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16. ABSTRACT The objective of this study is to compare the characteristics of SST designed for the same mission by Lockheed, McDonnell Douglas, British Aerospace (U.K.), Aerospatiale (France) and the USSR. This comparison is to be used to calibrate parametric design studies of the tradeoff between SST direct operating cost (DOC) and noise levels at the FAR 36 certification points. The guidelines for this "common case" study are to design an aircraft with the following mission: payload - 23 247 kg (51 250 lbm), range - 7000 km (3780 n.mi.) cruise Mach number - 2.2. Field length is constrained to 3505 m (11 500 ft). Other airfield constraints and fuel reserves are also specified, but no noise constraints are applied. Technology level is ICAO Class II (1980-85 start of design). The aircraft designed is to be the minimum takeoff gross weight (TOGW) configuration. FAR 36 noise and DOC are to calculated. The powerplant selected for the study is a Lockheed design of a low bypass ratio (0.25) afterburning turbofan. Characteristics of the resulting design are TOGW - 269 483 kg (594 109 lbm), operating weight empty (OEW) - 116 918 kg (257 759 lbm), wing loading (W/S) - 3830 N/m^2 (80 lb/ft^2), thrust/weight (T/W) - 0.254, design point DOC - 1.65 ¢/seat km (2.66 ¢/seat st. mi), sideline noise - 119.0 EPNdB, flyover noise - 122.6 EPNdB, approach noise - 110.9 EPNdB. A second configuration was designed for a range of 7408 km (4000 n.mi.) with the same values of W/S and T/W. Detailed geometric, aerodynamic and performance characteristics are given.

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PREFACE

This report is submitted to NASA under the "Common Case Study" program; the work was performed as Mod 4 to Contract NAS 1-14625 during the period January to August 1978. The program is under the direction of C. Driver at the NASA-Langley Research Center, Hampton, Va., and was initiated to provide technical support to the ICAO Committee on Aircraft Noise, Working Group E, in order to provide a technical basis for the determination of noise limits for future supersonic transports. In particular, the "common case" design studies are being used to calibrate the parametric design results arising from member nation studies in the areas of noise-cost sensitivity. The report is a summary of work performed and the results therefrom, and is intended to be in a suitable format for use by Working Group E.

The study was managed by John Clauss (SCAR Assistant Program Manager). Lockheed personnel responsible for the aircraft design and technical support are: Mel Osborn (Design), Ben Saelman (Weight and Balance), Jim Wilson and Tom Oatway (Propulsion), Jack Werner (ASSET operation), Marv Baxendale (Aerodynamics), Dalen Horning (Economics), and Tony Hays (Acoustics). Personnel responsible for engine synthesis are Jim Wilson and Dave Gorz.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

THE COMMON CASE STUDY: LOCKHEED DESIGN OF A SUPERSONIC CRUISE VEHICLE

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SUMMARY

This study was performed in order to provide data for the FAA to assist the ICAO Committee on Aircraft Noise, Working Group E, in setting certification noise standards for future SSTs. The overall objective of this common case study is to calibrate the parametric design results arising from member nation studies of topics such as noise-cost sensitivity. Comparisons will be made of the characteristics of SSTs designed for the same mission by Lockheed-California Co., McDonnell Douglas, British Aerospace (UK), Aerospatiale (France), and the USSR. The effort reported herein describes Lockheed's common case design.

The guidelines for the common case study are to design an aircraft with the following mission: payload - 23 247 kg (51 250 lbm), range - 7000 km (3780 n.mi.), cruise Mach number - 2.2. Field length is constrained to 3505 m (11 500 ft), and other airfield constraints and fuel reserves are also specified. Technology level is specified as ICAO Class II (1980-85 start of design). The desired aircraft design is to be the minimum takeoff gross weight (TOGW) configuration, unconstrained by airport noise requirements. FAR 36 noise and DOC are to be calculated for this minimum TOGW aircraft.

The ICAO Class II technology requirements have primary impact on the structural and material concepts employed in the airframe structure and in the engine cycle chosen. Active controls are permitted, but no composite materials in the primary structure are allowed. The resulting airframe is about 58 percent titanium, 28 percent composites in secondary structure application, and 14 percent steel and other materials, by structural weight.

The powerplant selected for the study is an in-house Lockheed design of a low bypass ratio (0.25) afterburning turbofan with a combustion exit temperature of 1600°K (2880°R). This powerplant was synthesized specifically for the common case effort. This is the best engine cycle for the common case mission except for the variable cycle which is not included in Class II. The combustor exit temperature chosen is the maximum allowed by Class II.

A series of parametric aircraft designs were generated by varying wing loading (W/S) and thrust weight ratio (T/W) while adjusting TOGW to maintain the desired mission range of 7000 km (3780 n.mi.). These are summarized in a TOGW knothole chart which shows an unconstrained optimum configuration to have a T/W of about 0.26, a W/S of 4788 N/m^2 (100 lb/ft^2), and a TOGW of 260 816 kg (575 000 lbm).

The selected approach speed constraint of 81.3 m/s (158 keas) forces the constrained optimum configuration to a T/W of 0.254, a W/S of 3830 N/m^2 (80 lb/ft^2), and a TOGW of 269 483 kg (594 109 lbm). The takeoff field length (TOFL) constraint is somewhat artificial since, without noise constraints, any takeoff thrust setting up to full after burner could have been selected. The actual setting selected here employs a combustor exist temperature of 1489°K (2680°R), a value less than the maximum available, and does not utilize reheat.

Other leading characteristics of the resulting constrained minimum TOGW design are: operating weight empty (OEW) - 116 918 kg (257 759 lbm), design point DOC - 1.65 ¢/seat km (2.66 ¢/seat n.mi.), sideline noise - 119.0 EPNdB, flyover noise - 122.6 EPNdB, approach noise - 110.9 EPNdB.

A second configuration was designed for a range of 7408 km (4000 n.mi.) with the same constrained values of T/W and W/S. TOGW for this design is increased to 286 537 kg (631 705 lbm). Detailed geometric, aerodynamic and performance characteristics of both designs are given.

INTRODUCTION

Background

The International Civil Aviation Organization (ICAO) is responsible for setting standards for the regulation of international civil aircraft operations. In particular, the Committee on Aircraft Noise (CAN) has the responsibility of setting worldwide noise standards for civil aircraft. These standards represent minimum requirements, and they may be overridden by more stringent national standards. ICAO has set standards for subsonic civil aircraft (Reference 1), and is in the process of drawing up standards for supersonic civil aircraft. To this end, Working Group E (WG/E) was set up to recommend to CAN which noise standards should be applied (Reference 2). At the first WG/E meeting in March 1977, a working paper was presented that outlined the NASA Supersonic Cruise Aircraft Research (SCAR) program (Reference 3). As a result, it was decided to initiate contracts between industry (Boeing, McDonnell Douglas, and Lockheed) and NASA to provide technical assistance in support of WG/E.

Purpose of Study

At the January 4-10, 1978 meeting of the WG/E International Technical Experts, the Federal Aviation Administration (FAA) initiated contracts to determine the trade-offs between aircraft operating cost and noise at the FAR Part 36 measurement points. In order to calibrate the parametric aircraft designs arising from these studies (e.g., Reference 4), contracts were also initiated for each design group to derive a supersonic cruise vehicle (SCV) with a specified mission - a "common case" design. Identical design studies are being conducted in the United Kingdom, France, and the USSR. Final results from these common case studies are to be presented at the November 1978 WG/E meeting.

LIST OF SYMBOLS AND ABBREVIATIONS

Al	Aluminum
AR	Aspect Ratio
ASSET	Advanced System Synthesis and Evaluation Technique
ATA	Air Transport Association
CAB	Civil Aeronautics Board
CAN	Committee on Aircraft Noise
CET	Combustor exit temperature
C_L	Lift coefficient
DOC	Direct operating cost
EMS	Elastic mode suppression
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FMA	Flutter margin augmentation
GA	Gust alleviation
HP	High pressure
ICAO	International Civil Aviation Organization
ISA	International standard atmosphere
keas	knots, equivalent air speed
LCN	Load classification number
LP	Low pressure
MAC	Mean aerodynamic chord
M_c	Cruise Mach Number
MLC	Maneuver load control
RQ	Ride quality

LIST OF SYMBOLS AND ABBREVIATIONS (Cont.)

RSS	Relaxed static stability
SCAR	Supersonic cruise aircraft research
SCV	Supersonic cruise vehicle
SEP	Specific excess power
SL	Sea level
SLS	Sea level static
TET	Turbine entry temperature
Ti	Titanium
TOFL	Takeoff field length
TOGW	Takeoff gross weight
T/W	Thrust/weight ratio
V	Vanadium, wing volume
WG/E	Working Group E
W/S	Wing Loading (weight/reference wing area)
β	$\sqrt{M_c^2-1}$
Λ_{LE}	Wing leading edge sweep

1. TECHNICAL APPROACH

1.1 Study Ground Rules

The aim of the common case design study is to select the minimum takeoff gross weight (TOGW) vehicle capable of transporting 250 passengers 7000 km (3780 n.mi.) at a cruise Mach number of 2.2. Noise constraints are not to be considered. The level of technology selected for the design is defined as Class II (1980-1985 start of design). Details of the ground rules are listed below.

The terms of the contract between NASA and Lockheed for completion of the FAA-sponsored studies specify a range of 7408 km (4000 n.mi.) for the design mission. Using the optimized values of thrust/weight and wing loading obtained from the 7000 km range aircraft, the aircraft is to be resized to fly 7408 km (4000 n.mi.). The resized configuration is described in Appendix B.

For the remainder of this report, the 7000 km aircraft will be designated the CL 1627-1 while the 7408 km (4000 n.mi.) aircraft will be designated the CL 1627-2.

1.1.1 Class II Definition Summary. - ICAO Class II technology definitions from Reference 4 are listed in Appendix A. These definitions have the following impact on the baseline vehicle concept:

- No composite materials in primary structure
- Active controls employed
- No variable cycle engines permitted
- Combustor exit temperature = 1600°K (2880°R)

1.1.2 Mission Requirements. - The requirements presented in Table 1 are taken from the negotiated statement of work for Mod 4 to NASA Contract NAS1-14625. These ground rules are essentially identical to those of Attachment I of Reference 5. It should be noted that no approach speed is specified. Lockheed assumes that a maximum approach speed of 81.3 m/s (158 keas) is permissible, and this constraint is applied to the results. This approach speed value is the one used in Lockheed SCAR contract studies to date which in turn is based on Concorde capability.

The minimum TOGW aircraft is not to be constrained by any prescribed airport noise levels. However, noise levels at the FAR 36 measurement points are calculated for the selected minimum TOGW design.

TABLE 1. - MISSION REQUIREMENTS

Design Mach:	2.2 (ISA day)
Payload:	250 passengers (93 kg/pass (205 lb/pass) x 250 = 23 247 kg (51 250 lbm))
Range:	7000 km (3780 n.mi.) (Zero wind)
Fuel Reserve	5% block fuel Missed approach at destination Diversion 370.4 km (200 n.mi.) (ISA, zero wind) Hold at alternate 30 min @ 128.6 m/s (250 kt) at 3048 m (10 000 ft)
Airport Conditions	3505 m (11 500 ft) TOFL (ISA + 10°C (18°F), SL) 0.052 rad (3 deg) glideslope Full power takeoff Max tire speed of 115.75 m/s (225 kt) true ground speed Runway loading not to exceed Concorde if critical
Noise	Takeoff power cutback for Annex 16 monitor point climb gradient not less than 4%
Economics	DOC based on ATA '67 method modified for SCV operation and airline experience

1.2 Aircraft Design

1.2.1 Accommodation. - Passenger accommodation consists of a one class single aisle cabin with 5 abreast seating as shown in the interior arrangement of Figure 1. Seat pitch is 0.86 m (34 in.) and width 0.51 m (20 in.); minimum aisle width is 0.45 m (18 in.).

1.2.2 Aerodynamics and Controls. - A general arrangement of the configuration is shown in Figure 2. The airplane features a highly-swept arrow-wing planform with leading edge sweep angles of 1.225 rad (70.2 deg.), 1.154 rad (66.1 deg.), and 0.911 rad (52.2 deg.) for the root, mid, and tip wing sections, respectively. The aspect ratio is 2.06. The wing has leading and trailing edge high lift devices and an aft horizontal tail to satisfy airport field length and approach speed criteria. The wing is highly cambered to maximize cruise lift-drag ratio.

The selected wing planform for the common case aircraft is of the SCAT -15 arrow-wing family. The SCAT-15F planform is optimum for cruise at Mach 2.7 with the planform parameters of $\beta \cot \Lambda_{LE} = 0.719$, $\beta AR = 4.034$, and notch ratio of 0.14 set to define a wing of minimum induced drag at $M_c = 2.70$. In order to preserve this optimum wing, the common case planform was derived holding to the above planform parameters. The inboard wing sweep and aspect ratio are 1.225 rad (70.2 deg) and 2.06 respectively for $M_c = 2.20$.

Primary flight control surfaces also are indicated in Figure 2. Longitudinal and directional control are provided by an all moving horizontal stabilizer with geared elevator and all moving vertical fin, respectively. Lateral control is provided by outboard ailerons, flaperons, and spoiler-slot deflectors in a sequence scheduled by Mach number.

1.2.3 Propulsion. - The aircraft is fitted with four engines located in an all-under-wing arrangement. The engine selected for the common case is a low bypass ratio turbofan with a mixed-flow afterburner, designed for steady-state cruise operation at Mach 2.2. The cycle characteristics of the engine are summarized in Table 2.

The engine features an inverse throttle schedule. Combustor exit temperature (CET)† is 1489°K (2680°R) during takeoff as shown in the second column of

†Hot section technology is defined in terms of combustor exit temperature to avoid ambiguities associated with turbine entry temperature. Combustor exit temperature is the same as the temperature at the entry to the first turbine stator stage. Turbine entry temperature is usually referred to the temperature at the entry to the turbine rotor stage. The injection of cooling air through the stators upstream of the rotor stage results in a rotor inlet temperature that is cooler than combustor exit temperature.

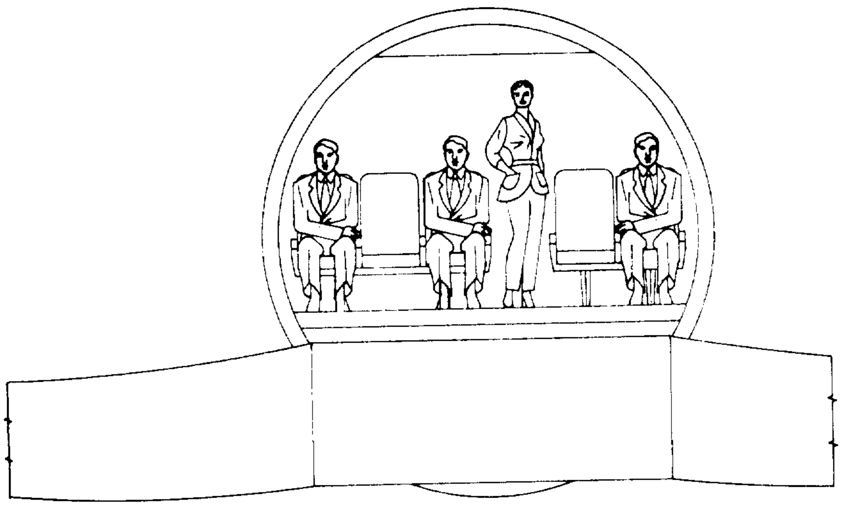
TABLE 2. - ENGINE CHARACTERISTICS

	Design Point (ISA, SLS)	Takeoff (ISA +10^{o}C, SL M = 0.3)
Thrust kN (lb)	265 (59 560)	167.92 (37 750)
Airflow kg/s (lbm/sec)	275 (605)	257 (566)
Corrected Airflow kg/s (lbm/sec)	289 (637)	255 (562)
Fan pressure ratio	4.0	3.23
Bypass ratio	0.25	0.34
Overall pressure ratio	20	15.4
Combustor exit temp ^{o}K (^{o}R)	1600 (2880)	1489 (2680)
Afterburner temp ^{o}K (^{o}R)	1330 (2395)	-

Table 2. Combustor exit temperature is scheduled to match the flow capability of the inlet during climb, and increases to 1600^{o}K (2880^{o}R) at end of climb and during cruise. Afterburner is not used for initial climbout nor the first (subsonic) portion of the climb to cruise. At Mach 0.8, the afterburner is lit, and the aircraft climbs to cruising altitude with the afterburner lit.

Engine design bypass ratio is 0.25. The bypass flow is mixed with the turbine exit gases as they enter the afterburner. The exhaust gases are expanded through a convergent-divergent actuated-door ejector nozzle.

The external compression inlet operates critical with only one oblique shock wave at the initial wedge and one strong solution oblique shock wave at the cowl lip. This shock system has demonstrated a pressure recovery of 90 percent with 3.4 percent bleed.



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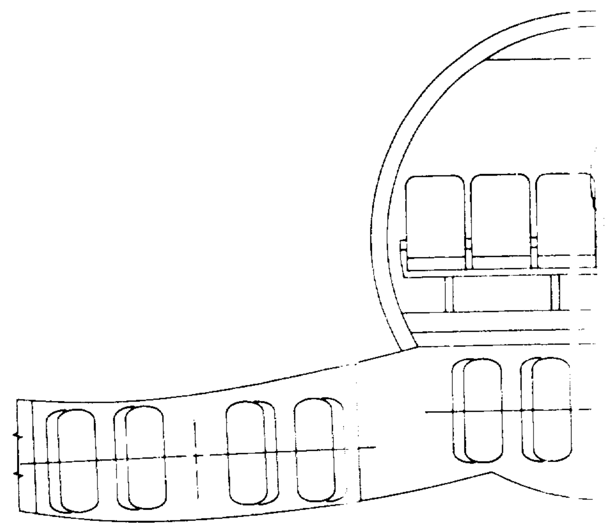

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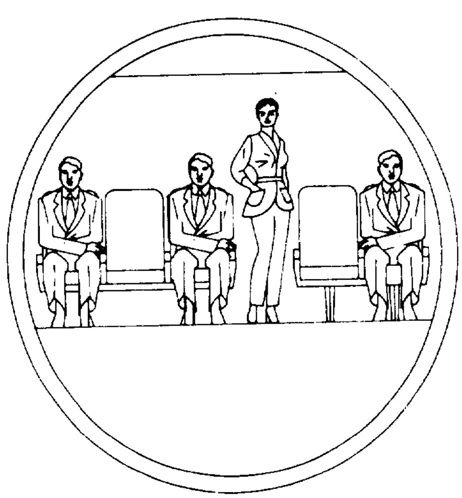

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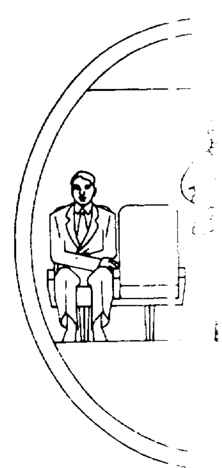

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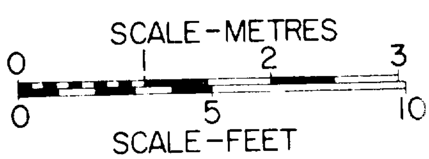

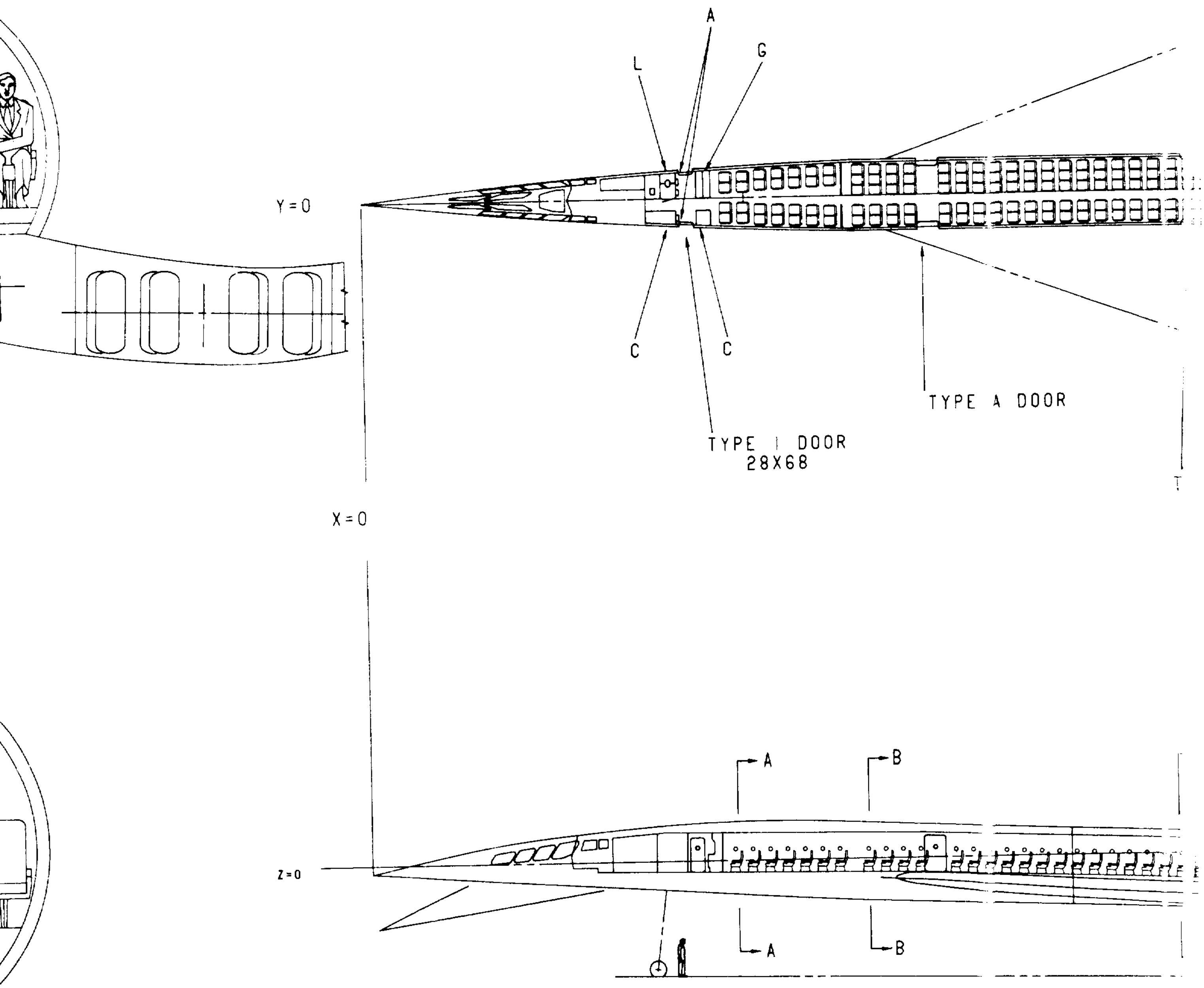
A
L
G
Y=0
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TYPE I DOOR
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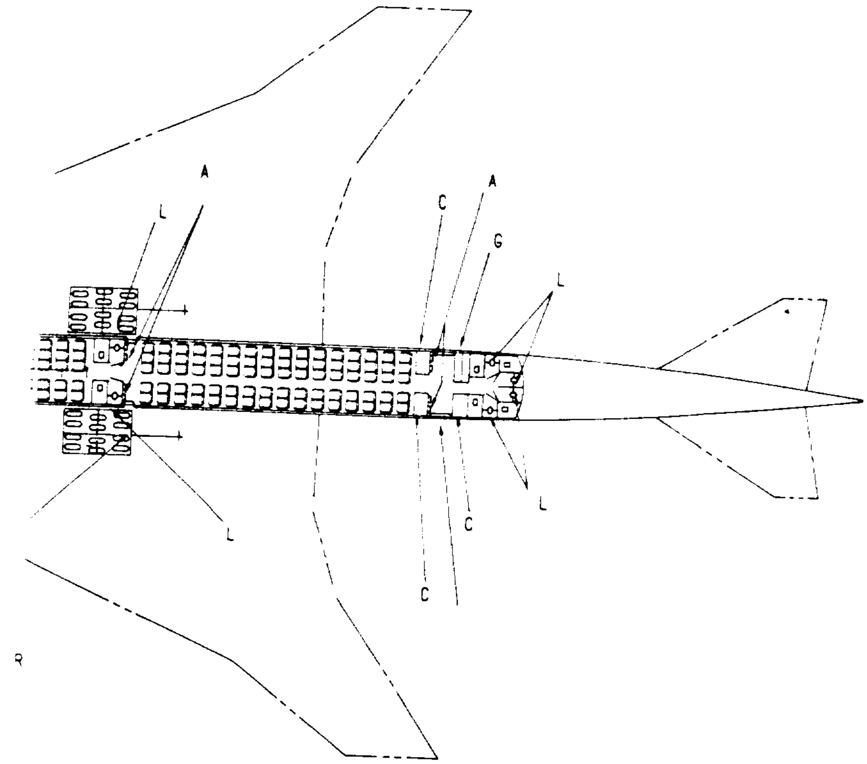
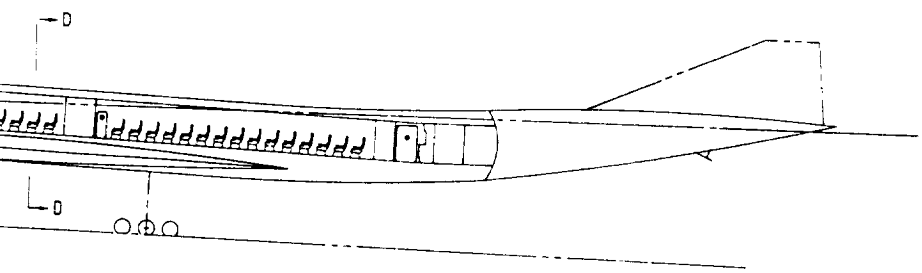
X=0
A
B
Z=0
A
B



A	FLIGHT ATTENDANT SEAT
C	CARRY-ON LUGGAGE
G	GALLEY
L	LAVATORY



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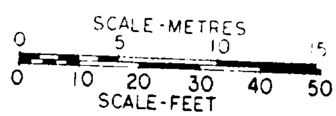


Figure 1. - CL1627-1 Interio arrangement.

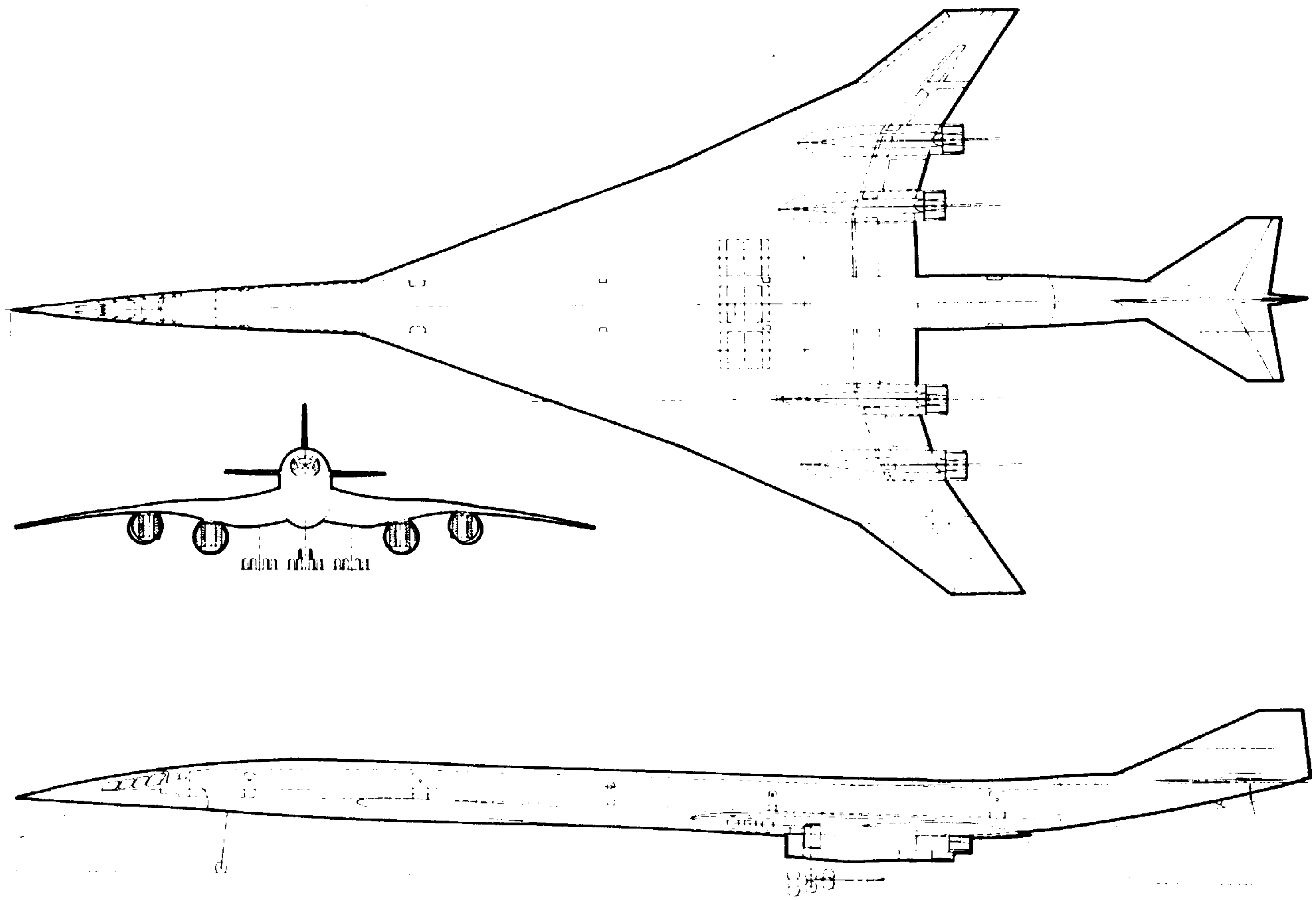


Figure 2. - Common case general arrangement.

1.2.4 Structure. - The airframe structure employs advanced technology consistent with ICAO Class II definitions. Titanium comprises about 58 percent of the structural weight with composite materials at 28 percent (all secondary application) and steel, aluminum, and other materials at 14 percent. Active controls systems are utilized to achieve structural weight savings; e.g., relaxed static stability, maneuver load control, flutter margin augmentation, gust alleviation, etc.

Figure 3 summarizes the structural concepts employed. The fuselage shell is a skin-stringer-frame design using titanium alloy (Ti-6Al-4V)† with weld-bonded assembly of components. The main frames use low cost no-draft forging technology. The wing and tail structural box are multispar construction with titanium sandwich surface panels. The skins are Ti-6Al-4V, and the core is Ti-3Al-2.5V. The face and core are joined by aluminum brazing. All wing trailing edge devices; i.e., plain flaps, flaperons, ailerons, and the horizontal tail, are selected as the control surfaces for the active controls system. Composite materials are employed for secondary structure application to both the fuselage and wing structures.

A three-post landing gear is employed with 12 wheels on each truck. Rigid and flexible pavement analyses have been conducted to verify that runway flotation requirements are no greater than those of Concorde. Both rigid pavement stresses and flexible pavement LCNs are less than Concorde. For Concorde the rigid pavement requirements are taken as 3.57×10^6 N/m^2 (518 lb/in^2) based on 0.305 m (12 in) thick pavement and subgrade modulus of reaction K=300. For a flexible pavement the limit is LCN = 116 for a 0.508 m (20 in) thick pavement.

1.3 Parametric Analysis and Selection of Minimum TOGW Aircraft

Design of the minimum TOGW aircraft to achieve a 7000 km (3780 n.mi.) range may be summarized in three steps:

- Initial or trial aircraft design resulting in a configuration which does not exactly meet the range requirement
- Resizing of aircraft to achieve range requirement exactly
- Parametric design variation to find minimum TOGW configuration

Aircraft sizing and parametric variation of design is performed with the Lockheed developed Advanced System Synthesis and Evaluation Technique (ASSET) vehicle synthesis model described in more detail in the next sections.

†This designation defines a titanium alloy containing 6 percent aluminum and 4 percent vanadium.

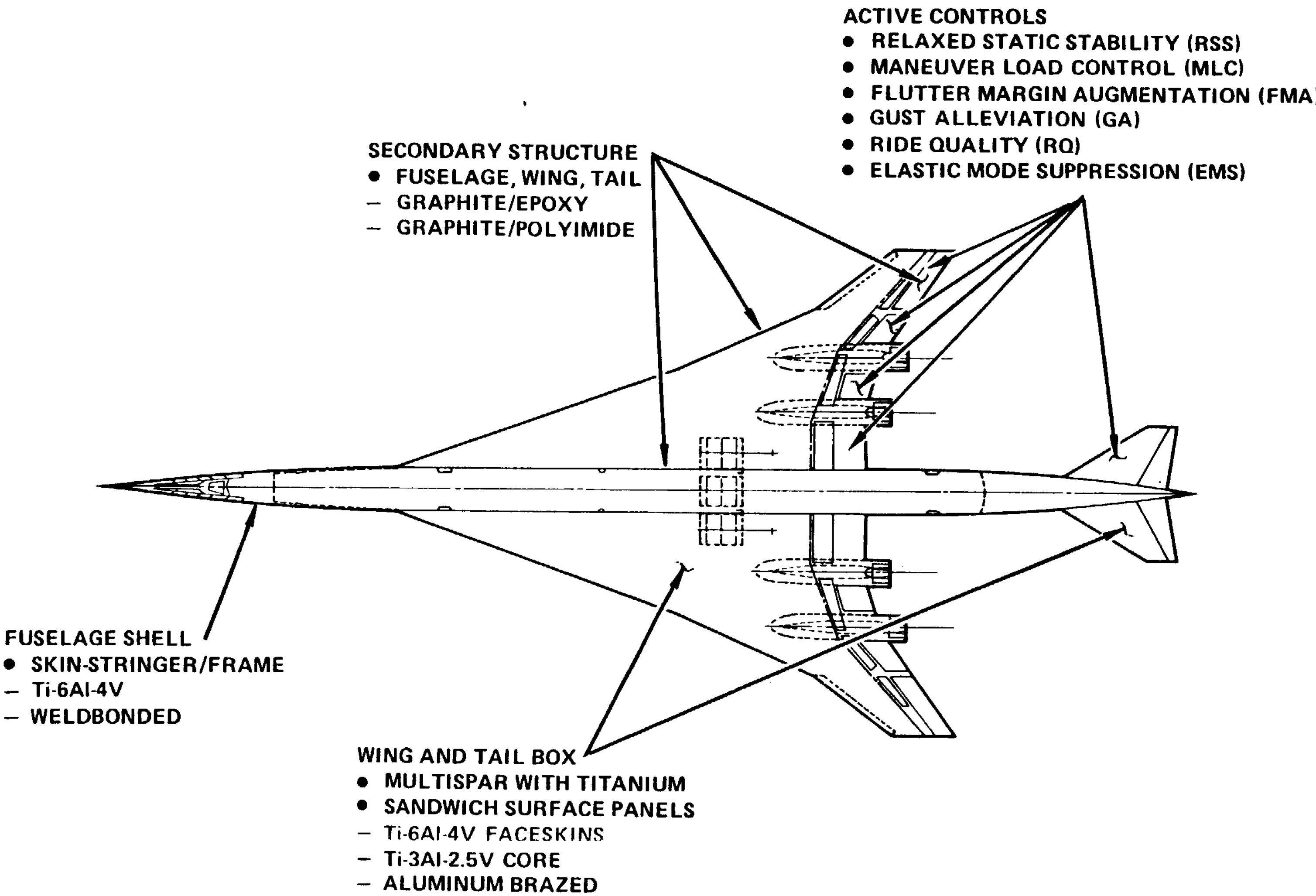


Figure 3. - Common case structural concepts.

1.3.1 Generation of TOGW Knothole. - Generation of a knothole with constraints is shown diagrammatically in Figure 4.

For the initial off-design-range configuration, a thrust/weight value of 0.252 and wing loading of 4.31 kN/m^2 (90 lb/ft^2) were chosen. From previous experience, these values were anticipated to be close to the center of the TOGW knothole, so that parametric sizing equations are well within the range of applicability. From the design-range baseline, thrust/weight and wing loading were varied parametrically in order to generate the TOGW knothole. When thrust/weight is varied the engine cycle (bypass ratio, compression ratio, CET, etc.) remains constant. When wing loading is changed, each wing design remains geometrically similar; engine location is at a fixed percentage of the wing semi-span.

1.3.2 Generation of Knothole Constraints. - In parallel with the mission analysis program, an airport constraint program is run.

Approach speed is 81.3 m/s (158 keas), and approach angle of attack is limited to a maximum of 0.131 rad (7.5 deg). Thus, C_L is limited and for a given value of T/W, the design is limited to a maximum value of wing loading. On a plot of T/W and W/S, an approach constraint line may be drawn that bounds feasible designs. In a similar manner, the takeoff field length constraint of 3505 m (11 500 ft) also precludes certain values of T/W and W/S.

Additional constraints evaluated are available fuel volume, transonic acceleration capability, and rate of climb capability at cruise initiation. Available fuel volume includes the outer wing out to the outboard engine, the wing center section, and 36 514 kg (80 500 lb) in the aft fuselage. Excess thrust/drag for transonic acceleration must be at least 0.3, and rate of climb available at initial cruise must be at least 1.524 m/s (300 ft/min).

1.4 Noise Estimation Procedure

The calculation of overall noise level as a function of relative jet velocity, and spectral distribution, is based on SAE AIR 876 (Reference 6). The directivity function, based on empirical Lockheed data, is dependent on flight speed.

The method of calculating jet noise used in AIR 876 (1965) does not consider the effect of ground reflections that were present in the experimental data. The method of measuring noise in FAR 36 also includes ground reflection effects. Although ground reflection effects are not exactly the same for the two situations, there is no requirement to add ground reflection effects to noise calculations used in this report.

Takeoff and approach noise is assumed to be measured using the methods of FAR Part 36 (1969). At takeoff, noise levels are computed for a microphone at 6482 m (3.5 n.mi.) from brake release on the runway centerline

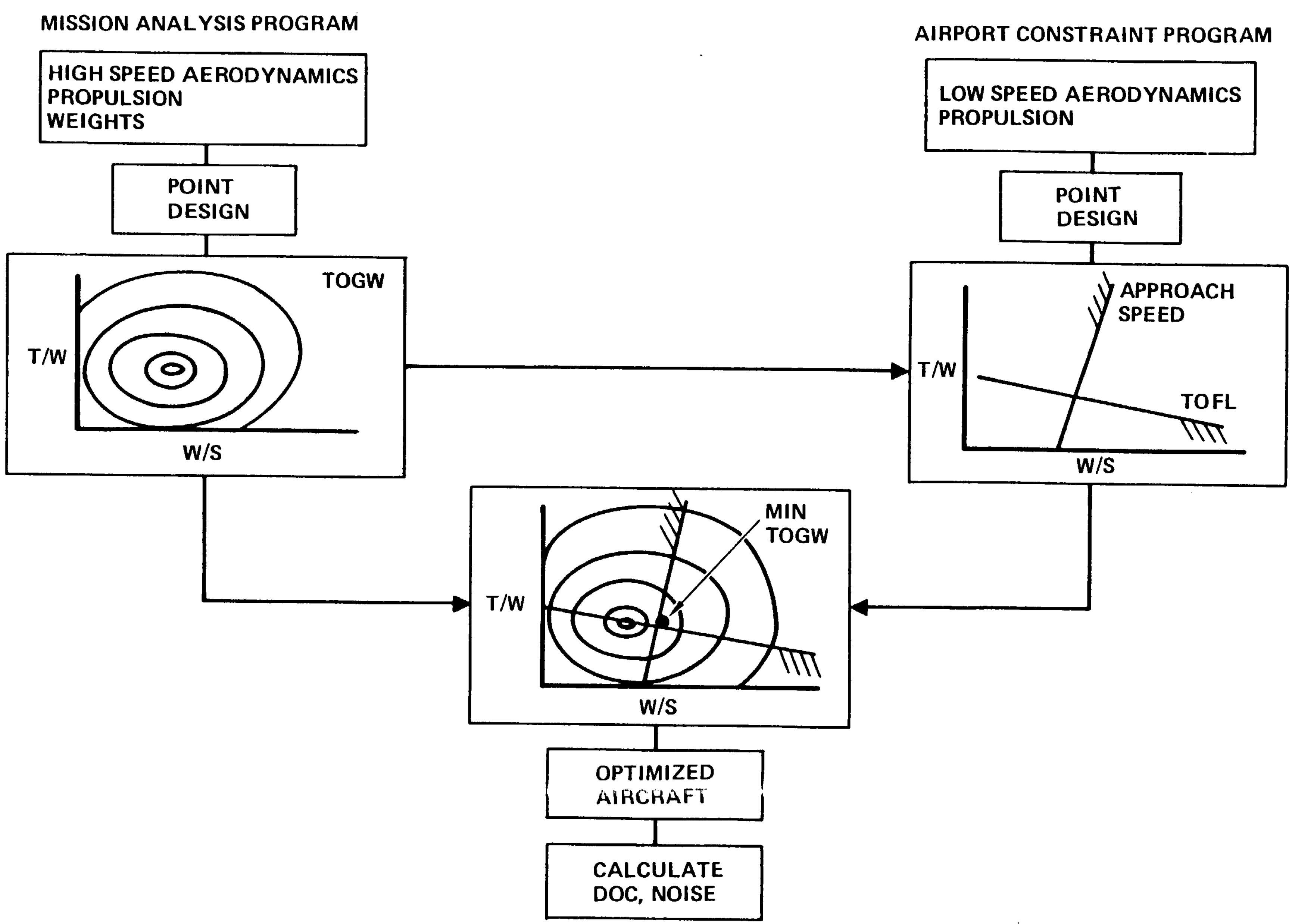


Figure 4. - Use of ASSET to generate constrained TOGW knothole.

extension and at the noisiest point along a sideline which is 648 m (0.35 n.mi.) from the runway centerline. On landing, noise levels are computed at 1852 m (1.0 n.mi.) from the landing threshold with the aircraft on a 0.052 rad (3 deg) glideslope, clearing the threshold at 15.24 m (50 ft) altitude.

1.5 Cost Estimation Procedure

The direct operating cost (DOC) elements used in estimating Supersonic Cruise Vehicle (SCV) operational costs are the same as those defined in the Standard Method of Estimating Comparative Direct Operating costs of Turbine Powered Transport Airplanes issued in December 1967 by the Air Transport Association (ATA) (Reference 7). These cost elements are flight crew, fuel and oil, hull insurance, direct maintenance of flight equipment, and depreciation. Although the same basic elements are used in calculating SCV DOCs, detailed formulae and factors vary considerably. Formulae and factors used by Lockheed have been developed from CAB and other applicable data. Costs are calculated in constant January 1976 dollars.

Crew cost is estimated using a Lockheed-developed formula with gross weight as the independent variable and based upon 1975 domestic actual costs. The results are adjusted for international operation (+10 percent) and supersonic operation (+35 percent) and escalated to January 1976 (6 percent/year). The original formula and adjustment factors are developed from actual CAB data. The 35 percent adjustment for supersonic operation was estimated by an airline.

The ATA formula is used in estimating fuel cost. The cost of fuel for international operation at $0.102/liter ($0.385/gallon) is developed as an average actual international cost of four U.S. airlines with significant international operations.

The ATA formula is used in estimating insurance cost. The insurance rate is multiplied by the aircraft cost. Aircraft cost includes total airplane production and investment costs, but excludes special support equipment. The insurance rate (0.553 percent) is developed as an average cost over sixteen years. The first year rate is set at 2.0 percent and brought down a curve similar to that experienced by other aircraft. The first year rate is set considerably higher than current aircraft (1.1 average) due to advanced technology and risk.

Maintenance calculations are performed a level below the ATA method using Lockheed-developed formulae. Labor and material are calculated separately for equipment and furnishings, landing gear, tires and brakes, other systems, structures, airframe related power plant, and engine. Each formula is composed of a flight cost and a flight hour cost. A direct labor rate of $9.00/hour is applied to direct labor hours. This is an average rate for

four major airlines. A maintenance burden factor of 2.32 is applied to direct maintenance labor. This is a selected average for international operation.

The ATA formula is used for estimating depreciation. Spares factors, however, are developed from airline usage related to fleet size. Spares usage is estimated as 10 percent of airframe and 26 percent of engine based upon common usage by several airlines with a common fleet of 26 aircraft. Period of depreciation or aircraft life is estimated at 16 years.

2. RESULTS OF STUDY

This chapter shows results of parametric analysis for the study and defines the optimized configuration.

2.1 Carpet Graph of TOGW

Figure 5 shows a carpet graph of TOGW for the CL1627-1. Unconstrained minimum TOGW is 261 269 kg (576 000 lb). For clarity, TOFL and approach speed constraints are omitted from the figure.

2.2 Knothole Plot of TOGW

The TOGW knothole (Figure 6) presents the same data as in the carpet plot but in a different form. In addition, the approach speed constraint, TOFL constraint and fuel volume constraint are shown.

2.2.1 TOFL Constraint. - The ground rules of this study do not state any noise limits, so there is no prohibition against using full afterburner on takeoff, if required. The takeoff field length constraint, as shown on Figure 6 is therefore somewhat artificial. Having selected the optimized configuration based on the TOGW knothole and approach speed constraint only, takeoff thrust is then selected within the range of available power settings (keeping the same basic engine size) so that the optimized configuration just achieves the required 3505 m (11 500 ft) TOFL.

2.2.2 Approach Speed Constraint. - The approach speed constraint of 81.3 m/s (158 keas) results in a significant penalty to TOGW (and hence direct operating cost). As a result, there would be considerable economic pressure to permit a higher approach speed. For comparative purposes, approach speed constraints up to 87.5 m/s (170 keas) are also shown on the knothole plot to indicate the sensitivity of TOGW to approach speed. A reduction of 6804 kg (15 000 lbm) in takeoff gross weight is achieved by a 6.2 m/s (12 keas) increase in approach speed.

2.2.3 Fuel Volume Limit. - Fuel is carried in the wing between the fuselage and the outboard engine mounts, in the wing carry through box, and in the fuselage outside the wing box if necessary. The fuel limit is therefore a strong function of wing area. However, it does not affect the design of the optimized configuration. Fuel volume available in the wing and carry through box alone is 132 813 kg (292 803 lbm) whereas only 129 320 kg (285 101 lbm) is required for mission and reserves.

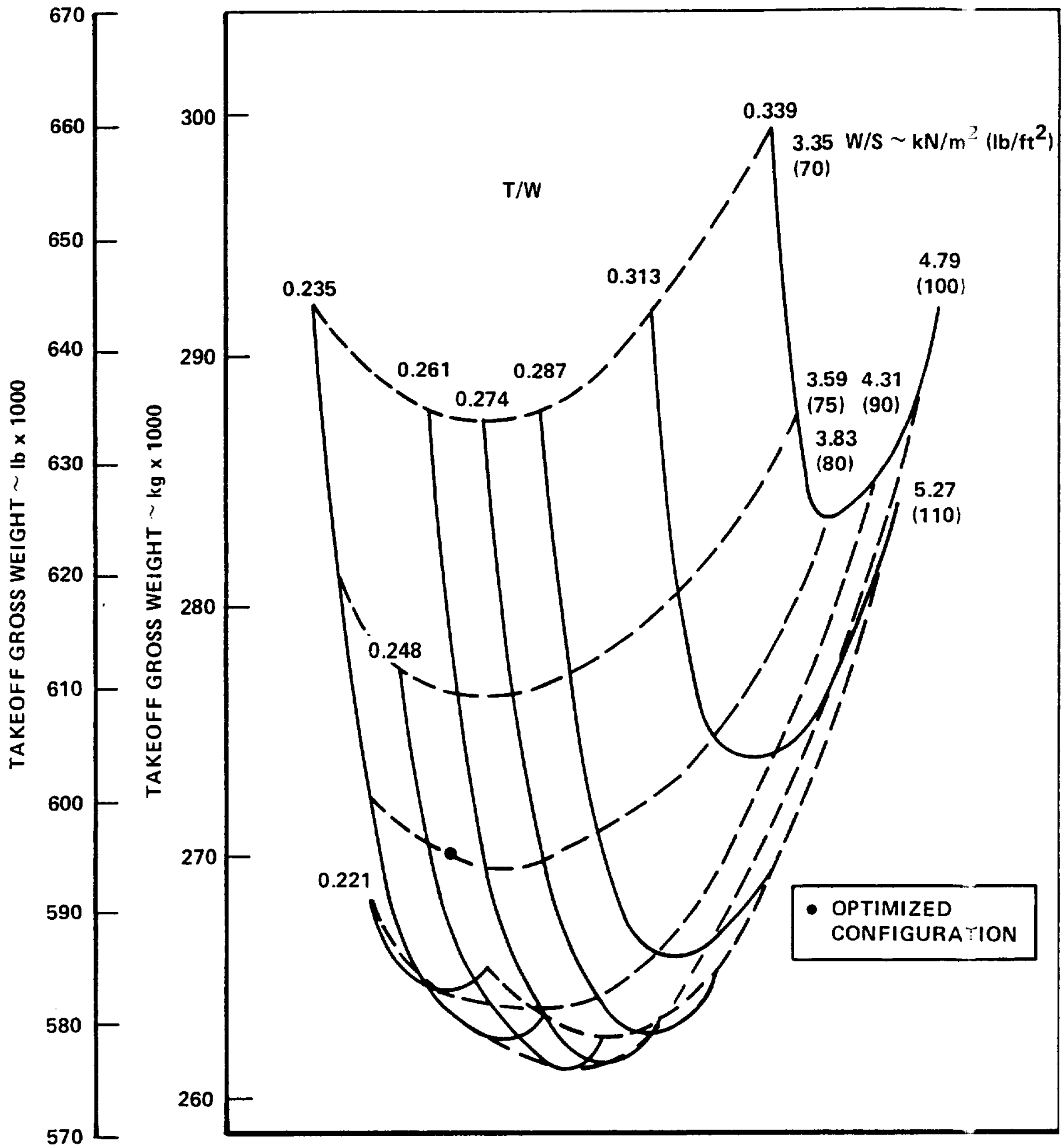


Figure 5. - CL1627-1 carpet graph of TOGW.

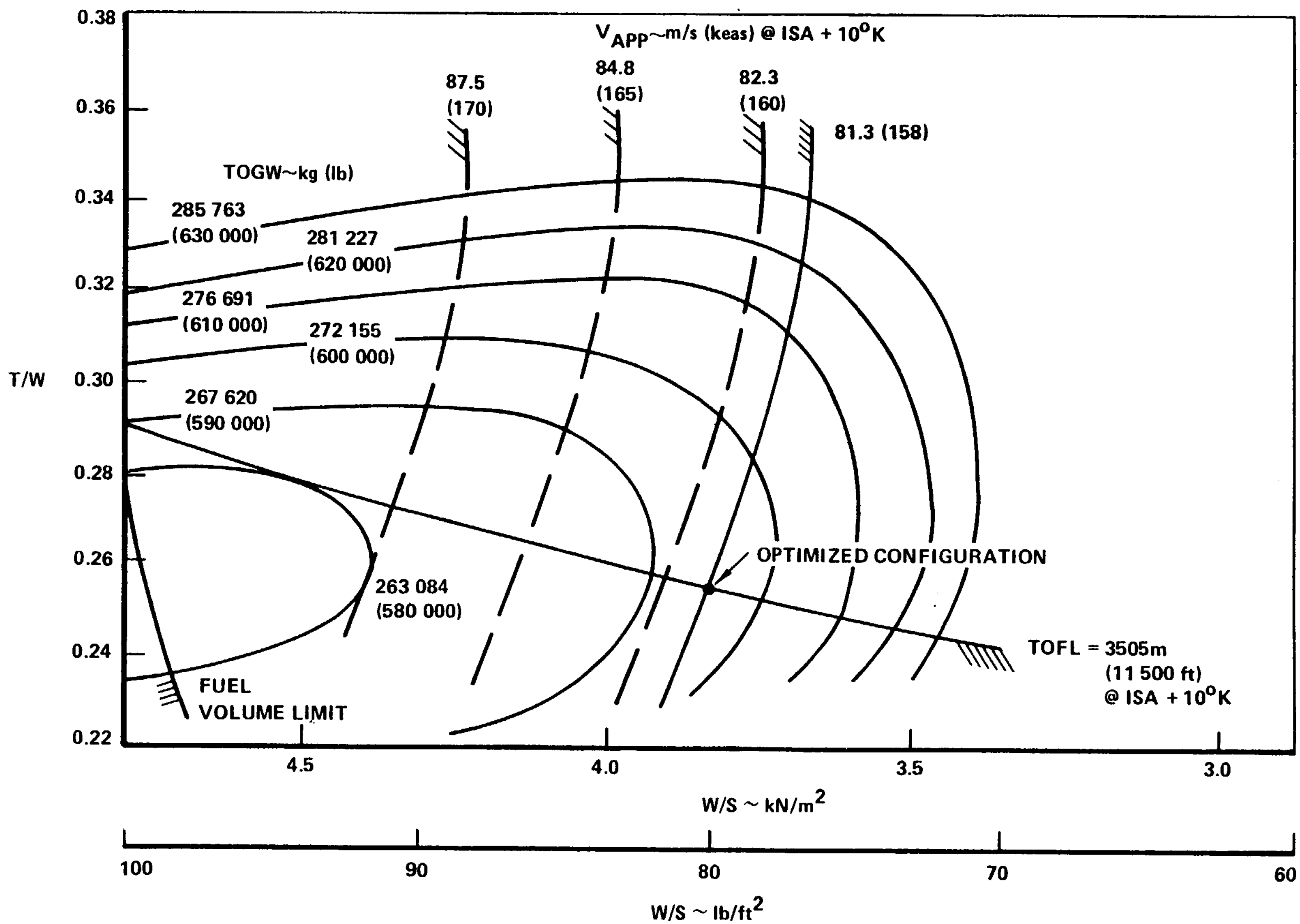


Figure 6. - CL1627-1 TOGW Knothole with constraints.

2.2.4 Thrust Margin at M = 1.15 and Start of Cruise. - A check was made of thrust margin (specific excess power) during transonic acceleration and at start of cruise. Constraints were set for a thrust margin of 0.3 at M = 1.15 and SEP = 1.524 m/s (300 ft/min) at start of cruise. Figures 7 and 8 show that neither of these constraints affect the optimized configuration.

2.3 Definition of Constrained Optimum Configuration

Based on Figure 6 the constrained optimum configuration is defined such that thrust/weight is 0.254 and wing loading is 3.830 kN/m^2 (80 lb/ft^2). Takeoff gross weight is 269 483 kg (594 109 lbm). A detailed listing of aircraft characteristics, in the format required by WG/E, is given in Table 3. A general arrangement drawing of the optimized configuration is shown in Figure 9. Installation drawings of the inboard and outboard engines are shown in Figures 10 and 11. The takeoff profile is shown in Figure 12. Noise levels and DOC are given in Table 4.

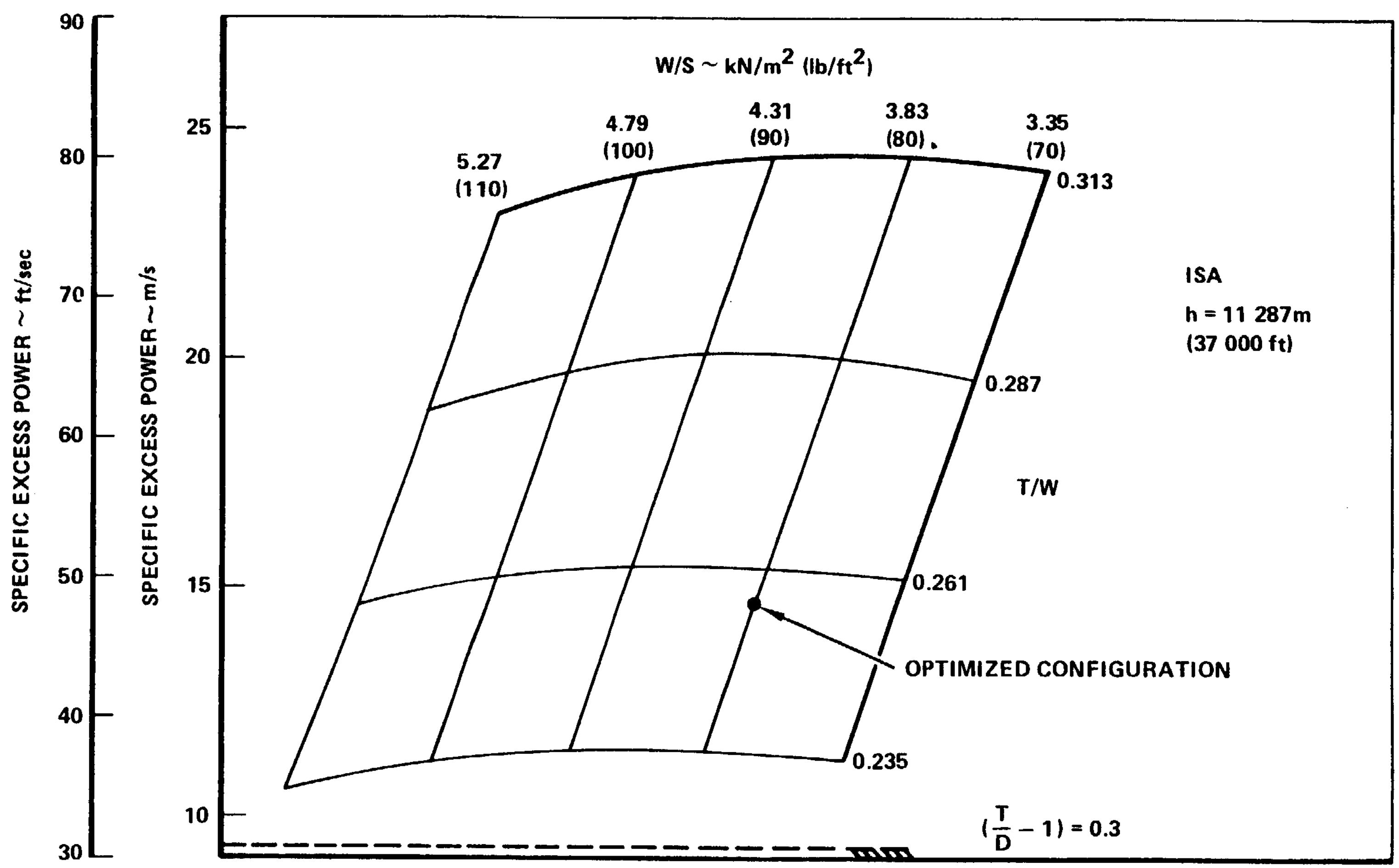


Figure 7. - CL 1627-1 Specific excess power at Mach 1.15.

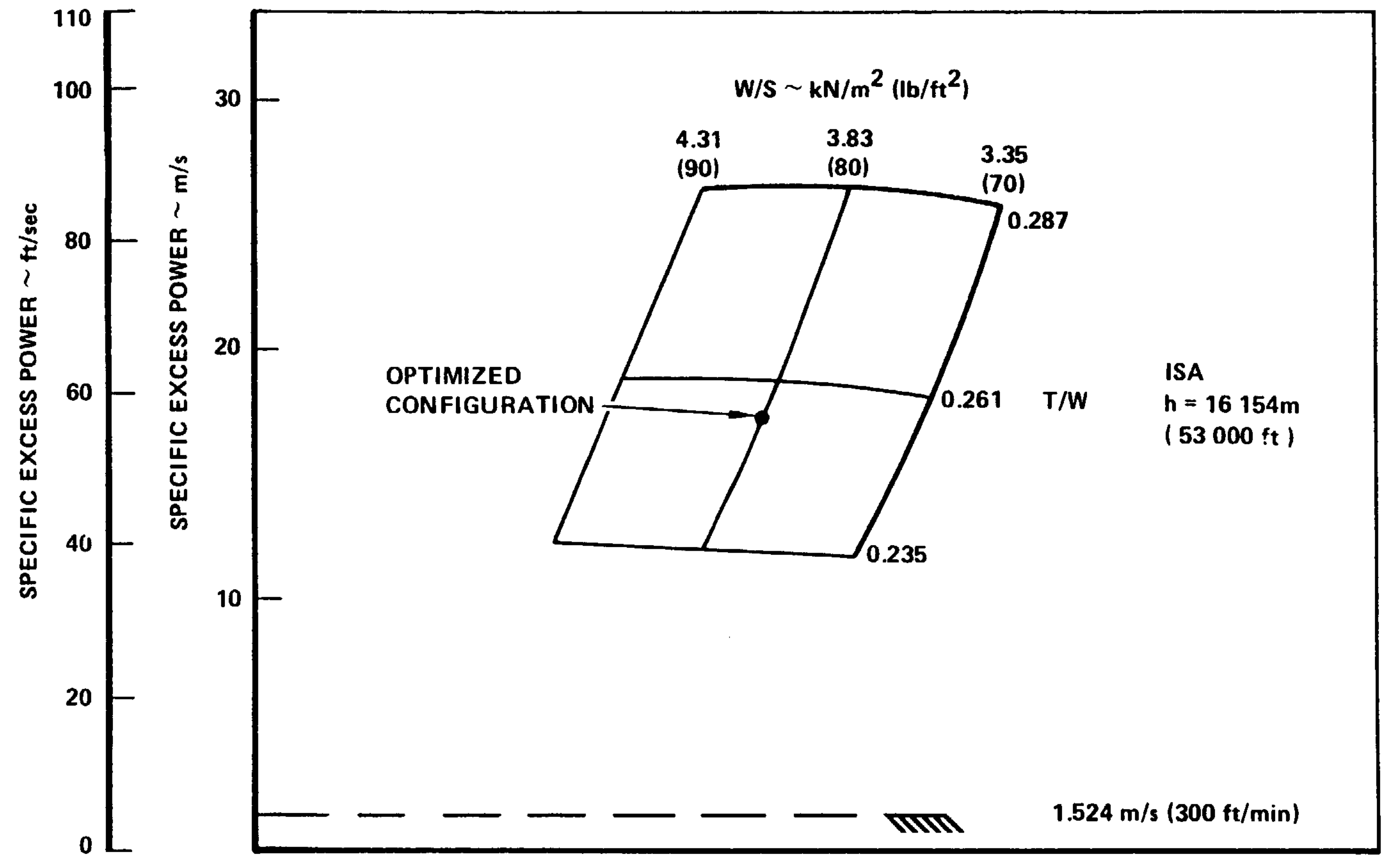


Figure 8. - CL1627-1 Specific Excess Power at Start of Cruise

TABLE 3. - CL1627-1 CHARACTERISTICS OF MINIMUM TOGW AIRCRAFT FOR 7000 km RANGE

Airframe		
Payload kg (lbm)	23 247	(51 250)
Takeoff Gross Weight kg (lbm)	269 483	(594 109)
End of Mission Weight kg (lbm)	156 618	(345 284)
Operating Weight Empty kg (lbm)	116 918	(257 759)
Maximum Tankage Available kg (lbm)		
Wing incl. center section box	132 813	(292 803)
Wing incl. center section box plus aft fuselage	169 327	(373 303)
Wing Area, Gross m^2 (ft^2)	689.9	(7426)
Wing Area, Outside Fuselage m^2 (ft^2)	551.8	(5939)
Aspect Ratio	2.06	
Span m (ft)	37.66	(123.56)
Root Chord m (ft)	40.88	(134.14)
Tip Chord m (ft)	4.77	(15.65)
Taper Ratio	0.117	
MAC m (ft)	25.04	(82.15)
L.E. Sweep root rad (deg)	1.225	(70.2)
L.E. Sweep mid rad (deg)	1.154	(66.1)
L.E. Sweep tip rad (deg)	0.911	(52.2)
t/c Root %	3.2	
t/c Tip %	2.85	
Average Thickness Ratio, $V/S^{3/2}$ %	2.18	
Fuselage Length m (ft)	89.51	(293.7)
Fuselage Diameter m (ft)	3.76	(12.33)
Cabin Diameter m (ft)	3.51	(11.50)
Fin Area m^2 (ft^2)	28.85	(310.6)
Tail Area, Gross m^2 (ft^2)	59.75	(643.0)

TABLE 3. - Continued

AERODYNAMICS

Segment	Lift/Drag Ratio	Lift Coefficient
Midcruise	8.45	0.094
Subsonic Cruise (At start of mission)	9.58	0.368
Hold	14.76	0.200

AIRFIELD PERFORMANCE

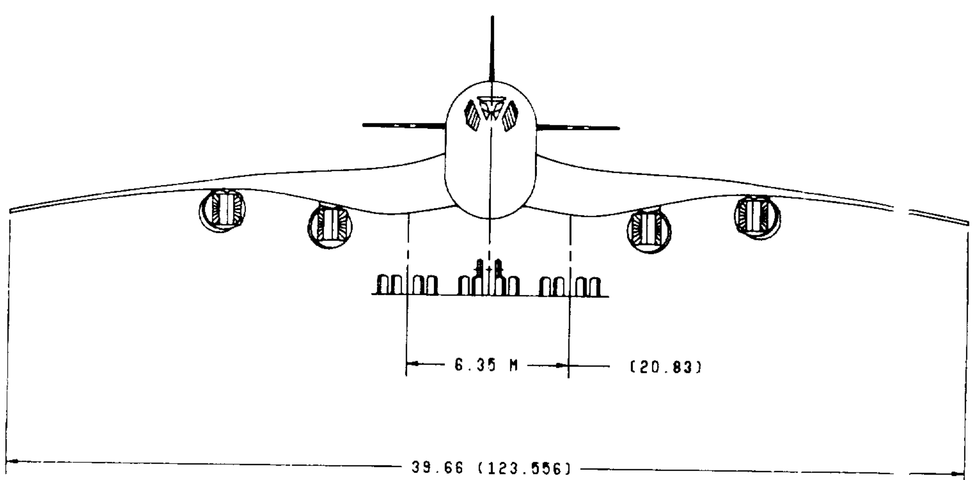
Condition	Speed, m/s (ft/sec)	L/D	Weight kg (lbm)
Screen, 10.67 m (35 ft)	107.1 (351)	5.7	264 531 (583 192)
Cutback	108.8 (357)	6.6	264 028 (582 083)
Approach	81.3 (267)	5.8	156 618 (345 284)

CHARACTERISTICS	WING	TAIL	
		HORIZONTAL	VERTICAL
AREA, SQ. METRES (SQ FT)	689.885 (7426.4)	59.75 (643.02)	28.85 (310.55)
ASPECT RATIO	2.06	1.707	0.517
SPAN, METRES (FT)	37.66 (123.558)	10.10 (33.13)	3.862 (12.67)
ROOT CHORD, METRES (FT)	40.884 (134.136)	9.744 (31.96)	12.144 (39.848)
TIP CHORD, METRES (FT)	4.77 (15.65)	2.21 (7.257)	2.793 (9.168)
TAPER RATIO	0.1167	0.23	0.23
MAC, METRES (FT)	25.044 (82.146)	6.688 (21.938)	8.446 (27.703)
SWEEP, RADIANS (DEG)	1.225(70.2)/1.1535(66.1)/0.911(52.2)	1.025 (58.72)	1.168 (66.91)
T/C ROOT	3.2	3.0	3.0
T/C TIP	2.847	3.0	3.0

GROSS WEIGHT - 269 496 KG (594,109 LBS)

POWER PLANT (4) LBPR TURBOFAN

INSTALLED THRUST - 167 858 NEWTONS (37,736 LBS) M=0.3 SL 30 DEG C



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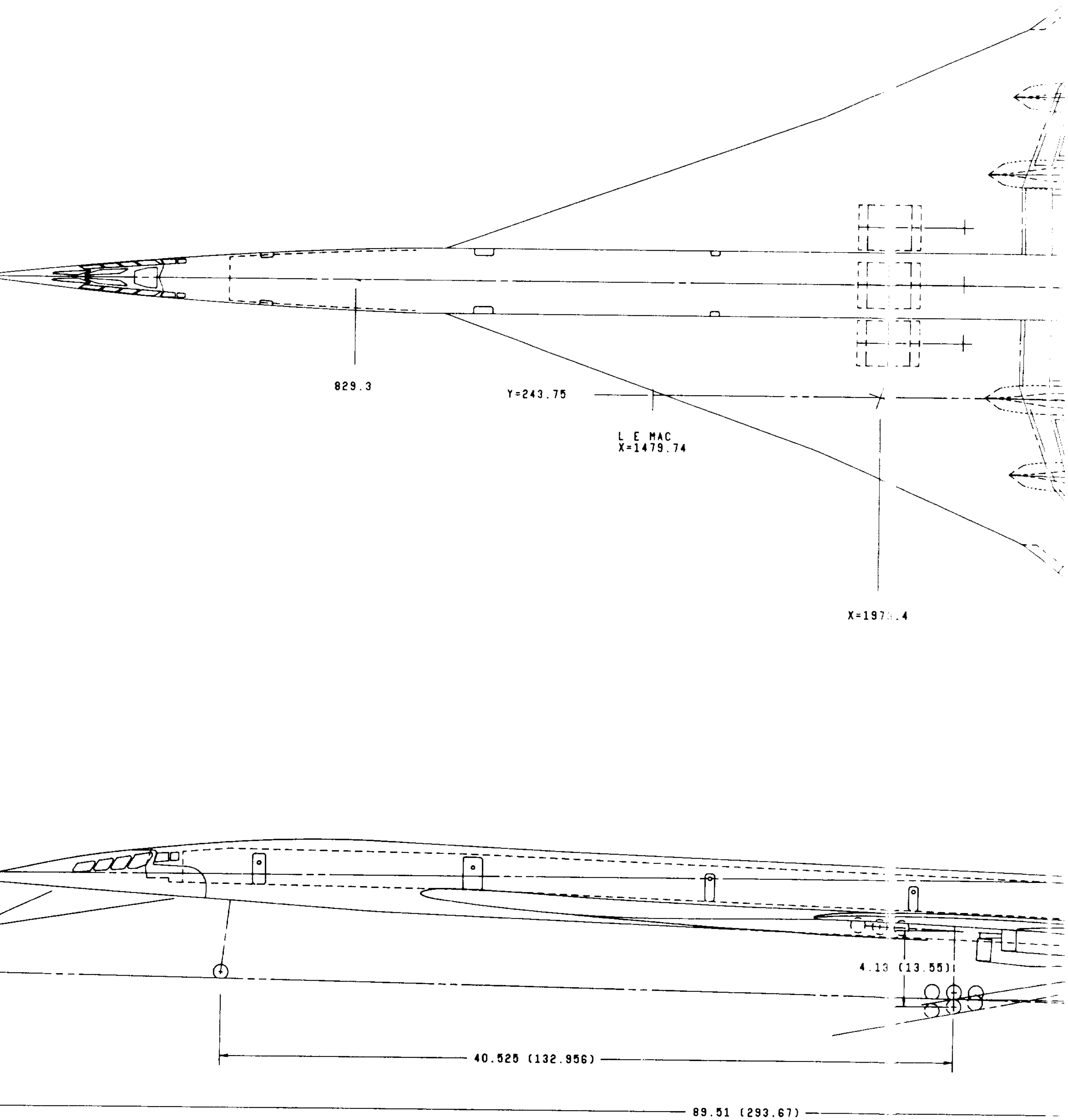
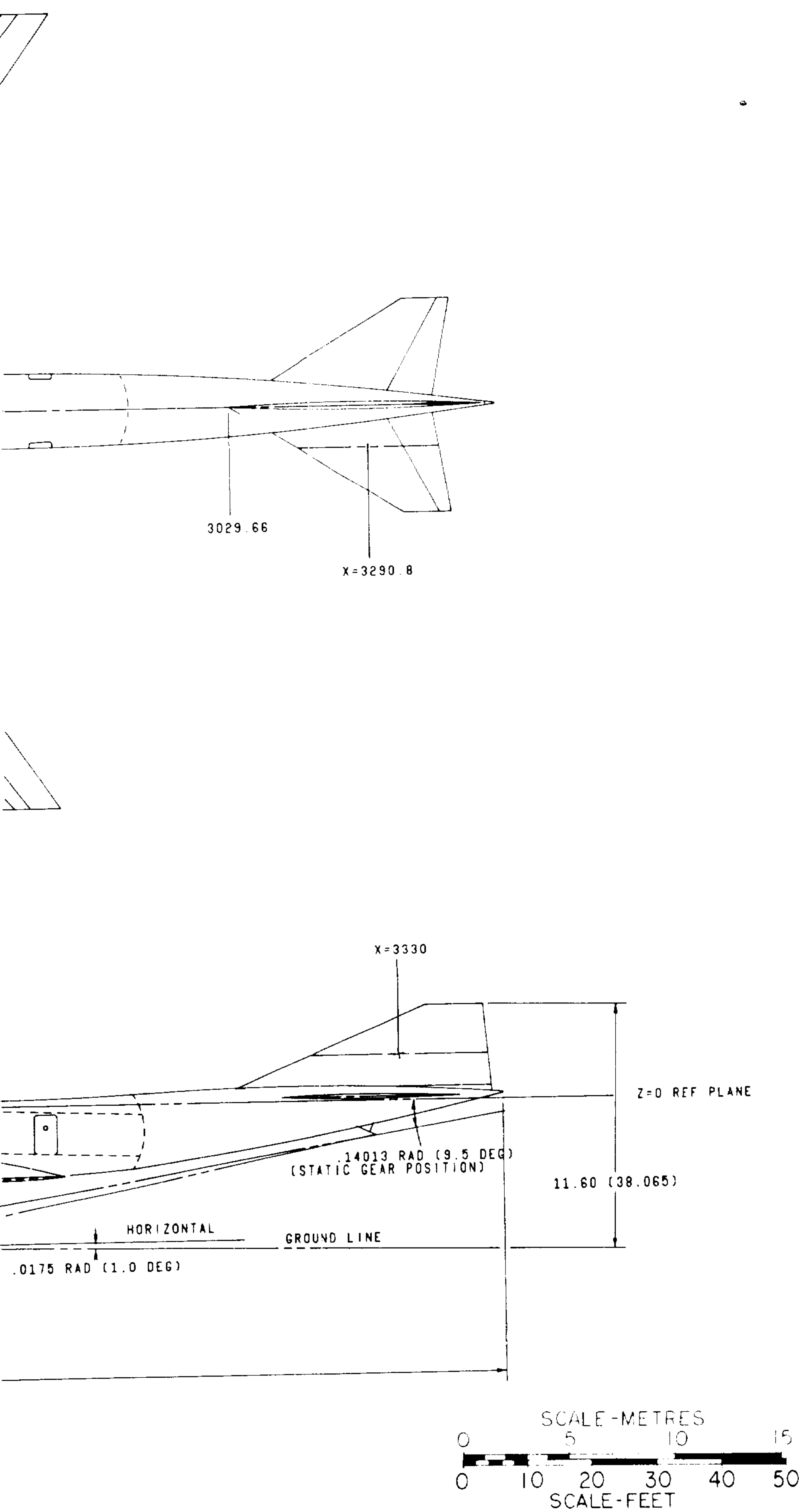
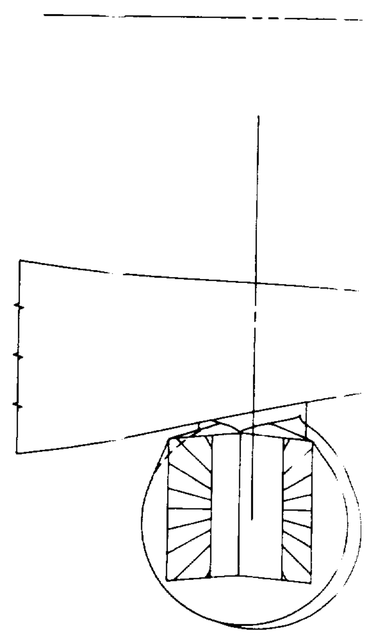

829.3
Y=243.75
L E MAC
X=1479.74
4.13 (13.55)
40.525 (132.956)
89.51 (293.67)

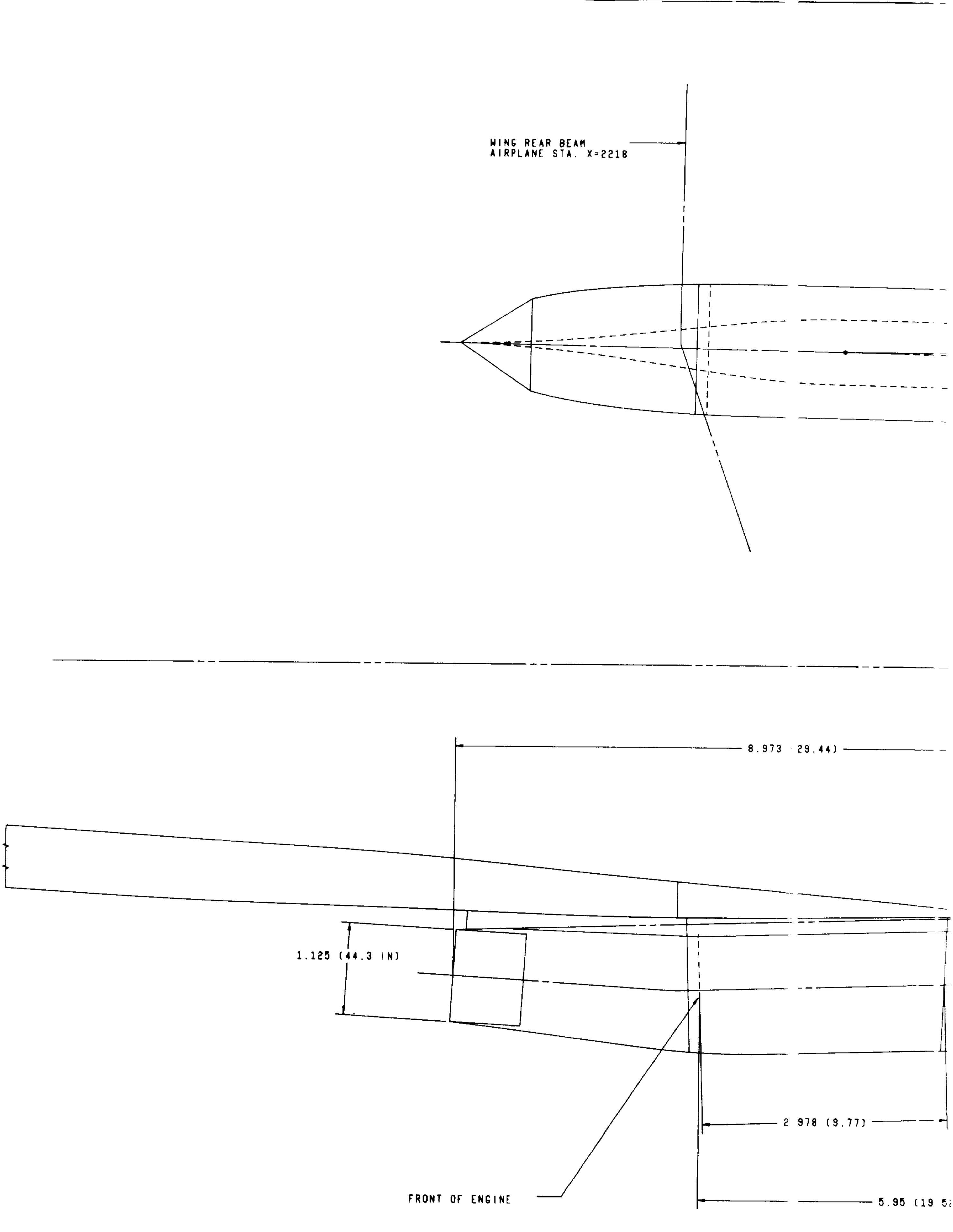


CADAM DWG NO CL1627-1-1,1&,2

DIMENSIONS IN METRES (FEET) OR NOTED.

Figure 9. - CL1627-1 General arrangement.




WING REAR BEAM
AIRPLANE STA. X=2218
8.973 (29.44)
1.125 (44.3 IN)
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FRONT OF ENGINE
5.95 (19 5

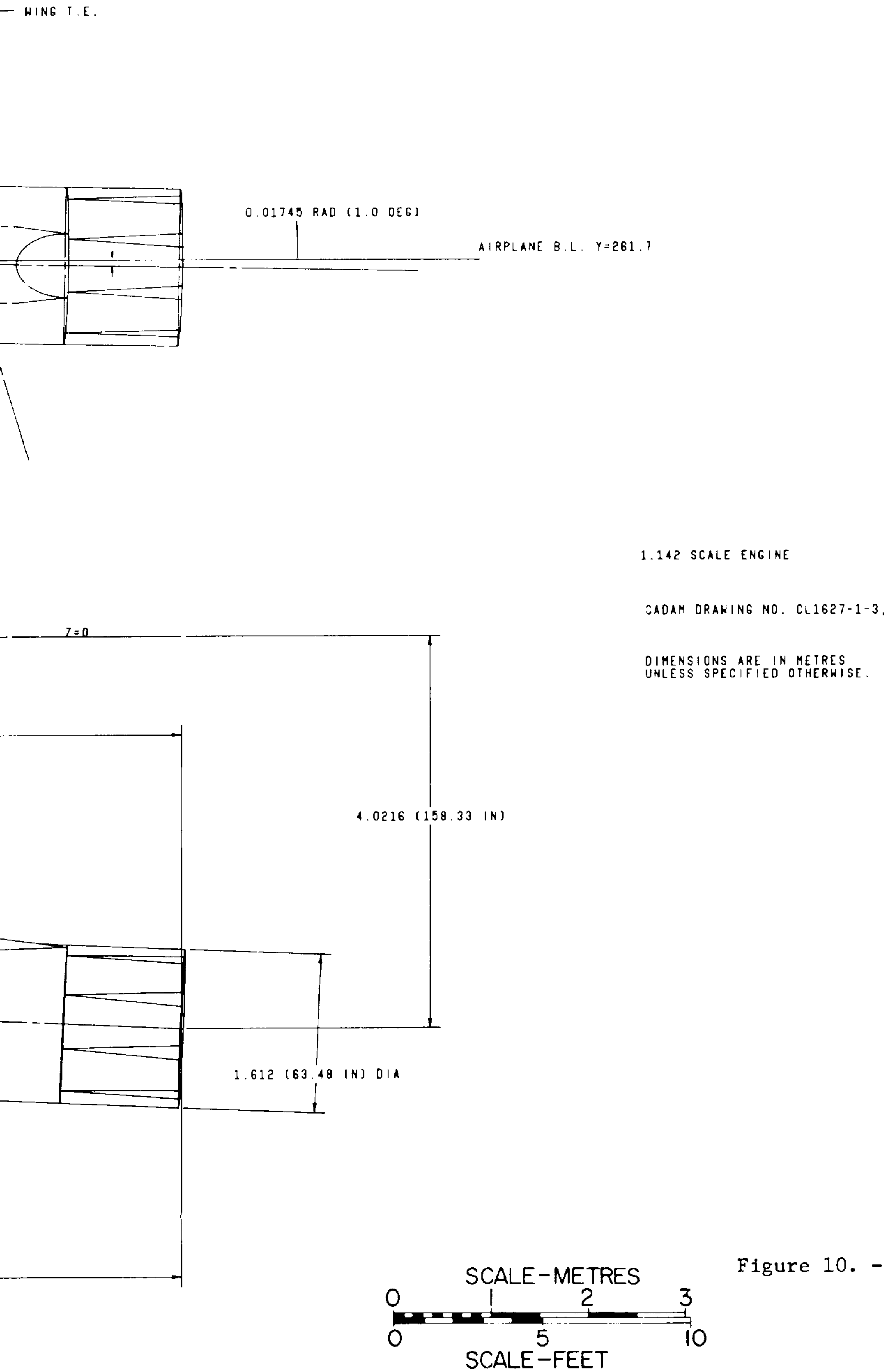
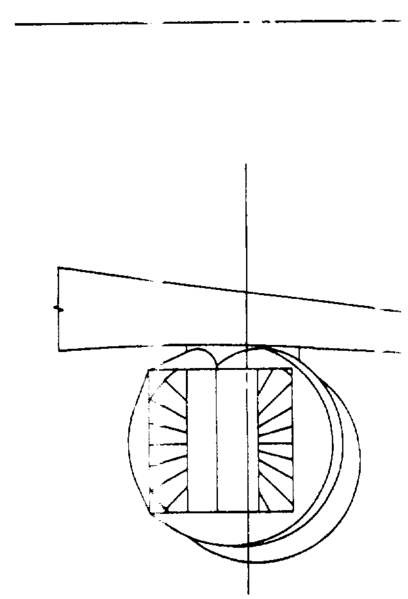
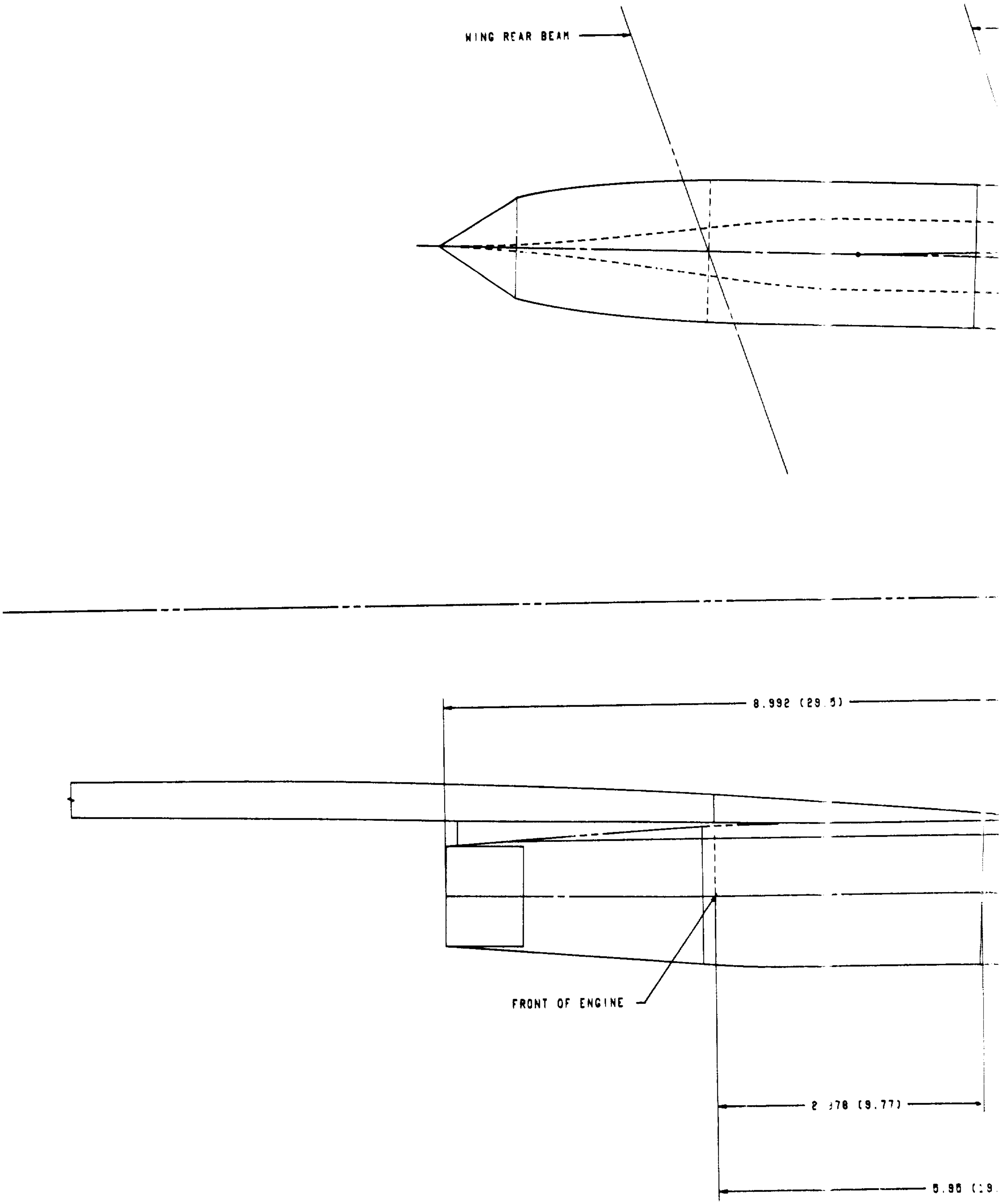


Figure 10. - CL1627-1 Inboard engi
installation.




WING REAR BEAM
8.992 (29.5)
FRONT OF ENGINE
(9.77)

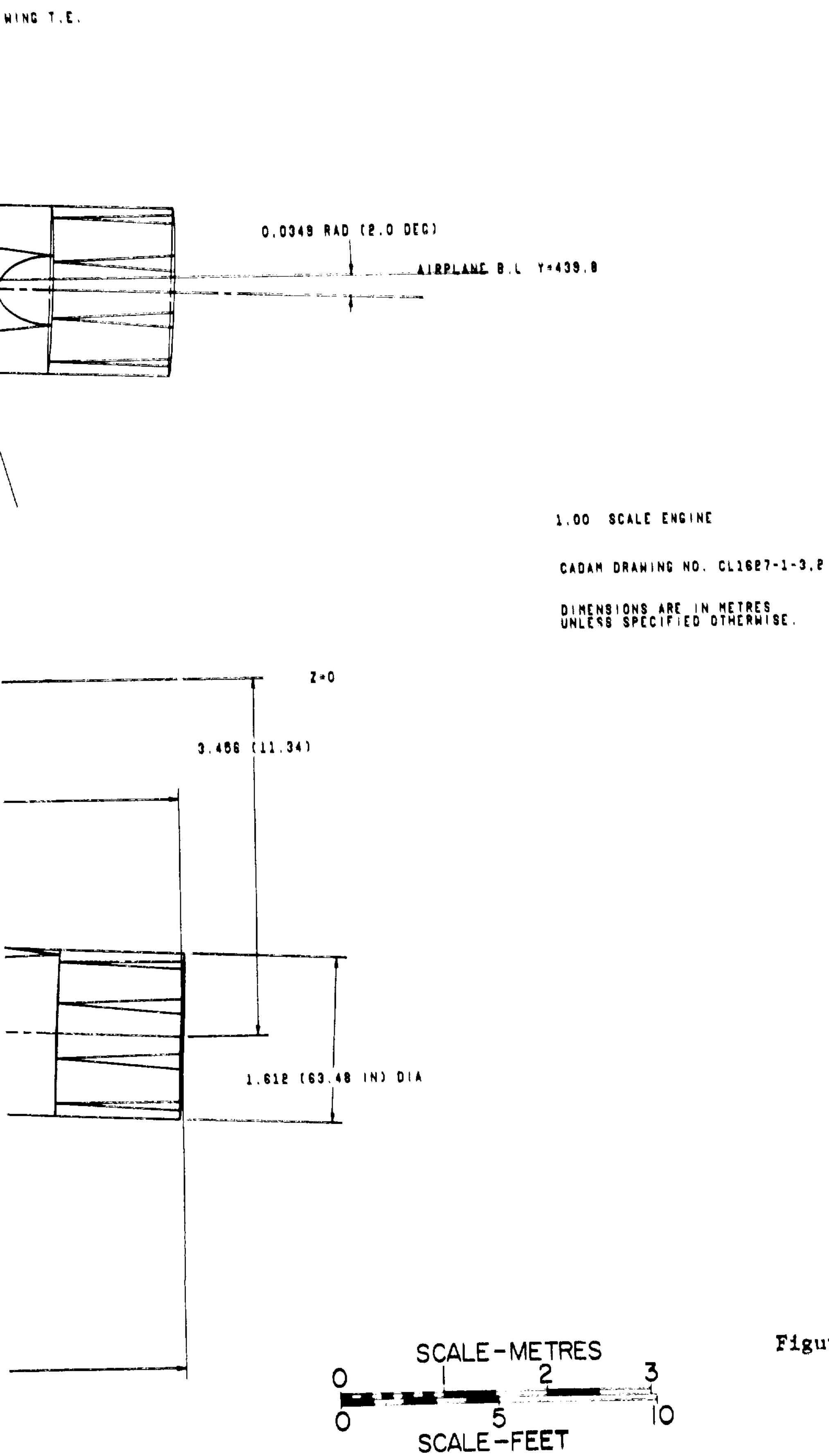


Figure 11. - CL1627-1 Outboard engi installation.

TABLE 4. - CL1627-1 NOISE LEVELS AND DIRECT OPERATING COSTS

Mission:		
	Seats	250
	Design Range	7000 km (3780 n.mi.)
	Cruise Mach No.	2.2
	Bypass Ratio	0.25
	Aspect Ratio	2.06

Stage Length		Load Factor	Take-off			Costs+ ¢/seat km (¢/seat st.mi.) Lockheed Method	
km	n.mi.		Weight* kg (lbm)	Wing Loading N/m^2 (lb/ft^2)	Thrust/wt Ratio	DOC	TOC
7000	(3780)	1.0	269 483 (594 109)	3830 (80)	0.254	1.65 (2.66)	3.12 (5.02)
6000	(3240)	0.6	233 846 (515 543)	3324 (69.42)	0.293	1.60 (2.58)	2.80 (4.51)
7000	(3780)	0.6	252 133 (555 858)	3584 (74.85)	0.272	1.59 (2.56)	2.70 (4.35)
7871	(4240)	0.6	269 483 (594 109)	3830 (80)	0.254	1.60 (2.57)	2.65 (4.27)

Noise Levels: (EPNdB) Sideline - 119.0 at 648 m (0.35 n.mi.)

Flyover - 122.6 at 6482 m (3.5 n.mi.)

Approach - 110.9 at 1852 m (1.0 n.mi.)

*Fuel is off loaded at reduced payload and range

+Costs are normalized by aircraft capacity, not by number of pax. carried

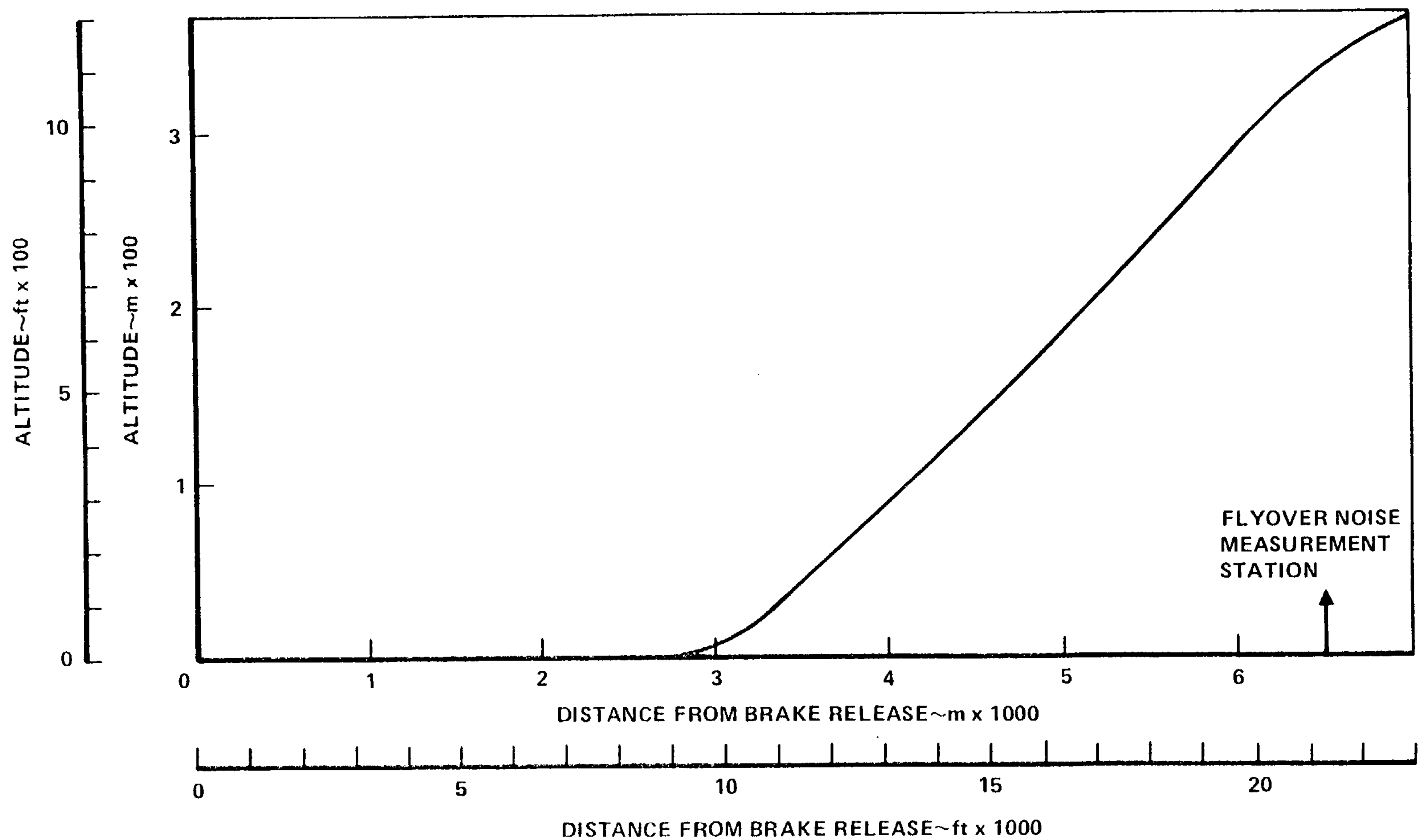


Figure 12. - CL1627-1 and -2 takeoff profile.

3. CONCLUSIONS AND RECOMMENDATIONS

The Lockheed-California Company has completed the synthesis of a supersonic cruise vehicle as a part of the "common case" study to compare characteristics of SSTs designed for the same mission by Lockheed, McDonnell Douglas, British Aerospace, Aerospatiale, and the U.S.S.R. The primary guidelines are ICAO Class II technology, payload - 23 247 kg (51 250 lbm), range - 7000 km (3780 n. mi.), cruise Mach number - 2.2, and takeoff field length no greater than 3505 m (11 500 ft).

The leading characteristics of the Lockheed design are TOGW - 269 483 kg (594 109 lbm), operating weight empty (OEW) - 116 918 kg (257 759 lbm), wing loading (W/S) - 3830 N/m^2 (80 lb/ft^2), thrust/weight (T/W) - 0.254, design point DOC - 1.65 ¢/seat km (2.66 ¢/seat st. mi.), sideline noise - 119.0 EPNdB, flyover noise - 122.5 EPNdB, approach noise - 110.9 EPNdB. A second configuration was designed for a range of 7408 km (4000 n.mi.) with the same values of T/W and W/S. TOGW for this design is increased to 286 537 kg (631 705 lbm). Detailed geometric, aerodynamic and performance characteristics of both designs are given in accordance with study requirements.

The Lockheed supersonic cruise vehicle design should be compared with the designs of the other "common case" study participants in order to calibrate the noise/cost sensitivity studies.

APPENDIX A

CLASS II TECHNOLOGY (1980-1985 Start of Design)

ICAO CAN WG/E TECHNOLOGY ASSESSMENT (10 March 1977)

Airframe Structure	
Primary -	
Composites	No
Titanium	Yes
Advanced Structural Concepts	Yes
Axisymmetric Inlet	Yes
Secondary -	
Composites	Yes
Systems	
Active Controls	Yes
Multiplexed Circulation of Data	Yes
Integrated Systems	Total
New Processing (Miniaturization)	Yes
Integration to Optimize Fuel Consumption	Yes
Powerplants	
Cycle	Turbojet / Low Bypass Fan
Higher TET	$1600^{o}K$
Improved Compressor/Turbine Aerodynamics	Yes
Higher Performance Materials	Yes
Variable Geometry Components	
Conventional	Yes
Advanced	No
Noise Suppression	
Compressor Noise -	
Design (2-3 stages)	Yes
Acoustical Treatment	Yes

APPENDIX A

CLASS II TECHNOLOGY (1980-1985 Start of Design) (Continued)

ICAO CAN WG/E TECHNOLOGY ASSESSMENT (10 March 1977)

Noise Supression

Internal Noise -	
Turbine Design	Yes
Combustor Design	Yes
Hot Treatment	Yes
Jet Noise -	
Primary Nozzle	Yes
Mixed Flow (internal)	Yes
Mechanical Suppressors (Retractable)	Yes
Coannular	No
Installation	No

APPENDIX B

CONFIGURATION AND PERFORMANCE DATA FOR 4000 N.MI. AIRCRAFT

This Appendix contains data for a configuration with the same thrust/weight and wing loading as the optimum configuration for a 7000 km (3780 n mi range. However, this aircraft is resized to fly a design range of 7408 km (4000 n. mi.). Takeoff gross weight is 286 537 kg (631 705 lb). The following tables and figures are given:

Table B-1 CL1627-2 Aircraft Characteristics for 4000 n.mi. range

Table B-2 CL1627-2 Noise Levels and Direct Operating Costs

Takeoff profile is the same as for the CL1627-1 (See Figure 12)

TABLE B-1. CL1627-2 AIRCRAFT CHARACTERISTICS FOR 4000 n.mi. RANGE

Airframe

Payload kg (lbm)	23 247	(51 250)
Takeoff Gross Weight kg (lbm)	286 537	(631 705)
End of Mission Weight kg (lbm)	162 962	(359 270)
Operating Weight Empty kg (lbm)	122 135	(269 261)
Maximum Tankage Available kg (lbm)		
Wing incl center section box	146 392	(322 738)
Wing incl center section box + aft fuselage	182 906	(403 239)
Wing Area, Gross m^2 (ft^2)	733.6	(7896)
Wing Area, outside fuselage m^2 (ft^2)	590.2	(6353)
Aspect ratio	2.06	
Span m (ft)	38.86	(127.5)
Root Chord m (ft)	42.16	(138.3)
Tip Chord m (ft)	4.92	(16.14)
Taper ratio	0.117	
MAC m (ft)	25.82	(84.71)
L.E. Sweep root rad (deg)	1.225	(70.2)
L.E. Sweep mid rad (deg)	1.154	(66.1)
L.E. Sweep tip rad (deg)	0.911	(52.2)
t/c root %	3.2	
t/c tip %	2.85	
Average thickness ratio, $V/S^{3/2}$ %	2.18	
Fuselage length m (ft)	89.51	(293.7)
Fuselage diameter m (ft)	3.76	(12.33)
Cabin diameter m (ft	3.51	(11.50)
Fin area m^2 (ft^2)	31.83	(342.6)
Tail area, Gross m^2 (ft^2)	65.75	(708.2)

TABLE B-1. CL1627-2 AIRCRAFT CHARACTERISTICS FOR 4000 n.mi. RANGE (Continued)

AERODYNAMICS

Segment	Lift/Drag Ratio	Lift Coefficient
Midcruise	8.50	0.092
Subsonic Cruise (at start of mission)	9.60	0.368
Hold	14.95	0.196

AIRFIELD PERFORMANCE

Condition	Speed, m/s (ft/sec)	L/D	Weight, kg (lb)
Screen, 10.67 m (35 ft)	107.1 (351)	5.7	281 275 (620 106)
Cutback	108.8 (357)	6.6	280 778 (619 010)
Approach	81.3 (267)	5.8	162 962 (359 270)

TABLE B-2. CL1627-2 NOISE LEVELS AND DIRECT OPERATING COSTS

Mission: Seats 250

Design Range 7408 km (4000 n. mi.)

Cruise Mach No. 2.2

By-Pass Ratio 0.25

Aspect Ratio 2.06

Stage Length km	Stage Length n.mi.	Load Factor	Take-Off Weight kg (lb)	Take-Off Wing Loading N/m^2 (lb/ft^2)	Take-Off Thrust/wt. Ratio	Costs ¢/seat km (¢/seat st.mi.) Lockheed Method DOC	Costs ¢/seat km (¢/seat st.mi.) Lockheed Method TOC
7408	4000	1.0	286 537 (631 705)	3820 (80)	0.254	1.69 (2.72)	3.14 (5.06)

Noise Levels: EPNdB Sideline = 119.3 @ 648 m (0.35 n.mi.)

Flyover = 122.8 @ 6482 m (3.5 n.mi.)

Approach = 110.9 @ 1852 m (1.0 n.mi.)

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1. Anon; 'The International Standards and Recommended Practices (Aircraft Noise) Annexe 16,' International Civil Aviation Organization, August 1971.

2. Anon; 'Report on Agenda Item 7, Appendix C, Terms of Reference of Working Group E (SSTs),' ICAO CAN/5 - Working Paper #62.

3. Mascitti, V.R.; 'Overview of U.S. Supersonic Cruise Aircraft Research Program (SCAR),' ICAO Committee on Aircraft Noise (CAN), Working Group E, Working Paper #10, March 7, 1977.

4. Hays, A.P.; and Clauss, J.S., Jr.; 'Noise/Cost Sensitivity Studies for a Supersonic Cruise Vehicle with an Over/Under Engine Concept' Lockheed-California Co. Report LR 28598, 30 June 1978.

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