(2975)	-157	(-346)	☆ 1192 (2629)	
	28104	(62796)	-4557	(-10087)	23560 (52249)	

SUBSYSTEM C.G. = 47.75m (1880 IN.) FROM NOSE

Table 9 Orbiter Wing Structure Weights

ITEM	ALRS 205 WT. kg	(lb)	Δ WT FROM ALRS 205 kg	lb	WT WING SUPT. B. L. 435 kg	(lb)
SURFACE PANEL	6985	(15400)	3447	(7600)	10432	(23000)
FRAMES & SPARS	5851	(12900)	1225	(2700)	7076	(15600)
SOB RIB	2404	(5300)	498	(1100)	2902	(6400)
LEADING EDGE	3441	(7600)	1298	(2860)	4745	(10460)
FWD + AFT BLK.	998	(2200)		(0)	998	(2200)
ELEVONS	3493	(7700)	680	(1500)	4173	(9200)
MAIN GEAR WELL	2313	(5100)	227	(500)	2086	(4600)
GROWTH	2313	(5100)	363	(800)	2676	(5900)
	27805	(61300)	8060	(17770)	35865	(79070)

CENTER OF GRAVITY 4539 cm (1787") FROM NOSE

Table 10 Orbiter Body Structure Weights

ITEM	ALRS 205 WT. kg	ALRS 205 WT. (lb)	△ WT 2 STAGE kg	△ WT 2 STAGE ▷x (lb)	WT. 2 STAGE kg	WT. 2 STAGE (lb)	C.G. LOC DIST. FROM NOSE m	C.G. LOC DIST. FROM NOSE in
NOSE COMP	272	(600)	—	—	272	(600)	1.52	(60)
FWD BODY	11294	(24900)	-3050	(-6725)	8244	(18175)	27.6	(1090)
MID BODY	10977	(24200)	999	(2200)	11974	(26400)	43.2	(1700)
AFT BODY	1769	(3900)	499	(1100)	2268	(5000)	50.93	(2005)
AFT SKIRT	1633	(3600)	-272	(-600)	1361	(3000)	54.18	(2133)
EQUIP. COVER	376	(830)	0	(0)	376	(830)	54.18	(2133)
NOSE GEAR WELL	590	(1300)	-59	(-130)	531	(1170)	16.76	(660)
THRUST STRU	1814	(4000)	-726	(-1600)	1089	(2400)	53.85	(2120)
AFT BLK	907	(2000)	-91	(-200)	816	(1800)	54.10	(2130)
SIDE OF BODY REINF	363	(800)	-91	(-200)	272	(600)	49.02	(1930)
PAYLOAD BAY BLK	472	(1040)	—	—	472	(1040)	40.39	(1590)
GROWTH	3050	(6720)			2770	(6100)		
					30445	(67115)	36.98	(1456)

▷x FOR 1690000 POUND ORBITER

The orbiter system fluid weights are shown in Table 6 together with the ALRS 205 weights. The orbiter fluid weights were perturbed from the ALRS 205 using the rationale defined under comments. Table 4 summarizes the orbiter weights by subsystem.

A major difference between the two vehicles is in the method of support during take-off. The ALRS 205 is supported by six cradles on the ground accelerator such that the wing bending moment during take-off does not exceed the inherent strength in the wing required by other conditions. The orbiter for this study is supported at wing buttock line (WBL) 434. The resulting wing loads are shown in Figure 33. At the side of the body corresponding values for the ALRS 205 are a bending moment of 10,000,000 Meter Newtons (120,000,000 in - lb and shear of 3,400,000 Newtons (750,000 pounds). These increases in loads represent a significant weight increase in the ALRS 254-22108 wing and wing-body carry through structure.

The orbiter wing structure weight distributed by major component is shown in Table 9. The corresponding weight for the ALRS 205 reference are shown for comparison. The increase in surface panel and frame and spar weights is the result of the large wing bending moment and shear loads during the take-off run due to an assumed 2.0 "g" bump load. Future studies of this type vehicle should include a 1.5 "g" bump load case and endeavor to locate the boosters as far inward as possible. The SOB (side of body) rib weight increase is due to the increased height and length of the wing root chord. The leading edge increase is the result of the addition of the forward strakes. The additional strakes weighed (635 kg) (1400 pounds) per side. Elevon weights were estimated on the basis of relative areas i.e. 600 square feet/side vs 500 square feet/

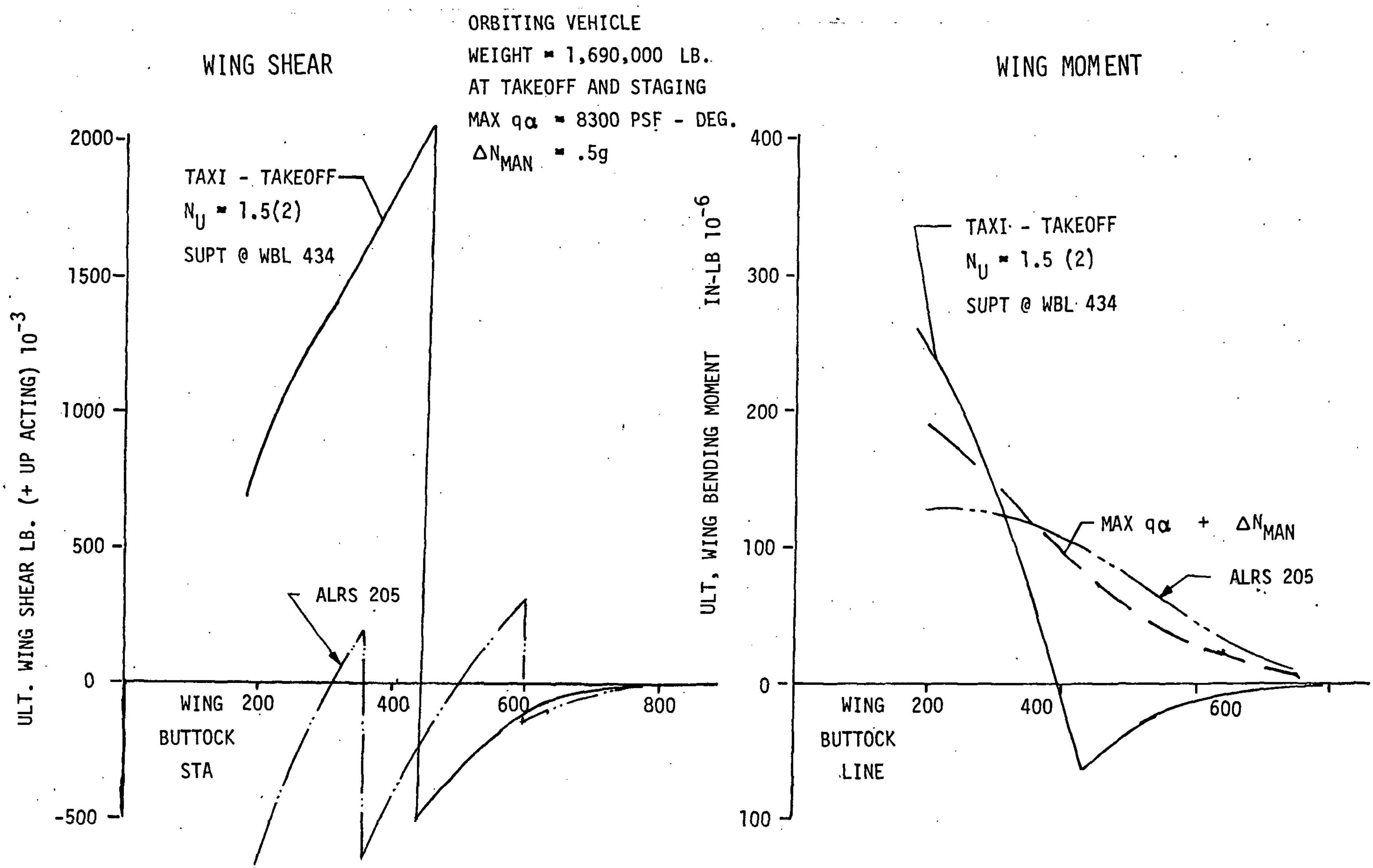


Figure 33 Wing Loads Orbiter

side for the ALRS 205. The elevon area was increased as a consequence of rear spar location.

Orbiter body structure weights are given by major component in Table 10. The ALRS 205 weights are shown for comparison and to define the base from which the orbiter weights were calculated.

The signficant reduction in the forward body is the result of lower liquid hydrogen volume requirement. These weights are established primarily by changes in "wetted area" requirements.

The aft body increase is due to the requirement to transfer increased wing bending moments through the body. The thrust structure reduction results from the reduced thrust requirements, three SSME's vs 4 engines for ALRS 205.

Study Achievements

There were several significant achievements or developments of the study which evolved as solutions to the problems exposed. These are identified with a definition of each in the following:

- Fixed Main Load Carrying Gear for Reduced Weight and Cross-Section Area

The high takeoff weight relative to the landing weight dictated large oleos, high retraction horsepower requirements and correspondingly large cross-section areas to house the retracted assembly, if usual design procedures were applied. Since the takeoff would be made from improved runways, the requirement for oleos appeared to be minimal. The mid-term configuration had a standard retractable gear which weighed 32848 kg (72418 lb) per booster. Through the change to fixed gear this was reduced to 9003 kg (19849 lb).

- Combined Inlet for Multiple Engines offers Weight Reduction

Transonic and supersonic inlets weights are composed of two main elements, first the spike and inlet shock control and second the expansion duct and engine inlet transition. The first element weight is a function of cross-section area and dynamic pressure, and therefore no significant penalty or benefit exists. However the second element weight is a function of surface area since length is approximately constant. Therefore, combined inlets of a given cross-section have the least surface area and consequently least weight.

- Combined Exit Ducting and Nozzle Offers Reduced Weight

The exit duct is parallel to inlet duct parametrics; surface area is the basic variable. This is also true for the nozzle to large extent. However, the nozzle has the additional requirement of area control necessary for the wide speed range as well as accommodating engine out. This is accommodated by flaps which open or close to regulate the area at the throat. This problem was made less difficult in that the configuration did not require a low thrust high efficiency cruise condition.

- TVC Design for Multi-Turbojet Configuration Evolved

A program has been underway for over a decade at Boeing to develop a thrust vectoring two-dimensional nozzle for fighter aircraft. This effort has produced drawings, analyses, wind tunnel test data, and performance projections which provided a sound basis for the evolution developed in the final configuration of this study. While the scope of this study did not permit an in-depth analytical development of the concept, it was considered feasible.

- Configuration which evolved met major tests of weight fraction, drag, lift, controllability, and feasibility within limits of capability for investigation of the study.
- Major concerns or problem areas were identified and solutions offered.

The above conclusions are very significant in that a wide variety of problem areas surfaced as the study proceeded. These areas ranged from inadequate mass fraction, control, and aero interference to high system costs. Many of the problems could be solved or mitigated by judicial geometrical adjustment. Additional study development and test would undoubtedly provide further enhancement of the system concept.

Operations

The main effort of the study became involved in the problem of configuration development. The configuration problems were such that without a feasible configuration arrangement, the remainder of the study could not proceed in a meaningful manner. For these reasons, a complete assessment of operation benefits or problems was not made. However, a cursory assessment did not indicate any major problems which would prevent system operation. A feasible operational sequence could be defined for the system within the scope of existing technology.

Normal Turnaround Sequence

Orbiter - The normal retrieval, payload operations, and refurbishment are essentially identical to the ALRS 205 vehicle. Preparation for assembly with the boosters is similar to that required by the 205 for assembly with the ground accelerator. Reference Figures 34 and 35

Booster fueling, propellant and storables loading, and payload operations immediately prior to launch would be similar to the sequence identified for the 205. Launch operations are different in that the booster turbojet start and power up provide the system timelines for launch. The boosters do provide a wider launch window in that azimuth, altitude, and time can be adjusted immediately prior to staging. Thus, takeoff time is less critical.

Boosters - Retrieval is an RPV operation which proceeds through touchdown, rollout, taxi to hardstand, and shutdown. Refurbishment is a normal operational sequence of systems checkout, orbiter attachment recycle as required and engine checkout. No exotic or unique structures or equipment is involved which minimizes skill level and manhours. The boosters are preflighted and positioned for assembly. Assembly may be accomplished either by (1) cranes which would place the orbiter on the prepositioned boosters; (2) ramps and jacks which would permit towing the orbiter into position over the boosters and lowering to the locked condition; (3) or by jacks and pads which raise the orbiter allowing the boosters to be towed underneath for assembly. The assembly, while significant due to the alignment necessary to assure proper attachment load carrying without excessive strain, is comparable to similar operations in many other current activities including the existing shuttle ferry system.

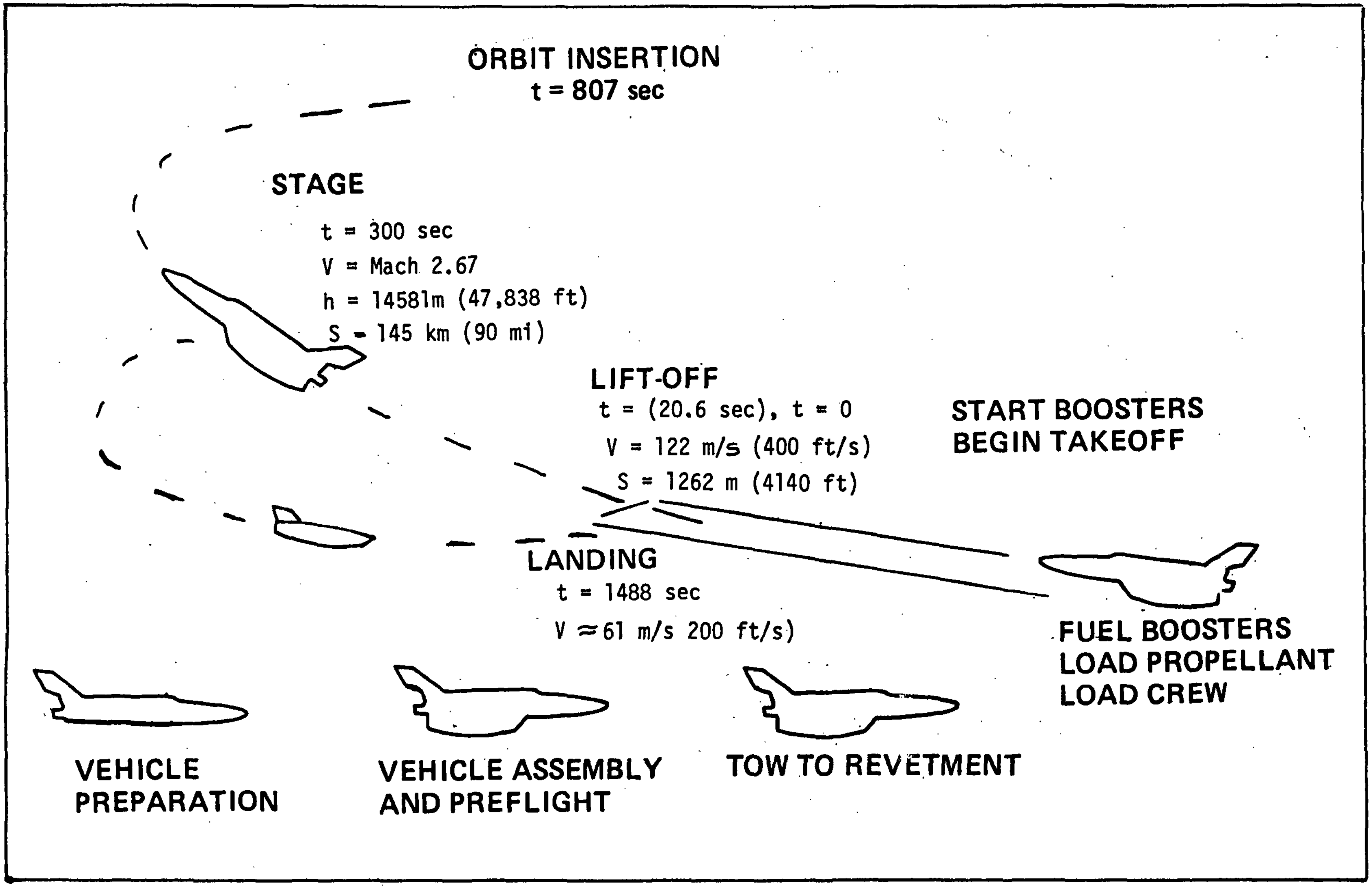


Figure 34 Turbojet-Boosted Orbital Transportation System Operations

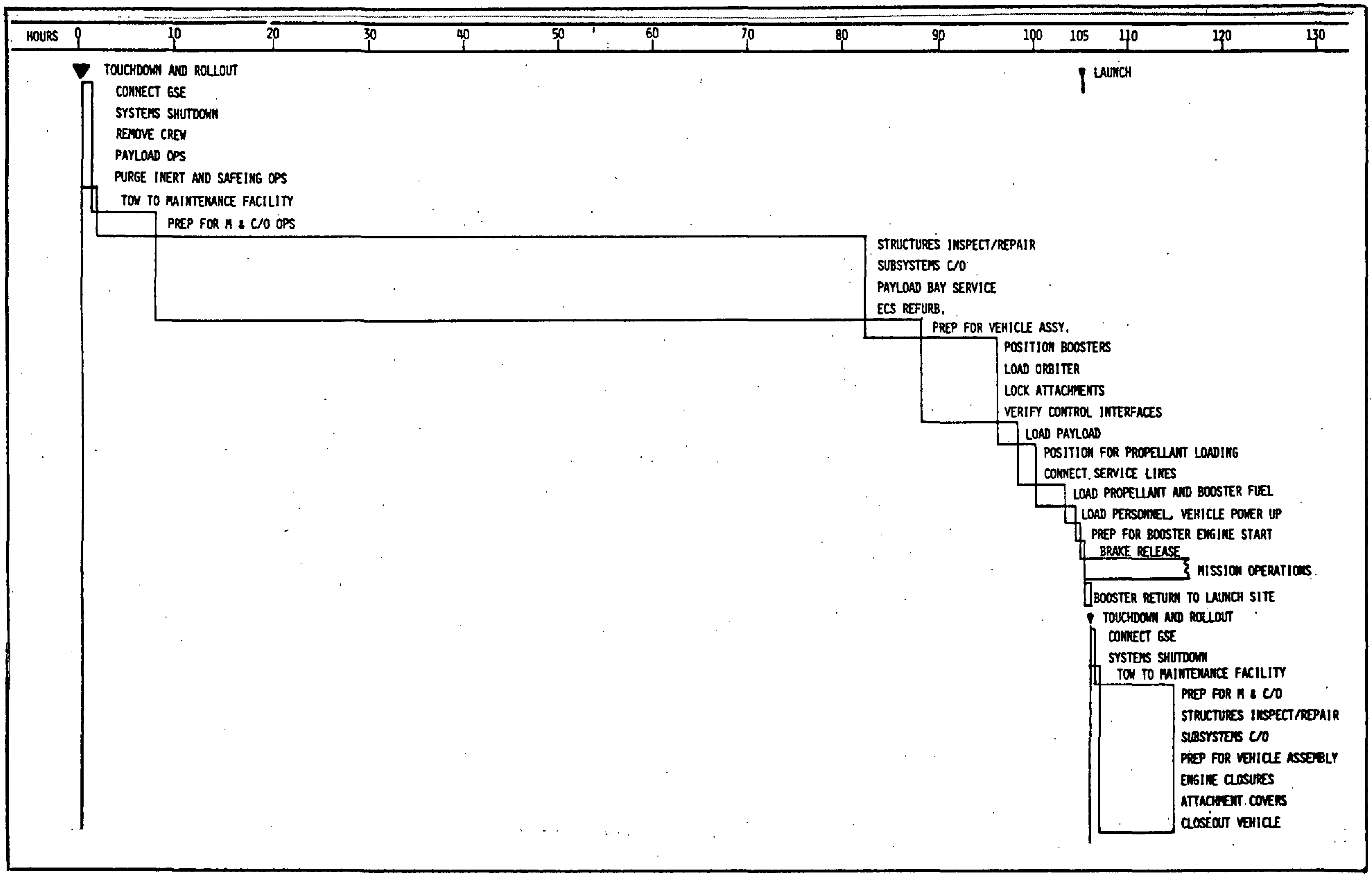


Figure 35 Baseline Operations Flow

Ferry Operations

Cruise ferry operations as the vehicle is configured would appear to offer a subsonic range of approximately 1450 km (900) miles. Additional range could be achieved by installation of an engine fairing on the orbiter to reduce drag and by additional booster fuel tankage installed in the orbiter payload bay. External tanks on the boosters are also an option. The orbiter subsystems power would be supplied by the on-board APU with additional fuel tankage as necessary. Adequate ferry range would not appear to be a problem.

Remote Site Operations

Orbiter/Booster Retrieval - Booster retrieval at a remote site would not require any additional equipment beyond that normally associated with an airport of the size to accommodate aircraft of the size and landing speed of the boosters.

Orbiter retrieval operations do require skilled personnel with the necessary inerting, purge, and safeing equipment much as the current shuttle has programmed.

Similarly, cranes are necessary to assemble the vehicles for the ferry return to main base or overhaul center. Payload operations requiring specialized equipment would be in addition to the basic system requirements.

Launch Operations - The system configuration offers an option unique to this two-stage system. The system could be prepared for launch at a main site centrally located, then ferried to a remote site for launch. The hazardous materials could be retained at this site for loading immediately prior to launch. This site could be situated such that launch ground tracks would avoid population centers. It is noted that the takeoff run is approximately the length of five super tankers, thus a mid-ocean facility would be a possibility, eliminating many of the environmental objections to similar systems.

Cruise/launch operation of the system is a potential wherein the vehicle would takeoff, cruise to a predetermined launch point where it would accelerate to staging velocity and then on to orbit. This capability permits adjustment of the orbit insertion window. This option would appear to be more desirable, perhaps, as a military mission than as a NASA mission. Some military missions which require rapid acceleration and minimum launch to orbit time could be achieved with the 2-stage system by parallel burn of orbiter rockets and booster turbojets, with some loss of payload capability.

An in-depth operations and mission capability study for the system would be necessary to fully define the benefits of a Turbojet Booster Earth to Orbit Transportation System.

COST ESTIMATES

Costing Model

Booster and orbiter DDT&E and production estimates were made using Boeing's System Parametric Cost Model (PCM). This model produces program cost estimates directly from physical descriptions of program hardware with accompanying information on hardware quantities and program support levels and schedules. The PCM model itself is a collection of relationships and factors that have been developed from Boeing's historical data base. Shown in Table 11 is a summary of typical inputs; in this case booster descriptive inputs. Each major subsystem is defined by (1) its weight; (2) its hardware category, which includes PCM defined complexity factors; (3) material, as applicable; (4) subsystem redundancy; (5) consideration of subcontractor profit; (6) the degree to which hardware is a modification of an existing design or "off the shelf" or a combination of both; and (7) other less significant descriptive factors. Program level inputs are used to define degrees of support, spares, test and production. The costing ground rules and guidelines are presented in Figure 36.

All costing is for the "Final Baseline Configuration" that used eight engines per booster. Costs for configurations using alternate numbers of engines, variations in GLOW, etc. may be obtained using the parametric curves of Figures 37, 38, 39 and 40.

Table 11 BOOSTER INPUTS TO PCM

ITEM	WT kg	WT lb	CLASS	MATERIAL	REDUNDANCY	BUY ITEM FEE	MOD	OTS
Booster Structure								
Wing	4324	9534	Nominal Struct	Tl	-	-	0	0
Tail	2288	5046	Simple Struct.	Tl	-	-	0	0
Body	7298	16091	Nominal Struct.	Tl	-	-	0	0
Landing Gear	9003	19849	Nominal Struct.	Steel	-	-	0	0
Nacelle, etc.	6477	14280	Simple Struct.	Tl	-	-	0	0
Pylon, etc.	2467	5440	Simple Struct.	Tl	-	-	0	0
Margin	3186	7024	Nominal Struct.	Tl	-	-	0	0
Booster Engines		Thruput	$1.5B Dev $9.6M Avg Unit Cost for 32 489302N (110,000 lb) thrust ea.					
Booster Fixed Equip.								
Surface Controls	575	1267	Electro/Mech Mechanism	-	-	10%	.20	.40
Hydraulics	1803	3975	Machinery	-	-	10%	.20	.40
Electrical	762	1680	Pwr Conditioning Equip.	-	100%	10%	.32	.60
Electronics	1270	2800	Medium Performance Computers	-	100%	10%	.48	.40
Emer. Equip.	276	608	Machinery	-	-	10%	0	1.00
ECS	77	170	Active Thermal Control.	-	-	10%	0	0
Margin	476	1050	Machinery	-	-	10%	.30	.50
APU		Thruput	Off the Shelf Hdwe	$328K Ave Unit Cost for 4			0	1.00

Program Support Levels	(1.0 = "Normal" Support Levels)
Sys Engr & Integ	1.5
Software	1.0
Sys Test	1.0
Support Equip. DSN	1.0
Support Equip. Mfg.	1.0
Tooling	1.0

Spares 10%
2.5 Test Units
4 Production Units @ 90% Learning

- PROGRAM (15) YEARS (114) LAUNCHES/YR (1710) FLIGHTS
- NUMBER OF LAUNCH VEHICLES

	DDT&E	PRODUCTION (A)
ORBITER:	1.5 (EQUIV)	3 + (1) REFURB'D
BOOSTER:	2.5	4 + (2) REFURB'D

(A) 90% LEARNING CURVE
REFURB'D = 10% UNIT COST

- 10% SPARES
- IN 1976 $ LIFE CYCLE COSTS (LCC)
- PROPELLANT COST LO_2/LH_2 = \$0.35/kg (\$0.16/lb)

  FUEL COST JP-4 = \$0.15/kg (\$0.07/lb)

Figure 36 Cost Ground Rules and Guidelines

DDT&E Life Cycle Costs

All estimates in 1976 dollars (see Table 12).

Estimated orbiter DDT&E costs are essentially equal to estimated DDT&E cost for the sled launched SSTO orbiter. (See Reference 1, D180-19168-4, "Technology Requirements for Advanced Earth Orbital Transportation Systems; December, 1977).

The largest cost element of booster development is engine development, estimated at $1.5 billion. The cost value is based upon a preliminary assessment by an in-house turbojet propulsion technology group along with informal contacts with engine vendor (i.e. United Technologies, P&W Aircraft Engine Group at West Palm Beach, Florida) personnel involved with advanced turbojet applications. Factors which influenced this estimate are the large thrust size of the turbojet engine and the anticipated very low production run of such an engine. As well, system engineering and integration is increased because of new engine development and because of the requirement to merge two programs (Booster and Orbiter) into one operating system.

2.5 equivalent test boosters and 1.5 equivalent test orbiters are assumed for this estimate.

Table 12 DDT&E Costs

2-STAGE TURBOJET BOOSTED

	BOOSTER	$X10^6$ \$	ORBITER
PROGRAM MANAGEMENT	117		185
SYS ENGR AND INTEG	492		486
DESIGN	2070		1178
SYS TEST & SOFT	434		323
TEST HDWE	479		1169
GROUND SUPPORT EQUIP	145		135
TOOLING	21		31
FACILITIES	30		40
TOTAL	3788		3547

Production Life Cycle Costs

All estimates in 1976 dollars (see Table 13).

As with DDT&E, production program estimates were made using Boeing's Parametric Cost Model (PCM).

Total estimated production program cost of $2.789 billion is $462 million more than estimated HTO/Sled production program cost (See Reference I, D180-19168-4, "Technology Requirements for Advanced Earth Orbital Transportation Systems; December, 1977). The primary difference is booster production versus sled production.

2-STAGE TURBOJET BOOSTED

	BOOSTER	x10^6 $	ORBITER
PROGRAM MANAGEMENT	48		94
SYS ENGR AND INTEG	17		36
HARDWARE	679 (4)		1126 (3)
GSE	42		89
TOOLING	72		323
ENGR SUPRT/LIAISON	15		44
SPARES	31		101
TEST UNIT(S) REFURB	34 (2)		38 (1)
TOTAL	938		1851

Operations Life Cycle Costs

All estimates in 1976 dollars (see Table 14).

The two-stage operations cost estimate were first scaled from HTO/SLED estimates. Then, cost allowances were made for orbiter reduced rocket engine thrust rating and propellants, elimination of (2) position rocket nozzles, removal of the sled and addition of turbojet booster costs. No reductions were assumed for orbiter ground operations, spares, or program support even though the orbiter was smaller. The resulting two-stage operations cost estimate is $9 million higher than that estimated for the HTO/SLED.

($M)

TABLE 14

x 10^6 $

	HTO/SLED	LESS: ORBITER	LESS:SLED	PLUS: BOOSTER	= TURBOJET BOOSTED 2-STAGE
GROUND OPERATIONS	513	[1] 0	-127	+300	686
MAIN ENGINE SUPPORT	675	-107	-170	+133	531
SPARES	195	0	- 61	+102	236
FUELS & PROPELLANTS	670	-137	- 13	+ 59	579
PROGRAM SUPPORT	249	0	- 10	+ 40	279
TOTAL	2302	-244	-381	634	2311

[1] REPLACE ADVANCED UPRATED SSME ENGINES (I.E. 3.1 X 10^6 NEWTONS PER ENGINE) INCLUDING (2) POSITION NOZZLES WITH STANDARD SSME ENGINES (2.18 X 10^6 NEWTONS PER ENGINE) AND FIXED NOZZLES.

Life Cycle Cost Comparison

All estimates in 1976 dollars (see Table 15).

Total estimated life cycle cost for the two-stage configuration is $4.41 billion greater than the HTO/Sled configuration. Booster engine development and booster production account for most of the difference. Further LCC comparisons obtained from previous studies are presented in the figure which follows. Recent performance improvements, shown in the performance section were not incorporated here.

Table 15 LCC COST COMPARISON

TOTAL PROGRAM $\$ \times 10^6$

	SSTO	TURBOJET BOOSTED 2-STAGE
DDT&E	3395	7335
PRODUCTION	2327	2789
OPERATIONS	2302	2311
TOTAL	8024	12435

TABLE LCC COST COMPARISON

Cost Comparisons with Past Studies

The cost results from GRC's recent study (Reference 5) indicated a very small life cycle cost difference in favor of a HTO/SLED SSTO over a turbojet/rocket 2-stage vehicle. However, there were significant input differences between that study and the present study. These are: (Relative to present study).

More Total Number Flights
Less Turbojets and Thrust Size
Higher Staging Mach Number
Less Turbojet Development Costs

A very preliminary estimate of adjusting the turbojet booster costs of reference 5 to be compatible with this study is summarized as follows:

Item	Δ $ (MILLIONS)
Develop.	
Turbojet Engine	+ 700
Production	
Turbojet Engine	+ 250
From (12) Engs @ 85K Thrust	
To (16 Engs @ 105K Thrust	
Operations	
From 4197 to 1710 Flights	+1200 (This is a relative adjust)
From Staging M = 3.5 to 2.7	+ 300
From Increased Number & Size Turbojet	+ 100
Total Increase	+ $2,550 Million

Then adding this adjustment to the cost of reference 5, the result is:

$$\text{Tot } \$\ \text{Cost} = 0.40 + 2.55$$

$$\$ = 2.95 \ \text{(Billion)}$$

Represents the reference adjusted increased cost of turbojet/rocket 2-stage vehicle over an all rocket SSTO/SLED vehicle for 1710 flights.

These cost are then compared with an all rocket HTO/SLED costs in Table 16. Using these adjusted values, the two studies indicate that turbojet/rocket booster life cycle costs are from 38 to 55 percent higher than an all rocket booster vehicle.

Table 16 Cost Comparisons with Past Studies

STUDY	* Δ\$ LCC (Billions)	** Δ Ratio \$ LCC (Percent)
Recent Study General Research Corp. (4192 Flights) Ref. 5	+ 0.40	+ 2
Adj. Gen. Research Corp. Study to 1710 Flights and Other Factors (Very Prelim)	+ 2.95	+ 38
Present Study	+ 4.41	+ 55

* Δ = Turbojet-boosted 2-stage - sled launched

** Δ Ratio = $100 \times \frac{\text{Turbojet-boosted 2-stage}}{\text{sled-launched}} - 1$

LCC $/kg Trades

As the number of turbojets is varied, then the payload changes as previously indicated in Figure 15. A fairer cost comparison then is to take this payload change into account and use $ per kg (lb) in orbit as the figure of merit, see Figure 37. The minimum cost occurs with (17) turbojets, whereas maximum payload is with (18) turbojets. The final baseline vehicle that was studied in detail used (16) turbojets at a fixed GLOW of 1.211 X 10^6 kg (2.67 million lb).

The sensitivity of $/lb in orbit to minimum drag is presented in Figure 38. Here also the payload varied for a fixed GLOW. $/lb rises at an increasing rate as the drag ratio is increased. The favorable effect of increasing the number of turbojets from 18 to 20 is also shown.

The effect of GLOW on $/lb is presented on Figure 39 for the number of turbojets fixed at (18). For comparisons, the all rocket SSTO vehicle costs are also shown. Similar comparisons are shown in Figure 40, on the basis of costs per flight which are not affected by differences in payload.

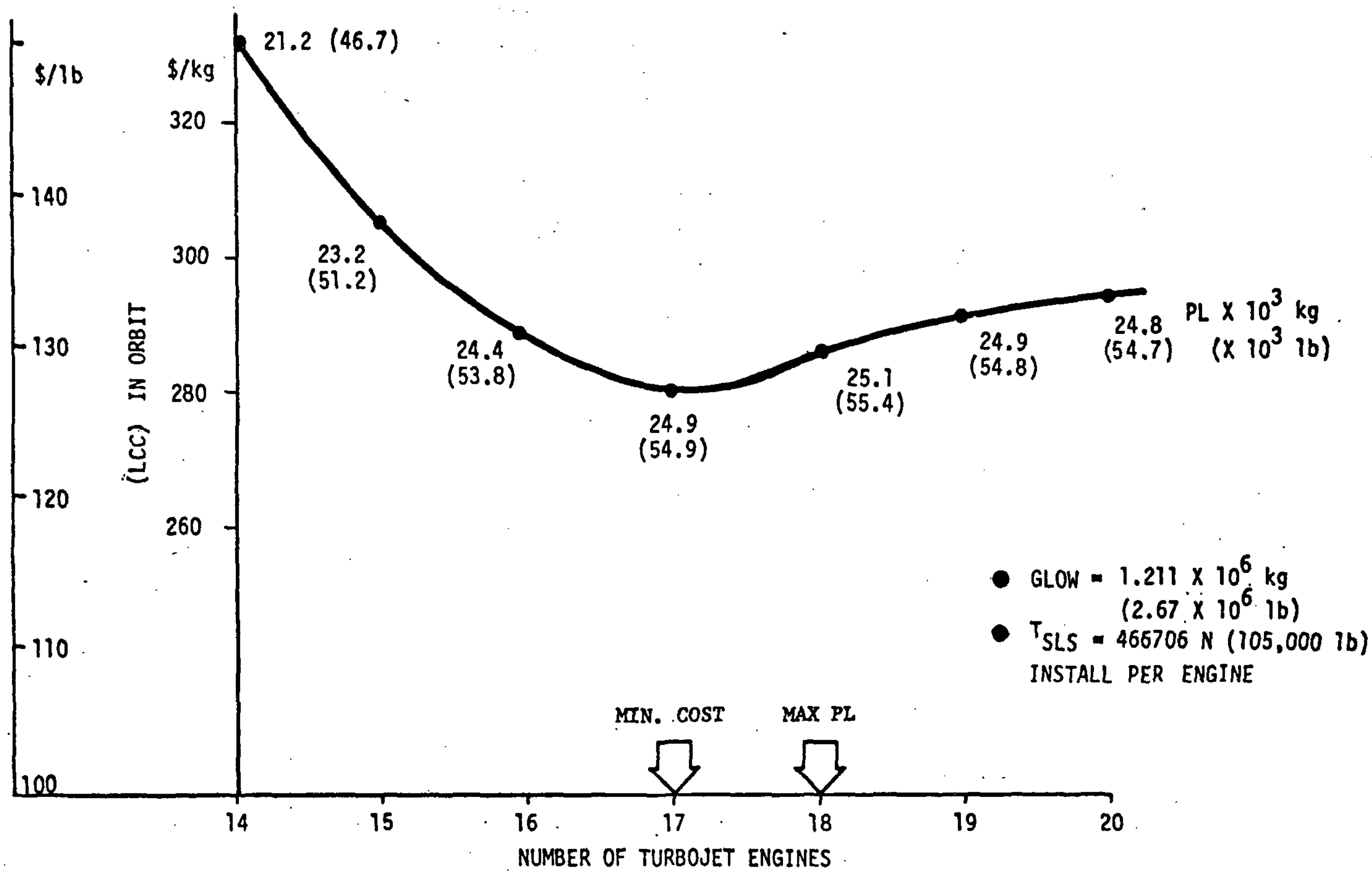


Figure 37 LCC $/kg (lb) Number Turbojets Trade

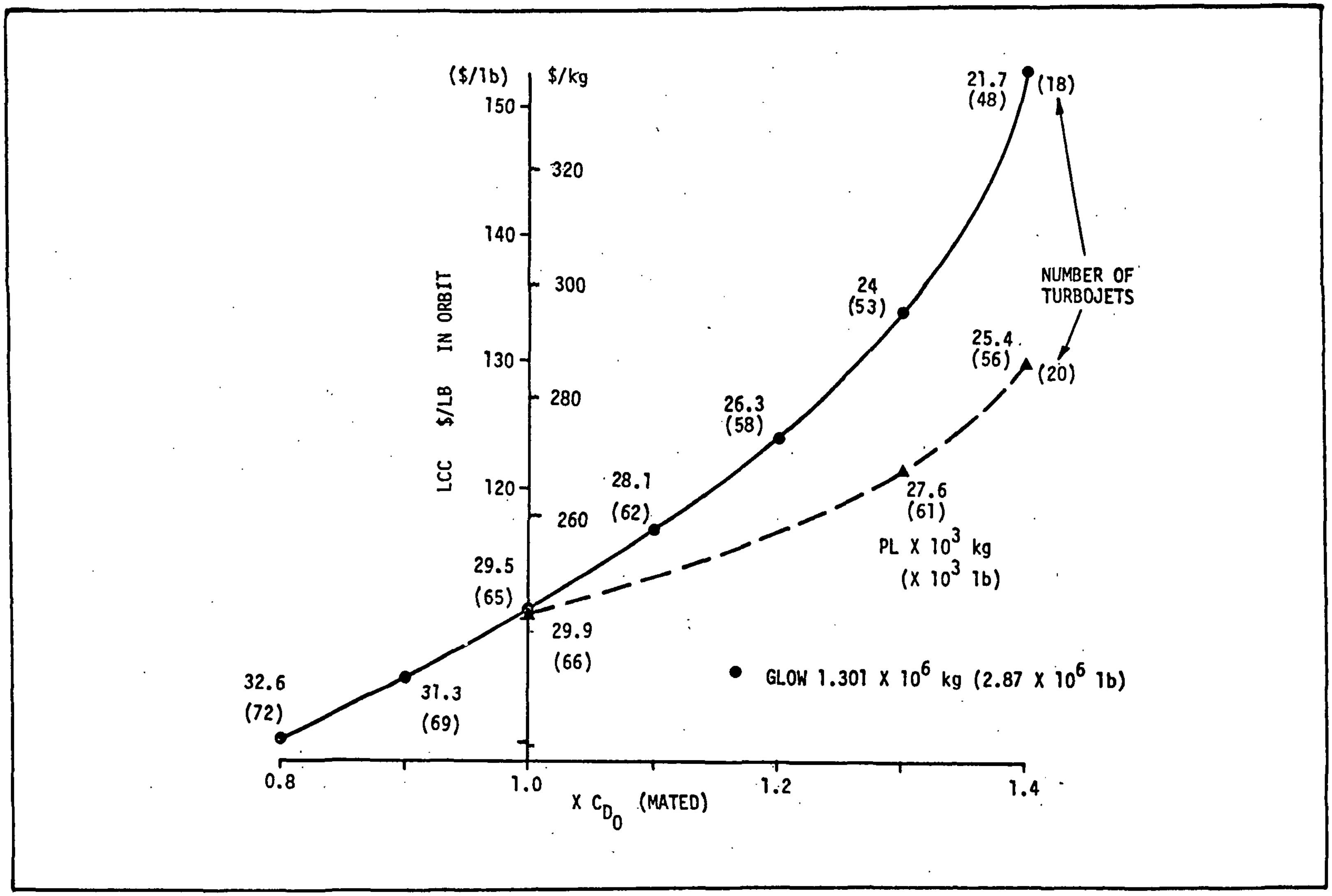


Figure 38 LCC $/kg ($/lb) Drag Sensitivity

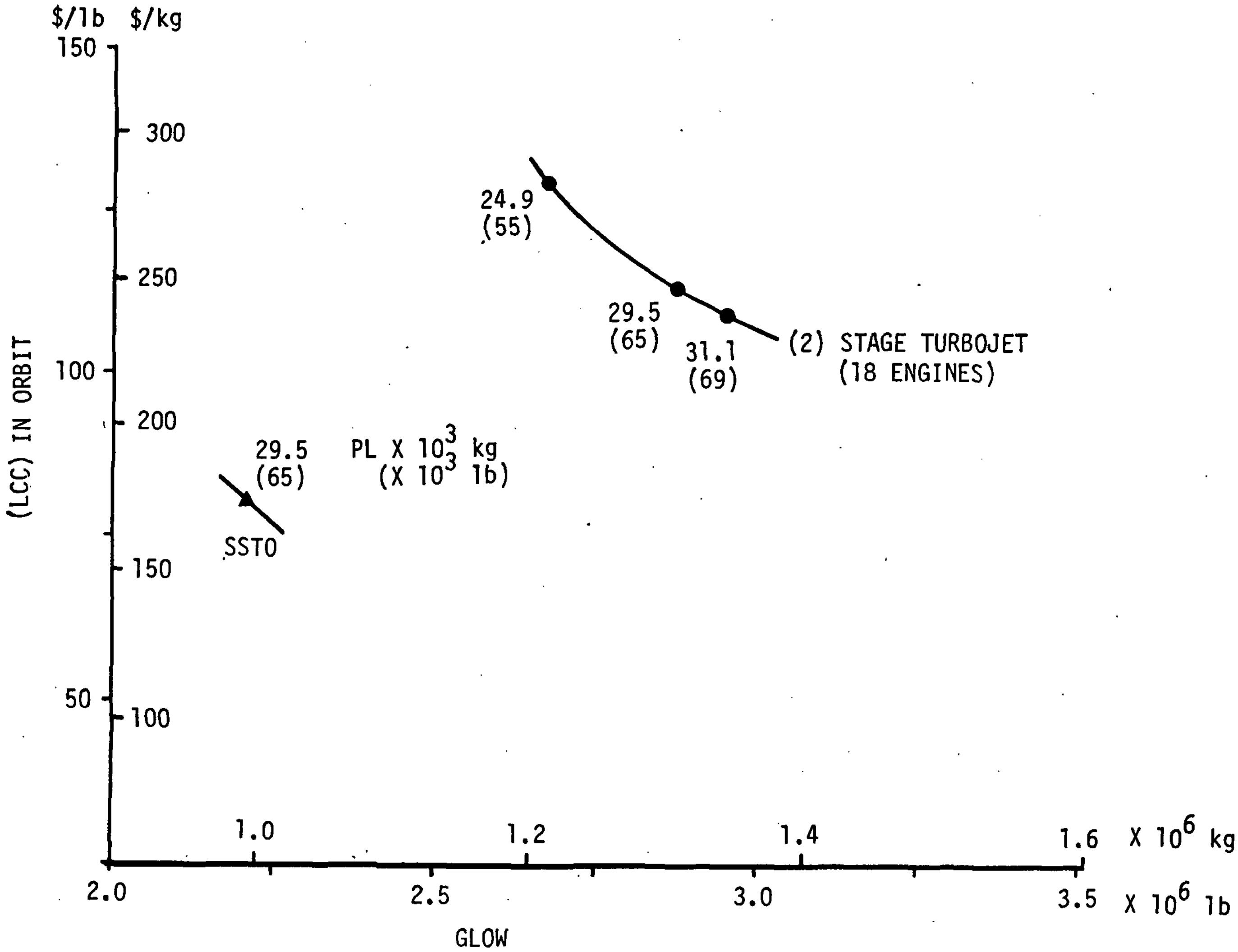


Figure 39 LCC - $/kg (lb) Comparison Vehicles

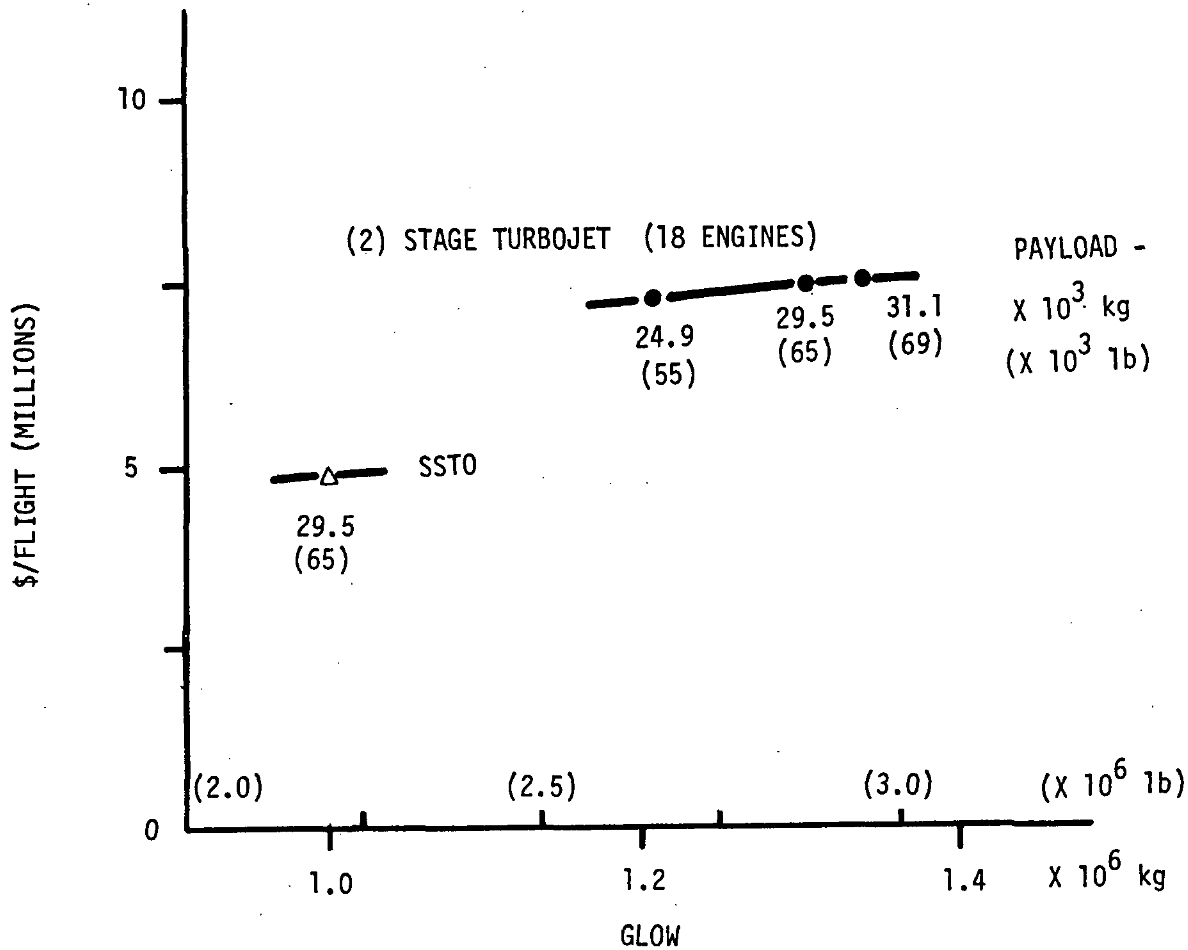


Figure 40 Cost per Flight Comparison

TECHNOLOGY ASSESSMENT

Since more than anticipated effort was required to iterate and develop the final baseline configuration, the scope of the technology assessment had to be curtailed.

The orbiter closely resembled that used for a recent previous study (NAS1-13944 Contract) and thus not evaluated again except for configuration differences, like area ruled and vortex lift parameters.

Aerodynamics: The two outstanding Aerodynamic features chosen for the final configuration were vortex lift and area rule. The vortex lift planform permitted takeoffs at α of 20 degrees without any increase in orbiter wing area. Full vortex lift theoretically increased lift coefficient about 25 percent. The method used for determining this result is that of Reference 4. Since the vehicle selected is a three body mated configuration with relatively large round nose leading edges, some questions rise as to the uncertainty of the theoretical methods. An area ruled configuration theoretically (from Reference 6) reduced transonic drag of the mated vehicle about (20) percent. Like the vortex lift, the theoretical drag reductions by area rule should be verified by wind tunnel test data of the mated configuration. Other aerodynamic issues (such as, stability and staging dynamics) are presented in Figure 41 which are beyond the scope of this study to resolve.

Propulsion: Rocket engine technology development has been detailed in reference 1, and no further assessment is made in this study. For Turbojets, basic technology is being developed under the Advanced Engine Gas Generator (ATEGG) Program, in which engine vendors like P&W, G.E., and Allison Corporations are participating. Component hardware elements are being built and tested. New test facilities will permit airbreathing engines at thrust ratings up to about 444800 Newtons (100,000 lb) to be ground tested. Engine designs which employ a variable area turbine appear to have performance advantages and should be pursued in future applications. Inlet design employs current state of art development and for staging Mach numbers up to 2.7 should employ a mixed external/internal compression inlet design.

The final booster configuration exhausted three engines into a common after burner and nozzle. This design appears attractive but has not been practically demonstrated. A key development is a system for controlling both the variable inlet and exit nozzle.

STRUCTURE - The booster structure is a simple frame-skin-stringer approach utilizing titanium which provides a basic state-of-the-art configuration for the design. This significantly reduces the development costs. The loads for this configuration are not completely defined which may locally increase weights. The orbiter structure is a very complex structural system which does not readily accommodate high local loads without significant weight impact. For this reason, it is mandatory that the local loads be fully defined for the system. This definition may significantly impact the structural configuration selection.

SUBSYSTEMS - The subsystems of the booster are simplified to the maximum extent possible within the constraints of limited load and operations definition. Although a nominal approach to weight has been utilized, this could vary as more definition becomes available. One area requiring development is the takeoff gear. The development of the high speed/high load carrying wheel and tire while not significantly beyond current state-of-the-art will necessitate dedicated funding to achieve. The secondary power and avionics systems are presumed to be at or near good state-of-the-art design.

ORBITER: SEE NAS1-13944 STUDY

BOOSTER: HAS BEEN EVALUATED AS FOLLOWS:
(AND MATED)

- AERODYNAMICS

  VORTEX LIFT AND AREA RULED CONFIGURATIONS HAVE POTENTIALLY ATTRACTIVE FEATURES, BUT ISSUES ARE:

  BLUNT AIRFOILS, VORTEX BURST AND PITCHUP
  INTERFERENCE BOOSTER/ORBITER
  GROUND EFFECTS
  HIGH TAKEOFF AND LANDING ATTITUDES
  STABILITY AND CONTROL
  SEPARATION DYNAMICS

(CONTINUED)

Figure 41 Technology Assessment

- PROPULSION
  - TURBOJET ENGINE TECHNOLOGY CURRENTLY UNDER DEVELOPMENT UNDER (ATEGG) PROGRAM
  - INLETS: EMPLOY CURRENT STATE OF ART DEVELOPMENT.
  - EXIT NOZZLE: SINGLE EXIT FOR MULTIENGINES NOT YET DEMONSTRATED.
  - ENGINE CONTROLS: FOR INLETS AND EXIT NOZZLE KEY DEVELOPMENT ITEM
- STRUCTURE
  - DYNAMIC LOADINGS OF MATED CONFIGURATION OF MAJOR CONCERN WHICH INCLUDE: SIDESLIP UNSYMMETRICAL SPANWISE LOADING, PITCHING AND TORSION LOADINGS.
- SUBSYSTEMS
  - LANDING GEAR
  - SECONDARY POWER
  - AVIONICS SCHEMATICS, LOCATIONS, COOLING - ANTENNA

Figure 41 (Continued) Technology Assessment

Study Observations

Turbojet boosted two stage to orbit concepts offer horizontal takeoff from conventional runways, self ferry, and potential advantages of offset orbit insertion, 360 degree launch azimuth, inland operational siting, and controlled landing after abort.

The study focused on aspects of developing a detailed configuration design to meet performance and study objectives. The final detailed configuration was scaled to a GLOW of 1.27×10^6 kg (2.8×10^6 lb) to attain a 29483 kg (65,000 lb) Space Shuttle type payload into an east low earth orbit. Each twin booster required (8) afterburning turbojet engines each with a static sea level thrust rating of 444,800 N (100,000 lb). Final design configuration features included:

- Wing Vortex Lift for Improved Takeoff
- Area Ruled for Low Transonic Drag
- Common Exit Nozzle for Low Weight and TVC
- Variable Area Turbine Turbojet for Performance
- Controlled Variable Area Inlet and Exit for Performance
- Low Profile Fixed Landing Gear for Reduced Weight

Life cycle cost comparisons of the Turbojet booster concept with a SSTO/Sled concept indicates that costs are comparable except for increases in develpment cost due to the turbojet engine propulsion system.

Technologies in need of development for the Turbojet booster concepts include: Aerodynamics (Vortex lift for takeoff and acceptable transonic drag), Orbiter Structure and Thermal Design, and booster propulsion integration.

Future studies of Turbojet Boosted concepts should pay close attention to the following cautions and recommendations:

- The large turbojet engine development could be a strong cost driver
- The concept is likely to be more appropriate for smaller and more dense payloads than the one used in this study.
- The orbiter thermal design is strongly affected by the high dynamic pressure boost trajectory to the Mach 3 staging point.
- Future studies of this approach should also consider subsonic staging with both single-vehicle boosters and twin boosters.

REFERENCES

1. Hepler, A. K. and Bangsund, E. L.: Technology Requirements for Advanced Earth Orbital Transportation Systems. NASA Contractor Report 2878 (July 1978).

2. Jackson, R. L.; Martin, J. and Small, W.: A Fully Reuseable Horizontal Takeoff Space Transport Concept with Two Small Turbojet Boosters. NASA TM-74087. (October 1977)

3. Freeman, D. C. and Fournier, R. H.: Static Aerodynamic Characteristics of a Single Stage to Orbit Vehicle with Low Planform Loading at Mach Numbers from 0.3 to 4.63. NASA TM-74056. Nov. 1977.

4. Lamar, J. E.: Recent Studies of Subsonic Vortex Lift including Parameters Affecting Stable Leading-Edge Vortex Flow. Journal of Aircraft, Vol. 14, No. 12, December 1977, PP 1205-1211.

5. Chase, R. L.: Earth to Orbit Reuseable Launch Vehicle - A Comparative Assessment General Research 709-02-CR (Feb. 1978)

6. Harris, Roy V., Jr.: NASA TMX-947, "An Analysis and Correlation of Aircraft Wave Drag" (March 1964).

APPENDIX I - FLIGHT PROFILE AND PERFORMANCE

Boost Profile

The final updated boost trajectory is presented in the following table. By closely matching the mass properties of the orbiter as given in Table 4 , updated booster fuel requirements and Gross Lift-Off Weight (GLOW) were determined. However, this resulted in less booster (JP-4) fuel required and a lower GLOW than that given in the booster mass properties of Table 3 . The total JP-4 fuel per booster is reduced from 111,147 kg (245,055 lb) to 93,455 kg (206,048 lb). The GLOW is correspondingly reduced from 1.22 X 10^6 kg (2.69 X 10^6 lb) to 1.170 X 10^6 Kg (2.579 X 10^6 lb).

The boost trajectory is determined by a series of angle of attack commands from flight control system and are described from lift-off to orbit injection as follows. With all (16) turbojet engines set to full afterburner, the configuration is accelerated down the runway and just prior to lift-off the mated configuration is rotated to a takeoff attitude of (20) degrees. At 20.7 seconds, a speed of 122 m/sec (400 fps) is attained and lift-off occurs at 1265 m (4151 ft) down the runway. The next event is a pull-up phase with a normal load factor of 1.25 to a maximum flight path angle of about 24 degrees followed by constant dynamic pressure, q, trajectory of 67,032 Pa (1400 psf). Just prior to staging at an altitude of 15545m (51,000 ft) another pull-up phase occurs to avoid exceeding heating constraints. This pull-up is accomplished by gradually increasing the angle of attack from about 3 to 9 degrees along with not exceeding a $q\alpha$ constraint of 397,404 Pa - DEG (8300 PSF-DEG). When an altitude of 19,812m (65,000 ft) and a M = 2.62 are reached, the configuration is staged.

After separation the twin-boosters perform a 180 degree maneuver and return to launch site. The orbiter after staging climbs and accelerates with all rocket engines turned on to orbit injection. A controlled angle of attack schedule for the orbiter is initially required to avoid exceeding the trajectory heating constraints. When a Mach number of 8 is reached, the flight control is shifted over to an iterative guidance mode to injection. See Table 17 for detail trajectory characteristics

The injection conditions are:

Altitude 92,354 m (303,000 ft)

Velocity 7891 m/sec (25,890 FPS)

Takeoff

The takeoff ground run was determined using the following method:

Incremental values are = Δ velocity = Accel. X Δ t = a Δt

Δ distance = Velocity X Δt = v Δt

Δ fuel = SFC X T X Δ t

Summing up $V = \Sigma a \Delta t$, $D = V \Delta t$, etc.

For α = (0) Deg. Along Ground

$$a = \left(\frac{T-D}{W} - \mu\right) \qquad \mu = .025$$

TIME SEC	ALTITUDE M	INERTIAL VELOC M/SEC	REL. VELOCITY M/SEC	REL GAMMA DEG	MACH	THRUST N	DRAG N	LIFT N	ALPHA DEG	WEIGHT KG	DYN PRESS PA
0.0	6.	531.	122.	0.0	0.36	7472976.	0.	0.	20.0	1162730.	9193.
20.0	231.	618.	208.	5.1	0.61	8186037.	1802266.	10445495.	7.4	1153788.	25827.
40.0	750.	719.	308.	6.3	0.91	10309511.	2737074.	10848129.	3.2	1143592.	53955.
60.0	2021.	770.	373.	19.9	1.12	10446331.	6060105.	14547493.	3.3	1130645.	69156.
80.0	4277.	794.	387.	10.1	1.20	8104621.	4460284.	3572646.	1.0	1119958.	58635.
100.0	4824.	846.	437.	4.5	1.36	10120332.	7217235.	19059276.	5.0	1109657.	70383.
120.0	6725.	860.	456.	13.5	1.46	8723893.	4996593.	6546713.	2.0	1098532.	62988.
140.0	8066.	902.	492.	3.3	1.60	8445085.	5118873.	7220626.	2.3	1088840.	63297.
160.0	8826.	937.	529.	7.5	1.73	8816396.	6230310.	12866687.	4.1	1078716.	67585.
180.0	10354.	965.	556.	6.8	1.87	8082891.	4879567.	6912213.	2.5	1068993.	63079.
200.0	11099.	1013.	603.	1.8	2.03	8200218.	5287784.	9889790.	3.6	1059689.	65619.
220.0	11894.	1050.	640.	5.2	2.16	7964104.	5115014.	9746795.	3.8	1050002.	65570.
240.0	12851.	1093.	683.	2.6	2.30	7438374.	4517127.	7796914.	3.2	1040827.	64003.
260.0	13403.	1135.	725.	2.8	2.45	7268862.	4965483.	10473462.	4.4	1031701.	66132.
280.0	14188.	1171.	760.	2.6	2.57	6690969.	4265896.	8159558.	3.7	1022859.	64372.
300.0	14703.	1208.	798.	1.5	2.70	6386641.	4368876.	9261053.	4.3	1014395.	65308.
320.0	15204.	1239.	829.	2.0	2.81	6088747.	4200944.	9109394.	4.4	1006102.	65219.
340.0	16415.	1237.	830.	6.7	2.81	5058184.	4994766.	12615109.	7.3	998494.	54262.
360.0	18965.	1194.	790.	10.7	2.68	3269159.	3965558.	9829338.	8.9	993000.	33076.

START SECOND STAGE

Table 17 Boost Trajectory

TIME SEC	ALTITUDE M	INERTIAL VELOC M/SEC	REL. VELOCITY M/SEC	REL GAMMA DEG	MACH	THRUST N	DRAG N	LIFT N	ALPHA DEG	WEIGHT KG	DYN PRESS PA
366.0	19843.	1178.	774.	10.9	2.62	2807525.	3569943.	8760641.	9.3	766216.	27692.
380.0	22261.	1204.	802.	15.0	2.71	6719917.	3151367.	7900222.	17.0	745294.	20425.
400.0	27010.	1259.	859.	17.2	2.88	6768979.	1637038.	4096290.	17.0	715405.	11162.
420.0	32008.	1363.	958.	14.3	3.15	6793614.	884237.	2189003.	17.5	685516.	6335.
440.0	36445.	1493.	1084.	10.9	3.49	6804134.	635674.	1466144.	20.5	655627.	4028.
460.0	40105.	1648.	1235.	7.4	3.90	6806398.	581225.	1246026.	21.3	625738.	2933.
480.0	42840.	1819.	1404.	4.6	4.38	6809182.	506255.	1079522.	21.7	595849.	2459.
500.0	44643.	2009.	1593.	2.4	4.92	6810497.	497126.	1046818.	22.0	565961.	2375.
520.0	45556.	2214.	1798.	0.8	5.53	6811046.	520880.	1090895.	22.0	536072.	2613.
540.0	45747.	2430.	2013.	0.0	6.19	6811155.	845773.	1748359.	22.0	506183.	4546.
560.0	45793.	2650.	2233.	0.2	6.86	6811179.	950996.	1932020.	22.0	476294.	5558.
580.0	46192.	2880.	2463.	0.8	7.56	6811376.	999212.	1988826.	22.0	446405.	6382.
600.0	47366.	3123.	2706.	1.8	8.26	6811906.	933049.	1817011.	22.0	416516.	6488.
620.0	49619.	3388.	2970.	2.7	8.97	6812709.	748087.	1425688.	22.0	386627.	5612.
640.0	53094.	3684.	3265.	3.6	9.96	6813538.	535678.	1017877.	22.0	356738.	4058.
660.0	57902.	4017.	3597.	4.4	11.24	6814174.	286856.	526540.	22.0	326849.	2417.
680.0	63986.	4407.	3985.	4.7	12.85	6814545.	71405.	129072.	15.0	296961.	1202.
700.0	70680.	4864.	4439.	4.4	14.83	6814708.	20297.	22865.	8.5	267072.	550.
720.0	77293.	5388.	4962.	3.7	17.20	6814769.	7937.	1780.	2.8	237183.	256.
740.0	83158.	5965.	5537.	2.7	19.85	6150164.	4069.	-333.	-1.5	208512.	132.
760.0	87687.	6547.	6118.	1.8	22.54	5405875.	2572.	-945.	-3.9	183245.	82.
780.0	90646.	7130.	6701.	0.9	25.14	4750981.	2011.	-1027.	-4.8	161038.	63.
797.6	92032.	7644.	7226.	0.4	27.35	4229278.	1967.	-1465.	-6.3	143735.	59.
801.6	92197.	7760.	7343.	0.3	27.82	4121293.	2080.	-1978.	-7.5	140073.	59.
805.6	92298.	7876.	7459.	0.1	28.28	4015182.	2665.	-3996.	-11.6	136506.	60.
805.7	92299.	7879.	7462.	0.1	28.29	4012505.	2712.	-4131.	-11.8	136418.	60.
805.8	92301.	7882.	7465.	0.1	28.30	4009818.	2764.	-4279.	-12.0	136330.	60.
805.9	92302.	7885.	7467.	0.1	28.31	4007122.	2823.	-4442.	-12.3	136242.	60.
806.0	92304.	7888.	7470.	0.1	28.32	4004413.	2889.	-4622.	-12.6	136154.	60.
806.1	92305.	7891.	7473.	0.1	28.33	4001688.	2965.	-4823.	-13.0	136067.	60.

Table 17 Contd

Using an option in minicomputer program HZ 600, the takeoff ground run is determined by summing these equations with an incremental Δt = 0.5 second. The rotation to an attitude of (20) degrees just prior to liftoff is neglected in the above estimate and is expected to have a small effect on the results (i.e. rotation at 3 seconds prior to lift-off increases drag and reduces thrust component by COS (20) degrees but, is partially compensated by increased lift and reduced wheel friction force). The take-off fuel (both Turbojet Boosters) burned is 6,943 kg (15,306 lb).

Flyback

The staging conditions to initiate the turbojet booster flyback trajectory are:

Altitude = 19,812 m (65,000 ft)

Velocity = 777 m/sec (2548 ft/sec)

Boost Range = 213 km (115 n.mi.)

Staging Weight (per booster) = 117,926 kg (260,000 lb)

The flyback trajectory for a turbojet booster is listed in Tables 18-20. The flyback is controlled by bank, angle of attack and engine throttle setting in order to return to launch site with minimum JP-4 fuel burned. This flyback procedure is further detailed as follows. Initially the angle of attack is set to 10 degrees with turbojet throttle settings to idle thrust, and a 45 degree bank to initiate a turning maneuver. The angle of attack is modulated slightly to damp out altitude oscillations. When the heading has changed 190 degrees to aim towards the launch site the bank angle is removed. With engine throttles on idle (or some turned off) the turbojet

TIME SEC	ALTITUDE METRES	VELOCITY-R M/SEC	GAMMA-R DEG	DYNAMIC PRES PASCALS	RANGE KM	ALPHA DEG	WEIGHT KG
0.0	19812.0	776.630	9.00000	29043.8	212.980	10.0000	117934.
10.0000	20996.2	722.080	8.87132	20469.0	220.345	10.0000	117934.
20.0000	21975.7	679.570	6.94070	15350.5	227.251	10.0000	117934.
30.0000	22602.2	647.635	3.70799	12549.7	233.825	10.0000	117934.
35.0000	22756.2	635.271	1.76316	11768.7	237.016	9.27593	117934.
40.0000	22793.9	625.424	-0.379995	11335.1	240.156	10.0780	117934.
50.0000	22531.7	610.068	-4.44776	11268.0	246.300	10.9133	117934.
60.0000	21873.9	598.869	-7.92850	12127.8	252.285	11.6280	117934.
70.0000	20918.8	588.881	-10.3808	13795.3	258.126	12.1720	117934.
80.0000	19803.6	576.663	-11.4171	16036.3	263.832	12.4502	117934.
90.0000	18692.2	559.098	-10.8772	18311.7	269.389	12.3053	117934.
100.000	17737.2	534.940	-8.99587	20173.1	274.766	11.8471	117934.
110.000	17042.6	504.547	-6.28335	20200.6	279.906	11.2902	117934.
120.000	16619.3	470.938	-3.73682	18886.4	284.753	10.7673	117934.
130.000	16396.9	436.921	-2.04038	16862.4	289.274	10.4190	117934.
140.000	16273.9	404.575	-1.50295	14751.0	293.467	10.3086	117934.
150.000	16157.7	375.164	-2.09900	12925.9	297.352	10.4310	117934.
160.000	15982.5	349.315	-3.58686	11526.6	300.957	10.7365	117934.
170.000	15713.9	327.122	-5.61072	10550.1	304.317	11.1521	117934.
180.000	15343.8	308.517	-7.83257	9943.71	307.462	11.6083	117934.
183.126	15207.2	303.857	-8.58357	9851.05	308.407	11.7625	117934.
183.126	15207.2	303.857	-8.58357	9851.05	308.407	11.7625	117934.
190.000	14943.3	294.317	-6.35008	9621.76	310.441	11.3039	117934.
200.000	14668.2	281.485	-4.92860	9171.96	313.299	11.0120	117934.
210.000	14433.4	270.956	-5.01630	8798.62	316.042	11.0300	117934.
220.000	14182.7	263.122	-5.83310	8605.57	318.693	11.1977	117934.
230.000	13897.4	257.637	-6.72161	8594.34	321.274	11.3802	117934.
240.000	13585.3	253.603	-7.23561	8700.29	323.804	11.4857	117934.
250.000	13264.8	250.227	-7.31808	8851.90	326.298	11.5026	117934.
260.000	12952.3	246.987	-7.08321	8995.11	328.759	11.4544	117934.
270.000	12657.8	243.655	-6.69613	9101.48	331.189	11.3749	117934.
280.000	12384.2	240.218	-6.29704	9166.29	333.589	11.2930	117934.
290.000	12129.7	236.781	-5.96710	9199.77	335.955	11.2252	117934.
300.000	11890.3	233.240	-5.74355	9199.16	338.289	11.1793	117934.
310.000	11660.9	229.556	-5.66287	9167.73	340.587	11.1628	117934.
320.000	11435.6	225.932	-5.71054	9128.39	342.850	11.1726	117934.
330.000	11210.2	222.498	-5.83571	9096.86	345.076	11.1983	117934.
340.000	10982.8	219.297	-5.98272	9079.48	347.269	11.2284	117934.
350.000	10753.2	216.317	-6.12379	9063.18	349.431	11.2574	117934.
360.000	10521.8	213.527	-6.23151	9073.40	351.564	11.2795	117934.
363.003	10452.2	212.711	-6.25226	9077.35	352.199	11.2838	117934.
363.003	10452.2	212.711	-6.25226	9077.35	352.199	11.2838	117934.
370.000	10294.8	215.214	-5.71933	9462.88	353.687	11.1744	117920.
380.000	10103.6	217.044	-4.37499	9838.10	355.838	10.8983	117900.
390.000	9963.79	217.017	-3.05475	9993.62	358.001	10.6272	117880.
400.000	9867.02	215.764	-2.15165	9987.56	360.160	10.4418	117859.
405.202	9827.85	214.857	-1.87794	9947.78	361.278	10.3856	117848.
410.000	9795.58	213.962	-1.73319	9901.04	362.305	10.3559	117837.
420.000	9732.88	212.120	-1.68883	9800.35	364.431	10.3468	117815.
430.000	9668.01	210.516	-1.85059	9723.38	366.539	10.3800	117793.

Table 18 Flyback Turbojet Booster Trajectory

TIME SEC	THRUST NT	LIFT NT	DRAG NT	LATITUDE DEG	LONGITUDE DEG	HEADING-R DEG	BANK DEG
0.0	0.0	0.179485E 07	539511.	50.0000	-97.0000	0.0	0.0
10.0000	0.0	0.135471E 07	390178.	50.0660	-96.9932	7.31217	45.0000
20.0000	0.0	0.106782E 07	296013.	50.1270	-96.9758	13.3263	45.0000
30.0000	0.0	904054.	242867.	50.1838	-96.9[illegible]04	18.4946	45.0000
35.0000	0.0	796564.	211721.	50.2108	-96.9353	20.8983	45.0000
40.0000	0.0	841785.	221078.	50.2369	-96.9187	23.1837	45.0000
50.0000	0.0	919042.	238603.	50.2867	-96.8814	28.1608	45.0000
60.0000	0.0	0.106316E 07	275173.	50.3328	-96.83[illegible]0	33.9113	45.0000
70.0000	0.0	0.127411E 07	329559.	50.3746	-96.7883	40.8471	45.0000
80.0000	0.0	0.153539E 07	396898.	50.4108	-96.7315	49.3922	45.0000
90.0000	0.0	0.178698E 07	461168.	50.4398	-96.6678	59.7955	45.0000
100.000	0.0	0.197895E 07	506910.	50.4597	-96.5987	71.9361	45.0000
110.000	0.0	0.200729E 07	508910.	50.4689	-96.5277	85.4452	45.0000
120.000	0.0	0.191074E 07	478915.	50.4670	-96.4595	99.4857	45.0000
130.000	0.0	0.175724E 07	436240.	50.4556	-96.3984	113.528	45.0000
140.000	0.0	0.160859E 07	397295.	50.4366	-96.3475	127.385	45.0000
150.000	0.0	0.149700E 07	370145.	50.4123	-96.3082	141.161	45.0000
160.000	0.0	0.143122E 07	356666.	50.3849	-96.2813	155.138	45.0000
170.000	0.0	0.140766E 07	355505.	50.3562	-96.2669	169.666	45.0000
180.000	0.0	0.139505E 07	346037.	50.3280	-96.2647	185.049	45.0000
183.126	0.0	0.139139E 07	338021.	50.3196	-96.2[illegible]64	190.000	0.0
183.126	0.0	0.139139E 07	338021.	50.3196	-96.[illegible]64	190.000	0.0
190.000	0.0	0.128866E 07	289945.	50.3016	-96.2713	190.032	0.0
200.000	0.0	0.117518E 07	240037.	50.2763	-96.27[illegible]	190.080	0.0
210.000	0.0	0.111218E 07	210724.	50.2520	-96.2850	190.128	0.0
220.000	0.0	0.109146E 07	195979.	50.2286	-96.2916	190.176	0.0
230.000	0.0	0.110205E 07	190840.	50.2058	-96.2980	190.223	0.0
240.000	0.0	0.112485E 07	189146.	50.1834	-96.3043	190.269	0.0
250.000	0.0	0.114512E 07	186706.	50.1613	-96.3105	190.315	0.0
260.000	0.0	0.115776E 07	182313.	50.1396	-96.3167	190.360	0.0
270.000	0.0	0.116230E 07	176102.	50.1181	-96.3228	190.406	0.0
280.000	0.0	0.116111E 07	168892.	50.0969	-96.3289	190.452	0.0
290.000	0.0	0.115734E 07	161561.	50.0760	-96.3349	190.499	0.0
300.000	0.0	0.115151E 07	160127.	50.0553	-96.3409	190.546	0.0
310.000	0.0	0.114483E 07	158904.	50.0350	-96.3467	190.592	0.0
320.000	0.0	0.113989E 07	158217.	50.0151	-96.3525	190.639	0.0
330.000	0.0	0.113760E 07	158074.	49.9954	-96.3582	190.685	0.0
340.000	0.0	0.113756E 07	158300.	49.9760	-96.3639	190.731	0.0
350.000	0.0	0.113758E 07	158523.	49.9569	-96.3695	190.777	0.0
360.000	0.0	0.114028E 07	159052.	49.9381	-96.3751	190.822	0.0
363.003	83190.7	0.114096E 07	159168.	49.9325	-96.3767	190.836	0.0
363.003	83190.7	0.114096E 07	159168.	49.9325	-96.3767	190.836	0.0
370.000	82080.8	0.117835E 07	163201.	49.9194	-96.3806	190.868	0.0
380.000	83836.7	0.119509E 07	162410.	49.9004	-96.3862	190.914	0.0
390.000	87101.5	0.118366E 07	157816.	49.8813	-96.3919	190.962	0.0
400.000	90002.3	0.116193E 07	152865.	49.8622	-96.3976	191.011	0.0
405.202	91084.1	0.115084E 07	150779.	49.8524	-96.4005	191.036	0.0
410.000	91793.1	0.114193E 07	149273.	49.8433	-96.4032	191.060	0.0
420.000	92477.0	0.112886E 07	147425.	49.8246	-96.4089	191.109	0.0
430.000	92386.4	0.112318E 07	146992.	49.8060	-96.4146	191.158	0.0

Table 18 Contd

TIME SEC	ALTITUDE METRES	VELOCITY-R M/SEC	GAMMA-R DEG	DYNAMIC PRES PASCALS	RANGE KM	ALPHA DEG	WEIGHT KG
440.000	9596.23	209.223	-2.06986	9681.97	368.634	10.4250	117772.
450.000	9517.35	208.185	-2.25241	9671.18	370.716	10.4625	117750.
460.000	9433.50	207.298	-2.36138	9679.04	372.788	10.4849	117729.
470.000	9347.37	206.463	-2.40114	9693.63	374.852	10.4930	117707.
480.000	9261.05	205.618	-2.39578	9706.88	376.908	10.4919	117686.
490.000	9175.69	204.737	-2.37173	9715.15	378.955	10.4870	117665.
500.000	9091.59	203.822	-2.34816	9718.20	380.993	10.4822	117644.
510.000	9008.55	202.887	-2.33445	9717.57	383.022	10.4793	117623.
520.000	8926.18	201.948	-2.33208	9715.23	385.042	10.4789	117602.
530.000	8844.10	201.017	-2.33807	9712.68	387.052	10.4801	117581.
540.000	8762.11	200.100	-2.34822	9710.74	389.053	10.4822	117560.
550.000	8680.13	199.197	-2.35908	9709.62	391.045	10.4844	117539.
560.000	8598.14	198.307	-2.36870	9709.14	393.028	10.4864	117518.
570.000	8516.23	197.428	-2.37647	9709.01	395.002	10.4880	117497.
580.000	8434.43	196.556	-2.38270	9708.98	396.968	10.4892	117477.
590.000	8352.80	195.691	-2.38801	9708.88	398.925	10.4903	117456.
600.000	8271.36	194.833	-2.39298	9708.65	400.874	10.4914	117435.
610.000	8190.11	193.980	-2.39798	9708.32	402.813	10.4924	117415.
620.000	8109.04	193.135	-2.40315	9707.92	404.745	10.4934	117394.
630.000	8028.14	192.296	-2.40846	9707.48	406.668	10.4945	117374.
640.000	7947.42	191.464	-2.41386	9707.07	408.582	10.4956	117353.
650.000	7866.87	190.638	-2.41922	9706.66	410.489	10.4967	117333.
660.000	7786.48	189.820	-2.42451	9706.26	412.387	10.4978	117312.
670.000	7706.27	189.008	-2.42969	9705.88	414.277	10.4989	117292.
680.000	7626.23	188.203	-2.43474	9705.50	416.159	10.4999	117272.
690.000	7546.37	187.404	-2.43969	9705.11	418.033	10.5009	117251.
700.000	7466.69	186.611	-2.44454	9704.72	419.899	10.5019	117231.
710.000	7387.19	185.824	-2.44933	9704.32	421.758	10.5029	117211.
720.000	7307.86	185.044	-2.45408	9703.90	423.608	10.5039	117191.
730.000	7228.72	184.269	-2.45876	9703.50	425.451	10.5049	117171.
740.000	7149.76	183.500	-2.46338	9703.07	427.286	10.5058	117151.
750.000	7070.98	182.737	-2.46795	9702.65	429.114	10.5067	117131.
760.000	6992.39	181.980	-2.47247	9702.23	430.933	10.5077	117111.
770.000	6913.98	181.228	-2.47692	9701.79	432.746	10.5086	117091.
780.000	6835.75	180.482	-2.48130	9701.37	434.551	10.5095	117071.
790.000	6757.70	179.741	-2.48559	9700.93	436.348	10.5104	117051.
800.000	6679.85	179.006	-2.48985	9700.49	438.138	10.5112	117031.
810.000	6602.18	178.276	-2.49407	9700.04	439.921	10.5121	117011.
820.000	6524.69	177.551	-2.49822	9699.59	441.697	10.5130	116992.
830.000	6447.39	176.831	-2.50234	9699.13	443.465	10.5138	116972.
840.000	6370.29	176.117	-2.50640	9698.66	445.226	10.5146	116952.
850.000	6293.36	175.407	-2.51041	9698.20	446.980	10.5155	116932.
860.000	6216.63	174.703	-2.51437	9697.72	448.728	10.5163	116913.
870.000	6140.08	174.004	-2.51829	9697.25	450.468	10.5171	116893.
880.000	6063.72	173.309	-2.52215	9696.77	452.201	10.5179	116873.
890.000	5987.55	172.619	-2.52597	9696.29	453.927	10.5187	116854.
900.000	5911.57	171.934	-2.52974	9695.79	455.647	10.5194	116834.
910.000	5835.77	171.254	-2.53349	9695.29	457.359	10.5202	116815.
920.000	5760.17	170.578	-2.53720	9694.78	459.065	10.5210	116795.
930.000	5684.75	169.907	-2.54087	9694.26	460.765	10.5217	116776.

Table 18 Contd

TIME SEC	THRUST NT	LIFT NT	DRAG NT	LATITUDE DEG	LONGITUDE DEG	HEADING-R DEG	BANK DEG
440.000	91914.6	0.112291E 07	147394.	49.7875	-96.4202	191.207	0.0
450.000	91375.0	0.112540E 07	148086.	49.7691	-96.4258	191.255	0.0
460.000	90950.4	0.112847E 07	148699.	49.7509	-96.4314	191.304	0.0
470.000	90699.6	0.113080E 07	149068.	49.7327	-96.4371	191.352	0.0
480.000	90597.0	0.113197E 07	149187.	49.7146	-96.4427	191.400	0.0
490.000	90583.4	0.113215E 07	149132.	49.6965	-96.4483	191.448	0.0
500.000	90599.7	0.113171E 07	148998.	49.6786	-96.4539	191.496	0.0
510.000	90607.9	0.113107E 07	148858.	49.6607	-96.4595	191.544	0.0
520.000	90591.1	0.113048E 07	148749.	49.6429	-96.4651	191.591	0.0
530.000	90549.8	0.113005E 07	148680.	49.6252	-96.4707	191.639	0.0
540.000	90492.1	0.112979E 07	148642.	49.6076	-96.4762	191.686	0.0
550.000	90427.3	0.112965E 07	148621.	49.5901	-96.4818	191.734	0.0
560.000	90362.8	0.112955E 07	148605.	49.5726	-96.4874	191.781	0.0
570.000	90302.0	0.112946E 07	148585.	49.5553	-96.4930	191.828	0.0
580.000	90245.4	0.112934E 07	148560.	49.5380	-96.4985	191.875	0.0
590.000	90192.6	0.112921E 07	148529.	49.5208	-96.5041	191.922	0.0
600.000	90141.8	0.112905E 07	148495.	49.5036	-96.5097	191.969	0.0
610.000	90091.6	0.112888E 07	148461.	49.4866	-96.5153	192.016	0.0
620.000	90041.6	0.112871E 07	148426.	49.4696	-96.5208	192.063	0.0
630.000	89991.3	0.112854E 07	148393.	49.4527	-96.5263	192.109	0.0
640.000	89941.1	0.112838E 07	148360.	49.4359	-96.5318	192.156	0.0
650.000	89890.6	0.112822E 07	148328.	49.4191	-96.5373	192.202	0.0
660.000	89840.9	0.112806E 07	148297.	49.4025	-96.5428	192.248	0.0
670.000	89791.4	0.112790E 07	148265.	49.3858	-96.5484	192.294	0.0
680.000	89742.6	0.112775E 07	148234.	49.3693	-96.5539	192.340	0.0
690.000	89694.1	0.112759E 07	148202.	49.3529	-96.5594	192.386	0.0
700.000	89646.2	0.112743E 07	148170.	49.3365	-96.5649	192.432	0.0
710.000	89598.9	0.112727E 07	148139.	49.3202	-96.5704	192.478	0.0
720.000	89551.8	0.112712E 07	148107.	49.3039	-96.5760	192.524	0.0
730.000	89504.8	0.112696E 07	148076.	49.2878	-96.5814	192.569	0.0
740.000	89458.3	0.112680E 07	148044.	49.2717	-96.5869	192.614	0.0
750.000	89412.3	0.112664E 07	148013.	49.2556	-96.5924	192.660	0.0
760.000	89366.6	0.112649E 07	147982.	49.2397	-96.5978	192.705	0.0
770.000	89321.1	0.112633E 07	147951.	49.2238	-96.6033	192.750	0.0
780.000	89276.0	0.112617E 07	147920.	49.2080	-96.6087	192.795	0.0
790.000	89231.3	0.112602E 07	147889.	49.1922	-96.6142	192.840	0.0
800.000	89187.2	0.112586E 07	147858.	49.1765	-96.6197	192.885	0.0
810.000	89142.9	0.112570E 07	147828.	49.1609	-96.6251	192.930	0.0
820.000	89099.4	0.112555E 07	147797.	49.1454	-96.6306	192.974	0.0
830.000	89055.9	0.112539E 07	147766.	49.1299	-96.6360	193.019	0.0
840.000	89012.8	0.112523E 07	147736.	49.1144	-96.6414	193.063	0.0
850.000	88970.1	0.112508E 07	147706.	49.0991	-96.6468	193.107	0.0
860.000	88927.8	0.112492E 07	147675.	49.0838	-96.6523	193.151	0.0
870.000	88885.4	0.112477E 07	147645.	49.0686	-96.6577	193.195	0.0
880.000	88843.6	0.112461E 07	147615.	49.0534	-96.6631	193.239	0.0
890.000	88801.9	0.112446E 07	147585.	49.0383	-96.6685	193.283	0.0
900.000	88760.7	0.112430E 07	147555.	49.0233	-96.6739	193.327	0.0
910.000	88719.8	0.112414E 07	147525.	49.0083	-96.6793	193.371	0.0
920.000	88678.9	0.112399E 07	147495.	48.9934	-96.6847	193.414	0.0
930.000	88638.3	0.112383E 07	147466.	48.9785	-96.6901	193.458	0.0

Table 18 Contd

TIME SEC	ALTITUDE METRES	VELOCITY-R M/SEC	GAMMA-R DEG	DYNAMIC PRES PASCALS	RANGE KM	ALPHA DEG	WEIGHT KG
940.000	5609.52	169.241	-2.54452	9693.75	462.457	10.5225	116757.
950.000	5534.48	168.579	-2.54810	9693.23	464.143	10.5232	116737.
960.000	5459.63	167.921	-2.55166	9692.70	465.823	10.5239	116718.
970.000	5384.97	167.268	-2.55517	9692.16	467.495	10.5247	116699.
980.000	5310.49	166.619	-2.55867	9691.62	469.162	10.5254	116679.
990.000	5236.20	165.975	-2.56216	9691.08	470.822	10.5261	116660.
1000.00	5162.10	165.335	-2.56557	9690.53	472.475	10.5268	116641.
1010.00	5088.19	164.699	-2.56897	9689.97	474.122	10.5275	116622.
1020.00	5014.46	164.067	-2.57234	9689.41	475.763	10.5282	116602.
1030.00	4940.92	163.440	-2.57567	9688.83	477.398	10.5289	116583.
1040.00	4867.57	162.817	-2.57898	9688.26	479.026	10.5295	116564.
1050.00	4794.40	162.197	-2.58227	9687.68	480.648	10.5302	116545.
1060.00	4721.41	161.582	-2.58554	9687.09	482.264	10.5309	116526.
1070.00	4648.62	160.971	-2.58879	9686.49	483.873	10.5316	116507.
1080.00	4576.00	160.364	-2.59203	9685.90	485.477	10.5322	116488.
1090.00	4503.57	159.761	-2.59520	9685.29	487.074	10.5329	116469.
1100.00	4431.32	159.162	-2.59838	9684.67	488.666	10.5335	116450.
1110.00	4359.26	158.567	-2.60154	9684.05	490.252	10.5342	116431.
1120.00	4287.38	157.976	-2.60467	9683.43	491.832	10.5348	116412.
1130.00	4215.68	157.388	-2.60778	9682.80	493.406	10.5355	116393.
1140.00	4144.16	156.805	-2.61089	9682.16	494.974	10.5361	116374.
1150.00	4072.83	156.225	-2.61392	9681.50	496.536	10.5367	116356.
1160.00	4001.67	155.649	-2.61697	9680.84	498.093	10.5373	116337.
1170.00	3930.69	155.077	-2.62004	9680.18	499.643	10.5380	116318.
1180.00	3859.89	154.509	-2.62309	9679.52	501.188	10.5386	116299.
1190.00	3789.27	153.944	-2.62612	9678.84	502.728	10.5392	116280.
1200.00	3718.82	153.384	-2.62912	9678.17	504.261	10.5398	116262.
1210.00	3648.55	152.827	-2.63209	9677.48	505.790	10.5405	116243.
1220.00	3578.46	152.273	-2.63509	9676.79	507.313	10.5411	116224.
1230.00	3508.54	151.724	-2.63808	9676.09	508.830	10.5417	116206.
1240.00	3438.79	151.178	-2.64104	9675.39	510.342	10.5423	116187.
1250.00	3369.22	150.635	-2.64397	9674.68	511.849	10.5429	116169.
1260.00	3299.82	150.097	-2.64688	9673.97	513.350	10.5435	116150.
1270.00	3230.59	149.562	-2.64980	9673.23	514.845	10.5441	116131.
1280.00	3161.53	149.030	-2.65272	9672.50	516.336	10.5447	116113.
1290.00	3092.64	148.503	-2.65566	9671.77	517.821	10.5453	116094.
1300.00	3023.92	147.979	-2.65852	9671.03	519.301	10.5459	116076.
1310.00	2955.37	147.458	-2.66139	9670.28	520.775	10.5465	116057.
1320.00	2886.98	146.941	-2.66431	9669.52	522.245	10.5471	116039.
1330.00	2818.76	146.428	-2.66718	9668.76	523.709	10.5477	116021.
1340.00	2750.71	145.918	-2.67005	9667.99	525.168	10.5482	116002.
1350.00	2682.81	145.412	-2.67290	9667.21	526.623	10.5488	115984.
1360.00	2615.08	144.909	-2.67576	9666.43	528.072	10.5494	115966.
1370.00	2547.52	144.410	-2.67862	9665.64	529.516	10.5500	115947.
1380.00	2480.11	143.914	-2.68145	9664.86	530.955	10.5506	115929.
1390.00	2412.86	143.422	-2.68429	9664.05	532.389	10.5512	115911.
1400.00	2345.77	142.934	-2.68712	9663.25	533.819	10.5518	115892.
1410.00	2278.84	142.449	-2.68995	9662.44	535.243	10.5523	115874.
1420.00	2212.07	141.968	-2.69277	9661.61	536.663	10.5529	115856.
1430.00	2145.45	141.490	-2.69562	9660.79	538.078	10.5535	115838.

Table 18 Contd

TIME SEC	THRUST NT	LIFT NT	DRAG NT	LATITUDE DEG	LONGITUDE DEG	HEADING-R DEG	BANK DEG
940.000	88598.1	0.112368E 07	147436.	48.9637	-96.6954	193.501	0.0
950.000	88558.1	0.112352E 07	147407.	48.9490	-96.7008	193.544	0.0
960.000	88518.4	0.112337E 07	147377.	48.9343	-96.7061	193.587	0.0
970.000	88479.1	0.112321E 07	147348.	48.9197	-96.7115	193.630	0.0
980.000	88439.8	0.112306E 07	147319.	48.9052	-96.7168	193.673	0.0
990.000	88400.7	0.112291E 07	147290.	48.8906	-96.7222	193.716	0.0
1000.00	88362.1	0.112275E 07	147261.	48.8762	-96.7275	193.759	0.0
1010.00	88323.6	0.112260E 07	147232.	48.8618	-96.7329	193.801	0.0
1020.00	88285.4	0.112244E 07	147203.	48.8475	-96.7382	193.844	0.0
1030.00	88247.3	0.112229E 07	147174.	48.8333	-96.7435	193.886	0.0
1040.00	88209.6	0.112213E 07	147146.	48.8190	-96.7488	193.928	0.0
1050.00	88171.7	0.112198E 07	147117.	48.8049	-96.7541	193.971	0.0
1060.00	88134.3	0.112183E 07	147089.	48.7908	-96.7594	194.013	0.0
1070.00	88097.1	0.112167E 07	147060.	48.7767	-96.7647	194.054	0.0
1080.00	88060.1	0.112152E 07	147032.	48.7628	-96.7700	194.096	0.0
1090.00	88023.5	0.112137E 07	147004.	48.7488	-96.7753	194.138	0.0
1100.00	87986.9	0.112121E 07	146976.	48.7350	-96.7806	194.180	0.0
1110.00	87950.4	0.112106E 07	146948.	48.7211	-96.7859	194.221	0.0
1120.00	87914.3	0.112091E 07	146920.	48.7074	-96.7911	194.262	0.0
1130.00	87878.3	0.112076E 07	146893.	48.6937	-96.7964	194.304	0.0
1140.00	87842.3	0.112060E 07	146865.	48.6800	-96.8016	194.345	0.0
1150.00	87806.8	0.112045E 07	146837.	48.6664	-96.8069	194.386	0.0
1160.00	87771.6	0.112029E 07	146809.	48.6528	-96.8121	194.427	0.0
1170.00	87736.4	0.112014E 07	146782.	48.6394	-96.8174	194.468	0.0
1180.00	87701.1	0.111999E 07	146755.	48.6259	-96.8226	194.508	0.0
1190.00	87666.2	0.111984E 07	146728.	48.6125	-96.8279	194.549	0.0
1200.00	87631.4	0.111969E 07	146701.	48.5992	-96.8331	194.589	0.0
1210.00	87596.8	0.111953E 07	146673.	48.5859	-96.8382	194.630	0.0
1220.00	87562.2	0.111938E 07	146646.	48.5726	-96.8434	194.670	0.0
1230.00	87527.9	0.111923E 07	146620.	48.5594	-96.8486	194.710	0.0
1240.00	87493.6	0.111908E 07	146593.	48.5463	-96.8538	194.750	0.0
1250.00	87459.8	0.111893E 07	146567.	48.5332	-96.8590	194.790	0.0
1260.00	87425.9	0.111877E 07	146540.	48.5202	-96.8642	194.830	0.0
1270.00	87392.3	0.111862E 07	146513.	48.5071	-96.8694	194.869	0.0
1280.00	87358.7	0.111847E 07	146487.	48.4942	-96.8746	194.909	0.0
1290.00	87325.2	0.111832E 07	146461.	48.4813	-96.8797	194.949	0.0
1300.00	87291.9	0.111817E 07	146435.	48.4684	-96.8849	194.988	0.0
1310.00	87259.0	0.111801E 07	146408.	48.4557	-96.8900	195.027	0.0
1320.00	87225.9	0.111786E 07	146383.	48.4429	-96.8951	195.066	0.0
1330.00	87193.2	0.111771E 07	146357.	48.4302	-96.9003	195.105	0.0
1340.00	87160.3	0.111756E 07	146331.	48.4175	-96.9054	195.144	0.0
1350.00	87127.9	0.111741E 07	146305.	48.4049	-96.9105	195.183	0.0
1360.00	87095.3	0.111726E 07	146280.	48.3923	-96.9157	195.222	0.0
1370.00	87063.0	0.111711E 07	146254.	48.3798	-96.9208	195.260	0.0
1380.00	87030.9	0.111696E 07	146229.	48.3673	-96.9259	195.299	0.0
1390.00	86998.9	0.111681E 07	146204.	48.3549	-96.9310	195.337	0.0
1400.00	86966.9	0.111666E 07	146178.	48.3425	-96.9361	195.375	0.0
1410.00	86935.1	0.111651E 07	146153.	48.3301	-96.9411	195.413	0.0
1420.00	86903.5	0.111636E 07	146128.	48.3178	-96.9462	195.451	0.0
1430.00	86871.8	0.111621E 07	146103.	48.3056	-96.9513	195.489	0.0

Table 18 Contd

TIME SEC	ALTITUDE METRES	VELOCITY-R M/SEC	GAMMA-R DEG	DYNAMIC PRES PASCALS	RANGE KM	ALPHA DEG	WEIGHT KG
1440.00	2078.98	141.015	-2.69843	9659.95	539.489	10.5541	115820.
1450.00	2012.67	140.544	-2.70127	9659.12	540.894	10.5547	115801.
1460.00	1946.51	140.077	-2.70407	9658.27	542.295	10.5552	115783.
1470.00	1880.50	139.613	-2.70690	9657.42	543.691	10.5558	115765.
1480.00	1814.64	139.153	-2.70970	9656.57	545.083	10.5564	115747.
1490.00	1748.93	138.696	-2.71253	9655.70	546.470	10.5570	115729.
1500.00	1683.37	138.243	-2.71532	9654.83	547.853	10.5575	115711.
1510.00	1617.95	137.793	-2.71815	9653.96	549.231	10.5581	115693.
1520.00	1552.68	137.347	-2.72096	9653.09	550.604	10.5587	115675.
1530.00	1487.55	136.905	-2.72375	9652.20	551.974	10.5593	115657.
1540.00	1422.57	136.465	-2.72659	9651.30	553.338	10.5599	115639.
1550.00	1357.72	136.030	-2.72937	9650.39	554.699	10.5604	115621.
1560.00	1293.02	135.598	-2.73223	9649.48	556.055	10.5610	115603.
1570.00	1228.45	135.169	-2.73504	9648.58	557.407	10.5616	115585.
1580.00	1164.02	134.744	-2.73786	9647.67	558.754	10.5622	115567.
1590.00	1099.72	134.322	-2.74066	9646.74	560.097	10.5627	115549.
1600.00	1035.56	133.904	-2.74350	9645.81	561.437	10.5633	115531.
1610.00	971.539	133.490	-2.74630	9644.88	562.772	10.5639	115514.
1620.00	907.646	133.079	-2.74912	9643.93	564.103	10.5645	115496.
1630.00	843.883	132.672	-2.75196	9643.00	565.429	10.5651	115478.
1640.00	780.249	132.268	-2.75480	9642.04	566.752	10.5656	115460.
1650.00	716.743	131.868	-2.75760	9641.07	568.071	10.5662	115442.
1660.00	653.364	131.471	-2.76044	9640.11	569.386	10.5668	115425.
1670.00	590.109	131.078	-2.76331	9639.15	570.697	10.5674	115407.
1680.00	526.979	130.688	-2.76613	9638.16	572.004	10.5680	115389.
1690.00	463.971	130.302	-2.76901	9637.18	573.307	10.5686	115371.
1700.00	401.083	129.920	-2.77186	9636.20	574.606	10.5692	115354.
1710.00	338.316	129.541	-2.77470	9635.20	575.902	10.5697	115336.
1720.00	275.667	129.166	-2.77758	9634.20	577.194	10.5703	115318.
1730.00	213.133	128.795	-2.78044	9633.21	578.482	10.5709	115301.
1740.00	150.714	128.427	-2.78328	9632.19	579.766	10.5715	115283.
1750.00	88.4099	128.063	-2.78615	9631.17	581.047	10.5721	115265.
1760.00	26.2164	127.702	-2.78906	9630.15	582.324	10.5727	115248.
1764.22	0.119062E-02	127.550	-2.79027	9629.65	582.861	10.5729	115240.

Table 18 Contd

TIME SEC	THRUST NT	LIFT NT	DRAG NT	LATITUDE DEG	LONGITUDE DEG	HEADING-R DEG	BANK DEG
1440.00	86840.3	0.111606E 07	146078.	48.2934	-96.9564	195.527	0.0
1450.00	86808.8	0.111591E 07	146053.	48.2812	-96.9615	195.564	0.0
1460.00	86777.7	0.111576E 07	146029.	48.2691	-96.9665	195.602	0.0
1470.00	86746.4	0.111561E 07	146004.	48.2570	-96.9716	195.639	0.0
1480.00	86715.4	0.111546E 07	145980.	48.2449	-96.9766	195.677	0.0
1490.00	86684.4	0.111531E 07	145955.	48.2329	-96.9816	195.714	0.0
1500.00	86653.7	0.111516E 07	145931.	48.2210	-96.9866	195.751	0.0
1510.00	86622.7	0.111501E 07	145907.	48.2090	-96.9917	195.788	0.0
1520.00	86592.2	0.111486E 07	145882.	48.1972	-96.9967	195.825	0.0
1530.00	86561.6	0.111471E 07	145858.	48.1853	-97.0017	195.861	0.0
1540.00	86531.1	0.111456E 07	145834.	48.1735	-97.0068	195.898	0.0
1550.00	86500.9	0.111441E 07	145810.	48.1618	-97.0118	195.934	0.0
1560.00	86470.5	0.111426E 07	145786.	48.1500	-97.0168	195.971	0.0
1570.00	86440.3	0.111411E 07	145763.	48.1383	-97.0217	196.007	0.0
1580.00	86410.1	0.111396E 07	145739.	48.1267	-97.0267	196.043	0.0
1590.00	86380.2	0.111381E 07	145715.	48.1151	-97.0317	196.079	0.0
1600.00	86350.3	0.111366E 07	145692.	48.1035	-97.0367	196.115	0.0
1610.00	86320.5	0.111352E 07	145669.	48.0920	-97.0416	196.151	0.0
1620.00	86290.8	0.111337E 07	145645.	48.0805	-97.0466	196.187	0.0
1630.00	86260.9	0.111322E 07	145622.	48.0691	-97.0516	196.222	0.0
1640.00	86231.4	0.111307E 07	145599.	48.0576	-97.0565	196.258	0.0
1650.00	86201.9	0.111292E 07	145576.	48.0463	-97.0615	196.293	0.0
1660.00	86172.6	0.111277E 07	145553.	48.0349	-97.0664	196.328	0.0
1670.00	86143.1	0.111263E 07	145530.	48.0236	-97.0713	196.363	0.0
1680.00	86114.0	0.111248E 07	145507.	48.0123	-97.0762	196.398	0.0
1690.00	86084.7	0.111233E 07	145484.	48.0011	-97.0811	196.433	0.0
1700.00	86055.5	0.111218E 07	145462.	47.9899	-97.0860	196.468	0.0
1710.00	86026.6	0.111203E 07	145439.	47.9787	-97.0910	196.502	0.0
1720.00	85997.6	0.111188E 07	145417.	47.9676	-97.0959	196.537	0.0
1730.00	85968.6	0.111174E 07	145394.	47.9565	-97.1008	196.571	0.0
1740.00	85940.0	0.111159E 07	145372.	47.9454	-97.1057	196.606	0.0
1750.00	85911.3	0.111144E 07	145349.	47.9344	-97.1106	196.640	0.0
1760.00	85882.4	0.111129E 07	145327.	47.9234	-97.1154	196.674	0.0
1764.22	85870.9	0.111122E 07	145317.	47.9187	-97.1175	196.688	0.0

Table 18 Contd

booster slows down from supersonic to subsonic speeds. At a Mach number of 0.7 the engine throttles are adjusted to maintain a glide slope to arrive over the launch site at M = 0.4 at an altitude for final approach to touchdown.

This procedure significantly reduces the flyback fuel burned to about 2585 kg (5700 lb) per booster. A footprint of the flyback trajectory in terms of latitude and longitude positions is presented in Figure 42 .

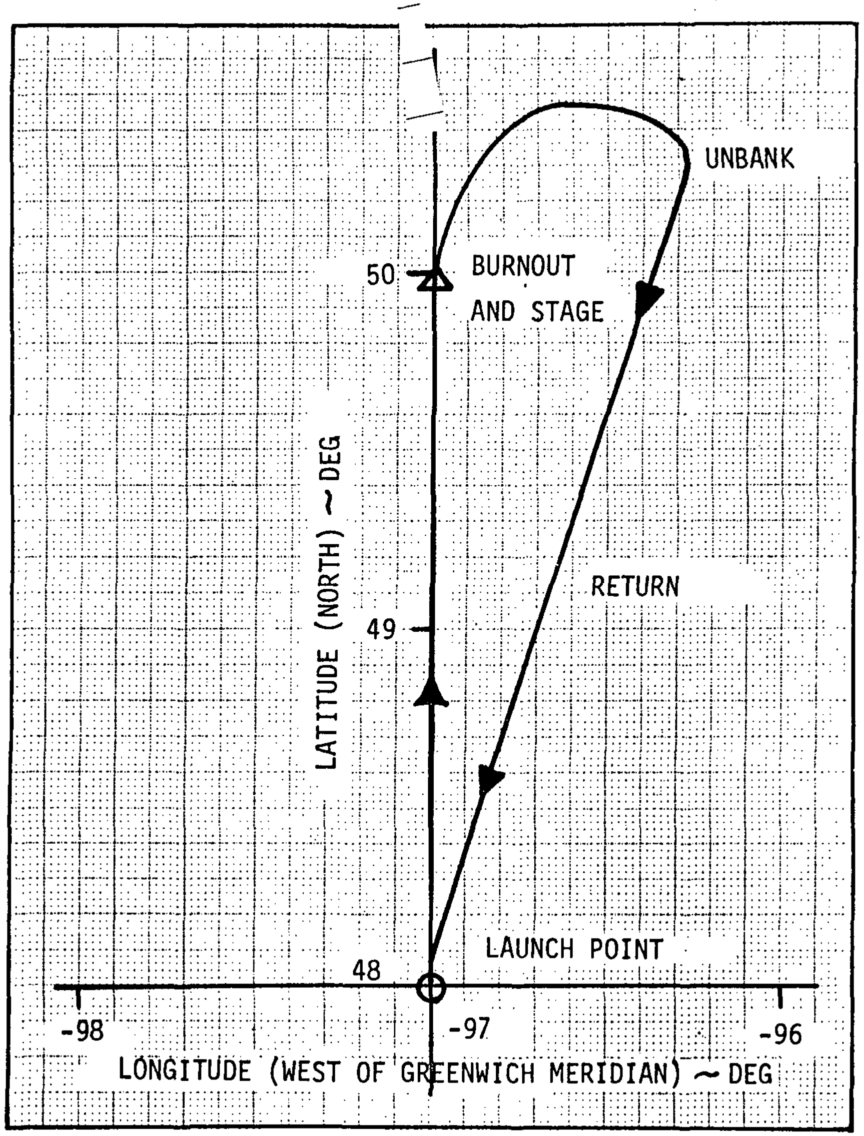
Booster Fuel

The component buildup to booster fuel requirements are as follows:

(Per Turbojet Booster)

Phase	kg	lb
Takeoff (JP-4) Fuel	3471	(7653)
Boost to Staging Fuel	85448	(188395)
Flyback Fuel	2583	(5696)
Reserve Allowance Fuel	1952	(4304)
* Total	93455	(206048)

* Which is significantly less than tentative estimate of 111,155 kg (245,055 lb) used in Table 2 Booster Mass Properties. This updated fuel requirement is used in the following final performance.



NOTE:

- AFTER STAGING IDLE THRUST AND BANK 45 DEG
- WHEN MACH DEC TO 0.7 INCR THROTTLE TO MAINTAIN SPEED

Figure 42 Footprint FLYBACK - TURBOJET BOOSTER

Performance

The Mass Properties for the final baseline configuration shown on Table 2 did not have the finalized fuel requirements for the turbojet boosters as indicated in above paragraph. By taking into account these reduced requirements and through weight scaling relationships, the booster(s) inert weight can be reduced about (3000 lb) per booster. This also has an effect of reducing GLOW from 1.22 X 10^6 kg (2.69 X 10^6 lb) to 1.17 X 10^6 kg (2.579 X 10^6 lb). The reduced GLOW was used for the final trajectory characteristics presented in Table 21 .

Offset Range

A preliminary assessment of offset range capability indicated that for every (1) degree of latitude range change 24,946 kg (55,000 lb) of JP-4 is burned at subsonic cruise speeds and for a GLOW of 1.18 X 10^6 kg (2.6 X 10^6 lb). This offset range of 111 km (60 n.mi.) is also equivalent to a (1) degree plane change of orbit inclination. The extra fuel required could possibly be carried by strap-on body or wing tip tanks on the turbojet boosters. To match this capability for the orbiter in terms of a (1) degree plane change in low earth orbit a ΔV = 138 m/sec (453 FPS) or 3719 kg (8200 lb) of extra orbiter propellant would be required. Strap-on propellant tanks on the orbiter would be a more difficult design task than that required for the boosters.

APPENDIX II - AERODYNAMICS

Input aerodynamic values to the boost trajectory computer program are tabulated in the following tables for both the mated (twin boosters/orbiter) configuration and the orbiter only. The mated values covers a Mach range from 0.70 to 3.2 and the orbiter from M = 3.0 to 6.0. Individually tabulated are angle of attack, minimum drag coefficient, drag due to lift coefficient, total drag coefficient and lift coefficient. Mated values of C_{DO} and subsonic C_L were based upon NASA Langley estimates. Other values were established by various techniques including: wind tunnel test data of Boeing ALRS-205, single stage to orbit configuration, linearized and modified shock expansion theory, and DATCOM sources. The effects of the mated configuration at supersonic speeds on C_L and dC_D/dC_L^2 were approximated by assuming that the effective reference area was equal to the orbiter reference area plus (2/3) of the total booster(s) area. Since most of the boost phase for the mated configuration is performed at relatively low angles of attack (2 to 5 degrees) any discrepancies in the estimated values should have only a small effect on the overall flight profile and injected weight of the system configuration. Due to the intricacies of the mated configuration wind tunnel test data is required to establish updated values with any degree of confidence. Such tests are planned by NASA Langley and the results should be available in the near future.

Table 21 Aerodynamics - (Mated Configuration)

AERODYNAMICS TURBOJET BOOSTER SYSTEMS

MATED CONFIG.

MACH	ALPHA	CDO	CDLIFT	CDTOT	CL
0.70	0.0	.0371	.0000	.0371	0.000
0.70	5.0	.0371	.0199	.0570	0.315
0.70	10.0	.0371	.0795	.1166	0.631
0.70	15.0	.0371	.1789	.2159	0.946
0.70	20.0	.0371	.3179	.3550	1.261
0.70	25.0	.0371	.4967	.5338	1.576
1.20	0.0	.0850	.0000	.0850	0.000
1.20	5.0	.0850	.0326	.1176	0.341
1.20	10.0	.0850	.1302	.2152	0.682
1.20	15.0	.0850	.2928	.3778	1.023
1.20	20.0	.0850	.5204	.6054	1.364
1.20	25.0	.0850	.8131	.8981	1.705
1.70	0.0	.0850	.0000	.0850	0.000
1.70	5.0	.0850	.0306	.1156	0.265
1.70	10.0	.0850	.1224	.2074	0.531
1.70	15.0	.0850	.2752	.3602	0.796
1.70	20.0	.0850	.4892	.5742	1.061
1.70	25.0	.0850	.7643	.8493	1.326
2.20	0.0	.0715	.0000	.0715	0.000
2.20	5.0	.0715	.0280	.0995	0.222
2.20	10.0	.0715	.1118	.1833	0.443
2.20	15.0	.0715	.2514	.3229	0.665
2.20	20.0	.0715	.4469	.5184	0.886
2.20	25.0	.0715	.6982	.7697	1.107
2.70	0.0	.0582	.0000	.0582	0.000
2.70	5.0	.0582	.0243	.0825	0.188
2.70	10.0	.0582	.0970	.1552	0.377
2.70	15.0	.0582	.2182	.2764	0.565
2.70	20.0	.0582	.3878	.4460	0.753
2.70	25.0	.0582	.6059	.6640	0.941
3.20	0.0	.0449	.0000	.0449	0.000
3.20	5.0	.0449	.0201	.0650	0.161
3.20	10.0	.0449	.0805	.1254	0.321
3.20	15.0	.0449	.1810	.2259	0.482
3.20	20.0	.0449	.3217	.3666	0.642
3.20	25.0	.0449	.5027	.5475	0.803

AERODYNAMICS TURBOJET BOOSTER SYSTEMS

ORBITER CONFIG

MACH	ALPHA	CDO	CDLIFT	CDTOT	CL
3.00	0.0	.0407	.0000	.0407	0.000
3.00	5.0	.0407	.0103	.0510	0.118
3.00	10.0	.0407	.0413	.0820	0.236
3.00	15.0	.0407	.0929	.1336	0.353
3.00	20.0	.0407	.1652	.2059	0.471
3.00	25.0	.0407	.2581	.2988	0.589
4.00	0.0	.0363	.0000	.0363	0.000
4.00	5.0	.0363	.0074	.0437	0.085
4.00	10.0	.0363	.0300	.0663	0.170
4.00	15.0	.0363	.0683	.1046	0.255
4.00	20.0	.0363	.1238	.1600	0.340
4.00	25.0	.0363	.1982	.2345	0.425
5.00	0.0	.0349	.0000	.0349	0.000
5.00	5.0	.0349	.0051	.0401	0.058
5.00	10.0	.0349	.0206	.0555	0.117
5.00	15.0	.0349	.0469	.0819	0.175
5.00	20.0	.0349	.0850	.1199	0.233
5.00	25.0	.0349	.1361	.1710	0.292
6.00	0.0	.0348	.0000	.0348	0.000
6.00	5.0	.0348	.0031	.0379	0.036
6.00	10.0	.0348	.0125	.0473	0.071
6.00	15.0	.0348	.0286	.0634	0.107
6.00	20.0	.0348	.0517	.0865	0.142
6.00	25.0	.0348	.0828	.1176	0.178

MACH	ALPHA	CDO	CDLIFT	CDTOT	CL
7.00	0.0	.0348	.0000	.0348	0.000
7.00	5.0	.0348	.0013	.0361	0.015
7.00	10.0	.0348	.0054	.0402	0.031
7.00	15.0	.0348	.0123	.0471	0.046
7.00	20.0	.0348	.0223	.0571	0.061
7.00	25.0	.0348	.0357	.0705	0.077
8.00	0.0	.0348	%-.257264E-9	.0348	-.000
8.00	5.0	.0348	%-.258436E-3	.0345	-.003
8.00	10.0	.0348	%-.104068E-2	.0338	-.006
8.00	15.0	.0348	%-.237138E-2	.0324	-.009
8.00	20.0	.0348	%-.429422E-2	.0305	-.012
8.00	25.0	.0348	%-.687638E-2	.0279	-.015
9.00	0.0	.0348	%-.171776E-8	.0348	-.000
9.00	5.0	.0348	%-.172559E-2	.0331	-.020
9.00	10.0	.0348	%-.69487E-2	.0279	-.039
9.00	15.0	.0348	%-.158338E-1	.0190	-.059
9.00	20.0	.0348	%-.286727E-1	.0061	-.079

Table 21 Contd Aerodynamics - (Orbiter)

APPENDIX III - TURBOJET PROPULSION

This section presents more detailed information on the turbojet engine performance used with the final configuration. Included are thrust, fuel flow, C_T and SFC along the boost trajectory (See Table 22) along with other engine, inlet and nozzle characteristics as presented in Figures 43 to 52 . Information is also given on engine weight, scaling laws and a procedure on how they are used to size the final engine.

Base Engine and Scaling

The base engine is designed at sea level static conditions at a maximum airflow of 181 kg/sec (400 lb/sec). The uninstalled static thrust is 227952 N (51246 lb) (or 204497 N (45973 lb) installed). The weights and dimensions are given in Table 22 and Figure 43 . Engine performance for other size engines of the same family as that of the base engine may be obtained by use of the scale factors for thrust, weight and dimensions as presented in Figure 44.

Inlet Weight Scaling

Figures 53 and 54 present inlet weight scaling criteria for a mixed compression inlet. Inlet weight is shown as a function of inlet diameter and dynamic pressure for length to diameter ratio of 4.91. For inlets longer than this ratio Figure 55 shows the additional inlet duct length as a function of diameter.

Table 22 Base Turbojet Engine Characteristics Along Nominal Flight Trajectory

MACH.	ALTITUDE m	(ft)	THRUST N	(lb)	WEIGHT FLOW RATE kg/hr	(lb/hr)	Sfc 1/hour	C_T
0	0	(0)	515871	(115973)	36776	(81078)	1.764	-
.36	6.1	(20)	528615	(118838)	41766	(92079)	1.885	17.38
.49	89.3	(293)	225946	(50795)	44311	(97690)	1.923	9.86
.80	522.1	(1713)	256185	(57593)	52829	(116470)	2.022	4.42
1.07	1301.8	(4271)	293274	(65931)	62600	(138011)	2.086	3.11
1.11	2080	(6824)	281286	(63218)	59819	(131879)	2.086	3.05
1.21	3808	(12494)	256492	(57662)	54313	(119742)	2.077	2.92
1.33	4834	(15861)	250562	(56329)	54946	(121137)	2.077	2.79
1.43	6259	(20537)	247422	(55623)	51937	(114503)	2.059	2.80
1.55	7287	(23909)	245473	(55185)	50825	(112052)	2.030	2.74
1.69	8425	(27643)	237889	(53480)	49677	(109521)	2.029	2.65
1.87	10322	(33865)	212868	(47855)	44107	(97241)	2.032	2.53
2.08	11518	(37789)	217387	(48871)	46273	(102016)	2.087	2.53
2.30	12607	(41361)	206783	(46487)	45466	(100236)	2.156	2.33
2.54	14240	(46718)	177207	(39838)	40504	(89298)	2.242	2.12
2.79	15064	(49424)	170219	(38267)	40595	(89497)	2.339	1.92
2.83	20806	(68261)	67981	(15283)	16534	(36453)	2.385	1.83
2.87	15527	(50942)	161714	(36355)	39164	(86344)	2.374	1.85
2.87	19523	(64053)	85467	(19214)	20719	(45979)	2.393	1.83
2.90	17873	(58641)	112205	(25225)	27471	(60565)	2.401	1.82
2.91	16481	(54074)	141532	(31818)	34638	(76364)	2.400	1.83

(base engine)

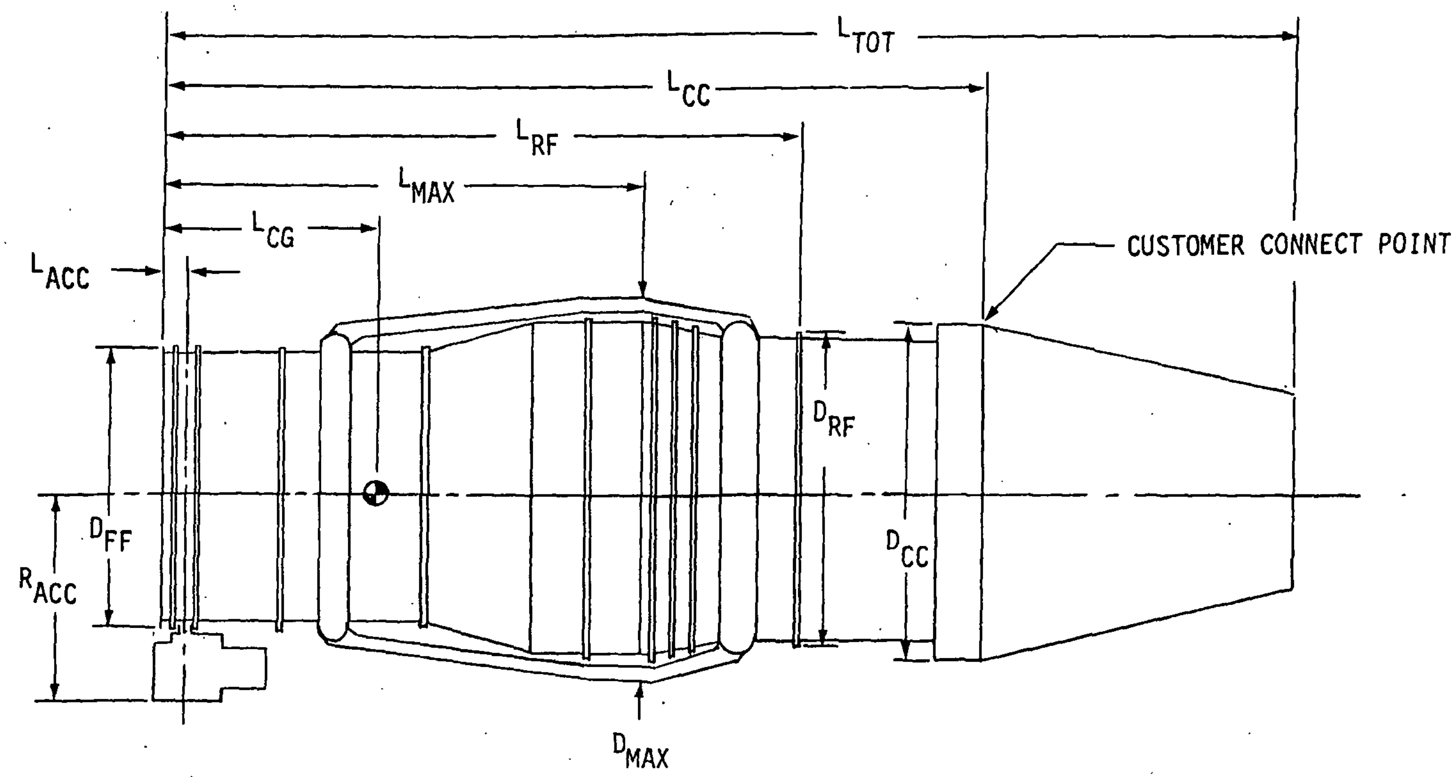
SLS Uninstalled Thrust = 227952 N (51246 lb)
Inlet Ref. Capture Area = 1.359 m^2 (14.634 ft^2)
Base Engine Weight = 2587 kg (5703 lb) (with Standard Circular Exit Nozzle)

m (inches)

D_{FF}=1.247(49.1) D_{CC}=1.259(49.6)
D_{MAX} 1.376(54.2) L_{CC}=3.573(140.7)
L_{MAX} 2.26(89) L_{CG}=1.69 (66.6)
D_{RF} 1.158(45.6) L_{ACC}= .076 (3.0)
L_{RF} 32.84(1293) R_{ACC}= .762 (30)

FIGURE 43 ENGINE SCHEMATIC

VARIABLE GEOMETRY TURBINE AFTERBURNING TURBOJET



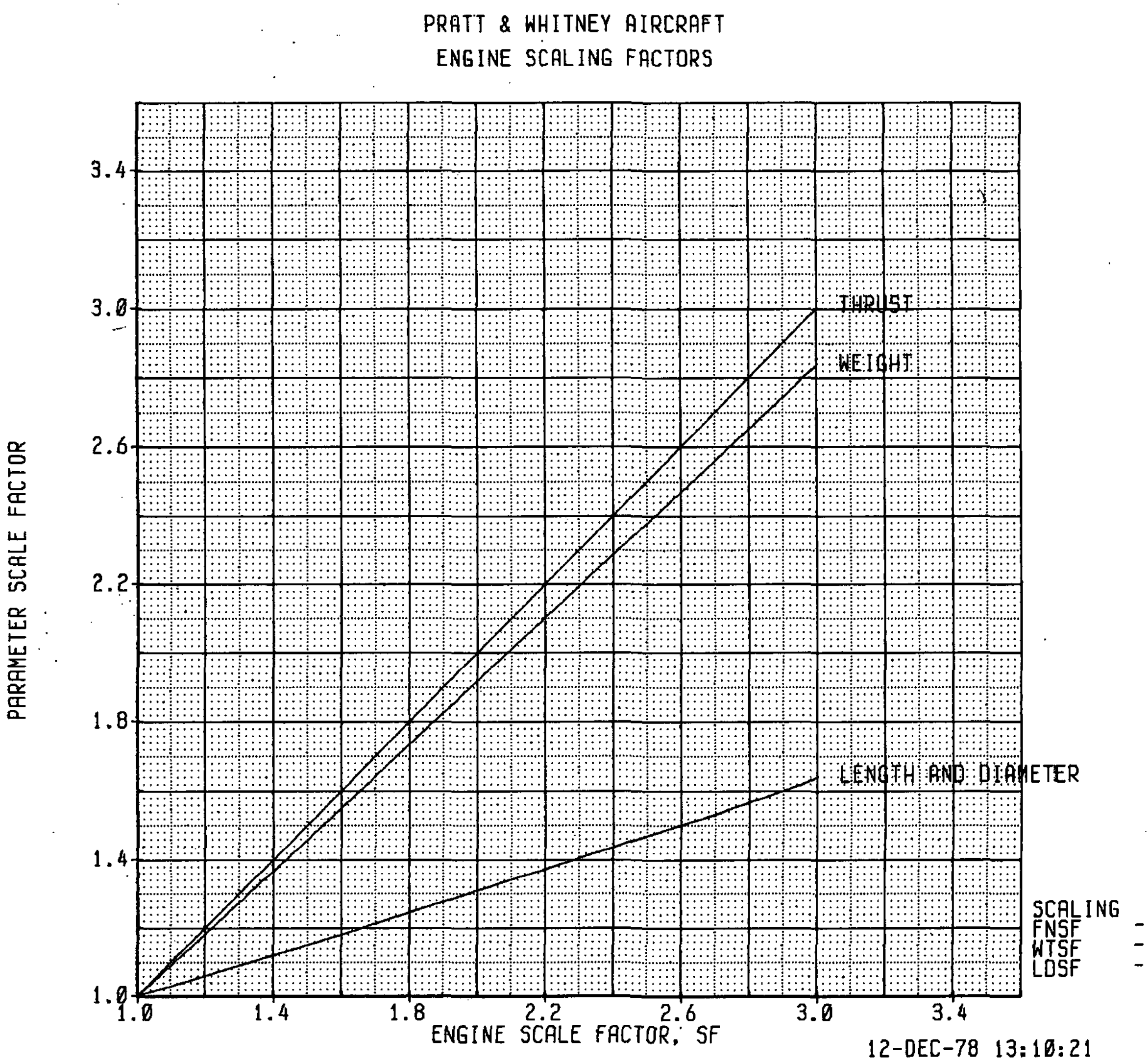


Figure 44 Advanced Turbojet Engine Scaling Factors

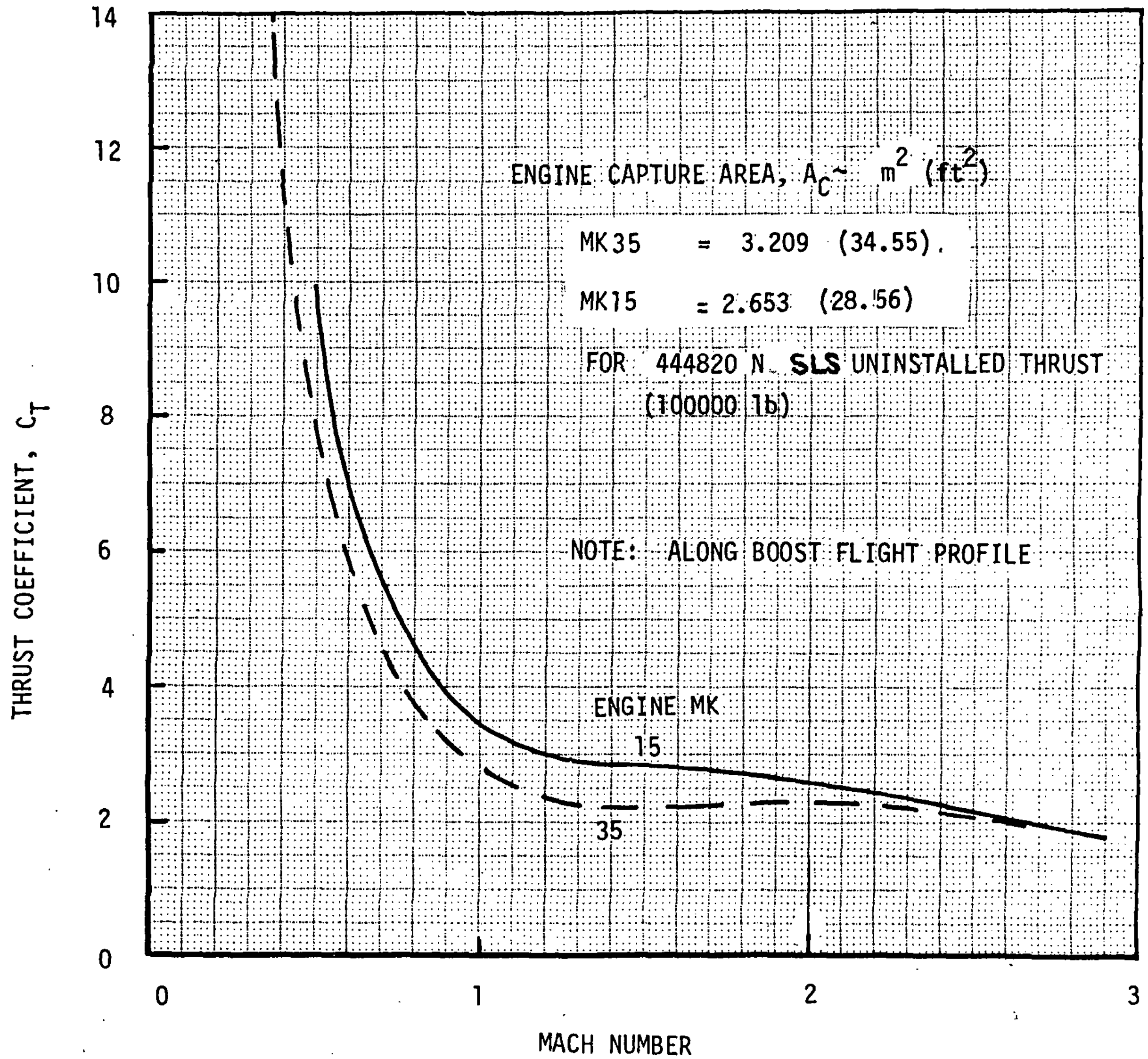
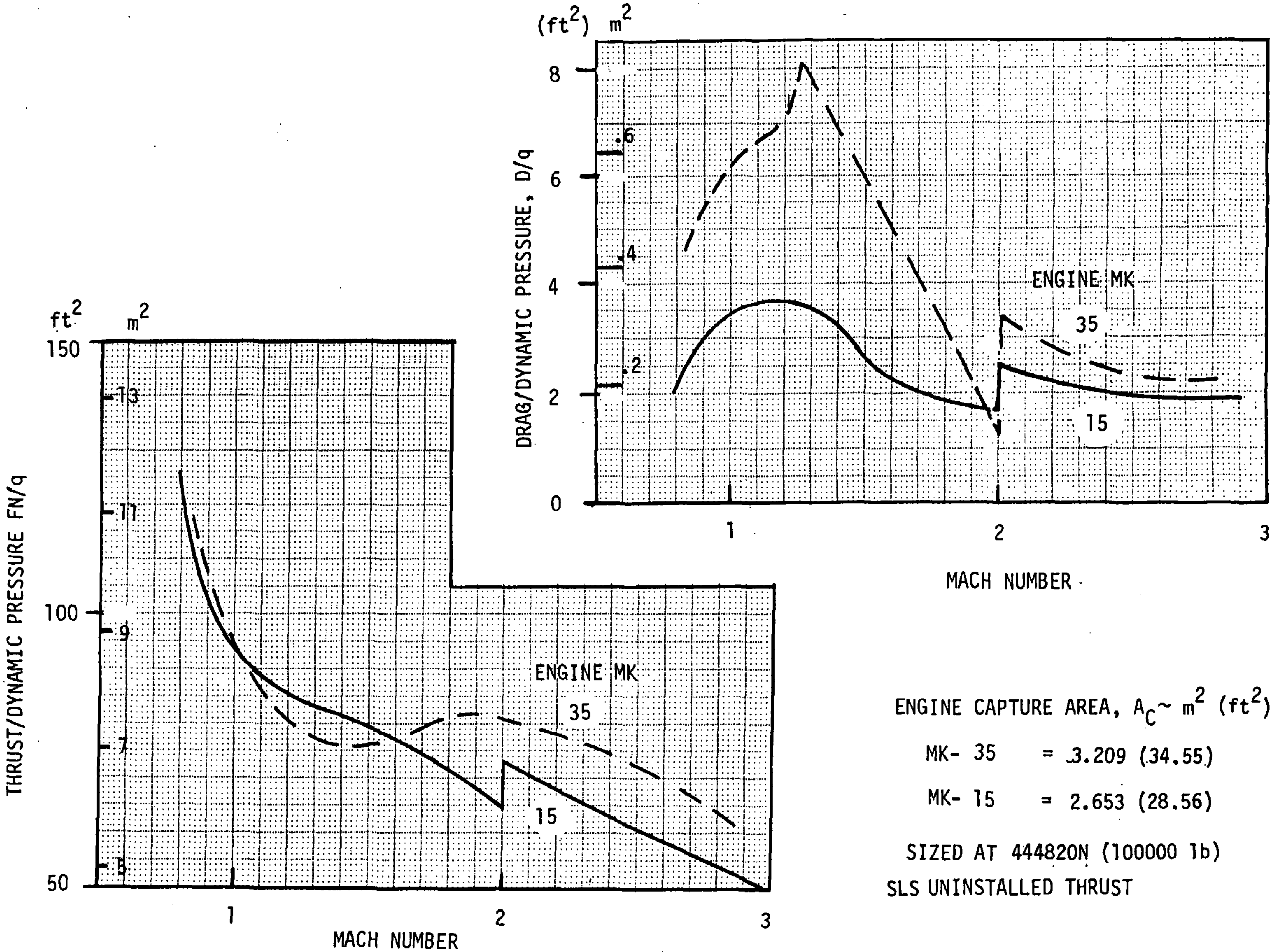


Figure 45 Turbojet Engine Thrust Coefficient Characteristics



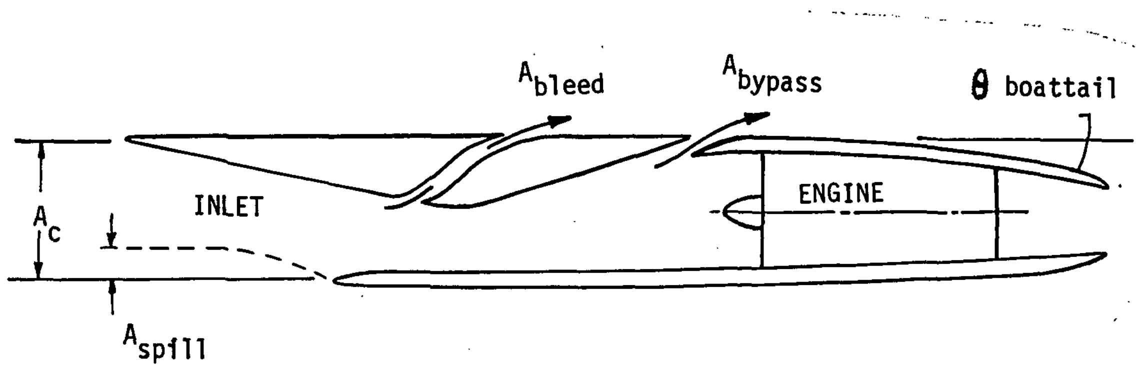
ENGINE CAPTURE AREA, $A_C \sim m^2\ (ft^2)$

MK- 35 = 3.209 (34.55)

MK- 15 = 2.653 (28.56)

SIZED AT 444820N (100000 lb)
SLS UNINSTALLED THRUST

Figure 46 Turbojet Engine FN/q And D/q Characteristics



- A_c = Capture Area
- A_{spill} = Spillage
- A_{bleed} = Bleed Flow
- A_{bypass} = Bypass Air Flow
- θ boattail = Nozzle Boattail Angle

Figure 47 ENGINE INTERNAL FLOW AND DRAG NOMENCLATURE

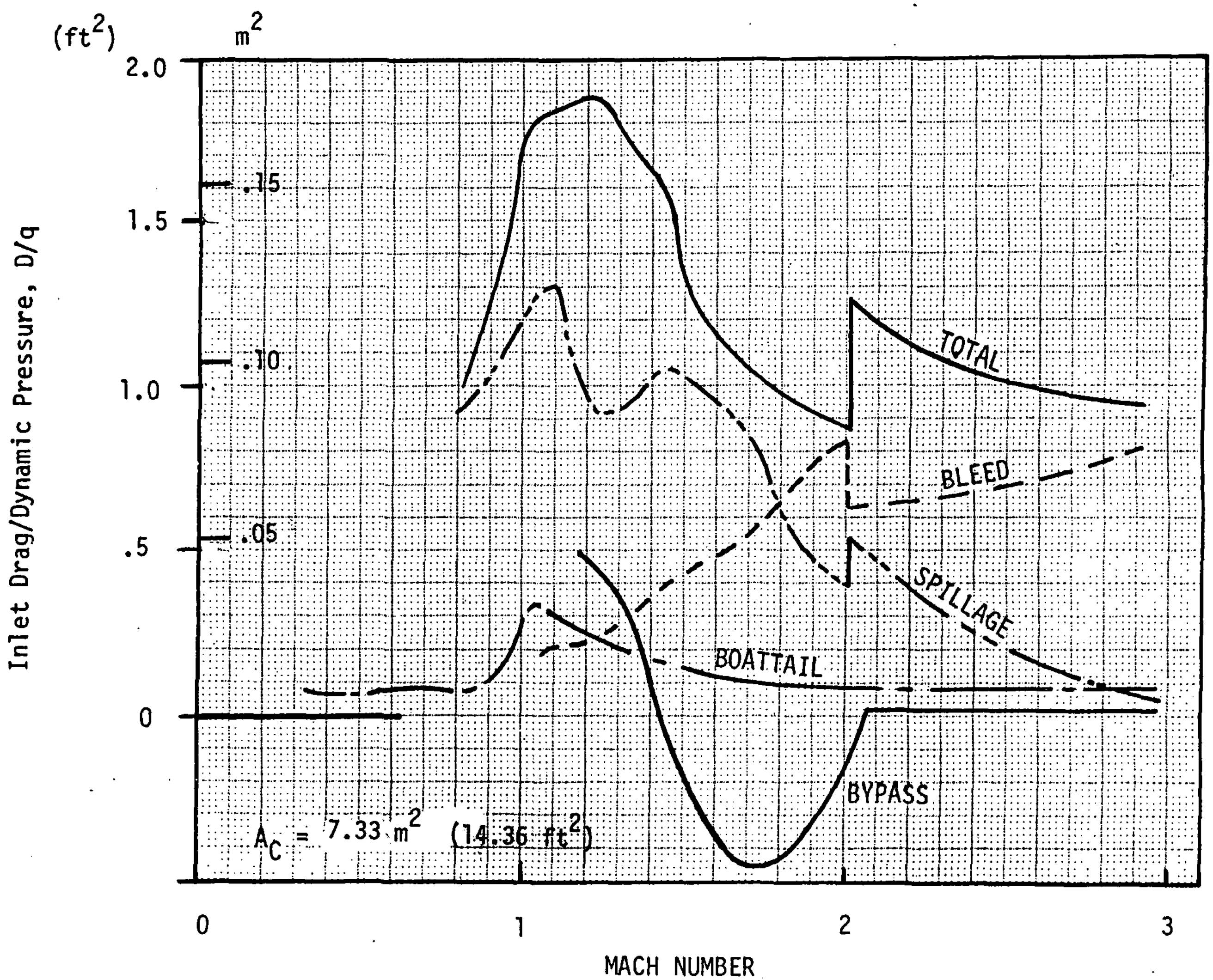


Figure 48 Typical Buildup of Turbojet Inlet Drag Losses

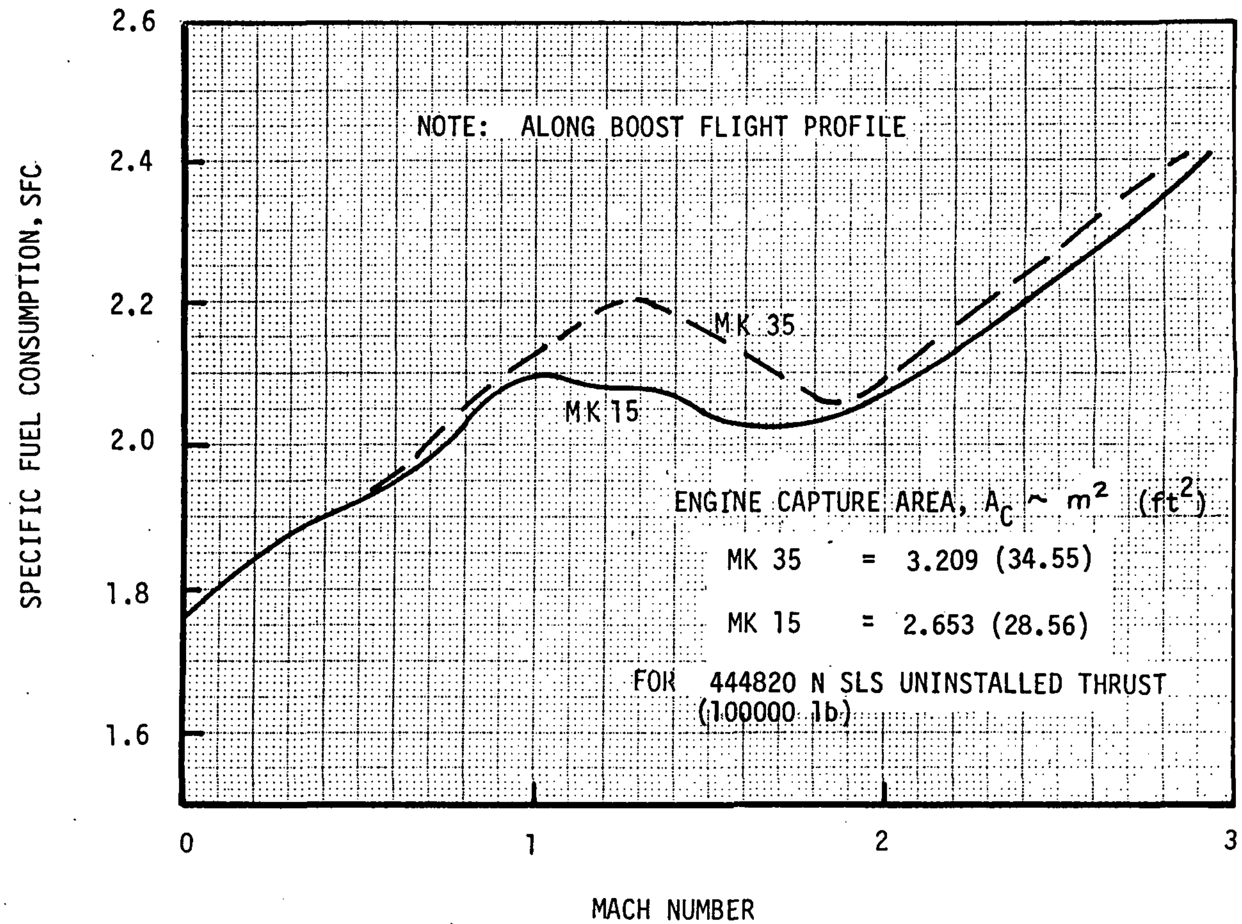


Figure 49 Turbojet Engine SFC Characteristics

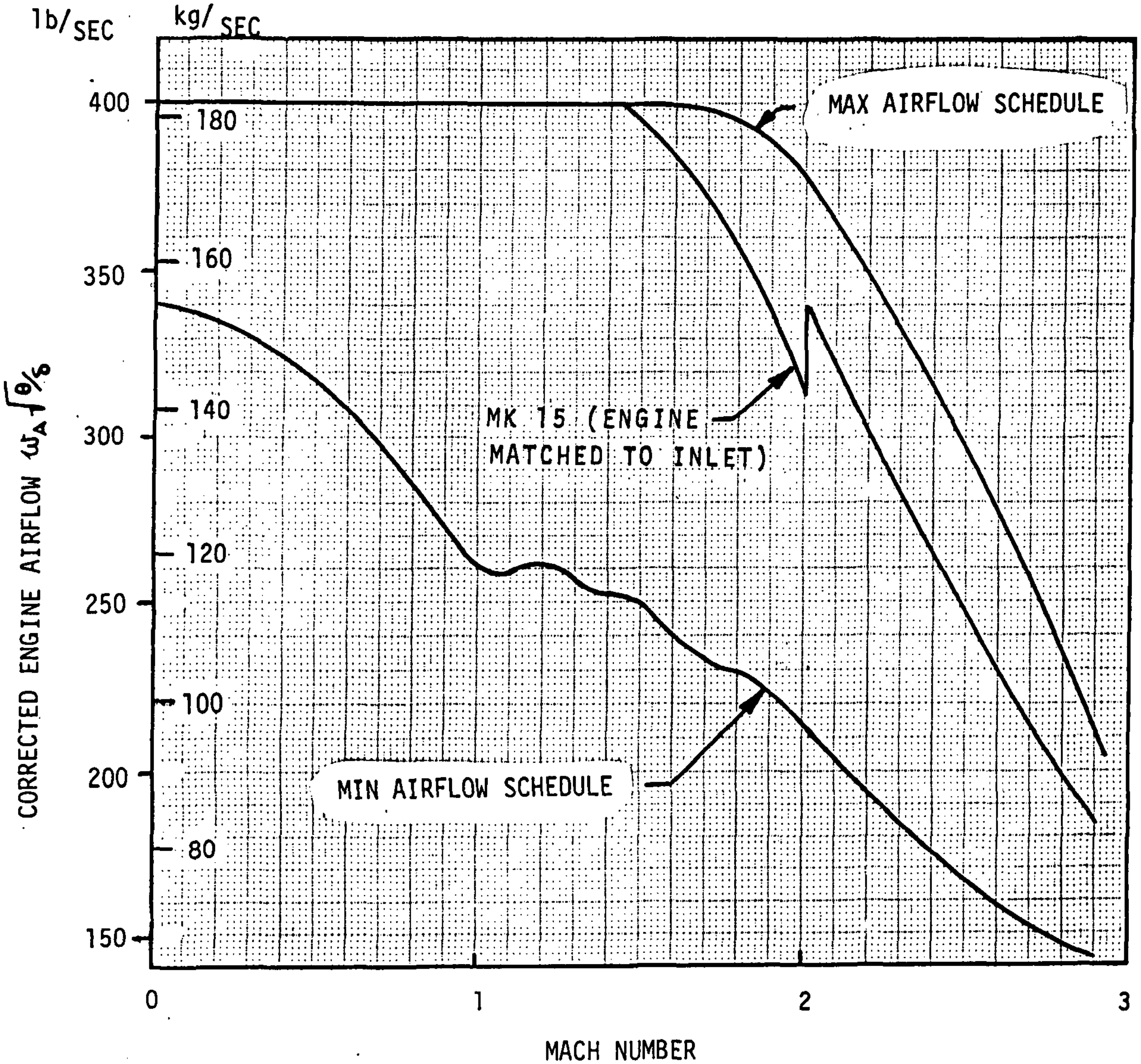
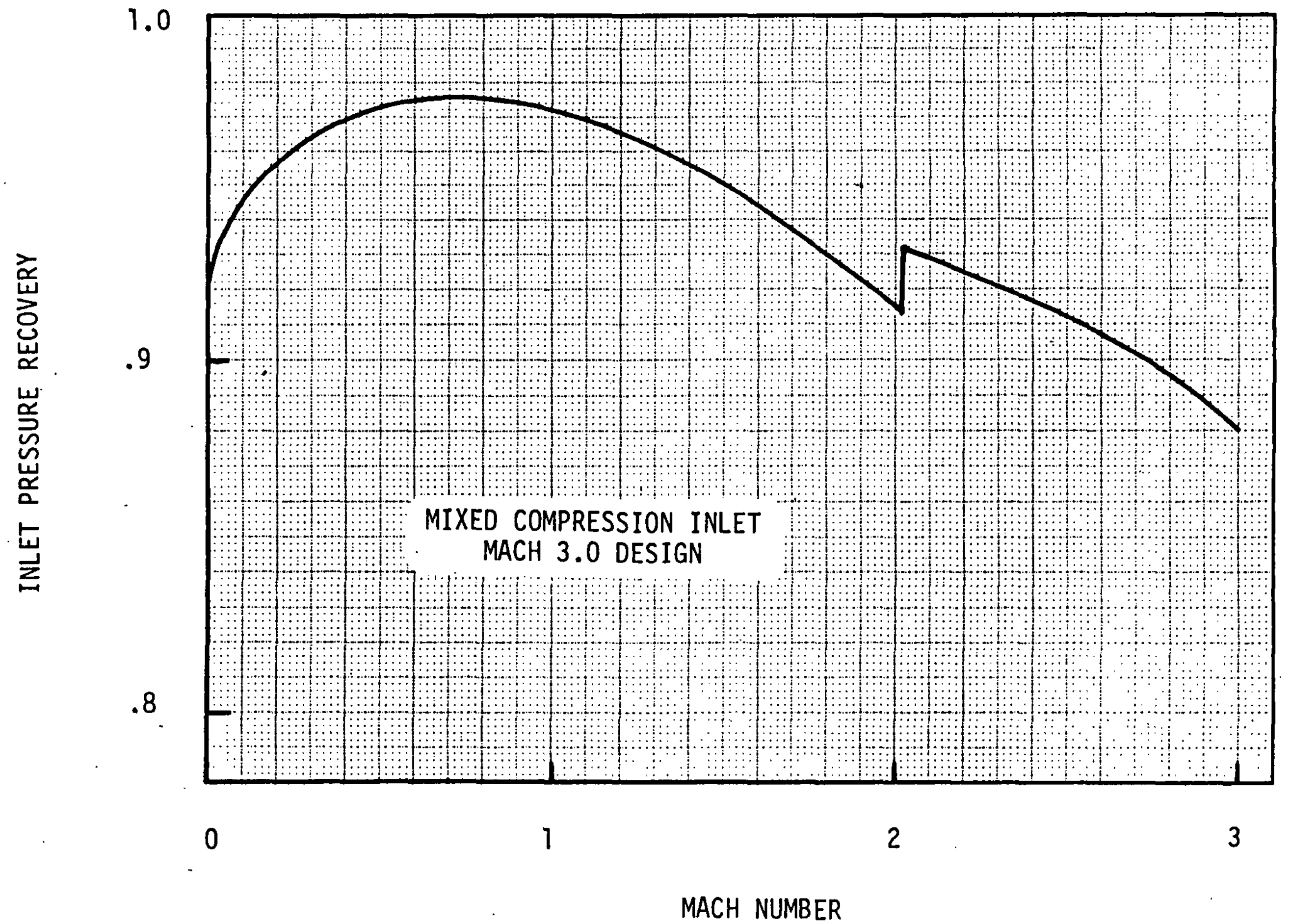


Figure 50. Turbojet Engine Airflow Schedule



REF: AFFDL-TR-72-147 - VOL. 4

Figure 51 MATCHED INLET RECOVERY VS LOCAL MACH NUMBER

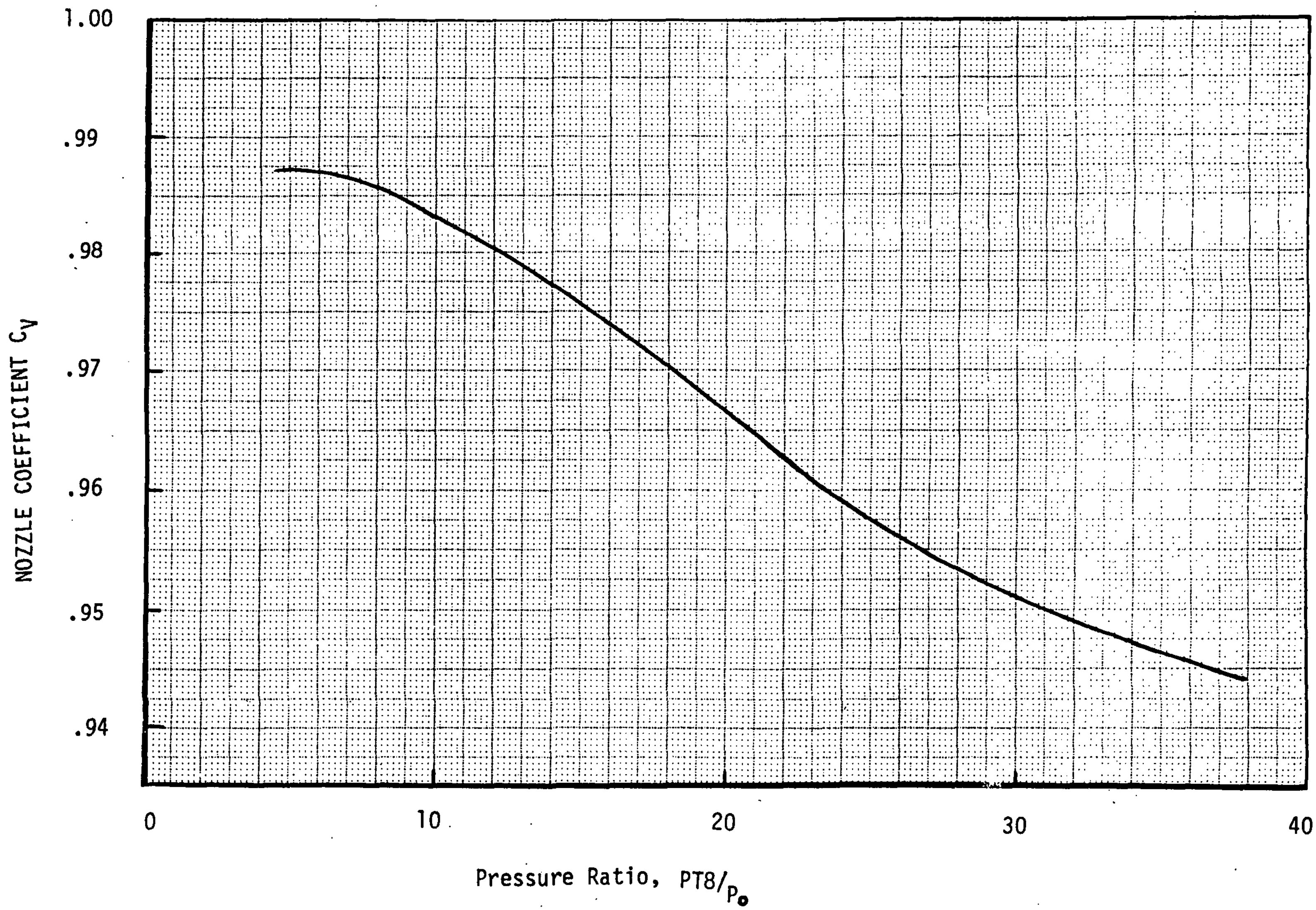


Figure 52 Turbojet Engine Nozzle Coefficient

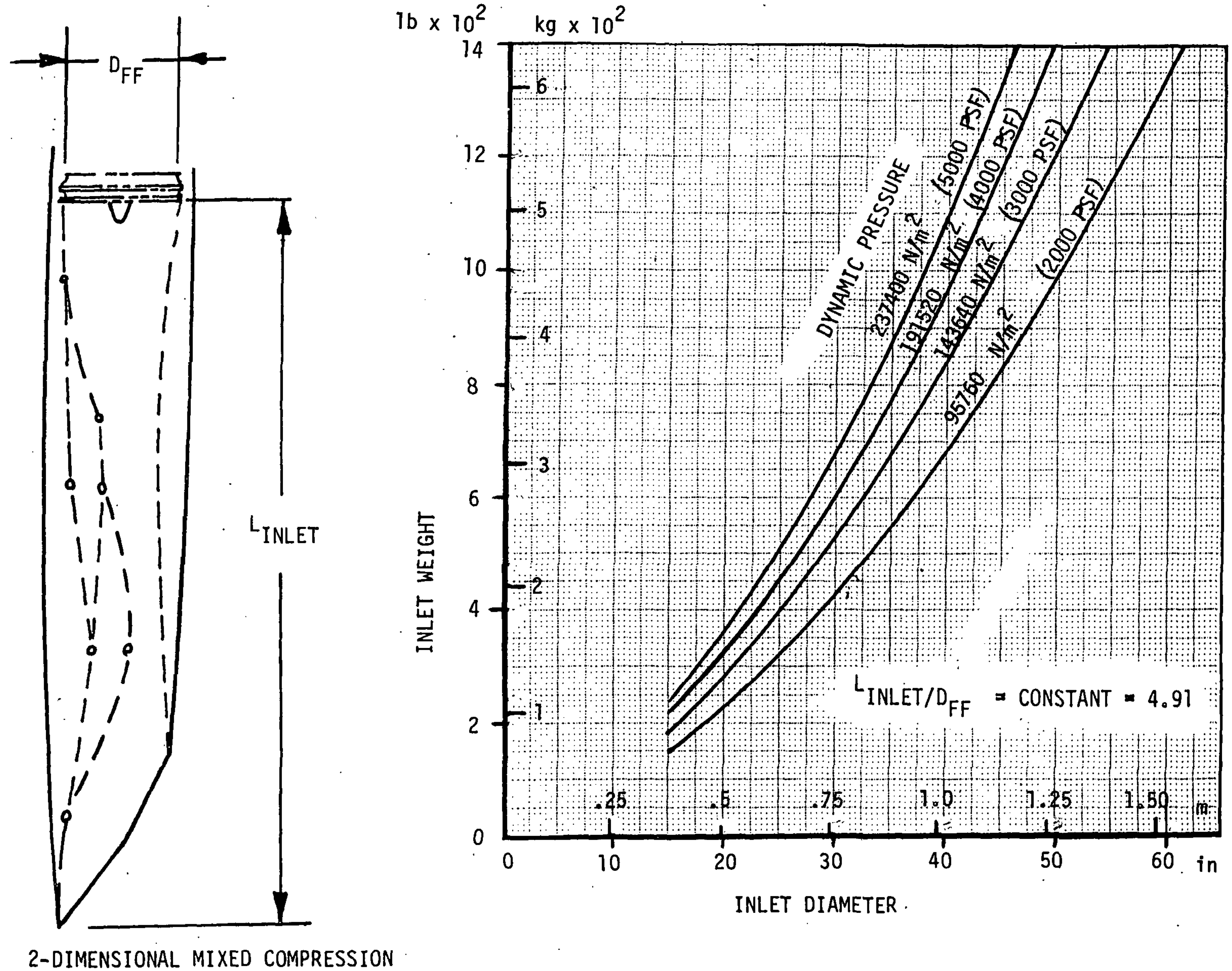


 Figure 53 2-Dimensional Mixed Compression Inlet Weight

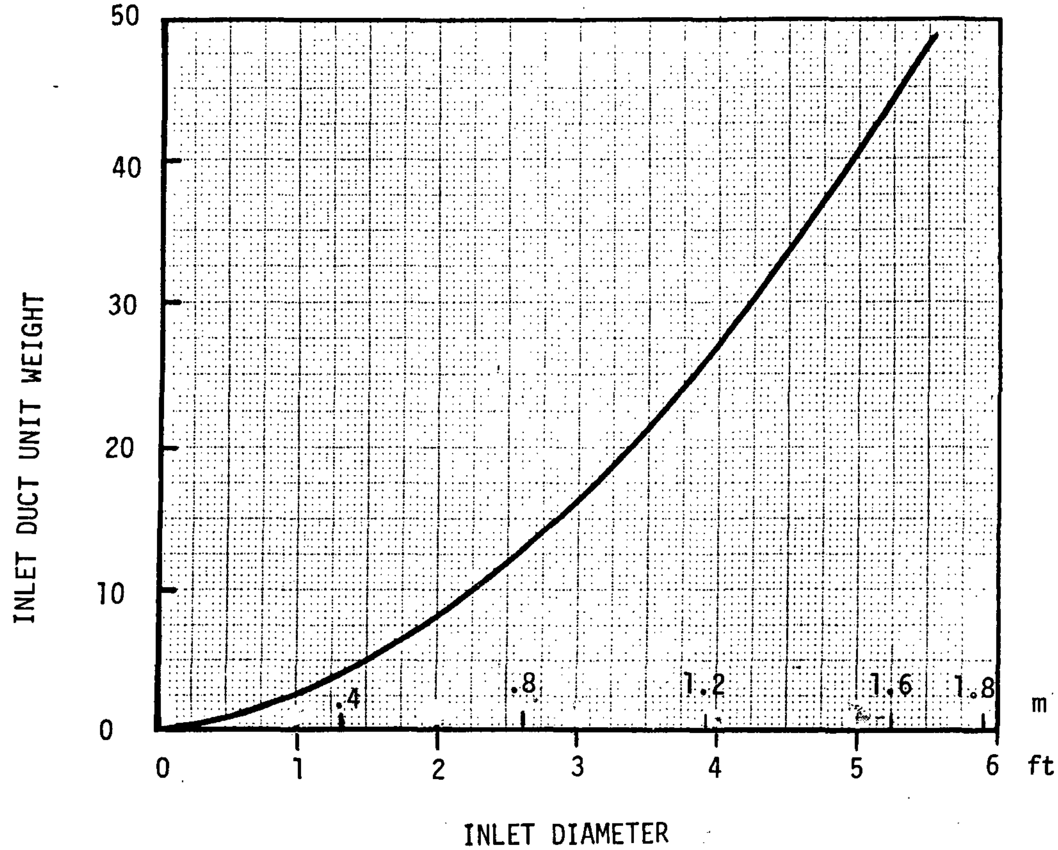


Figure 54 Inlet Duct Unit Weight

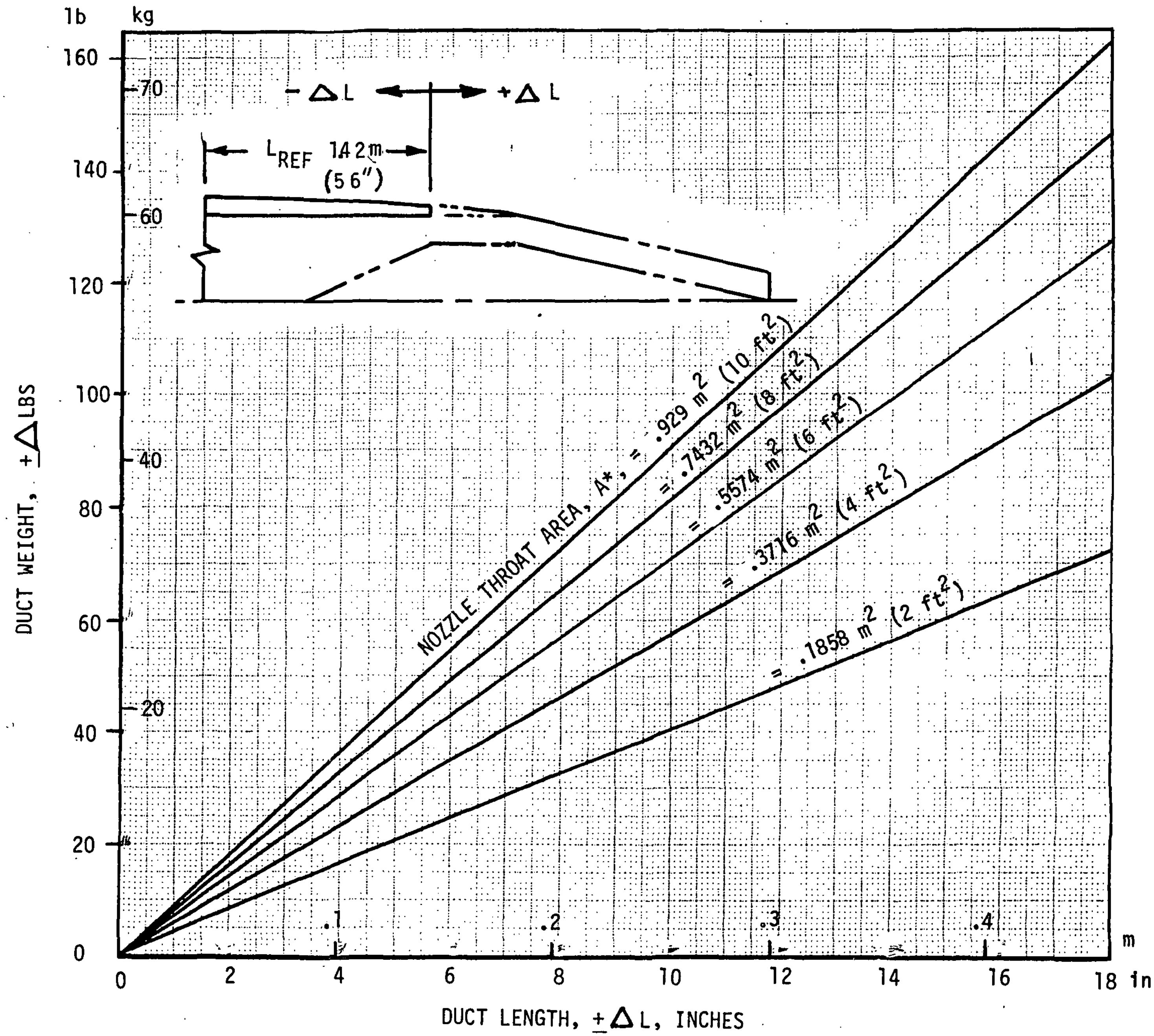


Figure 55 Turbojet Duct Weight

Exit Nozzle Weight Scaling

Nozzle weight scaling is given in Figure 56 for a fixed cowl design two-dimensional nozzle with and without vectoring Figure 56 shows the basic nozzle weight with vectoring for a 1.42m (56 inch) long nozzle cowl. The weight associated with any additional duct length over 1.42 m (56 inches) is determined with the aid of Figure 55.

Method for Turbojet Engine Sizing

The following procedure with example illustrates a method for sizing the turbojet engine:

- Determine base turbojet engine characteristics along nominal flight trajectory using advanced engine technology program.
- Required inputs are aerodynamics, trajectory, weight and reference areas.
- Equate thrust required to drag and weight component with a margin at transonic speed.
- Determine required inlet capture area and scale factor for engine
- Using scale factor size turbojet engine diameter, length, weight and SLS thrust size per engine.

Example - Given:

$W = 1.17 \times 10^6$ kg (2.57×10^6 lb)

$S_{REF} = 881.4\ m^2$ ($9484\ ft^2$)

Trajectory at $M = 1.22$ $h = 3810$ m (12,500 ft)

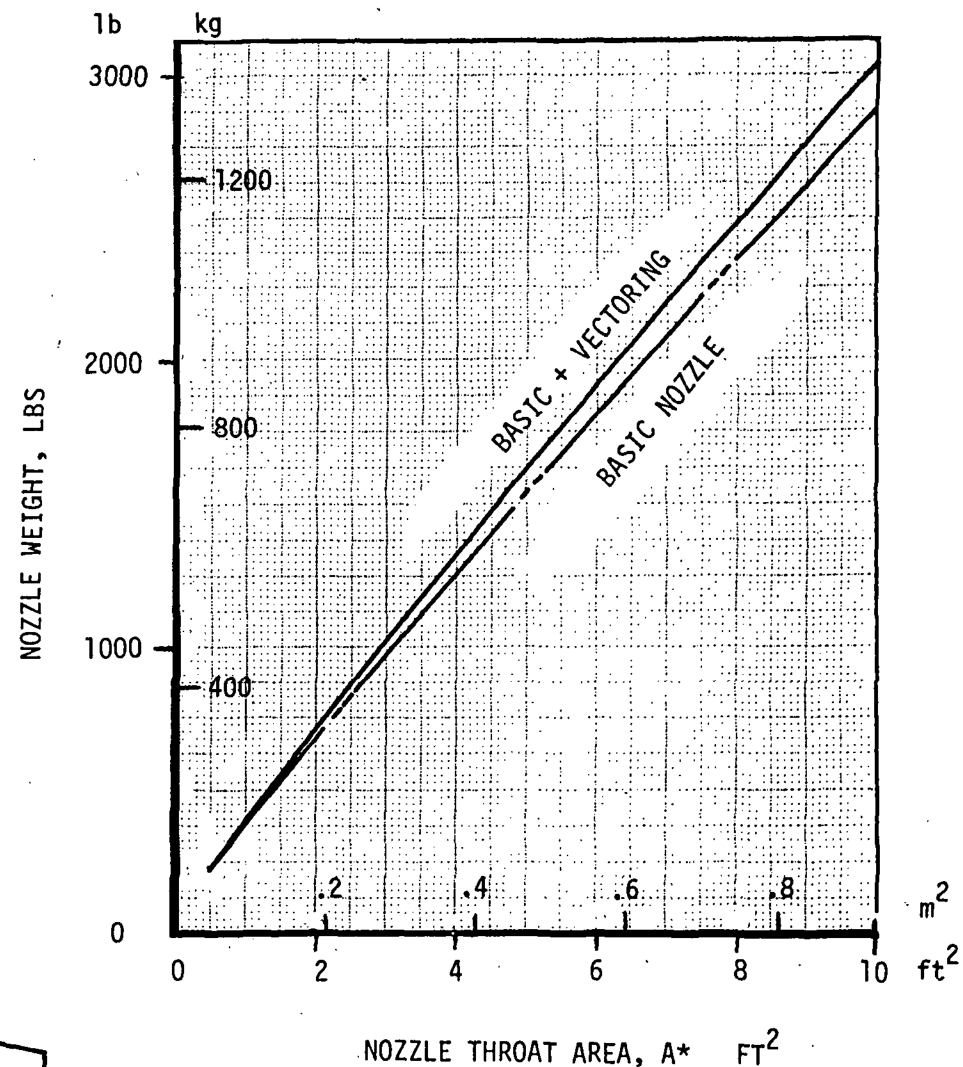
$q = 63935$ Pa (1308 PSF), $\alpha = 4.5$ Deg.

Drag Coeff, $C_{DO} = .09$

Base Turbojet Engine

Install ($T_{SLS/ENG}$) = 204230 N (45,913 lb)

Contd



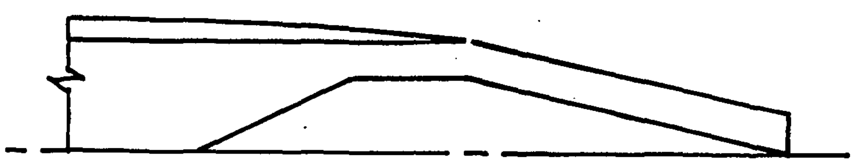


Figure 56 Turbojet Nozzle Weight

Max (Diam) Base = 1.38m (54.2 Inch)

Engine (Wt) $_{Base}$ = 2587 kg (5703 lb)

Inlet Capture Area, $(A_c)_{Base} = 1.359\ m^2$ (14.634 ft^2)

C_T = 2.92 at M = 1.22 along trajectory

Total number turbojet engines = 16

Now,

$$C_D = C_{DO} + \Delta C_{D_{Lift}}$$

$$1.15\ (C_{DO}) = 1.15\ (.09) = 0.103$$

Drag = $C_D q\ S_{REF} = 6.4 \times 10^6$ N (1.44×10^6)

ROD Thrust, $T_{RQD} = K\ (D + W \sin \gamma)$

Where Thrust Margin Ratio, K = 1.25 (Assumed)

Tot $T_{RQD} = 9.15 \times 10^6$ N (2.057×10^6 lb)

$T_{RQD/ENGINE} = \frac{T_{RQD}}{16}$ = 572123 N (128,619 lb) (@ Transonic Speed)

Now, inlet capture area, $(A_c)_{RQD} = \frac{T_{RQD}}{CTq} = 3.1\ m^2$ (33.42 ft^2)

Contd

The engine scale factor, S.F. relative to base engine is then,

$$S.F. = \frac{A_{C_{RQD}}}{A_{C_{BASE}}} = \frac{33.42}{14.634} = 2.284$$

From which,

$$RQD\ (T_{SLS})_{Scaled} = S.F.\ (TSLS)_{BASE} = 2.284 \times 204497$$

$$= 467061\ N\ (105{,}000\ lb)$$

$$RQD\ Max.\ (Diam)_{SCALED} = (S.F.)^{.45}\ (DIAM)_{BASE} = (2.284)^{.45} \times 1.3\ m$$

$$= 2.0\ m\ (78.6\ Inch)$$

$$Scaled\ RQD\ Wt = (S.F.)^{.95} (Wt)_{Base}$$

$$= (2.284)^{.95} \times 2587$$

$$= 5669\ kg\ (12{,}498\ lb)\ (for\ Axi\text{-}Sym\ Noz)$$

$$= 6264\ kg\ (13{,}810\ lb)\ (for\ 2\text{-}D\ Noz)$$

In actual practice, the excess thrust margin ratio, K must initially be assumed and the resulting engine size run through a trajectory and payload performance computer program (HZ 600) to arrive in the vicinity of the optimum turbojet size as presented in Figure 15.

APPENDIX IV WING ANALYSIS

Support of the orbiter at Wing Buttock Line 435 during the takeoff results in significantly larger loads and corresponding increase wing weights relative to the Boeing ALRS 205 (Base for developing orbiter weights). The takeoff condition is analyzed as follows:

The orbiter reactions are distributed uniformily between an area ahead of the main gear well and aft of the main gear well. The shear outboard of W.B.L. 435 is subtracted prior to distributing the vertical reaction. The equal distribution is based on the orbiter weight distributions which are fairly equal fore and aft of the main gear well inboard of W.B.L. 435. Forward loads are carried inboard by three spars. Aft loads are carried inboard by the aft wing box. Torsion balance occurs at the side of body.

Thrust loads are carried in upper and lower surface panels.

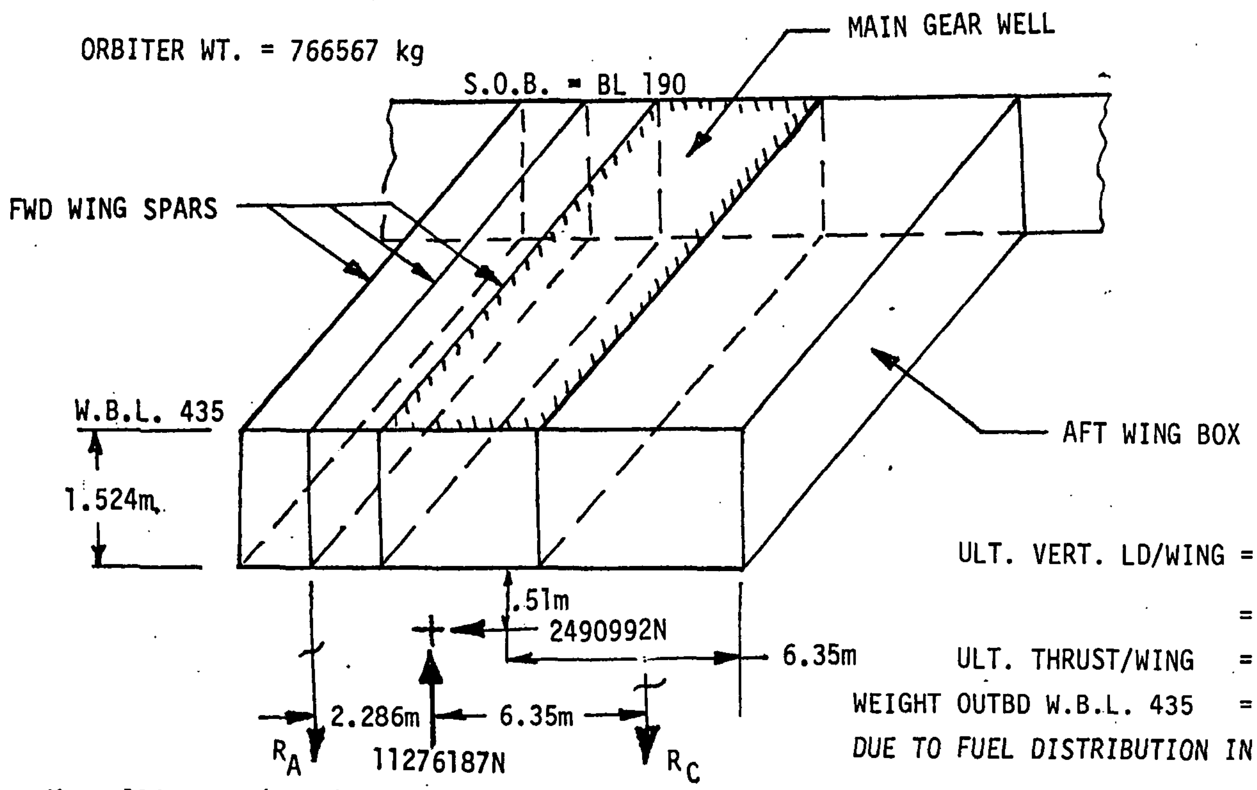
For structural sizing panel shears allowable of 4.13×10^8 N/m^2 for titanium and 5.17×10^8 N/m^2 for Rene'41 are used. Bending allowables of 8.27×10^8 N/m^2 are used for both materials. This permits margin for internal pressure loads. Resulting preliminary design weights are developed on the following pages.

WING STRUCTURAL ANALYSIS

NOTE: ORBITER MAIN GEAR WELL DIVIDES AFT. & FWD. WING

TAKEOFF CONDITION $N_{ULT} = 3$

ORBITER WT. = 766567 kg



ULT. VERT. LD/WING = $3 \frac{(7517458)}{2}$

= 11276187N

ULT. THRUST/WING = 2490992N

WEIGHT OUTBD W.B.L. 435 = 66,677 kg

DUE TO FUEL DISTRIBUTION IN WING

$M_C = 11276187\ (6.35) - 4635024(8.63)$

$= 31575720$ Nm

$R_A = R_C = \frac{2{,}535{,}000 - 3(147000)}{2} + \frac{560000\ (50)}{(0)\quad 340} \times 4.4482$

$R_A = 4999776$ N

$R_C = 4635024$N (NEGLECTING THRUST)

WING STRUCTURAL ANALYSIS (CONT.)

AFT. WING BOX

TORSION MOVING INBD = 31,345,228 Nm

$$q_T = \frac{279450000}{250(60)(2)} \times \frac{4.4482}{.0254} = 1631298 \text{ N/m}$$

ASSUME 1/2 THRUST GOES FORWARD, 1/2 AFT

$$q_{THRUST} = \frac{560000}{2(2)(250)} \times \frac{4.4482}{.0254} = 98070 \text{ N/m}$$

$$\text{UPPER SURFACE } t_{REQ} = \left(\frac{9315 - 560}{60000}\right) \times 25.4 = 3.81 \text{ mm (Titanium)}$$

$$\text{LOWER SURFACE } t_{REQ} = \left(\frac{9315 + 560}{75000}\right) 25.4 = 3.556 \text{ mm (Rene'41)}$$

$\triangle$ WEIGHT RELATIVE TO BOEING ALRS-205

UPPER SURFACE $\Delta t = (.15 - .05)\ 25.4 = 2.54$ mm

$$\text{WT.} = \left[.1\ (144)(.164) + .25^{\triangleright 2}\right] 425\ (1.1)^{\triangleright 1}\ .45359 = 553.4 \text{ kg/WING}$$

LOWER SURFACE $\Delta t = (.14 - .05)\ 25.4 = 2.286$ mm

$$\text{WT.} = \left[.09(144)(.298) + .25^{\triangleright 2}\right]\ 425^{\triangleright 1}\ (1.1)\ .45359 = 871.8 \text{ kg/WING}$$

$\triangleright 2$ HONEYCOMB CORE FOR THICK SKINS

$\triangleright 1$ FACTOR FOR JOINTS

SPAR ALONG AFT WHEEL WELL

$$q = 9315 + \frac{1042000}{9(60)} \times \frac{4.4482}{.0254} = 196929 \text{ N/m}$$

$$t = \frac{11243}{60000} \times 25.4 = 5.088 \text{ mm}$$

$$\Delta \text{WT.} = (.2 - .05)\ (1.3)\ (60)\ (243)\ (.16) \times .453$$
$$= 219.92 \text{ kg}$$

SHEAR IN OTHER SPARS APPROX. 2 TIME ALRS 205

$$\Delta \text{WT.} = .6\ (2)\ (425) \times .453 = 231 \text{ kg}$$

$$\Delta \text{WING WT.} = (510 + 470 + 1220 + 1923)\ .453$$

$$= 1866 \text{ kg/side}$$

$$\text{TOTAL } \Delta \text{ AFT WING WT.} = 2\ (4120)\ .453 = 3737 \text{ kg}$$

BEAMS FWD. ORBITER MAIN GEAR WELL

FWD REACTION CARRIED TO SIDE OF BODY BY 3 SPARS.

$$MOM_{SIDE\ BODY} = (1124000(243) - \frac{90(243)(100)}{1728}\ (72)(3)(122)\ \ (.453 \times 4.448)$$

$$= (273{,}132{,}000 - 33000000)\ 2.015$$

$$= 483{,}865{,}980 \text{ Nm}$$

AT SIDE OF BODY DEPTH = 2.794m

$$LD/IN = \frac{240,132,000}{110\ (90)} \times \frac{4.4482}{.0254} = 425556 \text{ kg/m}$$

$t = .2$ TOP & BOTTOM @ $f_c = f_t = 827.36$ MPa

AVE t = 3.55 mm (CONSIDERING DEPTH CHG. OUTBD.)

A t = (.14 - .03) 25.4 = 2.794 mm

$$\text{SURFACE WT.} = .11(144)(.164 + .298) + 2\ (.25)^{\triangleright}\ \frac{90(243)}{144}\ (1.1)\ (.453)$$

$$= 589 \text{ kg}$$

▷ CORE REINFORCEMENT

FWD. WING CONT.

$$\text{SPAR SHEAR FLOWS} \quad q = \frac{1124000}{190\ (3)} \times \frac{4.448}{.0254} = 728491 \text{ kg/m}$$

$$t = \frac{4160}{60000} \times 25.4 = 1.78 \text{ mm}$$

INCL. STIF. t = .07 (1.35) 25.4 = 2.41 mm

t = (.095 - .03) 25.4 = 1.61 mm

SPAR WT. = (.065) (90) (243) (.164) (3) (.4535)

= 317 kg

WING STRUCTURAL ANALYSIS (CONT.)

FWD WING = (700 + 1300) .4535 = 907 kg

FWD WING TOTAL = 2(2000) .4535 = 1814 kg/WING

Δ WING WT. = (4000 + 8240) .4535

= 5552 kg [1] DUE TO TAKEOFF LOADS

[1] INCREASE RELATIVE TO ALRS 205

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15. Supplementary Notes

Langley Technical Monitor: Joe D. Watts
Final Report

16. Abstract

Most studies of the next generation of advanced earth orbital transportation systems have only considered all rocket propulsion systems. An alternative approach by NASA Langley has considered air breathing turbojet engines for the first stage. Their novel concept proposed to use twin turbo-powered boosters for accelerating to supersonic staging speed followed by an all rocket powered orbiter. Both stages are fully reusable. This effort is a follow-on design study of such a concept with performance objective of placing 29483 kg (65000 lb) payload into a low earth orbit. Design features of the final configuration included: strakes and area rule for improved take-off and low transonic drag, and advanced afterburning large turbojets. Technologies in need of development for this concept are: aerodynamics, orbiter structure and thermal design and booster propulsion integration.

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