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CONCEPTUAL DESIGN STUDY OF IMPROVED 1985 REMOTE LIFT-FAN V/STOL COMMERCIAL TRANSPORTS

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16. Abstract

A design study has been conducted for a remote lift-fan commercial V/STOL transport for the 1985 time period. The investigation centered on the commercial short haul transportation application to carry 100 passengers over trip distances of 400 nautical miles from a vertical takeoff and landing, and 800 nautical miles after a 1600 foot STOL takeoff.

The scope of the study included investigation of alternate numbers and arrangements of lift fans and gas generators, fan control margins, and structural concepts. The sensitivity of direct operating costs to major airframe parameters, airframe costs, propulsion costs, yearly aircraft utilization rate, and trip distances were evaluated.

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OF
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1985 COMMERCIAL SHORT HAUL TRANSPORTS

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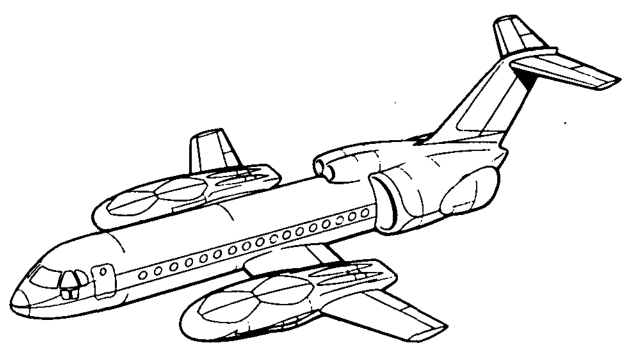
SUMMARY

This report presents results of a study by the Rockwell International Corporation for the NASA Ames Research Center of remote lift-fan commercial V/STOL transports for the 1985 time period. The purpose of the study was to identify the likely technical and operating characteristics and technology requirements for the ultimate development of this type of aircraft. Investigation of aircraft configurations and technologies centered on the commercial short haul transportation application to carry 100-passengers over trip distances of up to 400 nautical miles from a V-mode takeoff, and up to 800 nautical miles after a 1600-foot STOL mode takeoff. Achievement of proper levels at safety, handling qualities, acceptable noise levels and ride qualities were important constraints and goals of the study. Alternate propulsion/control system characteristics, arrangements and design cruise speeds were evaluated.



A promising configuration concept, as illustrated above, using six 1.25 fan pressure ratio remote tip turbine driven fans in the current Boeing 737 class weight and size (approximately 100,000 pounds) was identified. The aircraft is capable of completing the design V-mode and STOL mode trips in about one hour and two hours, respectively. All essential operating requirements were met. Technology developments were identified that would likely allow further improvements in the aircraft characteristics.

INTRODUCTION

The growing population in the United States is beginning to cause severe problems for existing CTOL air transportation systems. The concentrations of people in urban areas has driven the price of land upwards such that further expansion of existing airports is prohibitive in many areas. Airports have become surrounded by population growth and are now coming under attack due to a growing sensitivity of the population to noise, smoke and other types of environmental pollution. Most recently, the identification of a potential long term fuel and energy crisis may reduce the role of the private automobile as the major means for city to city travel and add to the above problems.

The introduction of the larger and quieter wide body CTOL jets appears to be only an interim solution because as traffic grows, airports project complete saturation even if all flights use wide body equipment. A means must be found to unload the growing traffic from the hubs. The many existing smaller airports are potential elements of a solution if aircraft capable of using them without arousing environmental antagonisms can be provided.

Recent developments in projected 1985 quiet lift-fan technology, References 1 and 2, indicate that V/STOL aircraft may be designed with the necessary low noise and steep operating trajectories to allow convenient, safe, high capacity, low annoyance air transport systems to operate within existing or expanded urban areas. These aircraft need minimum runways, thus their operations can be accommodated by space currently not in use for arrivals and departures at existing airports. Where new facilities will be required, the quiet V/STOL systems require less buffer zone acreage to shield flight operations from local populations and the facilities themselves are less expensive because of the minimum runway requirements. The V/STOL steep trajectory capability and use of area navigation, can contribute to more effecient use of airspace surrounding the airports and minimize engine emission pollution in the critical low altitudes.

Earlier NASA sponsored studies have identified remote tip-turbine driven lift-fan systems as having overall advantages relative to integral lift-fans for 1985 commercial short haul V/STOL applications, e.g., Reference 1.

The remote lift fan systems consist of separate fan and gas generator units that may be located contiguous or remotely from each other according to the demands of the individual installation. The remote systems allow more than one fan and gas generator to operate together through a common duct system to provide large amounts of low speed control thrust and provide backup supplies of propulsive gas to retain symmetrical lift after a propulsive system failure. Integral fans have both the fan and gas generator built into the same unit. Control forces from integral fans are achieved by gas generator throttle modulation only. Symmetrical vehicle lift after an intergral unit failure can only be maintained by shut down of a similar unit located in a diametrically opposite location on the flight vehicle. The potential advantages of the integral lift fan units arise from the relatively light weights of individual units and the avoidance of ducting requirements between units.

The purpose of the study reported here is to review further potential remote lift-fan aircraft configurations, propulsion system variations and technology applications for a 1985 V/STOL short haul commercial transport to identify the most promising areas to be pursued for further development.

A basic technology level for 1985 quiet remote tip-turbine driven lift-fan propulsion systems had been established by a NASA funded study for single-stage 1.25 fan pressure ratio systems, Reference 2. To meet the objectives of this study, it was necessary to expand the scope of this basic technology description to provide comparable data for other fan pressure ratios, fan scroll designs and fan designs with alternate amounts of control margin for low speed and hover control power. The contractor provided this expanded propulsion system technology description through the compilation, reduction and application of available trend data and selected supplementary lift-fan propulsion system studies provided by the General Electric Company of Evendale, Ohio.

The scope of the study included investigation of alternate numbers and arrangements of lift-fans and gas generators within the remote lift-fan propulsion system concept, consideration of alternate fan design pressure ratios, and variations in fan control margin for low speed control. A detailed flight control system concept and other advanced aircraft subsystem concepts appropriate for a 1985 commercial transport, emphasizing high dispatch reliability characteristics, were defined. Structural concepts and technology providing a 25 percent weight saving relative to current state-of-the-art all metal aircraft were identified. The effects of alternate design cruise speeds in the range from 0.75 to 0.85 mach number were assessed. The differences in aircraft community noise characteristics as a function of design fan pressure ratio were sampled relative to the noise footprints produced and preliminary time duration effects. The sensitivity of direct operating cost to major airframe design parameters, airframe costs, propulsion costs, yearly aircraft utilization rate and trip distances were evaluated. The final recommended configuration was validated for its estimated weights, performance and low speed and hover control characteristics. Low speed safety, handling qualities, internal and external noise, and ride qualities were evaluated.

The study identified that technology developable by the mid 1980's can provide attractive commercial short haul V/STOL transport aircraft. Selected technology and alternate design guidelines not included in the present study were identified for consideration in future studies because of expected potential to allow further design improvements.

CONTENTS

SYMBOLS

A/C	Aircraft
ACRE	Unit of Land Area, (4046.8564 meter^2)
ADV	Advanced
AIA	Aerospace Industries Association of America
ALT	Altitude
AR	Aspect Ratio
ASM	Available Seat Mile
ATTN	Attendant
C_f	Friction Drag Coefficient Based on Wetted Area
C_{D_P}	Friction Drag Coefficient Based on Wing Area
CG	Center of Gravity
C_L	Coefficient of Lift, L/qS
CRU	Cruise
CTOL	Conventional Takeoff and Landing
DES	Design
DIA	Diameter, ft (0.3048 meters)
	, in (0.0254 meters)
DOC	Direct Operating Cost
e	Drag Due to Lift Efficiency Factor
EOM	End of Mission
EPNdB	Effective Perceived Noise Level, Decibels
ETC	Energy Transfer Control

SYMBOLS (Continued)

°F	Temperature in Fahrenheit, Degrees (5/9 (°F + 459.67))°K
FAR	Federal Aviation Regulations
FPM	Feet Per Minute (0.00508 meters/second)
FPR	Fan Pressure Ratio
FPS	Feet Per Second (0.3048 meters/second)
G, g	Acceleration of Gravity, 32.2 ft/sec^2 (9.815 m/sec^2)
GEN	Generator
GG	Gas Generator
GPM	Gallons Per Minute (0.00006309 meters^3/second)
HVY	Heavy
KEAS	Knots Equivalent Air Speed, Knots (0.5144 meters/sec)
KTAS	Knots True Air Speed, Knots (0.5144 meters/sec)
L/C	Lift-Plus-Cruise Fan
L/D	Lift to Drag Ratio
L/F	Lift-Fan
L_{NOM}	Nominal Lift Thrust Per Fan at Neutral Control, Lb (4.44822 Newtons)
$L_{NOM-MIL}$	Nominal Lift Thrust Per Fan at Neutral Control at the Military Power RPM Setting of the Gas Generator, Lb (4.44822 Newtons)
M	Mach Number
MAC	Mean Aerodynamic Chord, Ft (0.3048 meters)
MAX	Maximum

MIN	Minute or Minimum
MSN	Mission
NM	Nautical Mile(s) (1852 meters)
NOM	Nominal
OPT	Optimum
PAX	Passenger(s)
PNdB	Perceived Noise Level, Decibels
PRESS	Pressure, Psia (6894.75478 Newtons/meter^2)
PWR	Power
Q, q	Dynamic Pressure, Lb/Ft^2 (4.8824 Kg/m^2)
REF	Reference
RPM	Revolutions Per Minute (0.016667 Revolutions/sec)
S, S_W	Wing Area, Ft^2 (0.09290304 meters^2)
SFC	Specific Fuel Consumption, LB FUEL/HR/LB THRUST (0.000028325 Kg Fuel/Sec/Newton Thrust)
SL	Sea Level
SLS	Sea Level Static
STD	Standard
ST MI	Statute Mile(s), miles (1609.344 meters)
STOGW	Short Takeoff Gross Weight
STOL	Short Takeoff and Landing
SYS	System
TEMP	Temperature

TOGW	Takeoff Gross Weight
TJ	Turbojet
T/W	Thrust to Weight Ratio
V/STOL	Vertical/Short Takeoff and Landing
V_s	Stall Velocity, Knots (0.51444 meters/sec)
VTO	Vertical Takeoff
VTOGW	Vertical Takeoff Gross Weight
VTOL	Vertical Takeoff and Landing
W, WT	Weight, Lb (0.45359 Kilogram)
W/S	Wing Loading, Lb/Ft^2 (4.8824 Kg/m^2)
W/W_o	Weight to Takeoff Weight Ratio
$\ddot{X}$	Forward Acceleration Along Flight Path, Ft/Sec^2 (0.3048 $meters/sec^2$)
$-\ddot{X}/g$	Deceleration Along Flight Path, Nondimensionalized to Gravitational Acceleration, g
α	Angle of Attack, Degrees (0.017453 Radians)
γ	Flight Path Angle, Degrees (0.017453 Radians)
Δ	Increment or Incremental
ΔN	Incremental Normal (Vertical) Acceleration Nondimensionalized to Gravitational Acceleration, Acceleration/g
$\Delta N/U_{de}$	Incremental Normal (Vertical) Acceleration per Unit of Atmospheric Gust Velocity, g/Feet Per Second (3.28083 N/meters per second)
ΔC_D	Incremental Drag Coefficient Based on Wing Area

SYMBOLS (Concluded)

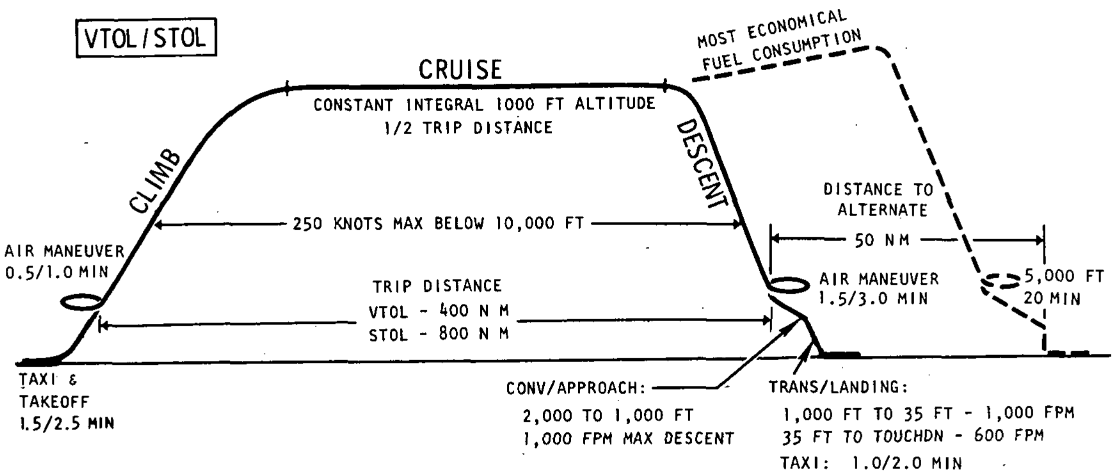
ϕ	Bank Angle, Degrees (0.017453 Radians)
θ_1	Pitch Angle After 1 Second, Degrees (0.017453 Radians)
$\ddot{\theta}_o$	Pitch Acceleration at Time Zero, Radians/Sec^2)
τ_{FAN}	Fan Control Force Response Time Constant (Time to reach 63% of final value), Seconds
τ_{SYS}	Control System Control Force Response Time Constant (Time to reach 63% of final value), Seconds

ILLUSTRATIONS

TABLES

STUDY GUIDELINES & CRITERIA

The majority of the projected short haul commercial V/STOL transportation market for 1985 is projected to be represented by trip distances less than 400 nautical miles. However, longer range capability may be necessary for efficient integrated airlines fleet operations during the market buildup period. To accommodate these two major considerations, the study design short haul mission was established as summarized in Figure 1.



- PAYLOAD - 100 PASSENGERS
- COMMUNITY NOISE - 95 PNdB 500 FT SIDELINE
- RIDE QUALITY - GUST SENSITIVITY VS ALTITUDE
- STRUCT MAT'LS - COMPOSITES, 25% WT SAVING
- SELECTED EQUIP, OPER & DESIGN REQMTS

Figure 1. Study Mission Performance & General Design Requirements

The design mission requirements indicated in Figure 1 provide for transport of 100 passengers with baggage over distances of 400 nautical miles using the VTOL mode exclusively. Longer trips, up to 800 nautical miles, are made using the STOL mode with a maximum required runway length of 1,600 feet. The desired design cruise speed for these trips is in the 0.75 to 0.85 mach number range to keep productivity and passenger satisfaction high. The reserves reflect the relatively larger number of alternate operating bases or safe landing areas available to a VTOL capable aircraft and contibute to more economical operations.

To provide acceptably quiet operating characteristics for use at VTOL and STOL ports near high density population areas, the study design goal was a 95 PNdB 500 foot maximum sideline noise level for the total aircraft.

Since many of the short haul flight operations would be conducted in the turbulent air of the lower altitudes, minimum vehicle ride quality goals were established in terms of allowable vertical acceleration per unit of atmospheric gust velocity, i.e., g/fps. The goals were made variable with altitude and set more stringent at the lower altitudes. Other passenger comfort criteria established included minimum cabin noise, aisle width, seat width and pitch, permissible cabin attitude angles, passenger service facilities and carry on baggage provisions.

Major study design guidelines were devoted to specifying low speed handling qualities and operating safety characteristics:

- Attitude Control Power
- Flight Path Control Power
- VTOL Control System Response Time
- Hovering, Low Speed and Cruise Stability
- VTOL Takeoff and Landing Safety Criteria
- STOL Takeoff and Landing Safety Criteria
- Conversion Requirements

These criteria were established to assure adequate low speed control and speed and angle of attack margins to accomodate gusts and their associated large angle of attack changes when flying at very low speeds. The criteria covered both normal and failure mode operations. Failures considered were fans, gas generators, and any single critical control system component. Specifications were provided for the special considerations of ground effect, crosswinds, gusts, CG travel, and the need for simultaneous control in more than one axis. Special performance requirements were established for takeoff and waveoff climbout gradients and steep approach simultaneous descent and deceleration capabilities.

An important study guideline was to define the structural concepts, technology and mass properties of the vehicle consistent with achievement of a 25 percent structural weight saving relative to current state-of-the-art metal aircraft using advanced 1985 composite materials.

Special study guidelines were provided to facilitate preliminary direct operating cost (DOC) estimates of the study aircraft consistent with the conceptual nature of the study. The direct operating cost methodology established by the Aerospace Industries Association of America, Reference 3, provided the basis of this methodology. Selected constants and specific guidelines for the input of propulsion system costs were provided. Minimum and maximum ranges of selected parameters were specified in some cases to survey the sensitivity of DOC to the parameters.

SELECTED CONFIGURATION

Based on the results of the trade studies, a 1.25 FPR six fan/six gas generator propulsion system using the same basic fan design for both lift fan and lift/cruise fan applications was selected. A design cruise speed of 0.75 mach number was selected based on the lower aircraft weight and direct operating costs projected relative to higher design cruise speed designs.

Concept Definition

The final selected aircraft configuration concept is illustrated in figure 2. The air vehicle is about the size and weight of the contemporary

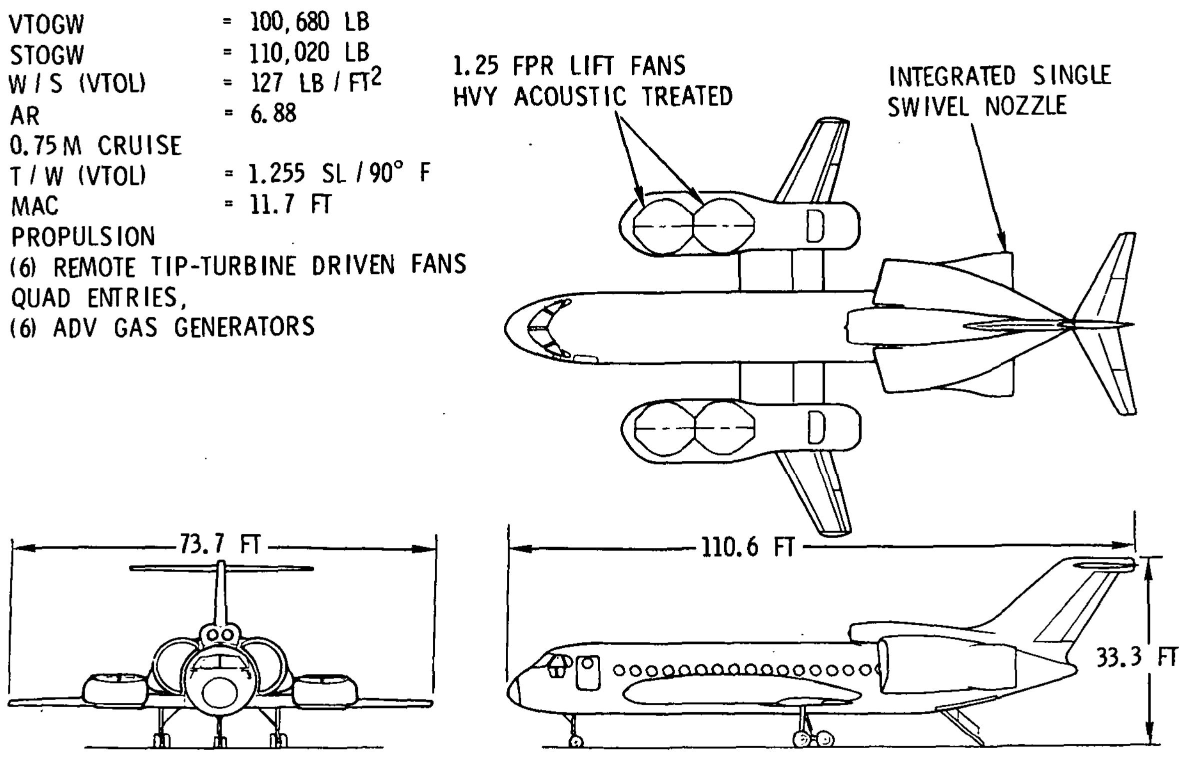


Figure 2. Selected Aircraft Configuration Concept

Boeing 737 short haul jet airliner. The fuselage is slightly longer but the wing span is considerably shorter. The wing area of 790 ft^2 provides a takeoff wing loading of 127 lb/ft^2 at the VTOL mission takeoff weight and 139 lb/ft^2 at the STOL mission takeoff weight. The horizontal and vertical tail areas are 170 and 223 ft^2, respectively. The total aircraft wetted area is approximately 7100 ft^2.

The propulsion system consists of six identical 1.25 FPR remote lift fans and gas generators and the associated ducting and control elements to provide low speed propulsive lift, control and symmetrical thrust after a failure of any major component. In the lift-fan installations, at the 30-minute (military) power setting, SL/90°F day conditions each fan/gas generator unit produces 21,811 pounds of nominal thrust. In the lift-cruise installations each unit produces 19,566 pounds of thrust because of the differences in the installations losses. The integrated single swivel lift-cruise nozzle allows thrust to be directed downward for the V-mode, forward for inflight and ground deceleration and aft for cruise. The level of thrust provides an installed vehicle T/W ratio of 1.255 for the above nominal SL/90°F conditions. The lift and lift-cruise fans use quad flow entries to the fan scroll to reduce overall fan diameter and save wing pod and lift-cruise nacelle wetted area and structural weight. The wing pod location of the lift-fans makes it easier to control the internal cabin noise to the guideline requirements.

Figure 3 illustrates the internal cabin arrangement and typical cross-section. The cabin provides seating for 100 passengers in three by three, six abreast seating with 34 inch pitch between seats. Folding tables are

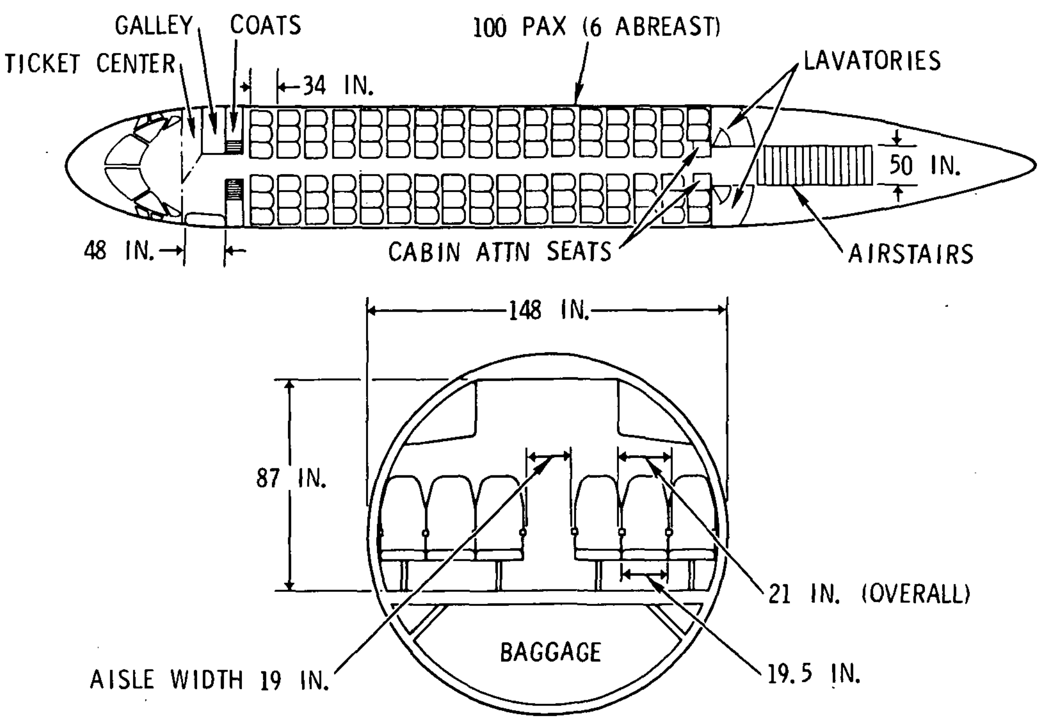


Figure 3. Passenger Cabin Arrangement

provided for each seat. Space is provided for carry-on items storage in overhead racks and under the seats. The interior dimensions of the configuration are comparable to the contemporary Boeing 737 jet airliner. A ticket center, galley, coat racks and magazine racks are provided in the forward part of the cabin. Two lavatories are provided in the rear. Double width doors with airstairs are provided at both ends of the cabin to speed loading and unloading of passengers. Approximately 500 cubic feet of baggage or cargo storage area is provided in the fuselage below the cabin floor.

Propulsion/Hover Control

Because the propulsion system and low speed/hover control system are an integrated system they are discussed together in this section.

System description. - The system utilizes six equal-size fans remotely driven by the exhaust gas flow from six equal-size turbojet gas generators. This system is schematically shown in figure 4 and consists of three separate duct systems. Each separate system consists of a pair of fans and gas gener-

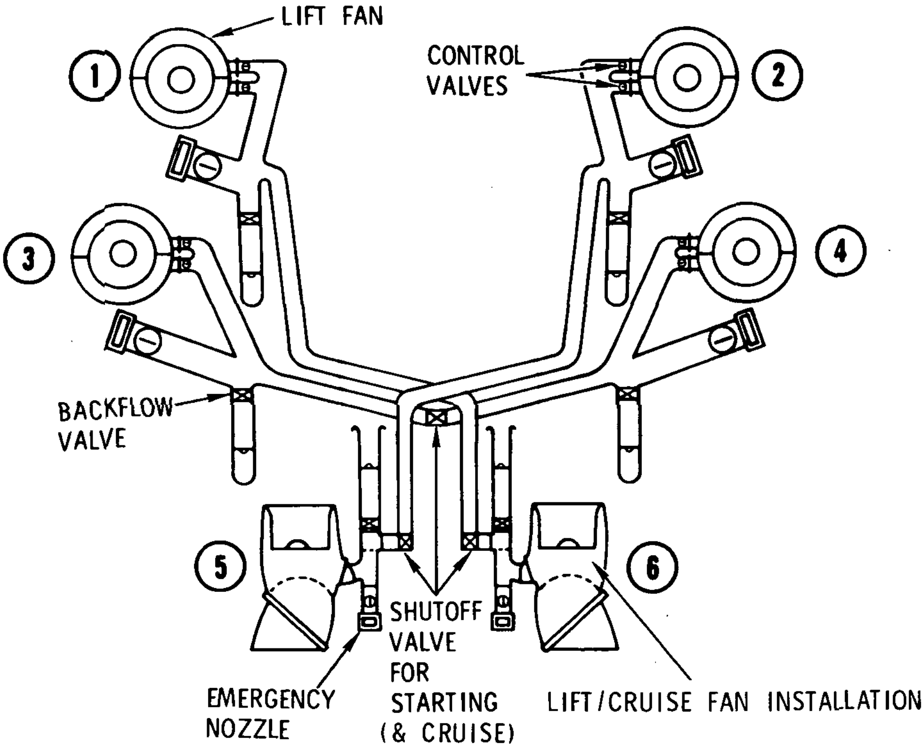


Figure 4. Propulsion/Hover Control System Schematic

ators joined together by a common interconnect duct. This arrangement of fans and gas generators, with the appropriate fan control/shutoff valves, uses the energy transfer control (ETC) method to provide differential fan thrust for air vehicle control during the V/STOL mode of operation. Fans 1 through 4 are lift fans and fans 5 and 6 are lift/cruise fans. Fans 1 and 3 are located in the left wing pod, 2 and 4 in the right wing pod, and 5 and 6 are in integrated nacelles located on the aft upper portion of the fuselage.

Each fan in the system has a design fan pressure ratio of 1.25 and a design control margin of 9.3 percent. Control margin is defined as the percent by which the maximum thrust attainable during maximum control excursion exceeds the nominal (neutral control) thrust at the military power (30-minute rating) RPM rating point. This level of control margin is based on consideration of the practical SL/90°F fan and gas generator RPM and temperature operating limits. Figure 5 presents the available control margin as a function of power setting presented as a function of the ratio of the nominal thrust at the power setting of interest to the nominal thrust at the military power RPM rating point during SL/90°F ambient conditions.

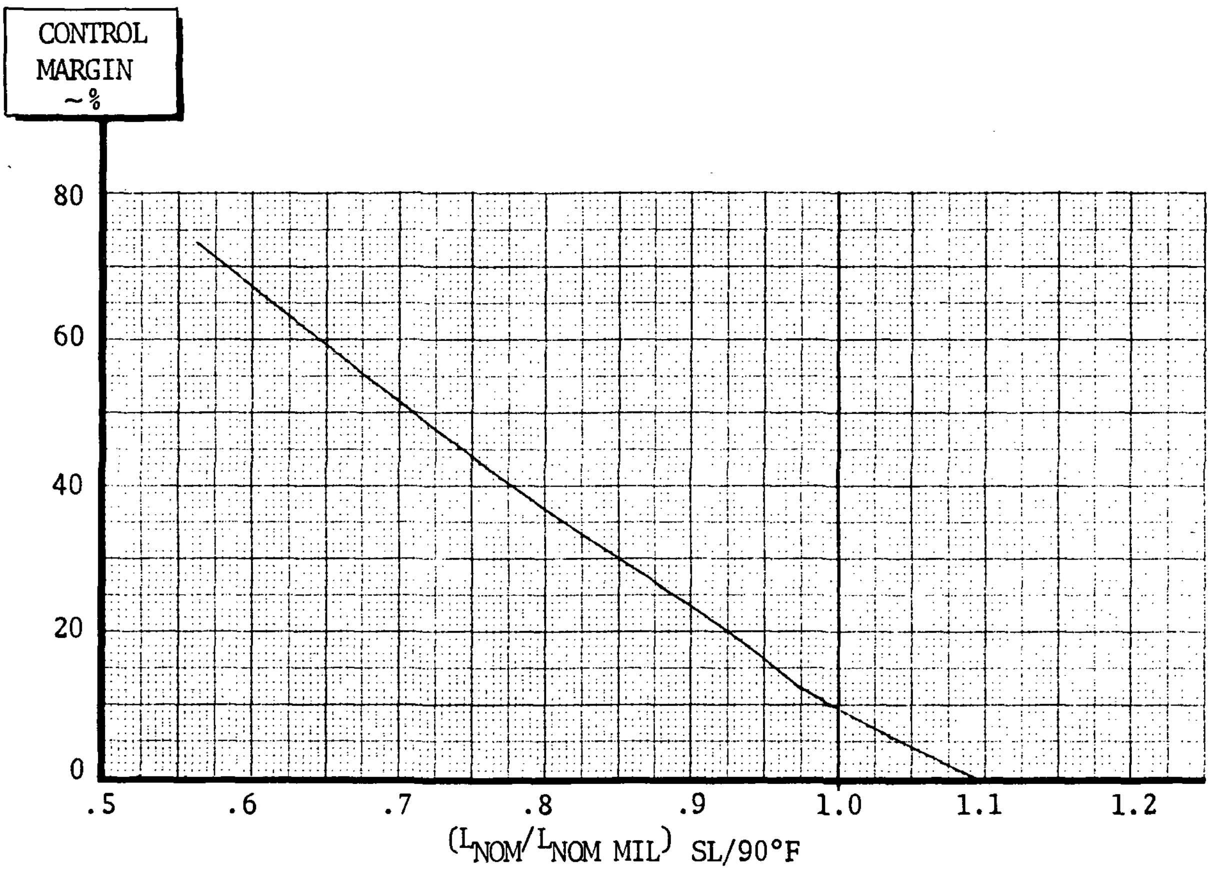


Figure 5. Control Margin Versus Power Setting

Each of the four lift fans incorporate four acoustic splitter rings corresponding to a heavy acoustic treatment to reduce takeoff and landing noise. During normal operation of the fans, each fan is designed to operate with a 360 degree admission arc and the entire gas flow from its corresponding advanced gas generator. Each half of the fan scroll arc is fed by two entries of a quad fan entry system as described in the Propulsion Technology section of the report. One control valve modulates the flow to each half of the fan scroll from a position upstream of flow split required to form the two entries on each side.

The exits of the lift fans are equipped with a louver system that deflects the thrust through a range of ±40 degrees from the axis of the fan during V/STOL mode operations and which close off the lower surface of the fan cavities during the cruise mode. The thrust deflection system selected for use with the lift/cruise fans is an integrated single swivel design evolved independently by the contractor as a part of an in-house V/STOL research program. This single swivel nozzle design is capable of vectoring from a position straight aft to straight down, to 40 degrees forward of the vertical to provide the reverse thrust required for steep decelerating flight paths. Pitch and roll control are achieved by use of ETC between opposing fans in the pairs that can cause differential moments on these axes. Yaw control is achieved by differential lift-fan louver angle and lift-cruise nozzle deflection on opposite sides of the vehicle.

The inlets of the lift/cruise gas generators and fans are designed for efficient operation at cruise speeds up to 0.75 M. They contain acoustic treatment to reduce the takeoff and landing noise.

In event of a gas generator failure, the remaining gas generator in each separate duct system provides 50 percent of its gas flow to each of the two fans in the system. This is accomplished by closing one control/shutoff valve to each fan such that each fan then operates with a 180 degree admission arc.

During a fan failure condition, the remaining fan of a pair is also operated on 50 percent of its gas generator flow with a 180 degree admission arc. The remaining 50 percent of the gas flow passes through the interconnect duct and joins the full gas flow of the opposite gas generator, for a total gas flow of 150 percent, and is discharged through a convergent emergency nozzle located in the vicinity of the failed fan. The thrust at the simple emergency nozzle with 150 percent flow is only about 2 percent higher than the thrust of the opposite fan operating at 50 percent flow, thus a moment balance after a fan failure is easily achieved. The emergency nozzles are vectorable to enhance the thrust control modulation available during the VTOL and STOL mode after a fan failure.

The hot gas ducting illustrated in schematic form in figure 4 has three basic duct sizes. The major portion of the duct system is interconnect ducting designed to conduct 55 percent of the gas flow from one gas generator. This size duct will handle the emergency plus control flow transfers. Small portions of ducting immediately downstream of the gas generator are designed for the full gas generator flow, and the ducting leading to the emergency nozzles accommodates the equivalent of 150 percent of the gas flow from one gas generator. The ducting is a unique light weight system of a fail-safe design developed independently by the contractor.

The gas generators employed in the system are representative of advanced gas generators having gas producing characteristics similar to a J97 but having significantly lighter weights due to the use of advanced 1985 material/structural technology. At the nominal S.L. static standard day power setting, each gas generator in the selected propulsion system supplies 122.7 lb/sec gas flow at 52.9 psia and 1373°F. During maximum control excursion the maximum gas temperature may reach 1600°F momentarily. These gas generators have an overall pressure ratio of about 13.0 and a design turbine inlet temperature of about 2034°F.

The thrusts produced by the lift-fans at their 30-minute (military) power nominal thrust on a SL/90°F day is 21,811 pounds. The thrust of the lift-cruise fans operating through the integrated single swivel nozzles is 19,566 pounds. The fan tip diameter of each fan is 90.15 inches.

System operation. - Due to the tailoring of the available system control margin to the vehicle characteristics to minimize weight, as presented in figure 5, all of the normal and emergency propulsion/hover control system operating points require less than the military power setting on the gas generators. Design of the system in this manner permits lighter fans than otherwise required and reduces the gas generator maintenance requirements. During normal operations at heavy weights or emergency operations at light weights, the system operates at power settings from 70 to 87 percent of military power where the control margin is from 27 to 52 percent of the nominal thrust. This level of lift control margin is adequate to comfortably exceed all the guideline hover control power requirements for these operations.

The system will only need to operate at power settings of 95 to 97 percent of military power for emergency operations at heavy weights in the V/STOL mode. Because of the characteristics of the system, as shown in figure 5, only the high power setting operations are potentially critical from the hover control power viewpoint. Table 1 presents a summary of results of the hover control power analysis of representative design conditions of the finally selected configuration. The VTOL hover control analysis data of Table 1 were developed for an aircraft weight slightly higher than the final VTOL weight for the selected aircraft, hense the results indicated are conservative. The table shows the control power available versus requirements for both the roll and pitch axes as a function of the flight load factor, center of gravity position, operating mode (failure case) and direction of the control motion desired. The nomenclature for the failure cases indicate a fan failure with the letter "F" and a gas generator failure with the letters "GG". The number following the letters designates the fan position of figure 4 whose component is affected by the failure. To establish control directions, left wing up (LWU) and nose up (NU) are designated to be positive in the roll and pitch axes, respectively.

Consideration of the data of Table 1 show that all design guideline requirements are met and that the hover control power requirements for normal operations (no failures) are easily met for all design conditions. The outlined critical failure cases are related to higher power setting flight conditions where a positive 1.05g flight path control maneuver is being commanded simultaneously with attitude control. The critical conditions are a lift-cruise fan (F5) or a front lift-fan gas generator (GG1) failure during a nose up control requirement in the pitch axis with maximum forward CG. The roll axis was not critical for any cases. Earlier analyses of the attitude control power requirements during the STOL mode had shown these requirements to be less stringent than the VTOL requirements due to the available assistance from aerodynamic controls.

TABLE 1. HOVER CONTROL ANALYSIS SUMMARY

(TOGW = 101,965 LB)

LOAD FACTOR	FAILURE CASE	ROLL CONTROL POWER REQD ~ RAD/SEC^2	CONTROL POWER AVAILABLE ~ RAD/SEC^2						PITCH CONTROL POWER REQD ~ RAD/SEC^2
			ROLL		PITCH				
					FWD CG		AFT CG		
			LWU (+)	LWD (-)	NU (+)	ND (-)	NU (+)	ND (-)	
1.1	NONE	0.3	1.54	-1.54	.283	-.640	.369	-.554	.165
1.0		0.6	1.91	-1.91	.408	-.739	.486	-.661	.33
0.9		0.3	1.97	-1.97			.511	-.672	.165
1.05	GG1	0.15	0.369	-1.01	$\boxed{.102}$	-.268	.184	-.186	$\boxed{.10}$
0.90		0.15	1.194	-1.74			.388	-.396	.10
1.05	GG3	0.15	0.369	-1.013	.198	-.211	.280	-.129	.10
1.05	F1	0.15	0.577	-0.886	.149	-.240	.231	-.158	.10
0.90		0.15	1.394	-1.653			.433	-.377	.10
1.05	F3	0.15	0.378	-1.037	.142	-.280	.223	-.198	.10
1.05	F5	0.15	0.773	-0.697	$\boxed{.100}$	-.327	.180	-.245	$\boxed{.10}$

Cruise Mode Lift to Drag Ratio. - The cruise lift/drag ratio is presented in figure 6 for a representative cruise Mach number and altitude. The maximum value for this ratio is 10.07. This order of magnitude is typical for aircraft having a small span in comparison to the square root of the total friction area.

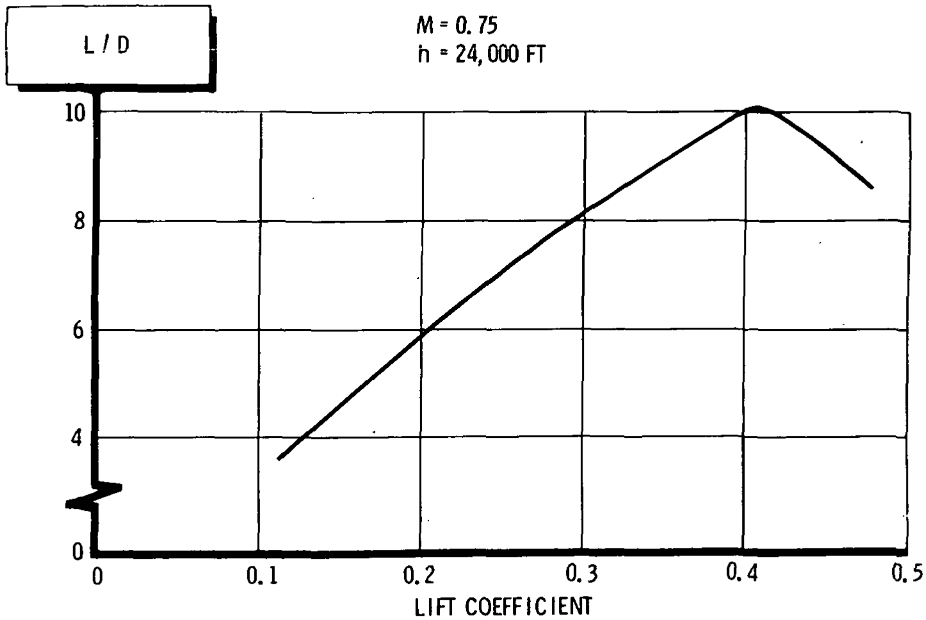


Figure 6. Cruise Lift To Drag Ratio

The major components of the drag build up are presented in figures 7 through 11. Figure 7 presents the friction drag portion of parasite drag. The friction drag coefficient based on wetted area, C_f, was computed to be 0.0035 based on the total friction area. Figure 8 presents the louver, separation and upsweep drags of the configuration. The separation and upsweep drags were kept to a minimum by careful attention to the wing pod and fuselage boattail angle designs. Wing pod interference drag was minimized using contouring techniques that were developed in a wind tunnel program using a model with similar pods. Figure 9 presents the configuration drag divergence mach number as a function of lift coefficient. The nacelle interference effects on the drag divergence mach number are based on a test of a wind tunnel model having almost identical nacelles. The wing design lift coefficient, 0.4, was established to allow flight speeds up to the 0.75 mach number design cruise speed at all weights up to the weight for beginning of cruise on the STOL mission. Figure 10 presents the vehicle compressibility drag for speeds exceeding the design drag divergence mach number. Figure 11 illustrates the drag due to lift tail-off efficiency factor versus lift coefficient. The upper curve of figure 11 applies to all subsonic speeds up to the design 0.75 mach number speed. The lower curve indicates the reduction in lifting efficiency as the aircraft is operated above its design speed.

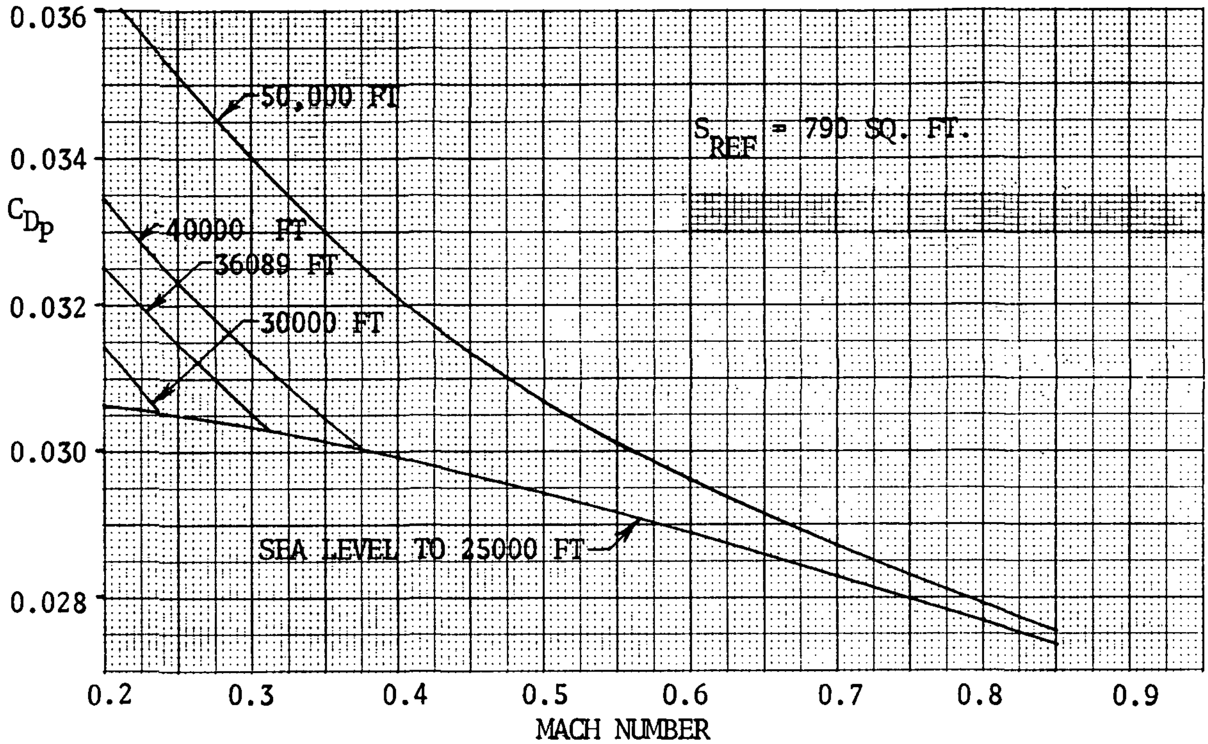


Figure 7. Friction Drag vs. Mach Number

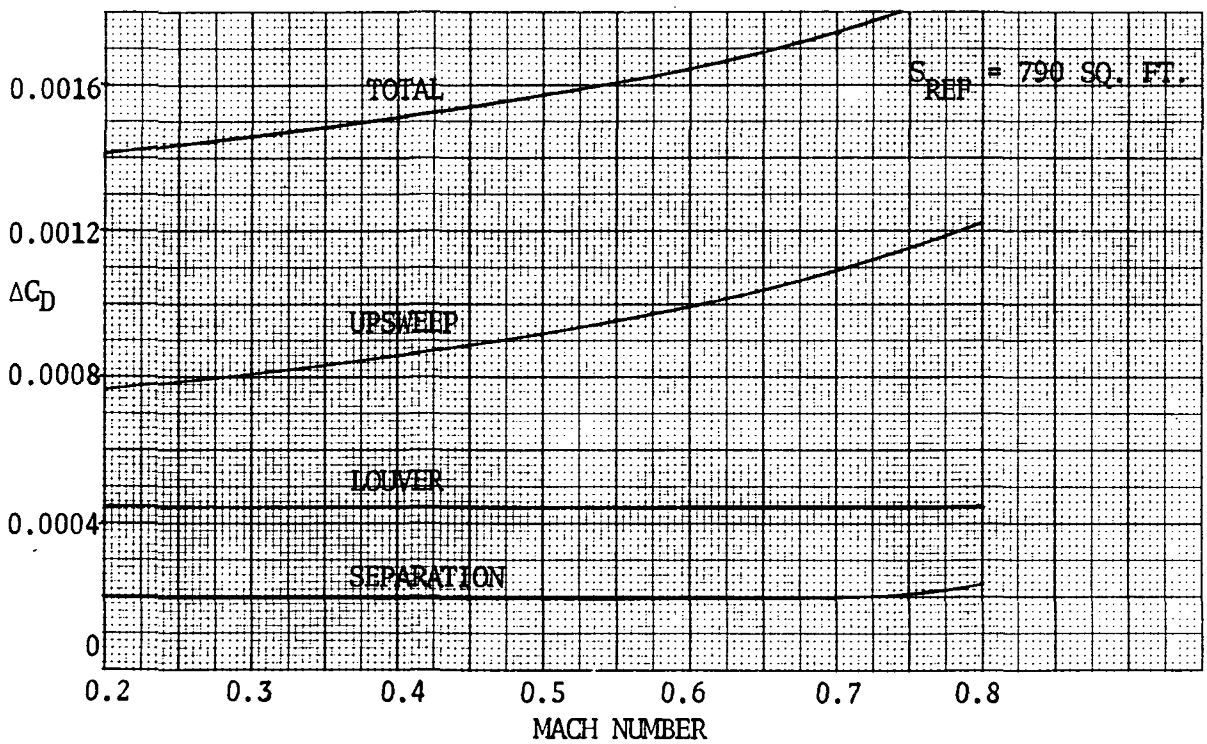


Figure 8. Louver, Separation and Upsweep Drag vs Mach Number

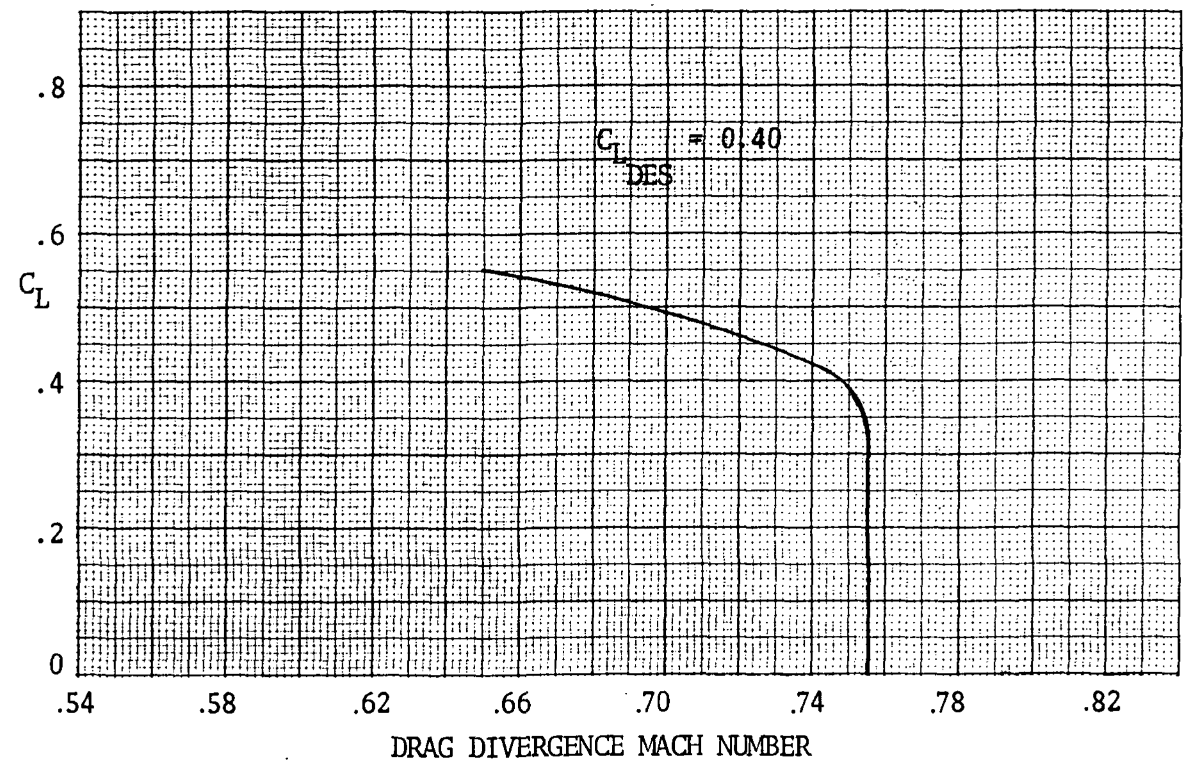


Figure 9. Drag Divergence Mach Number vs Lift Coefficient

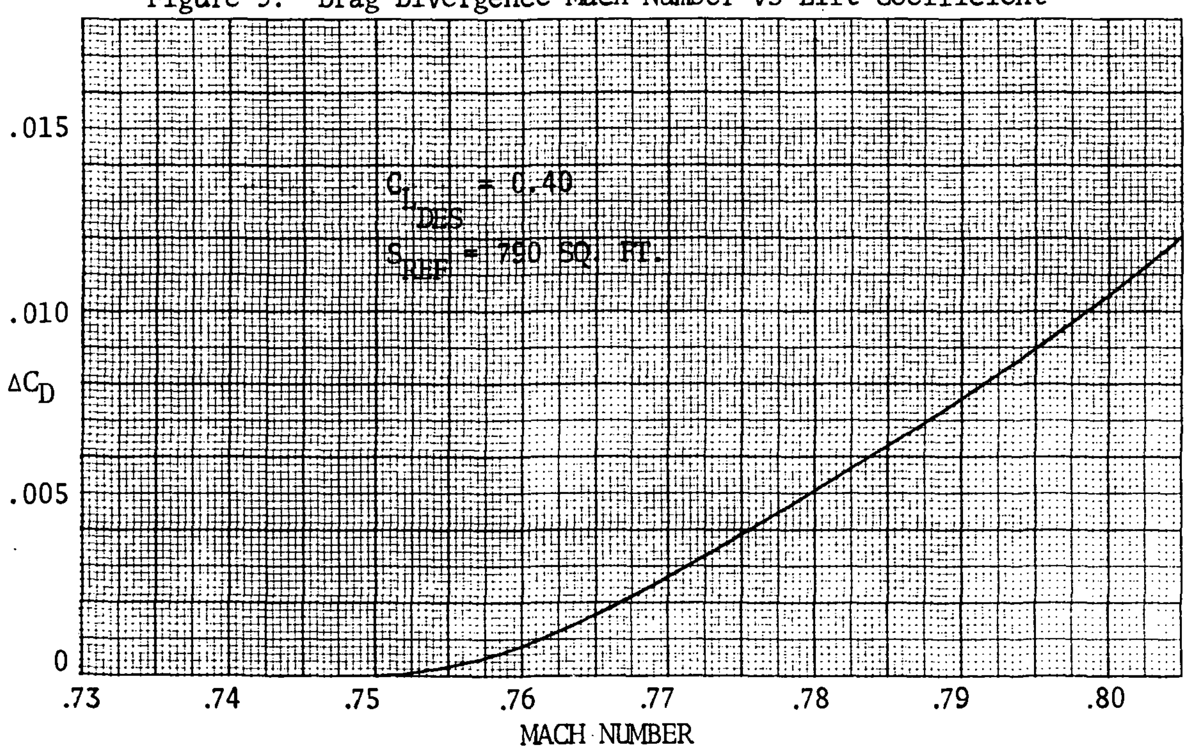


Figure 10. Wing Drag Rise vs Mach Number

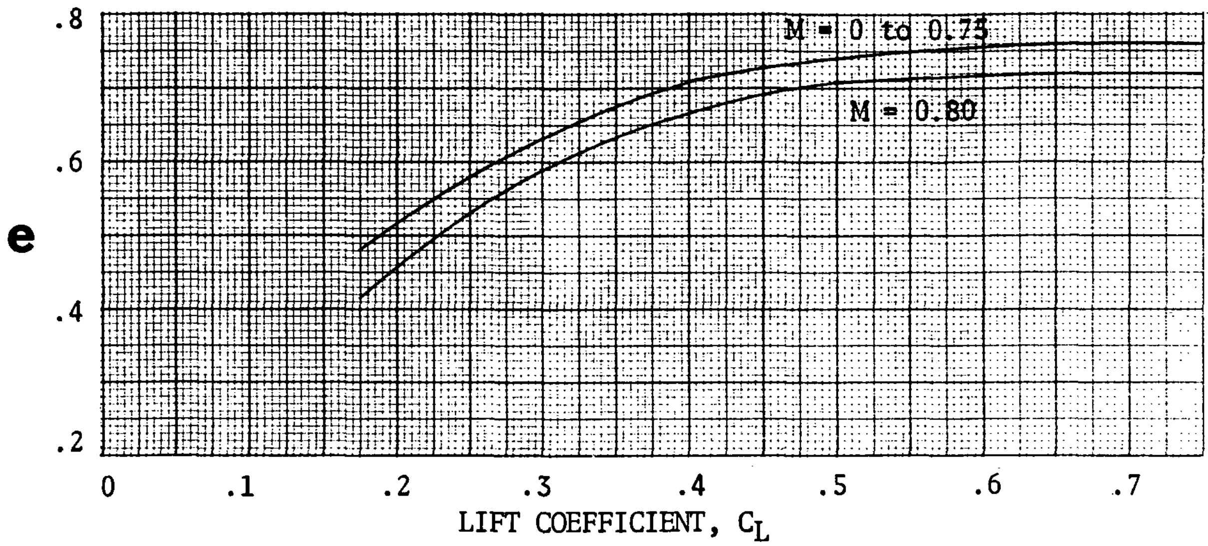


Figure 11. Tail-Off Efficiency Factor vs Lift Coefficient

Deceleration Capability. - The aircraft is capable of low speed deceleration in excess of the required 0.15 g's while in a very steep descent, except at speeds below 43 knots as shown in Figure 12. If the rate of descent is relaxed to less than 2000 ft/min at the low speed end, a significant improvement in the capability is obtained. The decelerations shown are in the direction of the flight path, i.e., no incremental lift is generated.

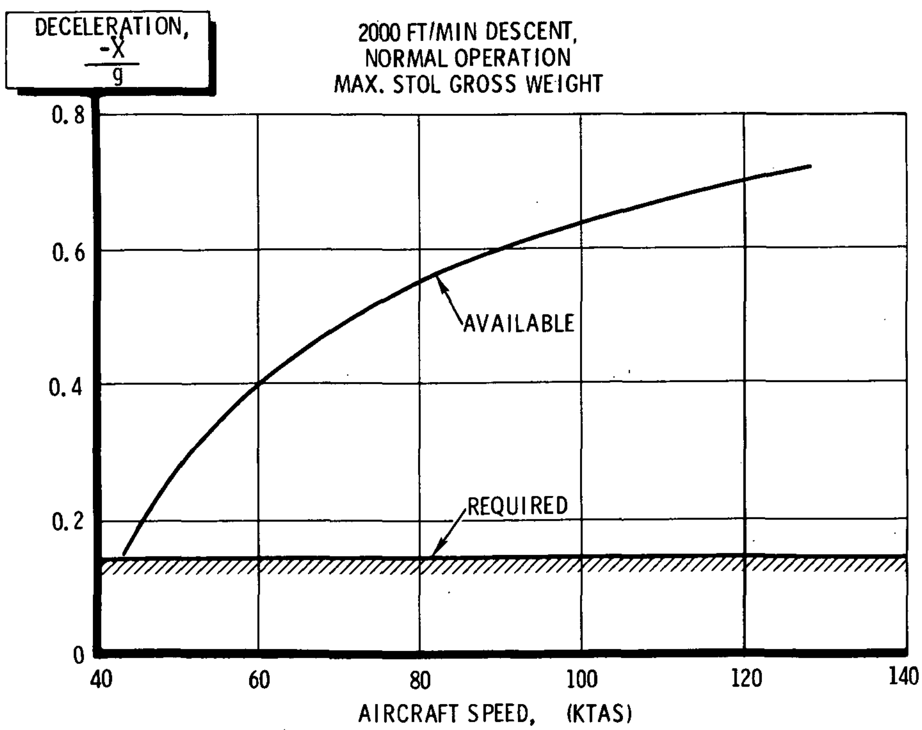


Figure 12. Deceleration Capability During Descent

Aircraft speed during conversion. - Maximum speed capabilities of the aircraft in the V/STOL mode are shown in figure 13 and are in excess of required minimum levels. The required speeds are 1.3 V_S in normal operation and 1.1 V_S in case of a failure. The critical failure is that of an inoperative lift/cruise fan. For this case, the only remaining operating lift/cruise fan must overcome a portion of the intake momentum drag of four fans.

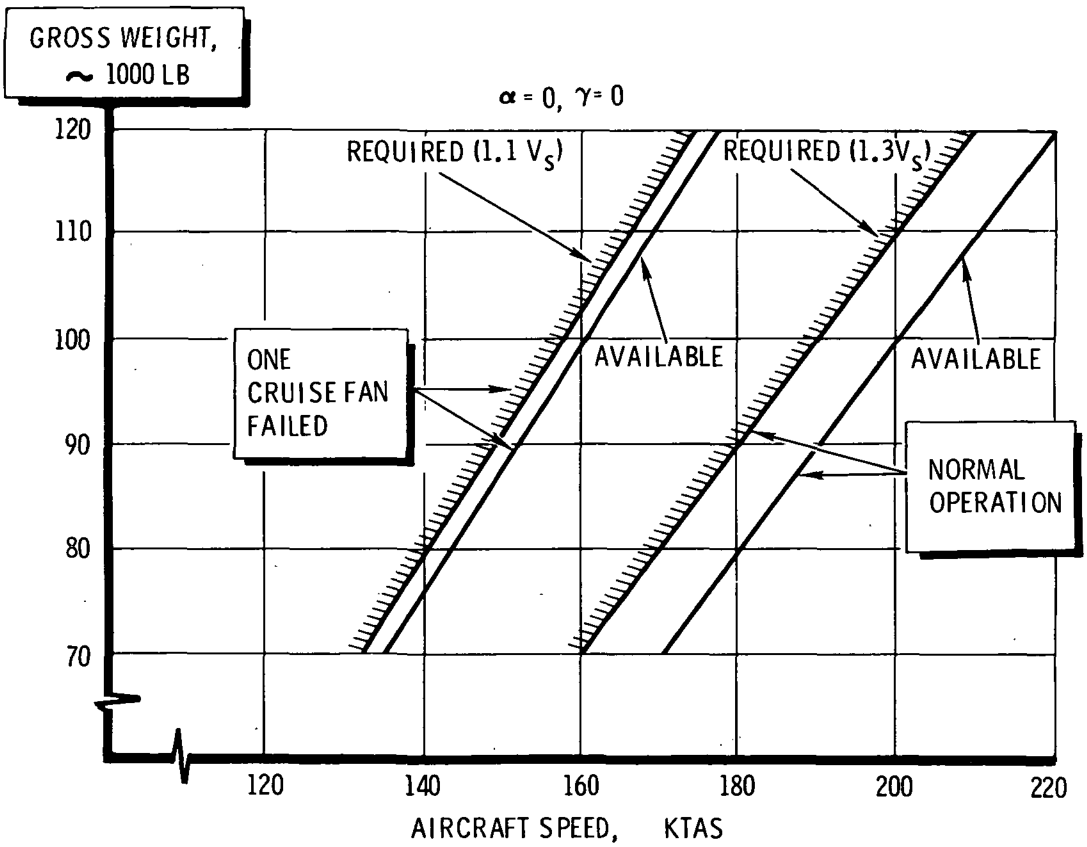


Figure 13. Conversion Speeds

Pitch, roll, and yaw characteristics. - The initial angular accelerations after a pilot step input, as well as the attitude change after one second, are all adequate to meet the requirements.

Particularly, a large control power is available in the roll axis as expressed in the bank angle reached after one second, figure 14. The control system time constant used herein is 0.2 seconds, however, the pilots input is a step input without time lag or time constant.

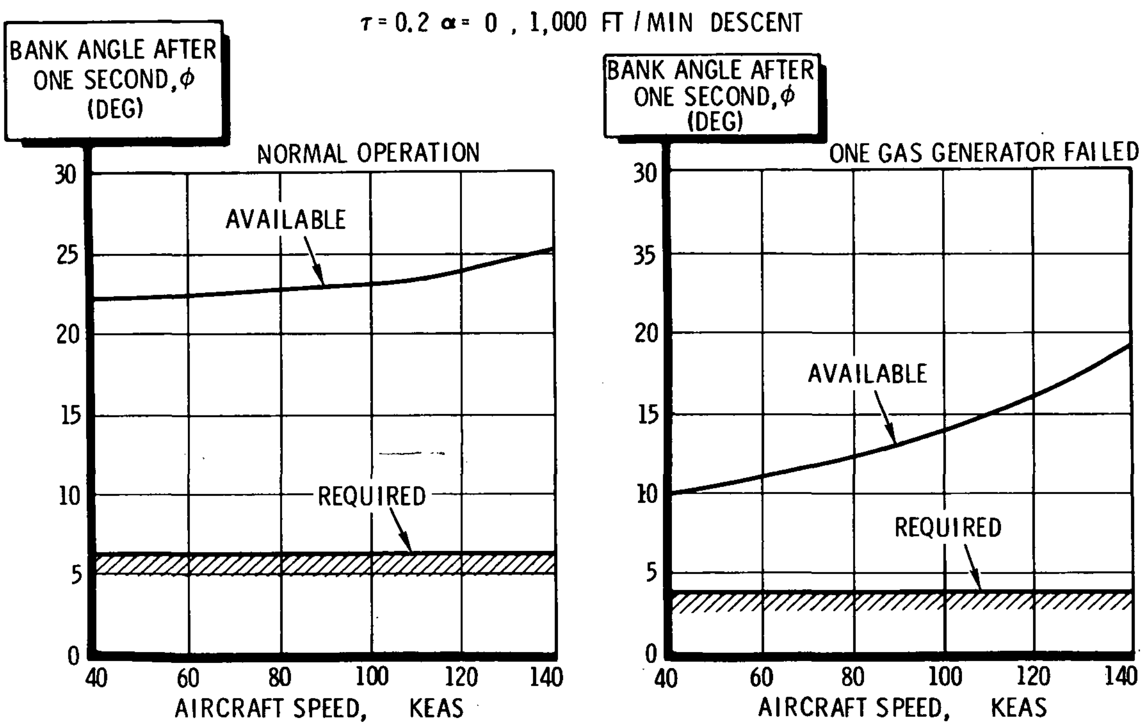


Figure 14. Bank Angle At One Second After A Pilot Step Input

A similar presentation, but for pitch control, is given in figure 15. The pitch axis is considered to be the critical axis for this aircraft. Initial pitch accelerations after a similar pilot step input but with zero control system time constant are given in figure 16. These values are by definition equal to the ratio of the control moment over the moment of inertia.

The tail contribution in the pitch control is adequate to compensate for an unexpected lift loss of a front fan during conversion speeds. The horizontal tail surface is also adequate to provide a static longitudinal stability margin of at least 5% MAC. The span of the horizontal tail is relatively large to assure effectiveness during deep stall.

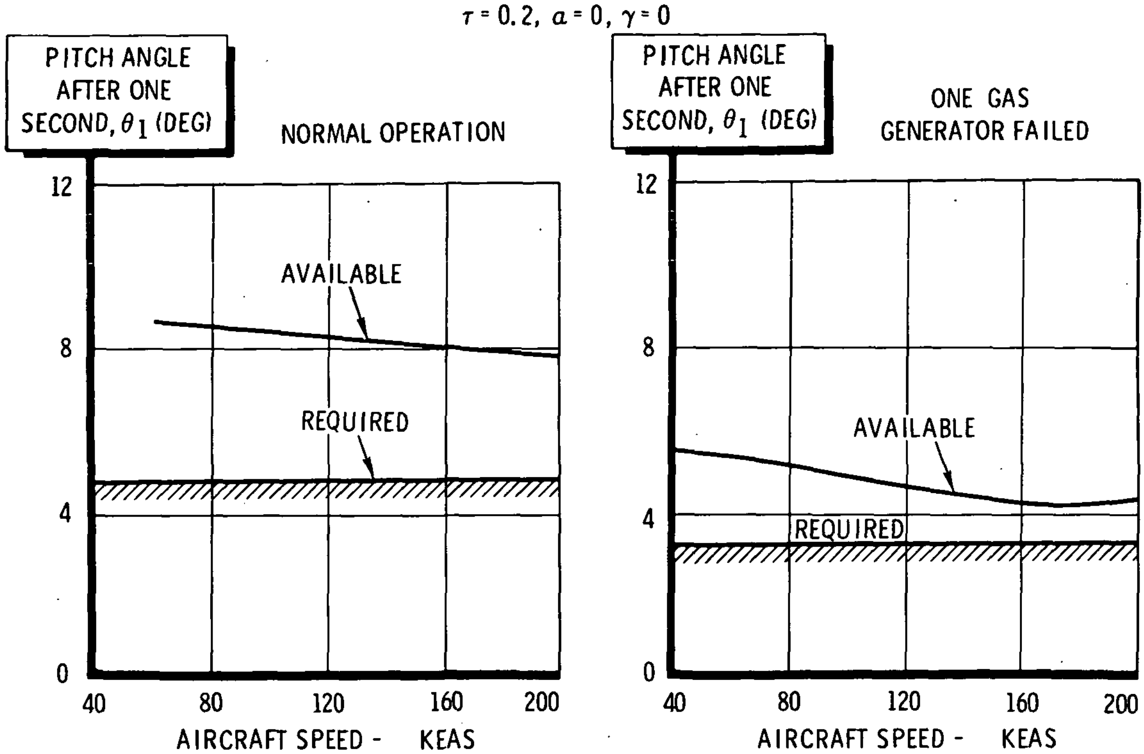


Figure 15. Pitch Angle At One Second After A Pilot Step Input

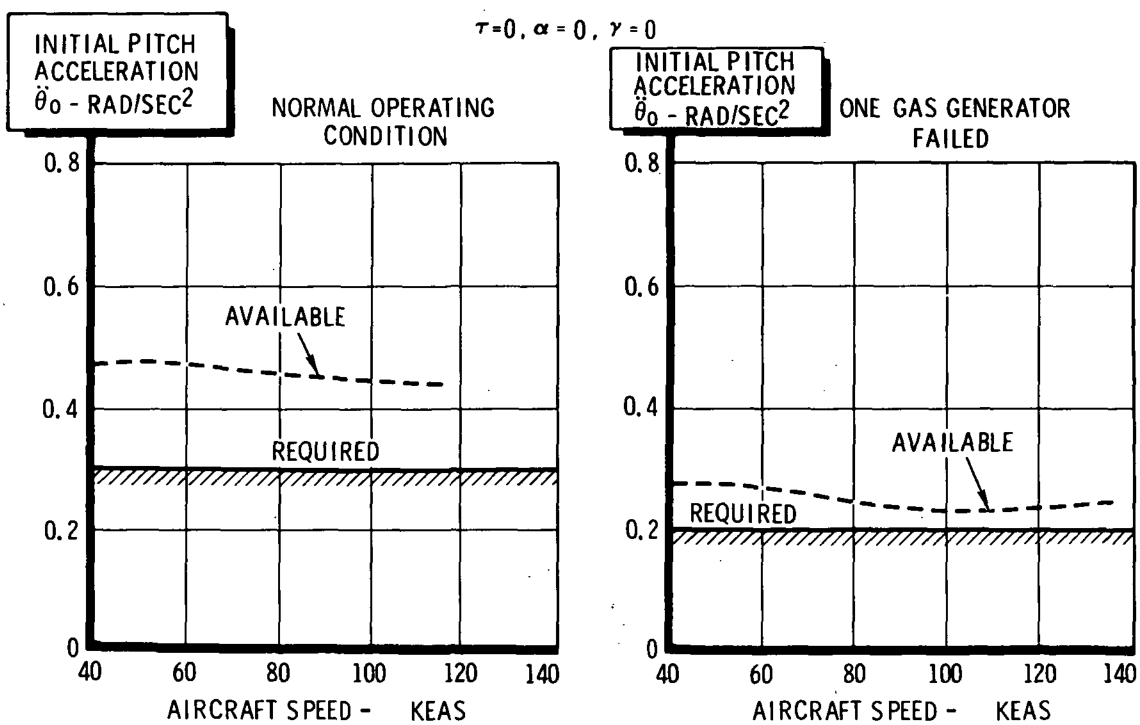


Figure 16. Pitch Acceleration After A Pilot Step Input

Lift control during approach and landing. - The aircraft meets the requirement to produce 0.1 g in normal acceleration in less than 1.5 seconds for flight tracking. This requirement is specified for a speed regime where it is possible to develop more than 0.1 g but less than 0.3 g by aircraft rotation. The requirement can be met by rotating the aircraft in pitch. The stall angle of attack margin before rotation is at least ten degrees.

The aircraft also meets the requirement to produce 0.1 g in normal acceleration in less than 0.5 seconds for flare and touchdown control, with ground effect. This requirement is specified for a speed regime where it is possible to develop more than 0.1 g but less than 0.15 g by aircraft rotation. The requirement is met by applying direct lift control for which wing tip spoilers are incorporated in the aircraft. The requirement cannot be met by aircraft rotation; aircraft rotation is often considered unsuitable for STOL operation in ground effect when the ground effect produces negative lift.

Structure

The objective of the structure analysis portion of the study was to identify the composite structural materials and concepts which would allow a structural weight saving (in comparison to all-metal structure) of 25 percent. Studies conducted by the contractor indicated this percent to be a potentially reasonable cost-effective level for the 1985 time period.

Structure definition for the selected configuration was based on an analytical assessment of existing structural tradeoff data. Composite materials considered included an appropriate mix of glass, boron, and graphite fiber-reinforced plastics of epoxy and polyester and with various fiber orientations for tailoring to straight, curved and complex shaped surfaces. These studies and analyses resulted in use of composites to produce weight savings amounting to 25 percent relative to a metal airframe structure. Description of the structural concepts expected to be used for major components are as follows:

Wing. - The wing primary structural box consists of upper and lower sandwich skins, two sandwich spars, and ribs. Wing skins are of stiffened skin construction with graphite composite facing sheets. The outer facing laminate orientation and thickness are tailored to provide optimum load capacity and the inner facing has stiffeners with concentrated build-up of directionally oriented zero degree reinforcing plies.

The flaps and aileron segments are sandwich construction with graphite composite facings and aluminum honeycomb core. The single front spar is of graphite-composite sheet. The chord-wise ribs are aluminum sheet metal stiffened ribs. A graphite-composite skin over full depth aluminum honeycomb core forms the trailing edge.

Spoiler segments are of full depth bonded honeycomb sandwich. Sandwich facings are graphite-composite laminates, and the core and support fittings are aluminum.

Fans and gas generator support structure. - The fans and gas generators are supported on welded steel frames attached to the wing pod or fuselage frames which are the primary load carrying members.

Fuselage. - The external shell is bonded sandwich structure and fabricated from 1 inch honeycomb core and graphite-composite laminated facings. Composite facing laminates are thickness tailored and fibers are directionally oriented for optimum structural efficiency. Frames are hat shaped sections of fiberglass fabric with reinforcing plies added to the cap. Ring frame segments are bonded to the skin panels prior to final assembly. Approximately every fourth frame and other local areas are reinforced with fasteners through the frame flange and inner skin face for added strength.

Cabin floor transverse beams are attached to each fuselage ring frame. These are formed graphite-composite laminate channels stiffened with fiberglass hat stiffeners bonded to the beam web. The cabin floor beams are fabricated essentially the same. Cabin floor panels are of sandwich construction using graphite-composite facings and either aluminum honeycomb or edge-grain balsa wood core depending upon the floor usage. Floor panels are installed directly on the floor beams. Cargo floor panels are installed in a similar manner.

Lift/Cruise Integrated Nacelles. - The inlet and diffuser sections of the lift/cruise nacelles are integrated into the side of the fuselage to reduce frontal area and friction drag. Access to the fans is through integral doors, on the side of each nacelle. These doors expose the entire fan for service or removal. Doors are constructed of part round frames, longerons and skin panels made of graphite-composite. Core panels are constructed of steel and/or titanium material to withstand high temperatures in local areas.

Horizontal Tail. The horizontal tail primary structural box has a front spar at the 15.0 percent chord line, a rear spar at the 62.0 percent chord line, upper and lower skins and multiple ribs. Front and rear spars and ribs are fabricated of sandwich construction with graphite-composite facings and aluminum honeycomb core. The upper and lower skins are composed of two facing sheets. The outer facing laminate orientation and thickness are tailored to provide optimum load capacity and the inner facing has stiffeners with concentrated buildup of directionally oriented zero degree reinforcing plies. The lower skins and spars are attached by nonexpanding shank rivets and the ribs are bonded. The removable upper skin is mechanically attached to the box. The secondary structure consists generally of graphite-composite laminated skin over aluminum honeycomb core and aluminum sheet metal ribs with beaded stiffeners. The elevators consist of graphite-composite facings, aluminum core and fiberglass wet layup edge members panels over aluminum sheet metal stiffened ribs. The trailing edges are made of fiberglass skins over full depth aluminum core.

Vertical Tail. - The vertical tail primary structural box is a two-spar box between the 15.0 percent and 65.0 percent chord lines. Spars are one piece, full-length components fabricated of sandwich construction with graphite-composite facings and aluminum core. Skins are composed of two facing sheets. The outer facing laminate orientation and thickness are tailored to provide optimum load capacity and the inner facing has stiffeners with concentrated buildup of directionally oriented zero degree reinforcing plies. Ribs are located to support the spars and rudder hinge points. The rudder structure consists of a single spar with chord-wise formed aluminum sheet metal ribs terminating on the aft closing channel. Skins are bonded sandwich panels with graphite-composite facings, aluminum core and fiberglass web layup edge members at the substructure intersection. The fixed leading edge segments are removable and replaceable segments and have chord-wise formed ribs covered by bonded sandwich skins. The segments are assembled by bonding and riveting and installed using mechanical fasteners.

Subsystems

A portion of the study was devoted to the definition of 1985 aircraft subsystems technology. This was done to the depth to define the subsystems basic concepts, establish volume and power requirements, prepare schematic diagrams showing system components, redundancy and interactions and to serve as a basis for realistic weight estimates. One goal of the subsystem conceptual definitions was to meet or exceed the dispatch reliability currently being achieved by contemporary wide body jet airliners. A summary description follows of the major subsystems.

Flight Control System (FCS). - The FCS provided is a fail-operate, fail-operate, fail safe, hydraulic powered fly-by-wire system in all three axes. The FCS consists of a primary flight control system (PFCS), the propulsion attitude control system (PACS) also hydraulically powered, an electrical thrust control system (ETCS) and the thrust vector control system (TVCS). Both the PFCS and PACS include command and stability augmentation subsystems (CASAS).

The PFCS provides the pilot with irreversible hydraulic powered control over the aerodynamic control surfaces consisting of elevator, ailerons, outboard spoilers, and rudder with the horizontal stabilizer providing aerodynamic pitch trim. The PACS provides pitch and roll control through differential fan thrust obtained by fan turbine inlet butterfly control valve deflections, and thrust spoilage by means of antisymmetrical deflection of fan exit louvers. Yaw control is obtained by differential vectoring of the left and right hand lift nozzle thrusts by means of the rotatable integrated single swivel lift/cruise nozzles and the lift-fan louvers. The PACS and PFCS are irreversible hydraulically powered systems with pilot feel provided by feel bungees. The ETCS provides the pilot with electrically powered control of fan thrust levels by means of gas generator power lever angle positioning in response to the pilot's throttles and lift-lever positions. Each gas generator throttle on the center console is connected to dual synchros which in turn control an electric motor brake servo. The pilot and copilot's interconnected lift levers collectively control six ganged synchros; each of these synchros in turn controls an electric motor brake servo. On each gas generator the throttle servos and lift servos are summed in a mechanical differential, driving the gas generator fuel controls. The power trim input is an indication of the means provided for automatic trim input as a function of thrust vector angle. The TVCS provides angular control of the net thrust vector angle by means of symmetrical deflection of the lift pod fan exit louvers, synchronized with rotation of the lift cruise fan swivelling exhaust nozzles. The pilot's control consists of a thumb switch located on the lift levers. Activation of this switch results in a thrust vector rotation at a controlled rate.

The CASAS functions to provide desired levels of air vehicle stability and maneuver control. To provide these functions air vehicle motions and pilot control displacements are electrically sensed, combined, and electrically summed in with the electrical pilot command signals and converted to mechanical control surface motions by electro-hydraulic servos.

Hydraulic System. - A triple redundant (fail operational, fail safe) 5000 psi hydraulic power generation and distribution system was selected for flight control and utility functions. Three completely independent systems are used, each with its own power source, sized so that any two systems will supply 100 percent of the power requirements. All critical-to-flight functions are powered by three systems; other functions are powered by two systems. Use of the 5000 psi system pressure is an improvement in the well demonstrated 4000 psi state-of-the-art systems and was selected because the V/STOL system will not exceed 225°F as compared to the 275°F now experienced in 4000 psi systems thus indicating leakage performance considerably better than 4000 psi systems. Other reasons for selection of the 5000 psi system include consideration for advances in the elastometric seal performance and the expected significant weight saving.

Electrical System. - The Primary Electrical Power Generating System selected consists of three (3), 400 Hertz, 3-Phase, AC generators which can be operated in parallel or isolated mode. Two of the gas generators are integrated with constant speed drives into integrated drive generator (IDG) power units with one IDG mounted on each of the two fuselage lift/cruise engines. An additional generator will be driven by the one of the lift fan gas generators functioning as an auxiliary power unit to permit self-sufficient ground operations when external power is not available. DC power will be provided by three (3) Transformer-Rectifiers. A nickel-cadmium battery with an associated battery charger will be installed in the airplane. The battery and an associated static inverter will be utilized to support start functions (instruments, fire detection and extinguishing, etc.) and to provide AC and DC power for those loads required to maintain flight for a minimum time to select landing site and land. An external power receptacle is provided for AC ground power during aircraft servicing and maintenance.

Fuel System. - The fuel system tankage and engine fuel supply system is composed of two similar units divided at the fuselage center line. Fuel is located in integral wing tanks and small tank areas in the aft portions of the nacelles. The inboard main wing tank is the last to empty. The outboard tanks drain into the intermediate tankage which is equipped with a scavenge pump to insure drainage. The intermediate wing tanks have transfer pumps which keep the main tank full. The inboard main tank holds two booster pumps plus an inlet for suction feed and for transient negative acceleration. One 600 GPM refueling receptacle is provided on one wing nacelle. The system allows flexible CG location for various operational requirements. Each of the two tank systems are separately vented to an outlet in the lower wing skin. Negative pressure vent valves at the wing tips allow emptying.

Environmental Control System. - A dual environmental control system was selected using engine bleed air routed through the air conditioning package. The air conditioning package consists of a steel heat exchanger, where the bleed air is first cooled by ram air, then further cooled in an expansion turbine before going through a water separator. The cooled air is routed to the cabin, cockpit, and avionics bay. The expansion turbine drives a fan which pulls air through the heat exchanger on the ground and assists the flow of ram air in flight. Hot bleed air is by-passed around the cooling package and mixed with cold air to control heating as required by the cabin, cockpit, or avionics temperature controllers.

Landing Gear. - The landing gear is designed for 10 FPS sink speed at takeoff gross weight and consists of two single-strut main gears, each with dual 34 x 9.9 wheels, tires and brake assemblies, and a single-strut, 24 x 7.7, dual wheel, steerable nose gear. All gears are hydraulically actuated, electrically controlled with dual systems.

Avionics. - The mission oriented avionics, by guideline, consist of 1200 pounds of uninstalled weight. This is considered to include communication, identification, navigation, selected computation and selected integrating systems. Other onboard air vehicle avionic equipment such as elements of the flight instruments and flight controls are provided separately in addition to the mission oriented avionics allocation. A 30 percent installation factor is added to the uninstalled avionic weights.

Mass Properties

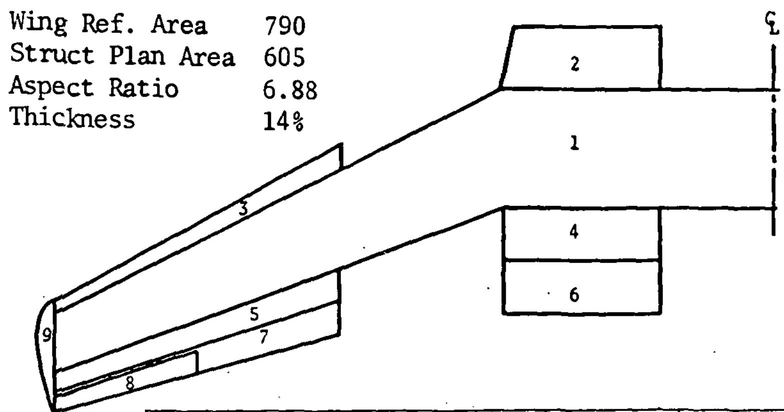
Composite technology in use at the time of design of 1985 V/STOL short haul transport should provide at least a 25% structural weight saving as prescribed by the study guidelines. Current all composite structural weight savings test data indicate values in excess of 27% are achievable. Use of a blend of metallics for cost reduction, however, with the advanced composites for weight reduction may be somewhat more cost effective. Table 2 indicates the estimated metal aircraft structural weights attainable during the 1980's. Allocation of the percentage of weight savings believed practical for each structural item when using advanced composites is shown along with the resulting estimated advanced composite structure weights. The basic composite

TABLE 2. COMPOSITE WEIGHT SAVINGS BREAKDOWN

	METAL AIRCRAFT WEIGHT	% WT SAVING	1985 ADV. COMPOSITE AIRCRAFT WEIGHT
Structure:			
Wing	6933	25.7	5150
Horizontal	1151	25.7	850
Vertical	935	24.6	705
Fuselage	12543	27.4	9105
Landing Gear	4251	26.4	3130
Surface Controls	2220		2220
Engine Section	4904	27.6	3550
Total	32937	25.0	24715

structural weight technology definition represented by the data of Table 2 was developed from the information presented in Reference 4.

The wing represents a large portion of the structural weight and is subjected to higher than usual torque loads due to the lift fan pods. A more detailed structural analysis was made of the wing structure to validate the estimated weights. Figure 17 presents a diagram of the actual wing structure planform, pertinent design parameters and a breakdown of the weight by structural component. Except for the torque loads introduced by the lift fan pods, the geometry, thickness and relieving weight factors indicate a basically light weight wing design. The weight increment for the pod induced torques was identified by scaling from a similar aircraft configuration designed for the same flight regime that had been analyzed in detail for aeroelastic loads, flutter, stiffness and strength requirements. Evaluation of the average weight per square foot of reference planform area would not lead to a proper assessment of the weight allocated to wing structure for this configuration because a large part of the reference planform area is covered by and absorbed into the structural weights listed for the fuselage and wing pods. The average



NO.	COMPONENT	SQ. FT./VEH.	WT-LB/VEH
1	TORQUE BOX	356	3799
2	INBOARD LEADING EDGE	52	372
3	OUTBOARD LEADING EDGE	31	221
4	INBOARD TRAILING EDGE/SPOILER	40	255
5	OUTBOARD TRAILING EDGE/SPOILER	35	227
6	INBOARD FLAP	43	131
7	OUTBOARD FLAP	27	83
8	EMBEDED AILERON	15	46
9	TIP	6	16
TOTAL (BOTH SIDES)		605	5150

Figure 17. Wing Weight Details

weight per square foot, based on actual wing structural planform area, is about 11.5 and 8.5 pounds per square foot for the metal and advanced composite structural weights versus the 8.8 and 6.5 pounds per square foot indicated if the wing aerodynamic reference area were used.

The other structural elements are of more conventional geometry and loading and exhibit no characteristics that indicate potentially significant deviation from statistical metal weight prediction methods. Thus, the weights for these components were developed using available statistical weight equations and preliminary design methods with corrections for advanced composite material technical applications as indicated earlier. The resulting aircraft weight breakdown is presented in Table 3.

TABLE 3. TOTAL AIRCRAFT WEIGHT BREAKDOWN

	WT-LB	PERCENT
PROPULSION	25,740	25.6
STRUCTURE	24,715	24.5
EQUIPMENT	13,260	13.2
USEFUL LOAD	22,230	22.1
FUEL (VTOL)	14,735	14.6
TOTAL	100,680	100.0

Review of the weight breakdown of Table 3 indicates that the propulsion and structure represent approximately 40 and 39 percent of the empty weight of the vehicle, respectively. The fuel for the VTOL mission represents only 14.6 percent of the total VTOL takeoff weight, this is due to the short trip distance requirements of the aircraft for operations in the VTOL mode.

The center of gravity and moment of inertia characteristics of the vehicle are illustrated in figure 18. The data show that the aircraft has a reasonably small CG shift with fuel load. The maximum forward and aft CG travel due to a $\pm$ 5% cabin length shift of the payload are indicated. The yaw axis has the highest moment of inertia, followed by pitch. The roll axis has the lowest moment of inertia -- primarily because the lift/cruise propulsion system does not contribute significantly to the inertia of this axis.

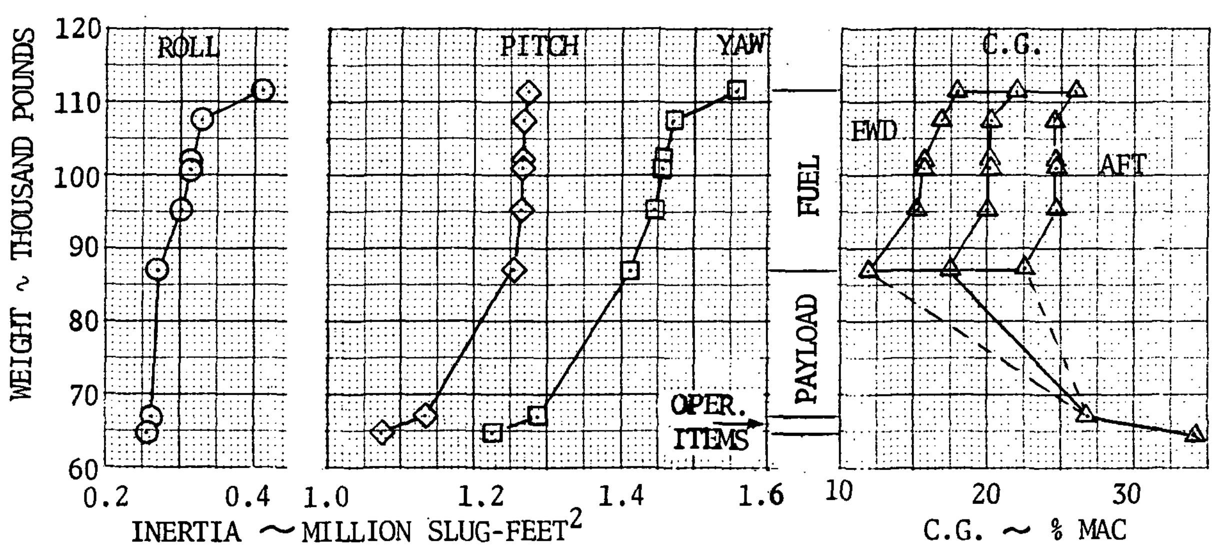
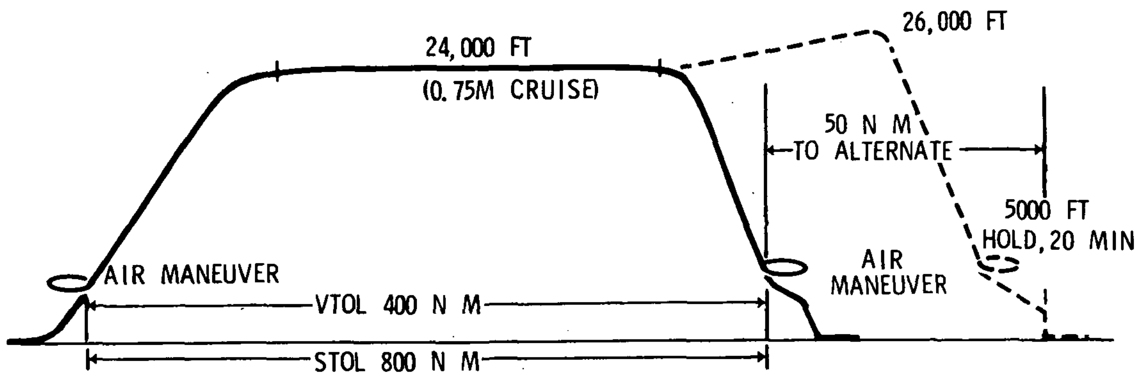


Figure 18. Inertia and Center of Gravity Characteristics

Performance

The selected aircraft configuration was sized to meet the design mission range/payload requirements at a cruise speed of 0.75 Mach number. Figure 19 presents the leg data for the design missions. The cruise altitude is 24,000



OPER MODE	PARAMETER	TAXI & TAKEOFF	AIR MANEUVER	CLIMB	CRUISE	DESCEND	AIR MANEUVER	APPROACH & LAND	RESERVE LEGS	TRIP TOTALS*
VTOL	TIME MIN DIST % FUEL %	1.5 0 7.7%	0.5 0 0.4%	15.2 21.3% 19.9%	36.6 69.0% 39.4%	4.8 9.8 2.1%	1.5 0 1.2%	2.9 0 6.8%	- - 32.5%	63.0 MIN 400 N M 14,733 LB
STOL	TIME MIN DIST % FUEL %	2.5 0 5.8%	1.0 0 0.6%	21.1 15.4% 16.7%	84.6 79.9% 58.1%	4.8 4.9% 1.3%	3.0 0 1.5%	3.9 0 5.3%	- - 19.9%	120.9 MIN 800 N M 24,075 LB

*TIME & DISTANCE FOR REVENUE TRIP, FUEL FOR THRU FLIGHT TO ALTERNATE

Figure 19. Design Mission Profile Performance

feet for both missions. This altitude is sufficient to avoid the majority of severe turbulence, icing and other undesirable features of the lower regions of the atmosphere. The STOL takeoff distance at the STOL takeoff weight of 110,020 pounds after a critical failure is 1240 feet to the 35 foot obstacle. Data on the VTOL takeoff trajectories are presented in the noise trade study subsection of the report.

Economic Analysis

The economic analysis of the selected airplane consisted of evaluation of the system direct operating cost (DOC) characteristics. The analysis was performed using the methodology of Reference 3 and constant factors provided by the study guidelines for propulsion and airframe costs and selected other parameters. Propulsion system costs are based upon a 20,000 pound thrust unit costing $690,000. Of this price 58% ($400,000) is assumed to be fan cost and 42% ($290,000) assumed to be gas generator cost. The costs are scaled for alternate sizes of propulsion system elements using the data of figure 20.

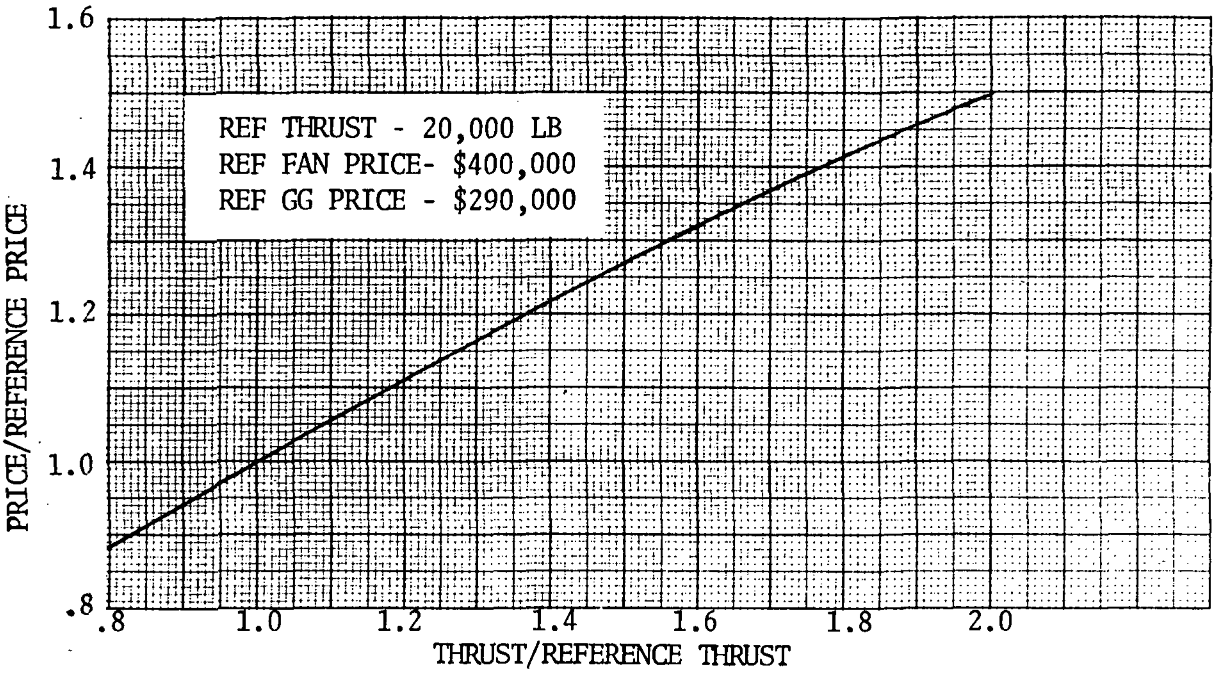


Figure 20. Propulsion System Cost Scaling Factors

The mission profiles used to develop the trip block times and fuel, etc., were as specified in Reference 3 and hence were slightly different from the profiles used to size the aircraft. The differences were in the final portions of the descent and the reserve leg fuel allocations. Figure 21 presents the estimated DOC versus trip distance for two different levels of airframe cost. The DOC's

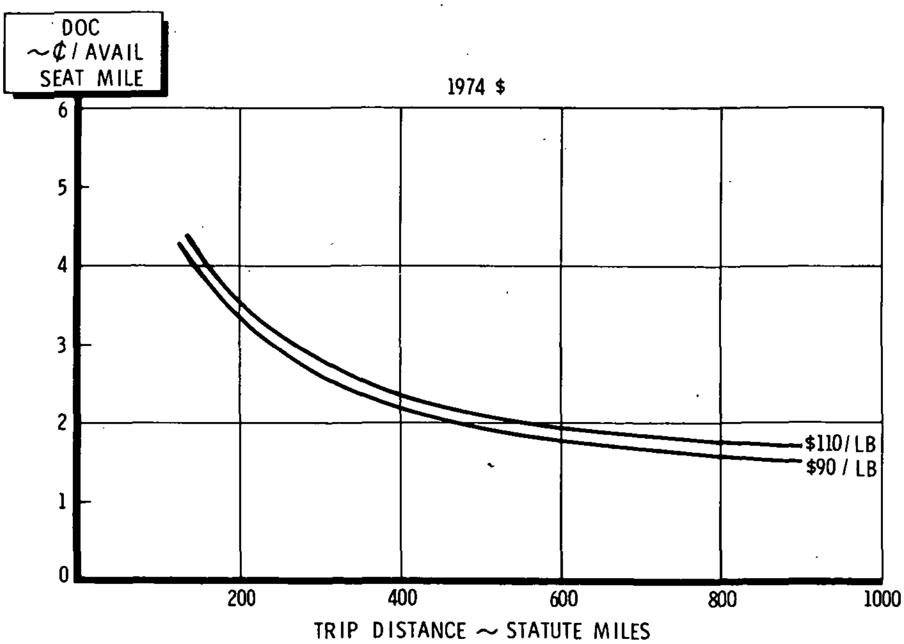


Figure 21. Direct Operating Cost vs Trip Distance

indicated are about 2.32 cents per available seat mile (ASM) for the VTOL mission and about 1.69 cents/ASM at the design STOL mission range. These operating costs, combined with the conveniences and surface travel savings offered by operations from close in V/STOL airports, should provide the required attractive characteristics for the beginning of profitable V/STOL short haul operations by the mid 1980's. Figure 21 also shows the sensitivity of DOC to variations in airframe costs. The data show that with an 18 percent drop in airframe cost per pound ($90/lb vs. $110/lb), DOC would drop about 4 percent.

Figure 22 shows representative DOC cost breakdowns for two trip distances in the short haul range, i.e., 175 and 425 statute miles. The changes in cost percentage distributions with increased trip distance are: (1) depreciation expense percentages increase, (2) airframe maintenance increases, (3) engine maintenance decreases, (4) insurance increases, (5) fuel and oil costs increase, and crew costs decrease.

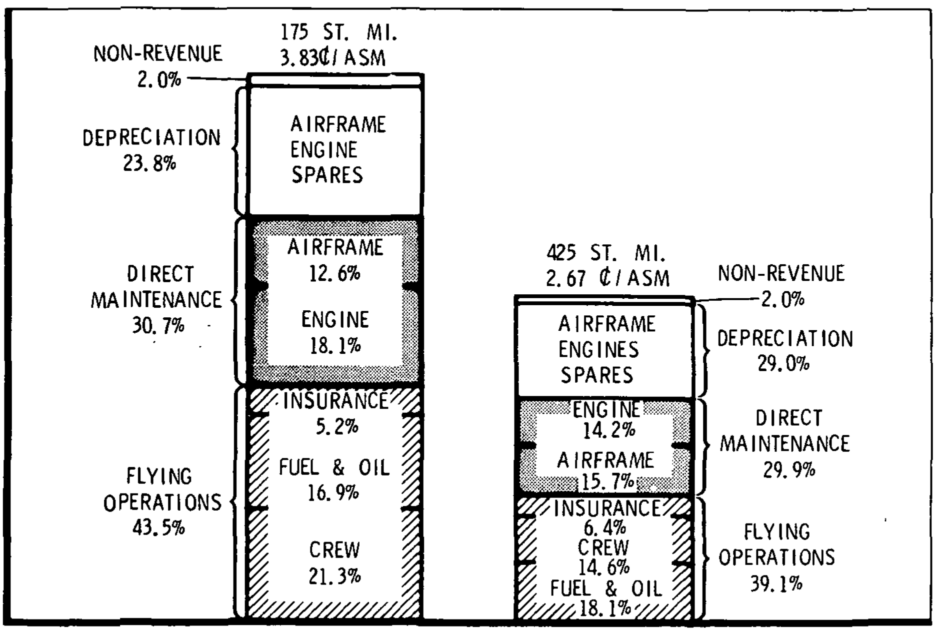


Figure 22. Direct Operating Cost Breakdown

Figure 23 presents the DOC sensitivity to propulsion system costs. The airframe cost is held constant at $110/lb as the propulsion system cost is varied ± 20 percent. The data indicate that the DOC varies from 4 to 5.5 percent with the 20 percent propulsion costs. This indicates that the DOC is slightly more sensitive to propulsion system costs than airframe costs. The higher sensitivity of DOC to propulsion costs is due to the propulsion maintenance material costs being typically 2.0 to 2.5 times larger than the airframe material costs. Within other elements of DOC effected by the relative airframe and propulsion system costs, i.e., depreciation and insurance, the propulsion and airframe portions are nearly equal within about 5 percent. Thus, a larger portion of the basic DOC is affected directly by propulsion costs because of its effect on maintenance material costs.

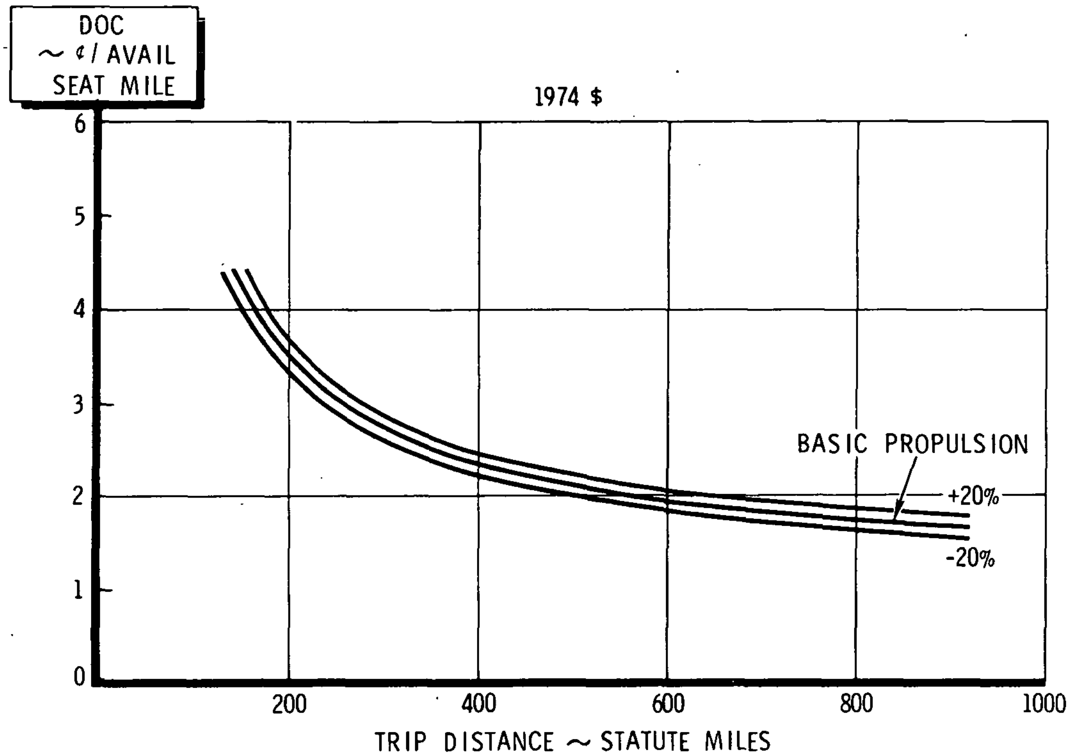


Figure 23. DOC Sensitivity to Propulsion System Cost

Figure 24 presents the data developed to show the DOC sensitivity to assumed utilization rate. The DOC data calculated using the AIA calculation

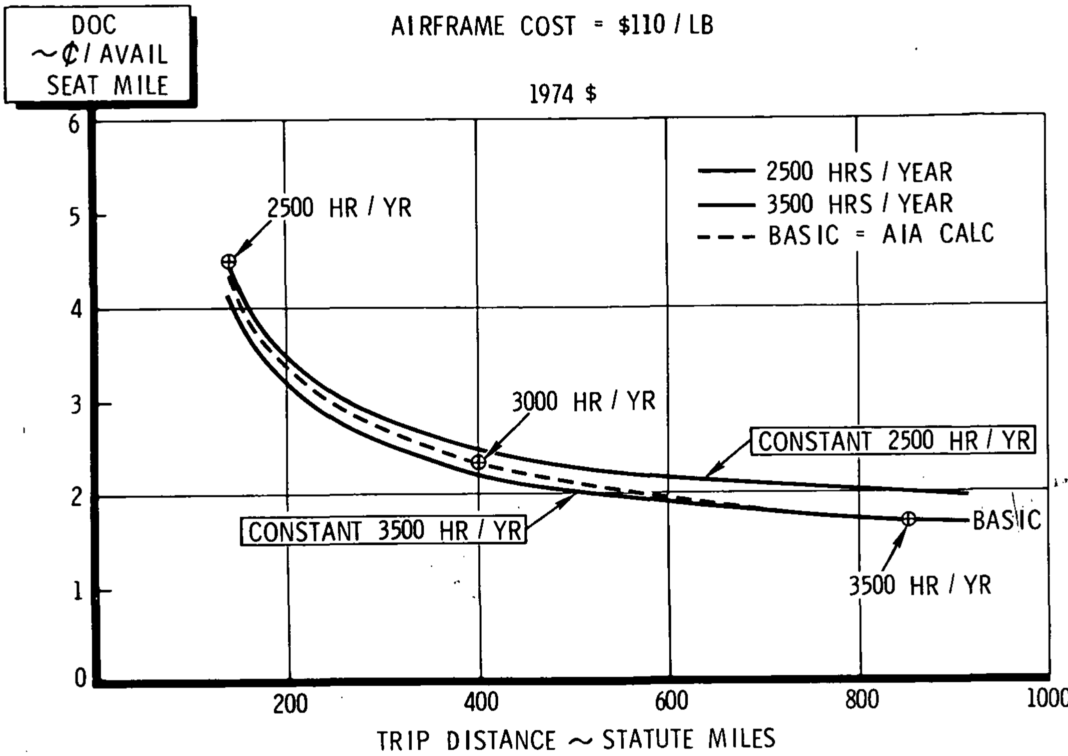


Figure 24. DOC Sensitivity to Utilization Rate

method for utilization is presented as a dotted line. The DOC's noted for fixed utilization rates of 2500 and 3500 hours per year are shown in solid lines. Note that the 2500 hours/year rate closely approximates the utilization calculated using the AIA formula at short trip distances and the 3500 hours/year rate approximates AIA utilizations at the longer STOL mission distances. The reduction in DOC noted for a 3500 hour/year rate versus a 2500 hour/year rate is about 6 percent at the very short distances and about 12 percent at the longest distances. These data indicate the need to design the short haul aircraft and ground system to minimize ground delays such that more time can be spent in the air on revenue producing trips.

Noise Analysis

The community noise characteristics of the selected 1985 V/STOL transport are presented in detail in the trade study portion of this report where various alternative takeoff procedures were considered. The basic community noise characteristic is defined by the 97.5 PNdB maximum 500 foot sideline noise level for a 1.05 g accelerating vertical liftoff. This is slightly higher than the 95 PNdB goal and indicates that more technology development is required in this area if the 95 PNdB goal is to be realized for the first generation V/STOL transport system. Noise footprint and preliminary noise time duration effects indicate that it may be possible to define acceptable 1985 V/STOL transports with higher than 95 PNdB sideline noise levels if the V/STOL ports can be designed to provide special arrival and departure areas of about 40 acres or so to contain the ground level areas that are affected by the 95 PNdB noise levels or higher.

The internal noise levels of the 1985 V/STOL transports were also investigated. The speech interference noise level objectives for occupied areas of the V/STOL transport are 70 dB for cruise and 75 dB for takeoff. The predominant noise sources are the engine and boundary layer noise. It is assumed that the aircraft environmental control system noise is suppressed and is therefore not a dominant noise source. The interior noise in the speech interference frequency range is obtained from the predicted external noise and the noise reduction of the fuselage. The noise reduction of the fuselage was increased by adding the acoustic treatment required to achieve the interior noise level objectives. The fuselage noise reduction was based on noise reduction measurements of conventional metallic skin-stinger fuselage configurations. The noise reduction of composite fuselage construction is currently unknown but is expected to be substantially different than conventional fuselage structure.

Boundary layer noise during cruise is the dominant noise source for the commercial aircraft due to the engine nacelle acoustic treatments. Acoustic treatment of 1094 pounds is required to achieve the cruise noise level of 70 dB. The average takeoff noise level is 73 dB which is 2 dB lower than the goal noise level. The cruise fans and gas generators mounted on the aft fuselage are acoustically treated. The vibration and related noise induced by the rotating machinery is assumed to be reduced to acceptable levels by proper structural design and vibration isolation.

Ride Quality Analysis

A ride quality analysis of the selected V/STOL transport configuration was performed to evaluate its performance relative to the goals established. Figure 25 presents the results. The ride quality goal is established by a specified boundary of maximum acceptable vertical acceleration, ΔN, experienced per unit of atmospheric gust velocity, U_{de}, in g's per foot per second between the altitudes of 10,000 and 30,000 feet. In general, the high wing loading of the selected design, 139 lb/ft^2 at STOL takeoff weight and 127 lb/ft^2 at VTOL takeoff weight, is adequate to provide acceptable ride quality throughout the operational flight envelope without recourse to special design features or flight speed schedules that are compromising to other primary operational objectives. Below 10,000 feet, flight is dominated by the FAR requirement to maintain speeds below 250 knots where the 1985 V/STOL transport high wing loading should make it much more comfortable than many contemporary transports that operate at these same speeds with significantly lower wing loadings. During normal operational climbs and cruises the 1985 transport can stay comfortably below the established goal ride quality boundary. During end of mission (EOM) light weight descents, the 1985 V/STOL transport will use its capability to decelerate simultaneously while maintaining descent rates up to 5000 feet per minute to 10,000 feet to minimize descent time. This descent profile also can be made to match the ride quality boundary with insignificant effects on fuel used or trip block times. A speed transition adjustment is made between 10,000 and 8,000 feet to accommodate FAR rules, the requirements of minimum block time, fuel used and guideline descent rates.

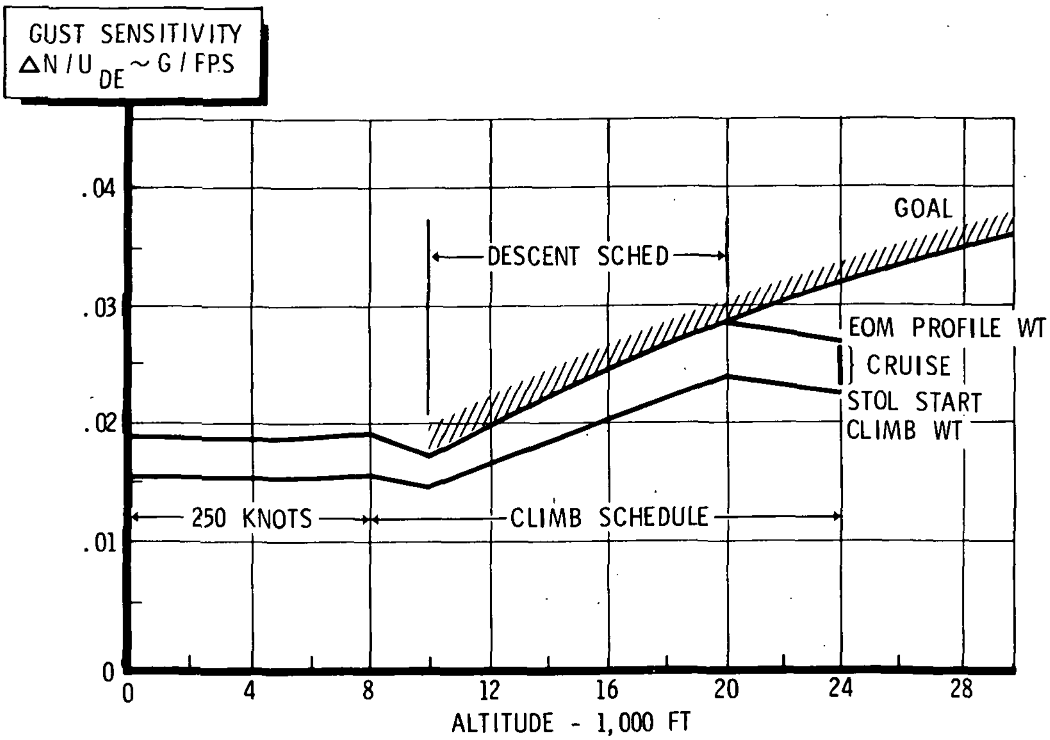
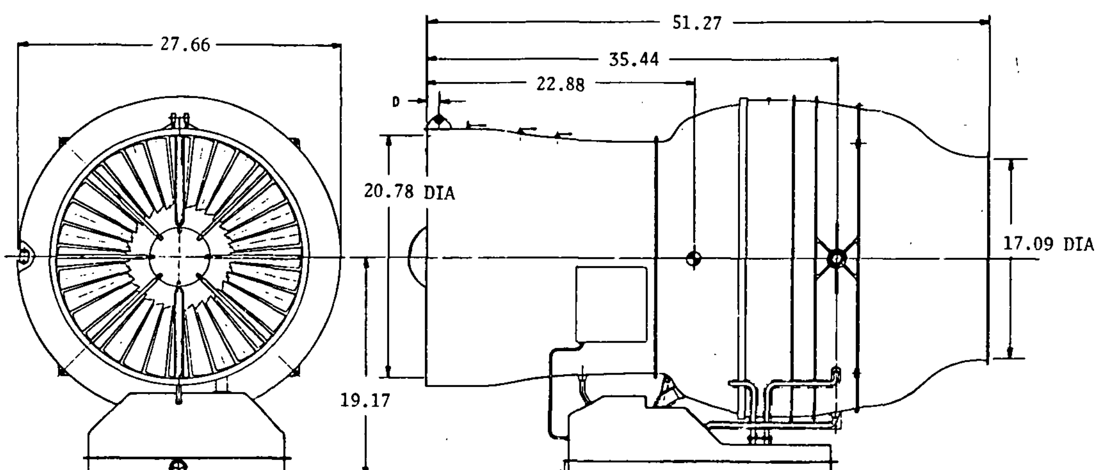


Figure 25. Selected Configuration Ride Quality Characteristics

The basic propulsion technology level used for the study was established by prior studies funded by the NASA Lewis Research Center, Reference 2. In order to provide a broader scope of propulsion data, this original data was expanded and compiled into a description of wider propulsion system design options through the use of trend data and selected studies provided by the General Electric Company of Evendale, Ohio, as summarized below.

Gas Generator Technology

The 1985 remote lift-fan system turbojet gas generator technology selected from Reference 2 for the study is illustrated in Figure 26. Its major characteristics are compared on Figure 26 with the characteristics of the existing J97 gas generator. The gas pumping characteristics of the 1985 advanced gas generator are very similar to those of the J97.



(all dimensions in inches)

	ADVANCED GAS GENERATOR	J97
AIRFLOW (NOM)	66.53 LB/SEC	69.20 LB/SEC
EXHAUST TEMP. (NOM)	1400°F	1375°F
EXHAUST PRESS. (NOM)	50.03 PSIA	52.90 PSIA
WEIGHT	445 LBS	720 LBS

Figure 26. Selected Study Gas Generator Technology Characteristics

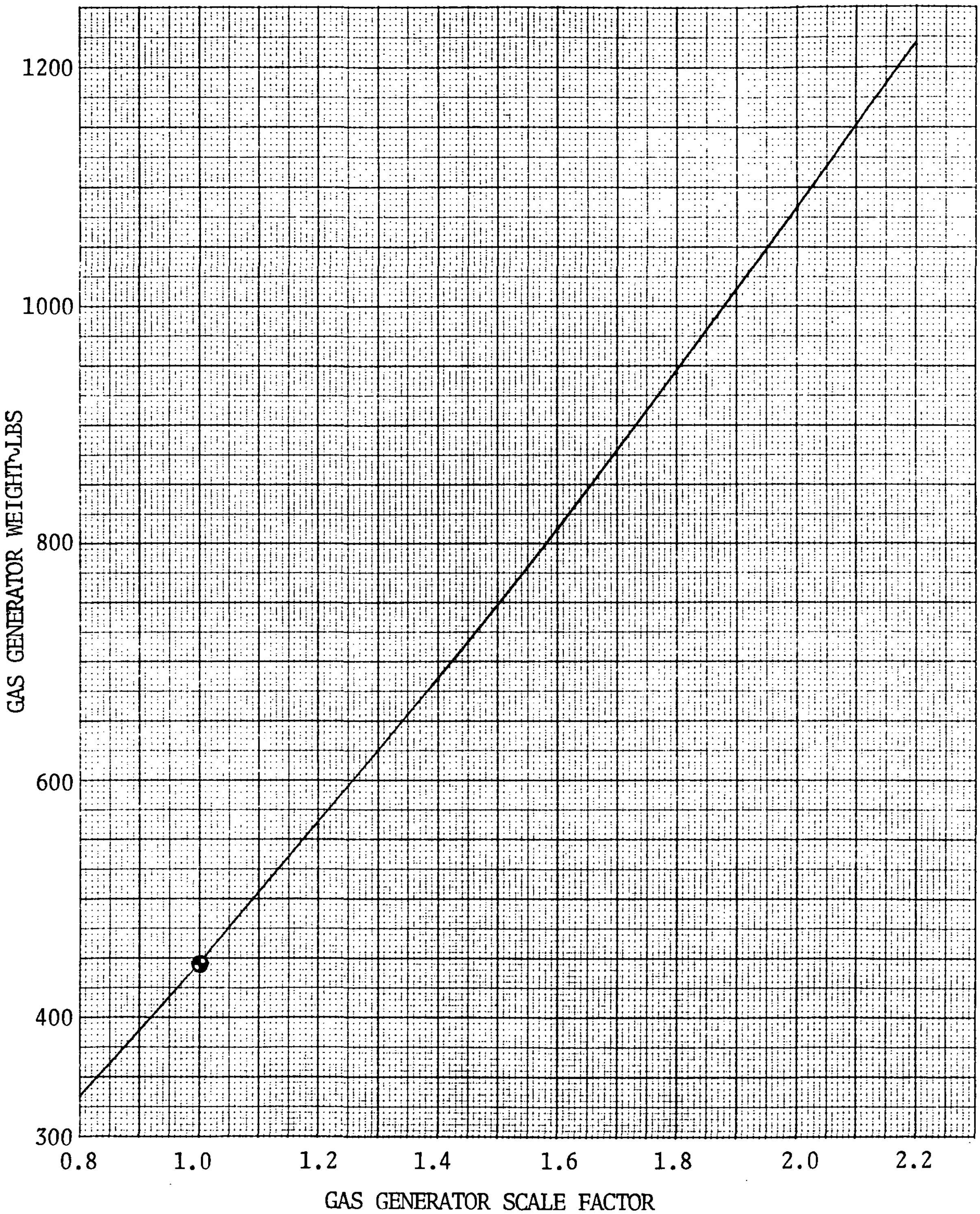


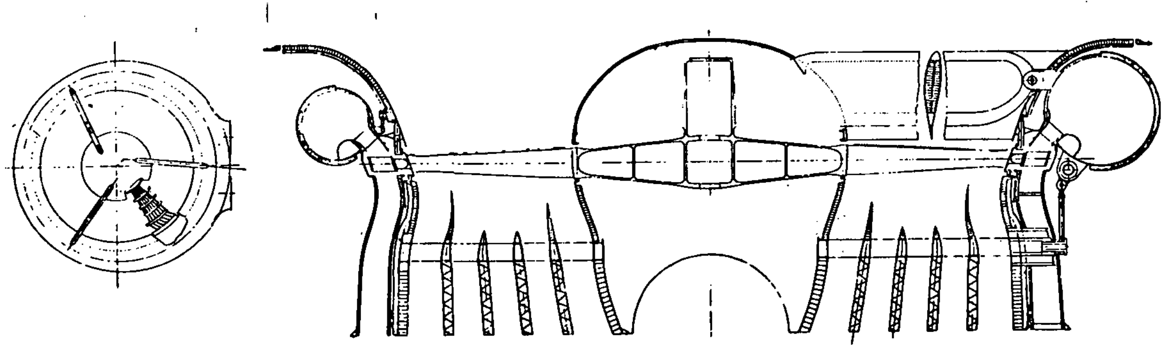
Figure 27. 1985 Advanced Gas Generator Weight Scaling Data

The exhaust gas pressure is lower and the temperature slightly higher than the J97. The major difference in the characteristics is that the advanced gas generator is about 40 percent lighter in weight than the J97 due to the use of advanced engine fabrication materials and techniques. Weight scaling data for the 1985 advanced gas generator are presented in Figure 27.

It is expected that the advanced gas generator will incorporate about a 14 to 1 pressure ratio, seven-stage single-spool compressor, a double annula combustor, and a single-stage turbine with a maximum hot day (90°F) turbine rotor inlet temperature of 2139°F.

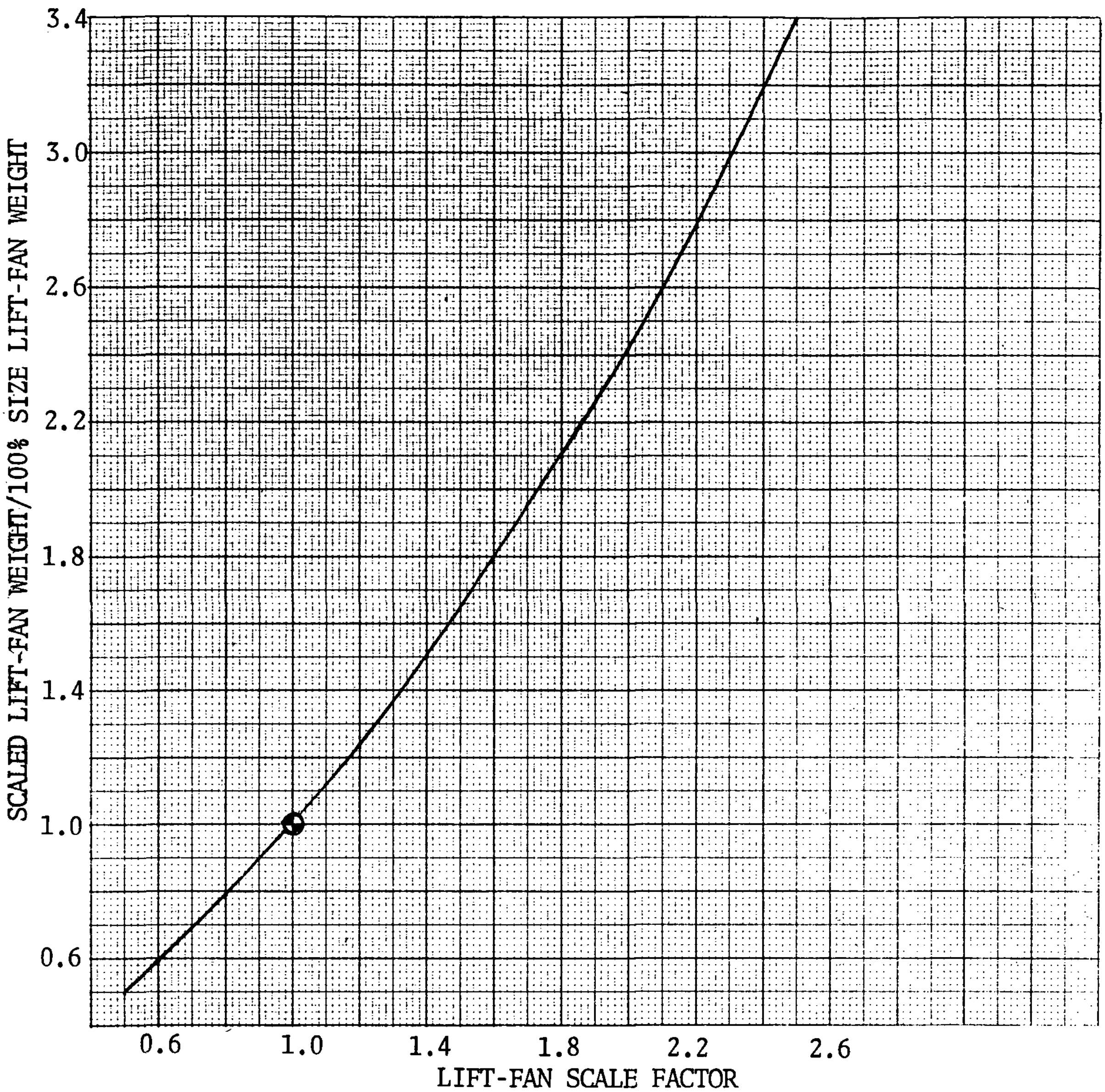
Lift-Fan Technology

The 1985 lift-fan technology selected for the study was based on the lift-fan system of Reference 2 expanded through available trend data made available through the General Electric Company. The fans were basically advanced quiet-technology three-strut supported, dual entry, single-rotor lift-fan systems of various pressure ratios with appropriate stator spacings and four exhaust acoustically-treated splitter rings to minimize the exhaust noise as illustrated in Figure 28. Through the use of parametric lift-fan data, originally developed for use with the J97 gas generator, as a function of fan pressure ratio, acoustic treatment, etc., a technology description of a range of lift-fan design options was compiled. The similarity of the advanced gas generator exhaust characteristics and those of the J97 made the fan design trend data directly applicable to this study. When considering



- DUAL ENTRIES
- 25 PERCENT CONTROL MARGIN
- HEAVY ACOUSTIC TREATMENT

Figure 28. Advanced Quiet Technology Lift-Fan Design Features



DESIGN FPR:	1.25	1.30	1.35	1.40
100% Size L/F Weight ~ Lb	1079	955	880	825
100% Size SL/90°F L/F Thrust ∿ Lb.	12145	11167	10352	9628
100% Size SL/90°F L/C Thrust ∿ Lb.	11040	10322	9739	9275

NOTE: Weights and thrusts are for fans designed with 25 percent control margin.

Figure 29. Lift-Fan Installed Thrust and Weight Scaling Data

the fans and gas generators together as a combined propulsion unit, the effective bypass ratio of the system covers the range of 11.8 to 7.8 as the fan pressure ratio varies from 1.25 to 1.40.

The fans, as illustrated in Figure 28, were all originally designed with 25 percent control margin and have dual gas inlet entries to the scrolls. Additional propulsion system manufacturer data provided information on fans with alternate amounts of control margin and fans having four (quad) entries to the scrolls. These alternate characteristics are described later.

The weights, weight scaling and thrusts of lift-fan (L/F) and lift/cruise fan (L/C) installations in the design pressure ratio range from 1.25 through 1.40 are presented in Figure 29. The weights of the fans shown are for a typical lift-fan installation with heavy acoustic treatment and include the weight of the bell mouth, three-strut front frame, double entry scroll, fan/turbine rotor, rear frame (stator), and four acoustic splitters. The weight of louvers are not included in the weights shown.

The L/F thrusts quoted are estimated installed thrusts for a lift-fan installation, such as illustrated in Figure 28, using one fan driven by one 100 percent size gas generator with a full set of thrust vectoring louver/closure doors mounted in the exhaust stream. The thrust quoted for the L/C fans are estimated installed thrusts assuming typical 0.75 mach number design cruise fan and gas generator inlets with sound suppression features and a cruise fan exhaust nozzle system typical of the integrated single-swivel nozzle design used by the contractor for this study.

The range of the characteristics of the lift-fan systems as a function of design fan pressure ratio (FPR) will be presented in the following paragraphs primarily by comparing a 1.25 FPR system and a 1.40 FPR system designed to the same SL/90°F static thrust. Figure 30 illustrates the L/F and L/F plus gas generator V-mode thrust-to-weight ratios for the range of fan pressure ratios. The SL/90°F static thrust used as a basis for the data

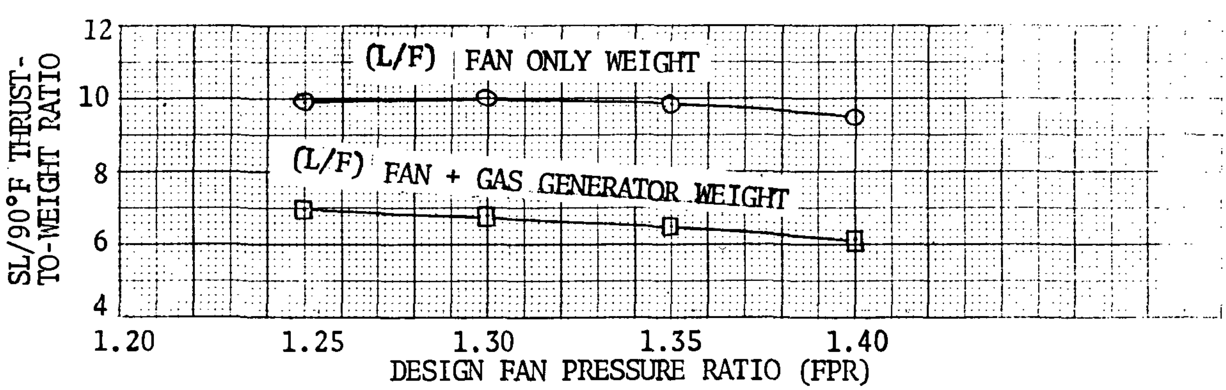


Figure 30. Lift-Fan and Lift-Fan Plus Gas Generator VTO T/W Ratio

is 20,000 pounds. The weights are the dry, uninstalled weights given in Figure 29 modified for the appropriate scale factor to provide the desired thrust. From the data of Figure 30 it can be seen that the basic VTO thrust-to-weight ratios of the fan systems decrease with increasing design fan pressure ratio in the range investigated for these single-stage systems. The VTO T/W for the 1.40 FPR system is about 4.5 percent lower than that for the 1.25 FPR system when the fan weight alone is considered, and about 12 percent lower when the required gas generator weight is included in the ratio.

Figure 31 illustrates the fan sizing characteristics as a function of selected design FPR. Figure 31 shows that the external maximum diameter of the fans change very little with design FPR. The larger gas generator flow, and hence scroll size, offsets the beneficial reduction in fan tip diameter as design fan pressure ratio is increased. The fan depth increases over 6 percent with a change from 1.25 to 1.40 FPR. This is due to the added acoustic treatment required to quiet the higher energy 1.40 FPR fan exhaust.

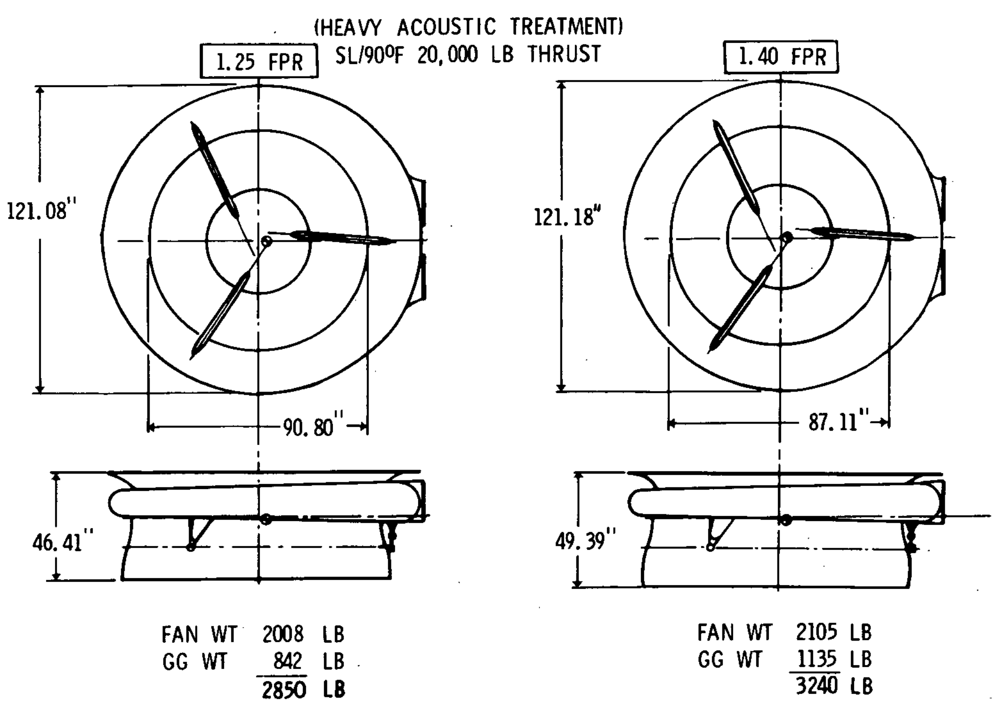


Figure 31. Fan Physical Size vs FPR at Constant VTO Thrust

Figure 32 shows the propulsion system cruise thrust-to-weight (T/W) ratios of a L/C installation for the constant VTO SL/90°F static thrust fan systems noted at various design cruise altitudes and speeds for standard day cruise thrusts. The weight used to develop the T/W ratio is the weight of the fan plus the gas generator.

Review of the data of Figure 32 shows that the 1.40 FPR fan system has superior cruise T/W characteristics throughout the mach number-altitude range except for very low speeds at sea level. The standard day sea level L/C T/W values indicated are higher than the SL/90° L/F VTO T/W values of Figure 30 because of the different atmospheric conditions and installation losses estimated for the lift/cruise fan installation as compared to those for a lift-fan installation.

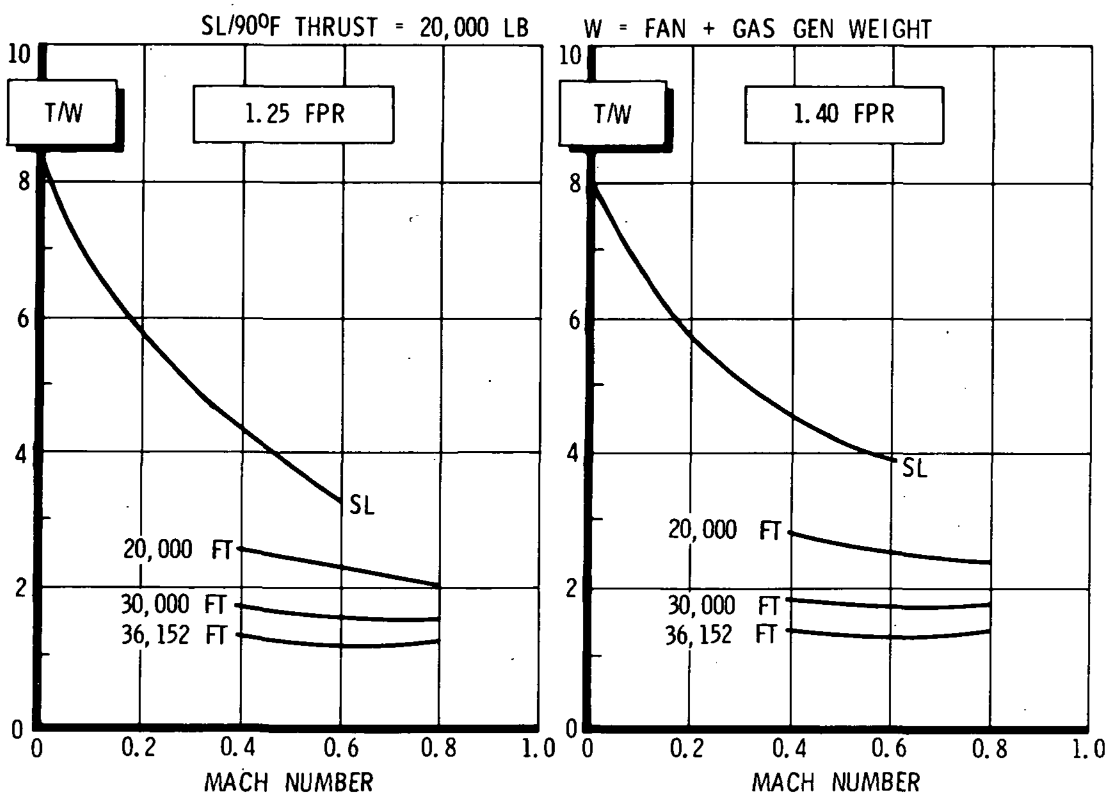


Figure 32. Propulsion System Standard Day Cruise T/W for Constant VTO Thrust Design Fans

Figure 33 presents the cruise specific fuel consumption comparison of the 1.25 and 1.40 FPR fan systems over a range of altitudes and speeds. The 1.40 FPR fan system shows a 2 to 6 percent lower SFC over the 1.25 FPR fan system for the range of cruise conditions surveyed. The data of this figure also indicate that lower speeds and higher altitude cruise conditions improve the cruise efficiency of the lift-fan systems independent of FPR.

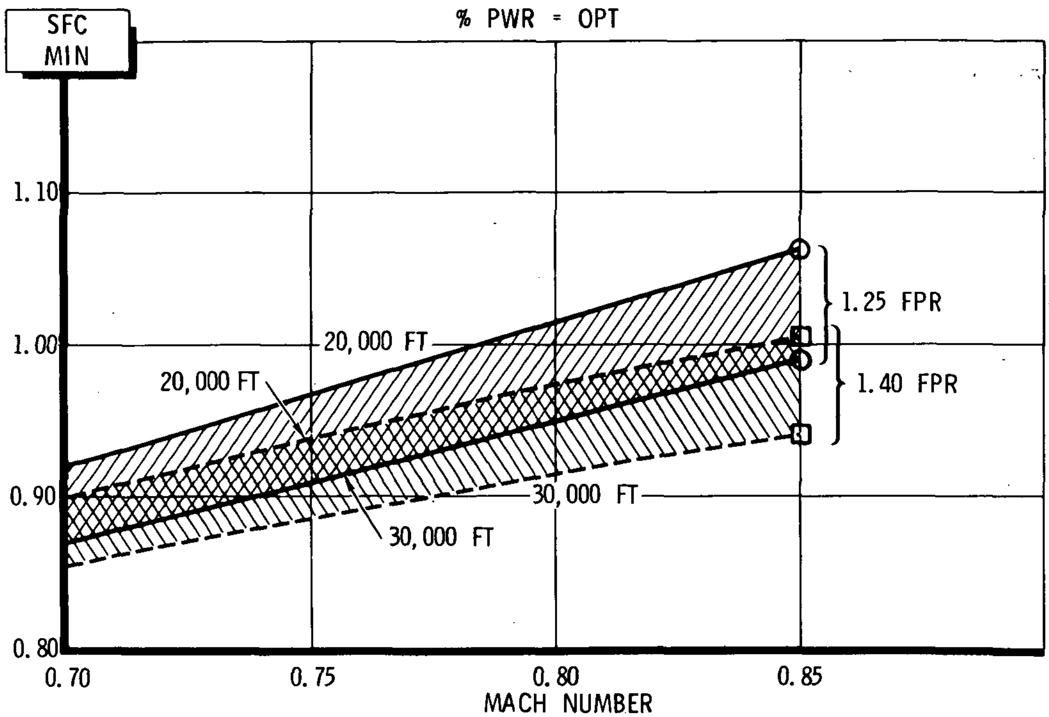


Figure 33. Lift/Cruise Fan System SFC vs Design FPR

Figure 34 illustrates the ratio of maximum STOL lift/cruise fan thrust available, i.e., net thrust at 0.2M/SL/90°F, to the standard day cruise net thrust available for various design cruise conditions for the two comparison single-stage FPR fan systems. Both fan systems are sized for a lift-fan static thrust of 20,000 pounds at SL/90°F conditions. The curve callouts indicate the selected variable cruise conditions. The STOL thrusts used to calculate the thrust ratios are held constant as a function of FPR. A net thrust of 11,595 pounds is used for the 1.25 FPR system STOL thrust and 13,595 pounds for the 1.40 FPR system. Lift/cruise fan thrust is 4% to 9% less than the corresponding lift-fan thrust at static conditions due to the

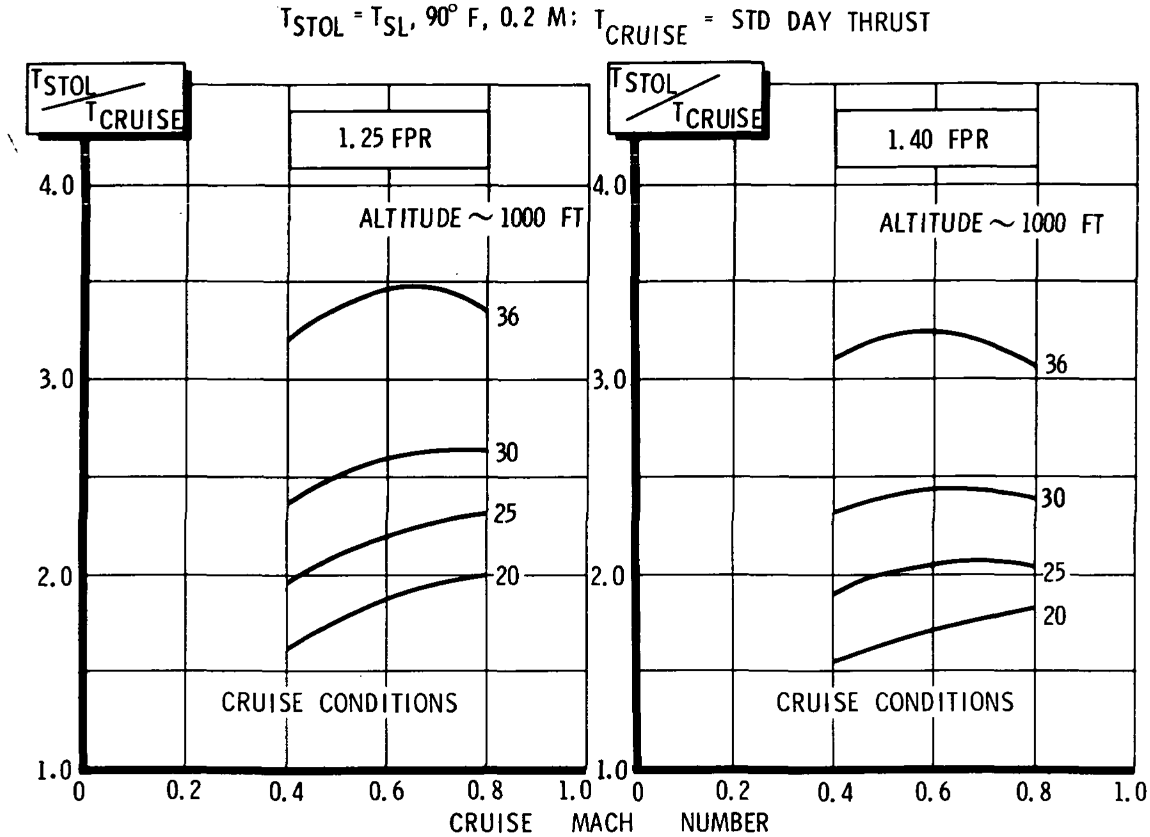


Figure 34. STOL Thrust-to-Cruise Thrust Ratio vs FPR

differences in installation losses; also, 29 to 36% additional lift/cruise fan net thrust is lost at a forward speed of 0.2M relative to the static values. The high 1.25 FPR T_{STOL}/T_{CRUISE} ratios indicated are primarily due to the low cruise thrusts of the 1.25 FPR systems. For example, for 0.80 mach number cruise at 30,000 feet, the 1.25 FPR lift/cruise fan system of figure 34 produces 4396 pounds of thrust while the 1.40 FPR lift/cruise fan sized to the same lift-fan static thrust produces 5733 pounds of thrust. Thus the STOL/cruise thrust ratios noted are 11,595/4396 or 2.64 for the 1.25 FPR system and 13,595/5733 or 2.37 for the 1.40 FPR system. If a cruise design condition sizes the propulsion system, the data of Figure 34 show that the 1.25 FPR fan system can provide a higher amount of thrust for the STOL takeoff condition relative to a 1.40 FPR fan system because of its inherently higher STOL/cruise thrust ratio. Conversely, if the STOL takeoff condition sizes the propulsion system, the 1.25 FPR system would have less thrust at the cruise condition than the 1.40 FPR system because the reciprocal of the indicated ratio of Figure 34 would be the applicable indicator.

The fans discussed in this section have 25 percent control margin above their nominal (neutral control) thrust level for low speed propulsive attitude control. Other levels of design control margin have advantages for selected applications because the basic fan weight and nominal thrust are affected by selection of the percent control margin. These variations are discussed in the trade study portion of the report.

Preceding discussions of lift-fan characteristics have also been related to basic fan designs using double (dual) entry scrolls. A recent lift-fan design innovation has introduced a quadruple (quad) entry scroll design as an attractive alternative for certain installations. Figure 35 illustrates the difference in the characteristics of the two scroll designs. The quad entry scroll provides the same amount of gas flow to the fan as the dual entry arrangement but introduces the flow at four rather than two locations. The auxilliary entries can be designed in a variety of axial or radial orientations with respect to the scroll to suit individual installation requirements as illustrated on the lower right hand portion of Figure 35.

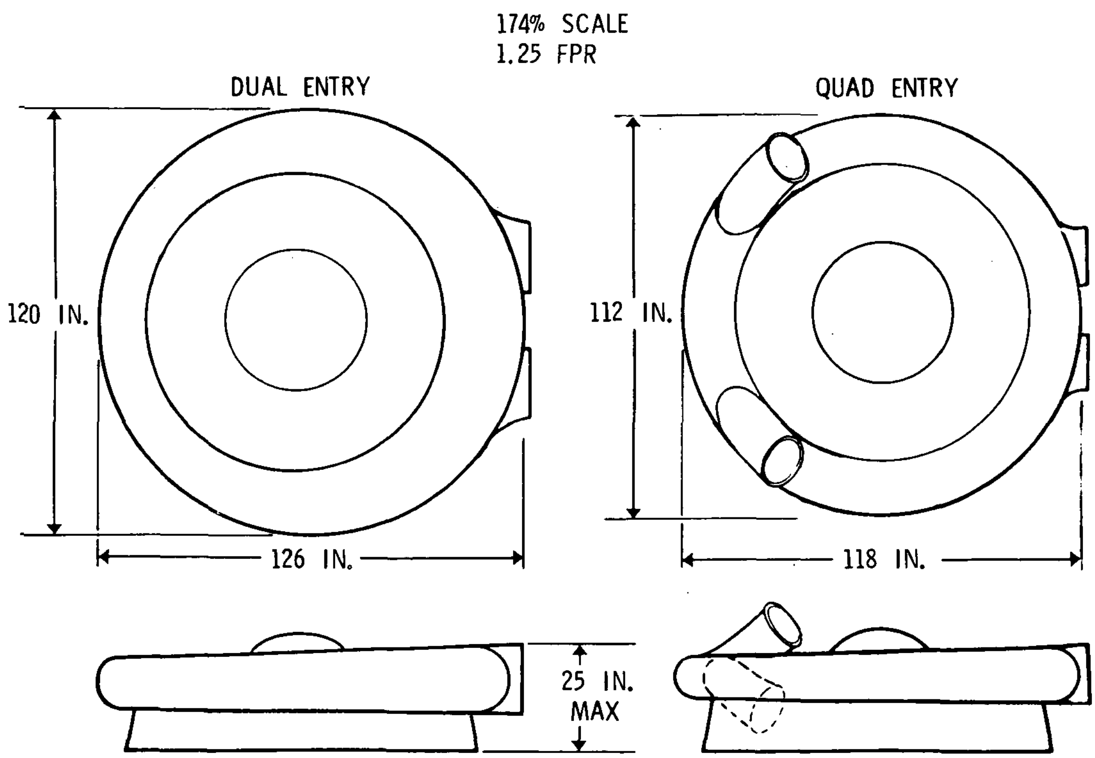


Figure 35. Dual vs Quad Entry Lift-Fan Scroll Designs

Figure 35 shows that the new quad scroll design allows about an 8 inch fan installation maximum diameter reduction relative to the original dual entry scroll design at a cost of 13 pounds added weight per fan. This design difference shows up as a potential benefit when the reduction in fan overall dimensions allows a significant reduction in nacelle or surrounding fuselage structural weight and drag.

Available noise data on lift-fan systems versus fan pressure ratio indicate that 1.40 FPR fan systems at the same thrust level can be expected to produce noise levels about 4 PNdB higher than 1.25 FPR fan systems. A 20,000 pound thrust 1.25 FPR lift-fan would produce an estimated 91.2 PNdB maximum 500 foot sideline noise level while the 1.40 FPR fan at the same thrust would register about 95.5 PNdB. These noise levels are achieved through the use of a projected 1985 fan noise reduction technology that reduces the fan exhaust noise by 17.5 PNdB and the inlet noise by about 7.0 PNdB from current technology fans as described in Reference 2.

A brief review of the lift-fan system characteristics presented above as a function of design fan pressure ratio indicates that if cruise requirements alone were to determine the FPR selection for the 1985 V/STOL commercial transport, a relatively high (1.40) FPR fan system would be the preferred choice. However, if noise considerations or VTO or STOL thrust capability enter as critical design considerations, then the low (1.25) FPR fan system has attractive advantages of lower noise and higher VTO T/W and STOL thrust. The level of 1985 technology for lift-fan systems for commercial V/STOL transport applications generally can be considered acceptable for first generation systems except for perhaps the noise characteristics. Further development of the propulsion system to improve operating efficiency, weight and noise characteristics would be beneficial, however, to provide more attractive overall systems.

TRADE STUDIES

At the initiation of the study, a basepoint transport configuration nominally meeting all study guideline requirements was established as a starting point for the study. The analysis of this configuration was used to establish the practical feasibility of a six fan/six gas generator propulsion system and low speed control concept for the commercial short haul transport application. Recommended configurations from earlier studies, e.g., Reference 1, indicated that 8 fan/8 gas generator concepts would most likely be required. Analyses of the six fan basepoint aircraft showed that adequate cruise thrust could be provided using only two of the six fans and gas generators each during the cruise mode and that estimated control force response rates of the large fans required would probably be fast enough, with adequate compensation from the control system, to meet minimum guideline low speed control requirements. Once the general feasibility and acceptability of the six fan concept was established, the basepoint aircraft was then used as the focal point for a series of trade studies to identify further promising alternative design features and to identify the acceptability of selected critical technical operating characteristics and design criteria. The major trade studies and results are summarized below.

Design Sensitivity

An early trade study performed on the basepoint airplane identified the takeoff gross weight sensitivity of the airplane to the major aircraft design parameters. The results of these studies are presented in Figure 36. Figure 36 shows that the propulsion system installed thrust-to-weight ratio is the most powerful parameter that influences the takeoff weight of the aircraft. This is a natural result of the fact that the propulsion system represents about 40 percent of the aircraft empty weight. The other significant parameters in their order of relative influence on the takeoff weight are cruise fuel flow, parasite drag, induced drag and lift engine fuel flow as indicated by the relative slopes of the incremental takeoff weight versus percent change lines. The relative significance of structural or other fixed weight changes are indicated by the dotted line and the lower auxiliary scale. This weight sensitivity curve shows that the takeoff weight changes 3 pounds for every one pound change in empty weight, i.e., the aircraft growth factor is approximately 3.0.

Use of the data of Figure 36 allows quick assessment of the potential merits of candidate design changes by estimating the effect of the change on each major design parameter and then using Figure 36 to compile a net takeoff gross weight effect. The data of Figure 36 also indicate by the relative sensitivities shown, where individual improvements should be sought to produce the highest payoff in terms of reduced aircraft takeoff weight.

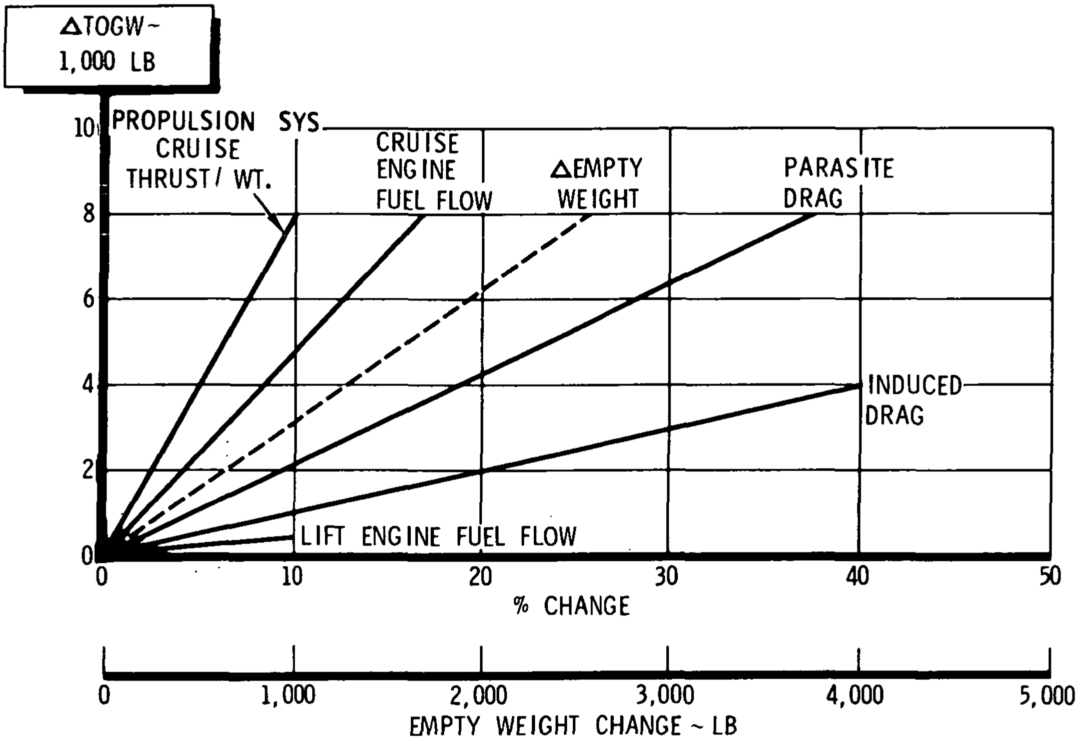


Figure 36. Takeoff Weight Sensitivity to Major Design Parameters

Economic Sensitivity

The sensitivity of direct operating cost (DOC) characteristics to selected airplane design and operating parameters was defined by a series of trade studies. The results of these studies are summarized in Figure 37. The data are presented for a 300 nautical mile trip distance representative of the short haul market extending over the range of 80 to 450 nautical mile trip distances. The slopes of the lines indicate the relative sensitivity of DOC to the respective parameters. The data in the figure indicate that cruise time, airframe weight and fuel required are the most significant parameters relative to the determination of the airplane operating DOC. The airframe weights for the studies were approximated by the manufacturer's empty weight less the gas generators and fans. The DOC is indicated to be more sensitive to increases than decreases of cruise time because of the effects of the other trip legs which were held fixed for the sensitivity study. The DOC is more sensitive to lift fan (L/F) costs and thrust than the corresponding lift/cruise (L/C) parameters because the basepoint configuration features four lift fans and two lift/cruise fans, respectively. The fan costs and thrust factor effects are influenced by the respective average

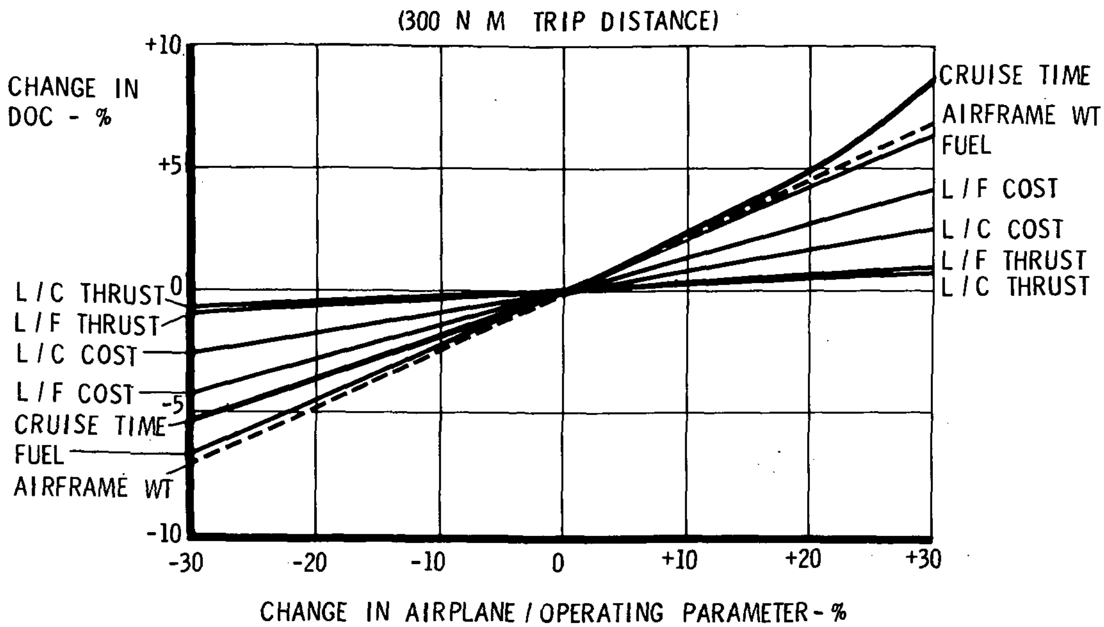


Figure 37. Direct Operating Cost Sensitivity to Aircraft Parameters

running times per trip for the two types and the proportional maintenance actions generated thereby. The thrust levels, as well as running times, are used to scale the maintenance costs of the fan systems.

The data of Figure 37 allow preliminary assessment of the impact candidate aircraft features or operating procedure changes on the DOC. If a particular change impacts more than one of the indicated airplane or operating parameters, the total individual effects are algebraically summed to identify the net effect.

Propulsion/Hover Control

The basic propulsion system technology data for the study identified lift fans having 25 percent control margin for low speed and hover control applications. Additional design characteristics data provided by the General Electric Company indicated that lighter weight fans with other desirable characteristics could be designed using the same technology level if lower levels of control margin could be shown to be sufficient. Figure 38 presents a summary of the potential fan characteristics as a function of the required level of control margin for sea level standard day conditions, except as noted.

Control margin is the percentage of additional transient short period control thrust available above the fan nominal (neutral control) military thrust level to provide attitude control forces to the vehicle during the powered lift mode. The data of figure 38 are based on general fan and gas generator characteristics trends. Slight changes would be noted in the linear relationships shown at low design percent control margins as specific fan and gas generator RPM and temperature operating limits are encountered.

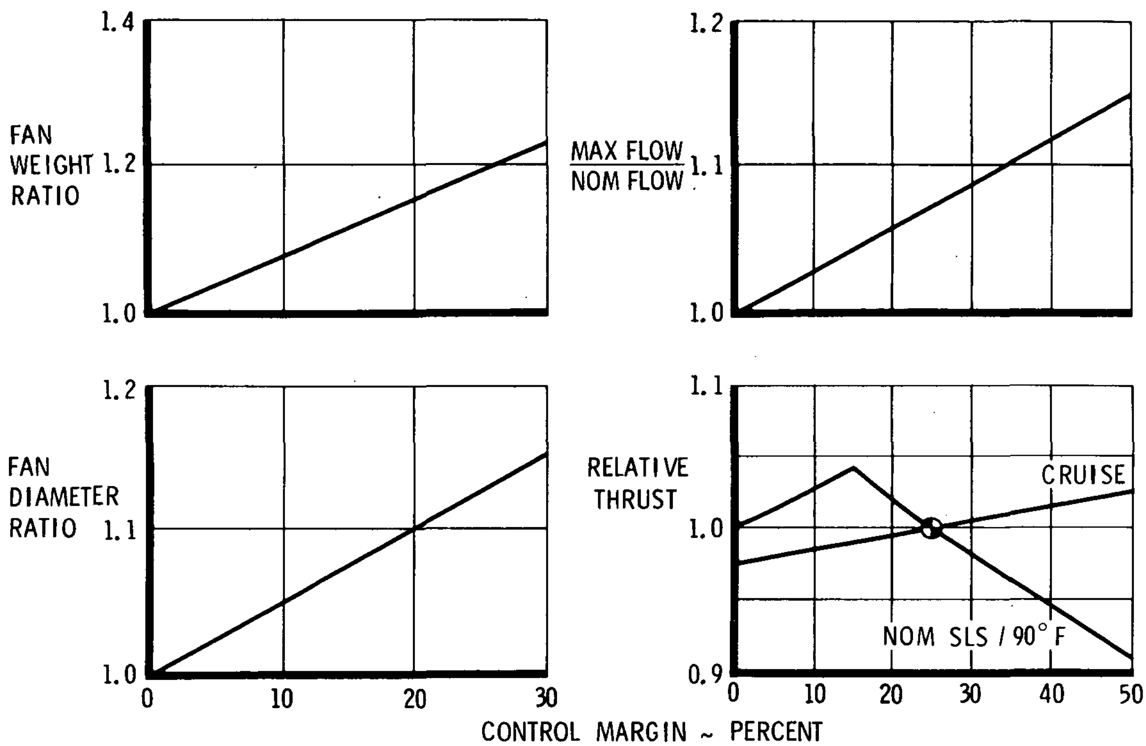


Figure 38. Fan Characteristics vs Design Control Margin

Trade studies were conducted to define compatible configuration and fan characteristics which would result in the lightest weight aircraft capable of meeting all guideline requirements. Several iterations of candidate design selections and arrangements were conducted. The final configuration adopted identified a fan system designed to approximately 12.3 percent control margin as a near optimum selection relative to the data of Figure 38. With consideration of the practical fan and gas generator temperature and RPM limits, the available control margin is slightly less as discussed in the section of the report dealing with the selected configuration. Relative to the basepoint fans having 25 percent control margin, the selected fan designs produce nominal thrusts 3.2% higher with a fan weight 8.8% lower. Other desirable characteristics of the selected fan relative to the basepoint fan are fan tip diameter 5.7% smaller and an inlet flow ratio of 3.7% less. These latter items indicate generally smaller nacelle and inlet provision requirements. These beneficial features are obtained with about a one percent reduction in cruise thrust. Review of the trade study results indicated that further refinements could be made in the detailed design phase of the aircraft by continued optimization not within the scope of this conceptual study.

Alternate Fan/Gas Generator Arrangements

A series of trade studies were undertaken to review the relative merits of alternate propulsion system fan and gas generator arrangements relative to the basepoint six fan/six gas generator concept. The basepoint propulsion system used four fans for lift only and two for the dual mode lift/cruise function. All fans and gas generators were the same size to minimize propulsion procurement and operating spares costs.

Fewer gas generators than fans. - The first trade study in the series examined the effect of the use of fewer gas generators than fans in the system. The potential advantage sought was the reduction in the number of units of rotating turbomachinery required and the associated expected reduction in operating costs. Analyses made, however, indicated that the reduction in the number of gas generators in the system results in an adverse trend in total propulsion system installed thrust-to-weight ratio as shown in Figure 39. A system employing four gas generators to drive six fans is compared with a six fan system using six gas generators for a range of potential aircraft sizes defined by amount of installed maximum SL/90°F nominal lift that would be required.

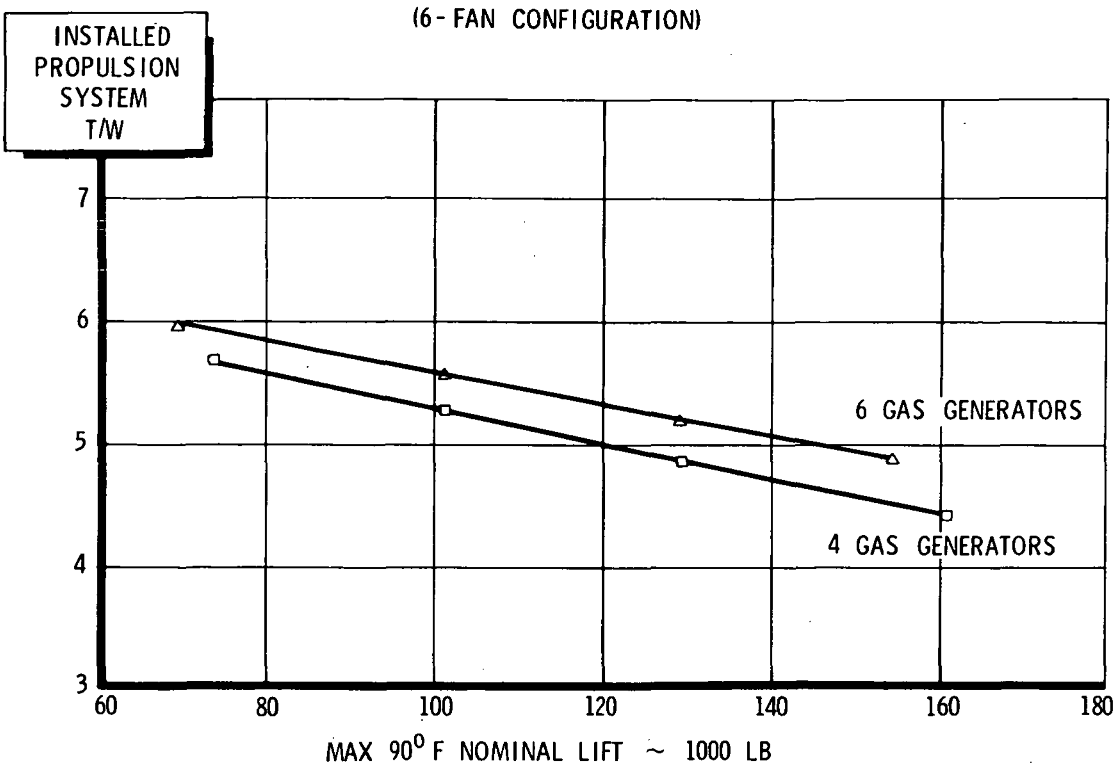


Figure 39. Effect of Fewer Gas Generators Than Fans

The data illustrate the effect on propulsion system T/W when the safety criteria require resizing the gas generators such that those remaining after a failure can continue to support the airplane with the available fans. For the four gas generator case, three gas generators must perform a function that five will do in the six gas generator arrangement. The result is that the individual gas generators sizes must be significantly increased such that they fall in a less efficient weight per pound per second of gas flow region of the gas generator scaling characteristics, e.g., see Figure 27 which shows that gas generator weight increases faster than the corresponding thrust or airflow scale factor.

The decrease in installed propulsion system T/W ratio, for the four gas generator system relative to the six gas generator system, is about 7 percent in the area most applicable to this study, i.e., in the area of about 140,000 pounds total installed nominal SL/90°F lift. From the sensitivity data of Figures 36 and 37 it can be seen that a 7 percent drop in installed propulsion T/W will cause an increase in takeoff weight of about 5,700 pounds. This is slightly over a 5.6 percent increase in takeoff weight which will cause similar increases in airframe weight, fuel, fan sizes, etc. From Figure 37, these increases to the individual DOC sensitivity parameters sum up to over a 4 percent increase in DOC for the airplane operating over 300 nautical mile trip distances. The analysis to this point does not specifically include the increase in fuel flow that may be caused by the larger gas generators potentially operating at lower power settings during cruise, though this would be a consideration.

A brief review of the portion of the DOC affected by the total propulsion system, e.g., see Figure 22 in this report, indicated that it would be very difficult for the maintenance effects of larger fans and four larger gas generators versus 6 smaller ones to offset the 4 percent increase in DOC, due to the increased system weight, except perhaps for very short trip distances. Engine maintenance is less significant for long trips because engine operation at the high power settings required for takeoff, climb and landing is a smaller portion of the total engine time accumulated. Fewer maintenance actions are generated by long periods of engine operations at the lower cruise power settings than by the comparatively short (high power setting) near terminal operations.

Because the DOC of the first generation V/STOL transport will likely be less, over most of the operating short haul market trip distances, with the six gas generator system and because the noise goals are adversely affected by increases in total system weight, it was determined that the lighter weight six gas generator system was the preferred propulsion system for a first generation V/STOL short haul aircraft.

Separate high cruise efficiency engines. - A trade study was conducted to evaluate the merit of using separate high cruise efficiency turbofan engines to augment the remote lift-fan system during the cruise mode. The benefit sought was the lower cruise SFC's that would be noted for a propulsion system designed for high cruise efficiency without the compromises needed to provide efficient low speed propulsive lift and attitude control. An advanced turbofan design defined by the General Electric Company, designated the GE13/F6A1, was selected as representative of this type of propulsion system.

The GE13/F6A1 engine is a mixed-flow, 6.2 bypass ratio, twin-spool turbofan engine which features a 1.46 fan pressure ratio, an overall compression ratio of 24.5, and a maximum turbine inlet temperature of 2450°F. The 100% size engine produces an uninstalled sea level static thrust of 22,000 pounds at maximum power setting and weighs 3375 pounds. The installed cruise SFC at 0.8M/36,000 feet conditions for the GE13 is about 0.70 versus 0.912 and 0.887 for the 1.25 FPR and 1.40 FPR remote lift-fan systems, respectively.

Use of the GE13's during the lift mode as a complement to a remote lift fan system presents several technical difficulties, however. These difficulties are primarily related to integrating the engine into the vehicle hover control system and the basic noise characteristics of this comparatively low bypass ratio and high fan pressure ratio engine. Since the GE13 has not built in capability to perform as an element of an ETC propulsive lift control system, its role in low speed control would be limited to its individual thrust modulation capability using throttle changes alone. Also, since safety requires that lift and control be sustained after any engine failure, it would be necessary to use at least two GE13's if its capabilities were to be employed in the low speed propulsive lift and control mode. Preliminary noise estimates of the GE13 indicate that it would produce a maximum 500 foot sideline noise level of about 111 PNdB at full power and 105 PNdB at 50 percent power in its current acoustically unsuppressed design configuration. If approximately 50 pounds of wall treatment and about 300 pounds of exhaust noise suppression splitters were added, these noise levels could likely be reduced to about 100 PNdB and 90 PNdB, respectively, for the 100% and 50% power settings. Thus, if an attempt were made to use the GE13's during the propulsive lift mode, significant vehicle weight penalties would accrue to provide operating characteristics compatible with the study low speed safety and noise guideline requirements and goals.

From consideration of the above, it appeared more appropriate to consider the GE13 as a supplementary propulsion system for the cruise mode only. To keep the number of powerplants required to a minimum, it was decided to investigate the use of a single additional GE13 type cruise turbofan of variable

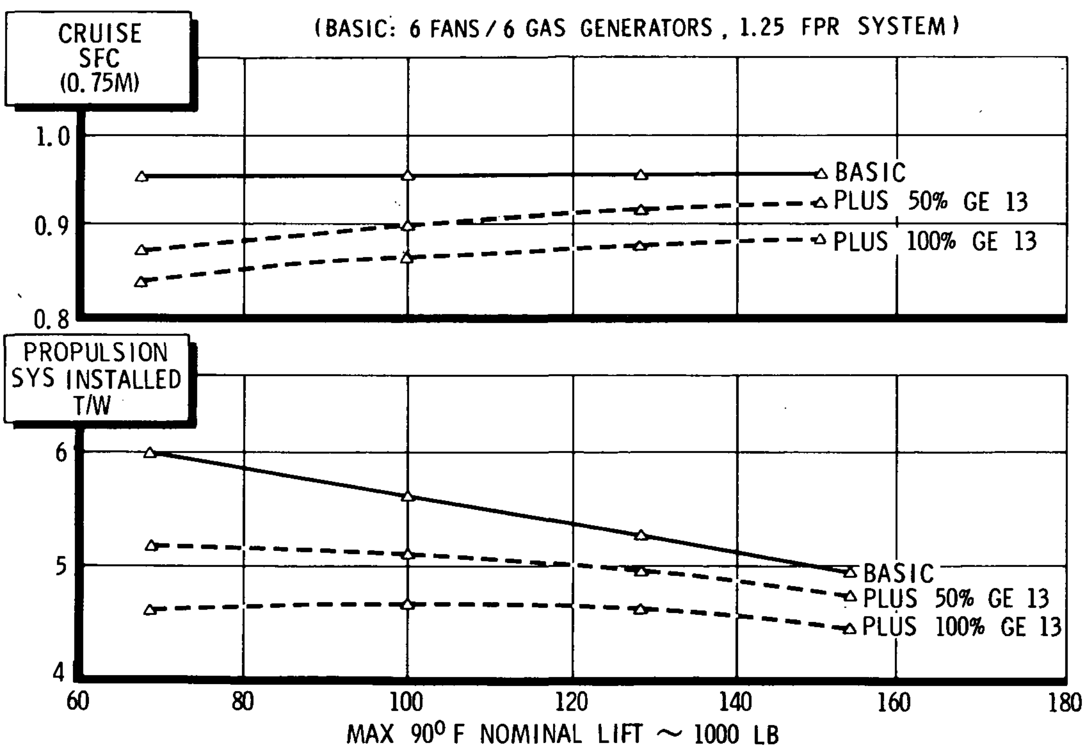


Figure 40. Effect Of Use Of Special Cruise Engines

size. This additional powerplant would be used in combination with the two remote lift/cruise fan installations already provided on the basepoint aircraft for use during the cruise mode. Figure 40 illustrates the effects of using a GE13 of variable size, during the cruise mode only at 36,000 feet, on the major characteristics of the propulsion system.

The upper portion of figure 40 shows that the use of a special GE13 cruise engine does drop the net cruise SFC's proportional to the percent of the total cruise thrust represented by the GE13. For the larger airplanes where more total installed thrust is provided by the basic remote lift-fan system, the net SFC reduction is less. For the aircraft sizes of interest in this study, using about 140,000 pounds of installed nominal lift, the SFC reduction amounts to about 3.7% using a 50% size GE13 and 7.9% using a 100% size.

The lower portion of figure 40 shows the effect of the GE13 installations on the net propulsion system installed thrust-to-weight. The weights used for the GE13 assume no additions for acoustic suppression because the engines are used in the cruise mode only. Nevertheless, the added weight of the GE13 supplementary cruise system degrades the installed propulsion system thrust-to-weight ratio. The degradation in T/W ratio is less for the larger aircraft where the GE13 installations represent a smaller portion of the total weight and thrust. In the region of aircraft requiring 140,000 pounds of nominal lift, the propulsion T/W is reduced by about 4.8 and 10.9%, respectively, for 50% and 100% size GE13 cruise engine additions. Since the magnitude of the percent reductions in T/W ratio are larger than the SFC savings, it is apparent from the sensitivity data of figures 36 and 37 that addition of the GE13's would cause a net increase in aircraft takeoff weight and DOC. The maintenance complexity and costs added by the inclusion of another type of engine on the same airplane are not specifically accounted for in the sensitivity data and would operate as an additional inhibiting factor with respect to adding the GE13's. The net conclusion reached from the above study was that it would likely be unprofitable to attempt to use a special cruise engine. The issue could be reopened, however, if a particular engine or technique was found which would allow integration of the cruise system with the basic remote lift-fan system for use during the low speed mode without ill effects on noise or T/W. A second engine might also be more palatable if it were of a design already being used in the airline fleet for another application such that no additional unique maintenance facilities or training would be required.

Different lift cruise fans. - A study was made to survey whether overall system advantages might be obtained by providing lift/cruise installations with a different fan design than used for the lift-fans. The gas generators in the propulsion system were to be all of one size and design. The objective sought was to identify if a supplementary fan development would provide significant advantages since an alternate fan development could be obtained at a lower cost than an alternate gas generator or cruise engine development.

An 8 fan/8 gas generator configuration was selected as the baseline for this study. The baseline configuration used two 1.25 FPR lift/cruise fans and six 1.25 FPR lift-fans all of the same size; during the cruise mode two gas generators drive the lift/cruise fans and two others operate in a pure turbojet mode to augment the thrust of the lift/cruise fans to provide adequate thrust. Since the cruise SFC of the baseline system was comparatively high due to the two gas generators operating in the turbojet mode, it was desired to provide an alternate fan design which could employ the flow of these two gas generators in a more efficient manner. The baseline aircraft configuration did not lend itself to modification to provide four lift/cruise fan installations; therefore, it was decided to consider the use of two large size lift/cruise fans that would use the flow from four gas generators during cruise. Because higher design pressure ratio fans were shown to provide improved SFC, e.g., Figure 33, it was desired to operate the new lift/cruise fan design at high FPR for cruise on the flow of four gas generators, and at a lower FPR for efficiency during the lift-mode on two gas generators. Investigation of these potentials showed that a lift/cruise fan design could be balanced to operate at a 1.25 FPR during the lift mode on two gas generators and at a FPR of 1.40 during cruise using four gas generators.

The requirements for the dual mode lift/cruise fans indicated they must have the capacity to handle twice the gas flow rates of the baseline configuration lift/cruise fans. Consideration of the appropriate scaling data indicated that, to accommodate this additional flow, the fan linear dimensions would increase approximately 40 percent and the weight would increase by about 140 percent. Reduction of the appropriate thrusts and the new total propulsion system weights to an installed propulsion system T/W ratio indicated that the net result was a reduction in propulsion T/W of slightly over 12 percent. This would cause a takeoff weight growth of over 9000 pounds. The differences in propulsion system costs were also estimated as shown in Figure 41. For aircraft requiring approximately 140,000 pounds of installed nominal lift, the difference in propulsion system costs noted was approximately $400, 000 per airplane, an increase of about 7.6 percent over the baseline propulsion system cost. The trend of the above results indicated it would be difficult to show advantages for different lift/cruise fan and lift-fan designs on the same airplane where the concept requires the alternate fan design to be significantly larger than the others.

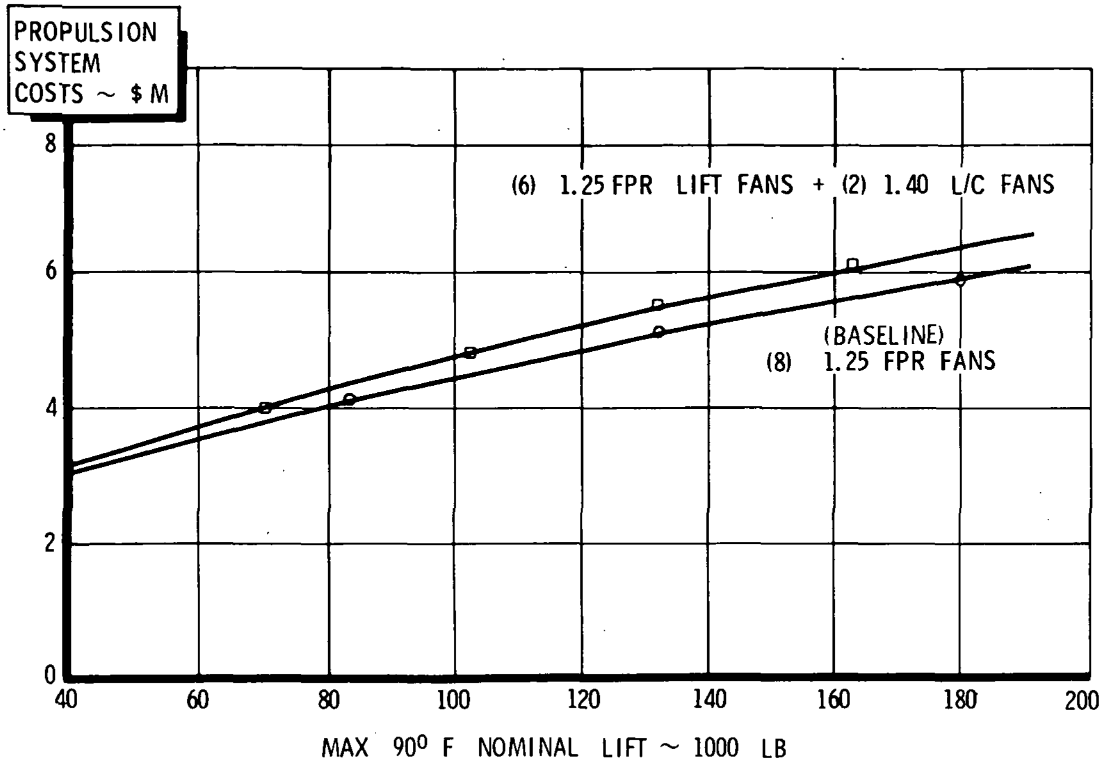


Figure 41. Different L/C and L/F Design Effects on Propulsion System Costs

Six fans versus eight fans. - A trade study was performed to provide a basis for a decision between a 6 fan/6 gas generator propulsion configuration and an 8 fan/8 gas generator arrangement. The prime issues to be resolved were (1) whether a 6 fan system could be defined that would meet the guideline control response time constant requirements and (2) could a feasible 6 fan arrangement overcome the advantages of an 8 fan/8 gas generator system caused by the relative weights identified by scaling small versus large fans and gas generators. Normally, weight scaling effects indicate that propulsion systems with a larger number of units will have a higher installed thrust-to-weight ratio because of the tendency of smaller units to be more weight efficient. Also, because the lift system must perform with any single unit failed, the oversizing to meet this requirement is larger as the number of units in the system decreases.

The fan alone time constant, τ_{fan}, i.e., the time required for the fan control force to reach 63 percent of the final commanded value, is a major factor in the determination of the total response rate of the control system, τ_{sys}. The τ_{sys} accounts for all the lag in the system from a pilot step input to the 63 percent control force point and is series dependent on the gas generator, valve actuator and other control system element characteristics in addition to the fan response. The critical response time constant is the 0.3 second τ_{sys} required for an upward flight path control command during normal operations. Special studies have indicated it is feasible through the use of small amounts of symmetrical thrust spoiling during neutral control and other control system quickening techniques to meet the critical system flight path control time constant requirement with fan time constants of the order of 0.3 seconds. Figure 42 presents estimated fan alone time constants, τ_{fan}, for a range of sizes of 6 and 8 fan systems. The figure shows that the

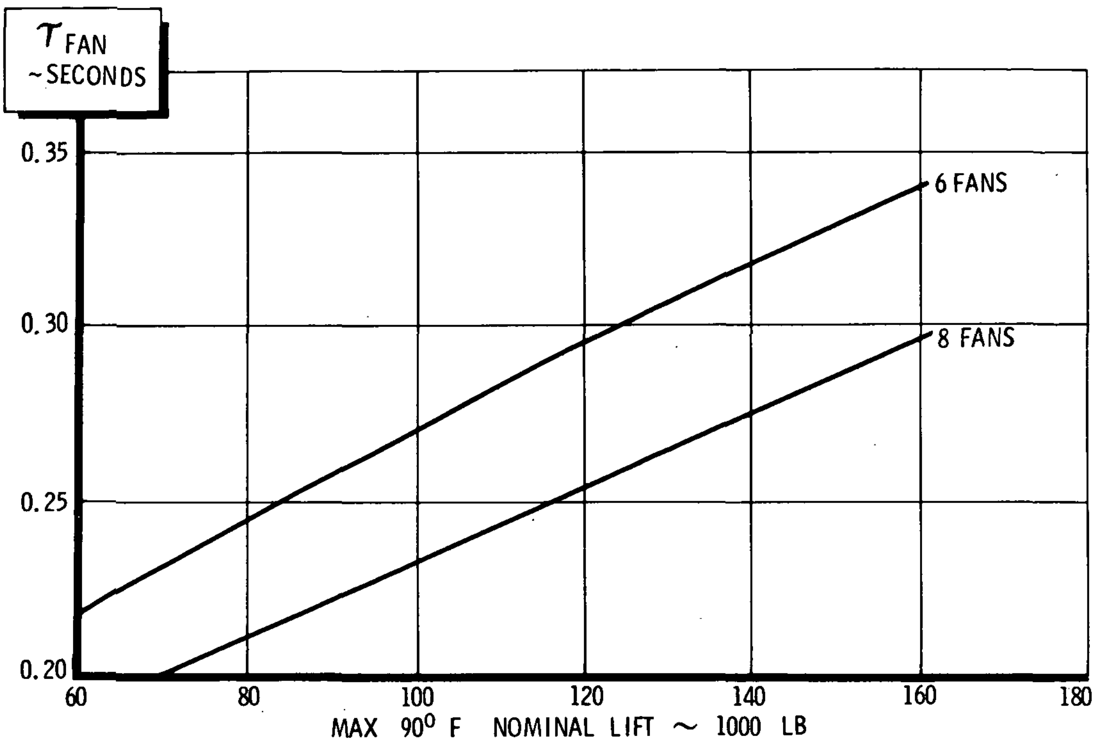


Figure 42. Fan Time Constants for Six and Eight Fan Systems

larger fans required in a 6 fan system required to produce a given total vehicle nominal lift will respond about 0.04 seconds slower than the smaller fans in an 8 fan system. All 8 fan systems indicated would meet the τ_{sys} requirements. Six fan systems will meet the response time requirements with only moderate amounts of spoiling and control quickening for vehicles requiring total installed nominal lifts of 140,000 pounds or less. Above 140,000 pounds the amount of thrust spoiling required would likely begin to severly affect the vehicle propulsion sizing required to maintain the required nominal lift.

To compare the overall relative advantages of a 6 fan/6 gas generator system with an 8 fan/8 gas generator system, an existing 8 fan design, from Reference 1, was modified to reflect the current study guideline of a 25 percent structural weight saving through the use of advanced composite material technology. This aircraft was then compared with the basepoint 6 fan airplane developed for this study. Table 1 summarizes the major elements of the results of this comparison.

TABLE 4. SUMMARY COMPARISON OF 6 FAN AND 8 FAN AIRCRAFT

PARAMETER	6-FANS	8-FANS
CRUISE MODE	2 L/C FANS	2 L/C FAN + 2 TJ
PROPULSION SYS T/W	4.95	6.09
PROPULSION SYS WT	26,300 LB	19,600 LB
FAN TIME CONSTANT	0.34	0.26
CRUISE FUEL FLOW	12,500 LB/HR	15,000 LB/HR
FUEL REQUIRED	15,850 LB	19,000 LB
NOISE	98.3 PNdb	98.5 PNdb
TOGW	106,000 LB	105,000 LB
AIRFRAME COST	$4,823,500	$5,104,000
PROPULSION COST	$4,326,300	$4,690,000
TOTAL COST	$9,149,800	$9,794,000
D O C	1.0	1.066
DISPATCH RELIABILITY	1.0	0.97 - 0.995

The data of Table 4 indicate that, as expected, the 8 fan arrangement has an installed propulsion system T/W ratio of over 20 percent better than the 6 fan system. The six fan system has a higher total installed thrust requirement than the 8 fan system to meet the higher takeoff weight and failure criteria with fewer remaining propulsion units. Due to the need to use two gas generators in the turbojet mode to provide adequate cruise thrust, however, the 8 fan system consumes about 20 percent more fuel than the 6 fan system. Because of the requirements for packaging 8 fans versus 6 and accommodating additional fuel, the airframe weight of the 8 fan system is 5.8 percent higher than for the 6 fan system. The net result of these counterbalancing factors is that the 6 fan system takeoff weight is only about 1,000 pounds heavier than the 8 fan system weight. Reflection of the above factors in the estimated purchase costs are indicated, assuming airframe costs of $110/lb and guideline propulsion cost factors, as indicated in the table. The 8 fan system airframe cost is higher than the 6 fan system in the same ratio as the airframe weights. The 8 fan/8 gas generator propulsion system costs are higher than the 6 fan/6 gas generator system primarily due to the added number of propulsion units even though the units are of smaller size.

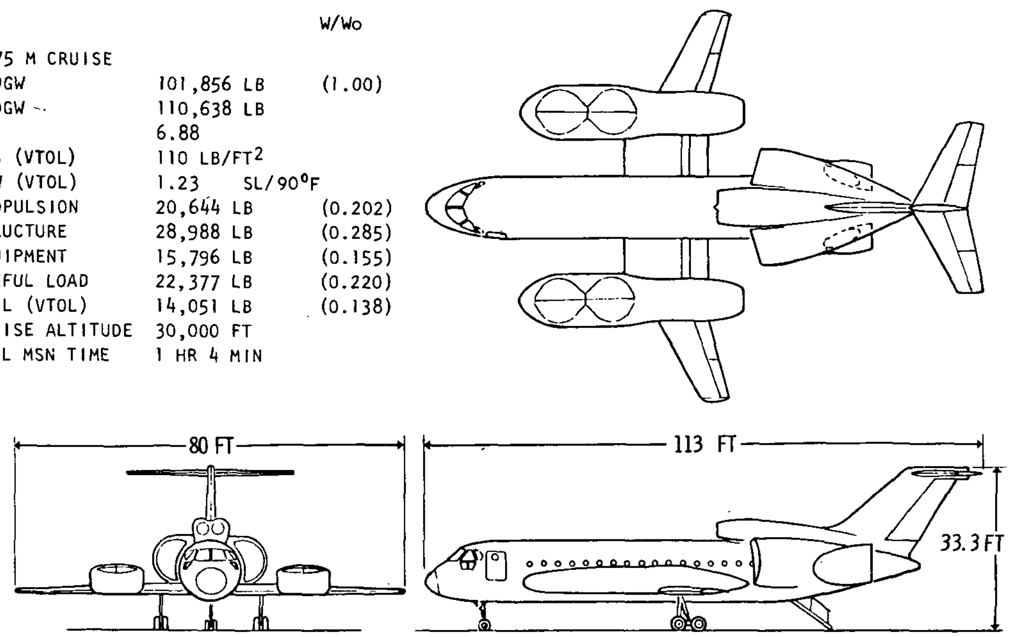
Using the DOC sensitivity information from Figure 37, the net effect is that the DOC projected for the 8 fan system is about 6.6 percent higher than for the 6 fan system. A review was made of the potential effect of the dispatch reliability of the 6 fan versus 8 fan systems. For a range of potential individual fan and gas generator reliabilities, it was determined that if similar component reliabilities are assumed, the 8 fan system could be expected to be from about one-half of one percent to as much as 3 percent less reliable than the 6 fan system due to effect of the added propulsion units. Due to the preliminary methods used to define the reliabilities and DOC's, these values are presented in Table 4, in normalized form, referenced to the 6 fan system values.

Consideration of the above, and the knowledge of airline preferences for fewer engines, indicated that a 6 fan/6 gas generator system should be the recommended basic propulsion arrangement for the 1985 V/STOL short haul transport configuration.

1.40 Fan Pressure Ratio Alternate Design

After the six fan/six gas generator general arrangement of the propulsion system was established, it was desired to investigate the merits of higher fan pressure ratios than the 1.25 FPR selected for the basepoint airplane. Review of the propulsion technology data indicated that as fan pressure ratio is increased, the cruise performance improves but the sea level low speed performance and noise characteristics would likely deteriorate. However, design iterations of the basepoint 1.25 FPR airplane indicated that the cruise conditions were significant in establishing the required propulsion system size and aircraft design wing loading (W/S). Also, it was not known whether alternate takeoff trajectories might neutralize the apparent less desirable noise characteristics of the higher pressure ratio fans.

To investigate the potential advantages of a higher pressure ratio fan system, an alternate 1.40 FPR six fan/six gas generator configuration was established. Starting with a vehicle concept similar to the basepoint 1.25 FPR airplane, the design was individually optimized to take advantage of the special characteristics of the 1.40 FPR system. The wing loading (W/S), vehicle T/W, wing design lift coefficient and cruise altitudes were varied to identify the combinations of options which would produce the lightest weight and lowest direct operating cost characteristics. This optimization process was continued until the relative merits of the 1.40 FPR configuration versus the 1.25 FPR approach were identified. Figure 43 summarizes the characteristics of the final 1.40 FPR configuration that was analyzed in detail.



		W/Wo
0.75 M CRUISE		
VTOGW	101,856 LB	(1.00)
STOGW	110,638 LB	
AR	6.88	
W/S (VTOL)	110 LB/FT^2	
T/W (VTOL)	1.23 SL/90°F	
PROPULSION	20,644 LB	(0.202)
STRUCTURE	28,988 LB	(0.285)
EQUIPMENT	15,796 LB	(0.155)
USEFUL LOAD	22,377 LB	(0.220)
FUEL (VTOL)	14,051 LB	(0.138)
CRUISE ALTITUDE	30,000 FT	
VTOL MSN TIME	1 HR 4 MIN	

Figure 43. 1.40 Fan Pressure Ratio Alternate Design

The 1.40 FPR configuration of figure 43 has approximately a 1200 pound heavier takeoff weight on the VTOL mission than the finally selected 1.25 FPR airplane. The wing loading of 110 Lb/Ft^2 is about 13 percent lower, yielding a wing area of 925 ft^2 versus a 1.25 FPR aircraft wing area of 790 ft^2. The cruise altitude is 30,000 feet versus 24,000 feet for the 1.25 FPR airplane. The difference in cruise altitude provides the 1.40 FPR airplane with a cruise SFC advantage of about 6% but the installed propulsion system cruise T/W ratio is degraded, see figures 32 and 33. The climb to and descent from the higher altitude adds about one extra minute of flight time to the 1.40 FPR airplane block time on the design mission relative to the 1.25 FPR airplane. To provide a larger amount of high pressure gas to the 1.40 FPR fans and meet the vehicle thrust requirements at the higher cruise altitude, the 1.40 FPR airplane has gas generators 15% larger than on the 1.25 FPR airplane. The net airframe empty weight of the 1.40 airplane, less fans and gas generators, is approximately 6.5 percent heavier than that of the 1.25 airplane, this is due primarily to the net effects larger wing required to provide a low wing loading so the airplane can fly at the higher altitudes where the 1.40 FPR system provides the best cruise efficiency and the slightly larger nacelles required to house the larger gas generators and deeper lift fans.

The takeoff weight indicated for the 1.40 FPR airplane in figure 43 is an optimistic approximation to the actual requirements for this airplane. The indicated weight resulted from ending the design analysis iteration of the configuration at a cruise thrust and performance check point. Complete design and analysis checks include STOL and VTOL performance as well. Earlier analyses had established that the particular vehicle T/W and wing loadings of the 1.40 airplane would produce acceptable STOL takeoff performance, including failure conditions. The hover control analysis of the final 1.40 airplane was extrapolated from an analysis of a 1.25 FPR airplane of similar gross weight and basic geometry. The analysis indicated no hover control problems for the 1.40 aircraft in either the yaw or roll axes. The analysis indicated, however, that an increase in hover control power for the pitch axis would be required to bring the control forces available up to approximately the levels provided by the 1.25 FPR aircraft. This can be provided most efficiently by incorporating a higher design percent control margin capability in the fans than the 12.3 percent (figure 38 data basis) assumed for the analysis; the 8 percent control margin increase required would amount to a TOGW increase of two thousand pounds.

Thus a final 1.40 FPR airplane meeting all guidelines would be slightly heavier than the aircraft presented in figure 43. Considering this takeoff weight growth and the DOC sensitivity data of figure 37, a preliminary DOC comparison was made of the 1.40 FPR airplane with the selected 1.25 FPR airplane. This comparison indicated that the two aircraft have nearly equivalent DOC characteristics for the representative short haul market 300 nautical mile trip distance with the 1.40 FPR airplane having a DOC about 6/10ths of one percent higher than the 1.25 FPR airplane. The fuel and installed thrust DOC advantages of the 1.40 FPR airplane were overshadowed by the higher airframe weight and gas generator costs relative to the 1.25 FPR airplane. The DOC of the 1.40 FPR airplane remains higher than the 1.25 FPR airplane out to trip distances of approximately 450 nautical miles (518 statute miles). At the 800 nautical mile trip distance, the 1.40 FPR airplane has a DOC about 1.2 percent lower than the 1.25 FPR airplane because of lower fuel requirements and reduced propulsion maintenance costs. The slightly lower DOC's of the 1.40 FPR aircraft for the longer trip distances is not believed to be a significant advantage since the STOL range capability of the aircraft is considered an interim feature, useful primarily during the short haul market build up period.

While no specific ride quality analysis was made of the 1.40 airplane, it was noted that the lower wing loading would tend to make the 1.40 FPR aircraft less desirable than the 1.25 airplane from the ride quality viewpoint.

A noise analysis of the 1.40 FPR aircraft, reported in the following subsection of this report, indicated that the 1.40 airplane has a noise print about twice as large and undesirable noise time duration characteristics compared to the 1.25 FPR airplane.

Review of the data produced to compare the characteristics of the alternate 1.40 FPR aircraft to the 1.25 FPR airplane indicated that the preferred choice would be the 1.25 FPR airplane. The selection was made on the basis of the better noise characteristics, lower DOC characteristics for the primary short haul market trip distances up to 450 nautical miles, better ride qualities, smaller and lighter weight 1.25 FPR airplane relative to the 1.40 FPR airplane.

Noise

Selected trade studies were conducted to evaluate operating and design options related to the noise characteristics of the 1985 V/STOL short haul transport.

The studies were concerned with external or community noise characteristics of the aircraft. It was desired to survey potential operational takeoff trajectories to define their effect on the community noise characteristics and the VTOL takeoff fuel usage efficiency. Minimum fuel, minimum noise and compromise trajectories were investigated. The minimum fuel trajectories were computed based on existing performance optimization routines for the purpose of minimizing the fuel used; no consideration being given to the effect on community noise. Minimum noise profiles were developed which would minimize independently the noise footprint or the time duration annoyance characteristics of the aircraft noise without regard to the effect on fuel used. An approach to a compromise trajectory that attempted to balance the considerations of minimum fuel and minimum noise was also investigated.

In order to evaluate the effects of the noise in the context of a conceptual study, existing approximate methods based on available noise trend data were used as developed by the contractor. These methods permitted rapid development of noise footprints once the basic propulsion configuration, components sizing and flight trajectory were identified.

It was also desired to include consideration of the time duration annoyance characteristics of the noise as a supplement to the noise footprint analysis. It is well known that the time duration and frequency of occurrence of noise also have large influences on the acceptability of non-acceptability of a given noise level. A rigorous methodology to integrate the noise levels and time durations as a function of sound frequency for an observer standing at a particular spot as an aircraft flies by has been generally developed and is known as EPNdB. This parameter generally correlates predicted noise levels well with available noise laboratory annoyance and opinion survey data. The methodology, however, is too complex to be employed in support of conceptual aircraft studies.

The contractor had developed an alternative simplified parameter which merges general time duration effects and footprint characteristics into one simple parameter. Figure 44 illustrates the concept for the development of the new parameter. The parameter "acre-seconds" is developed for an arbitrary

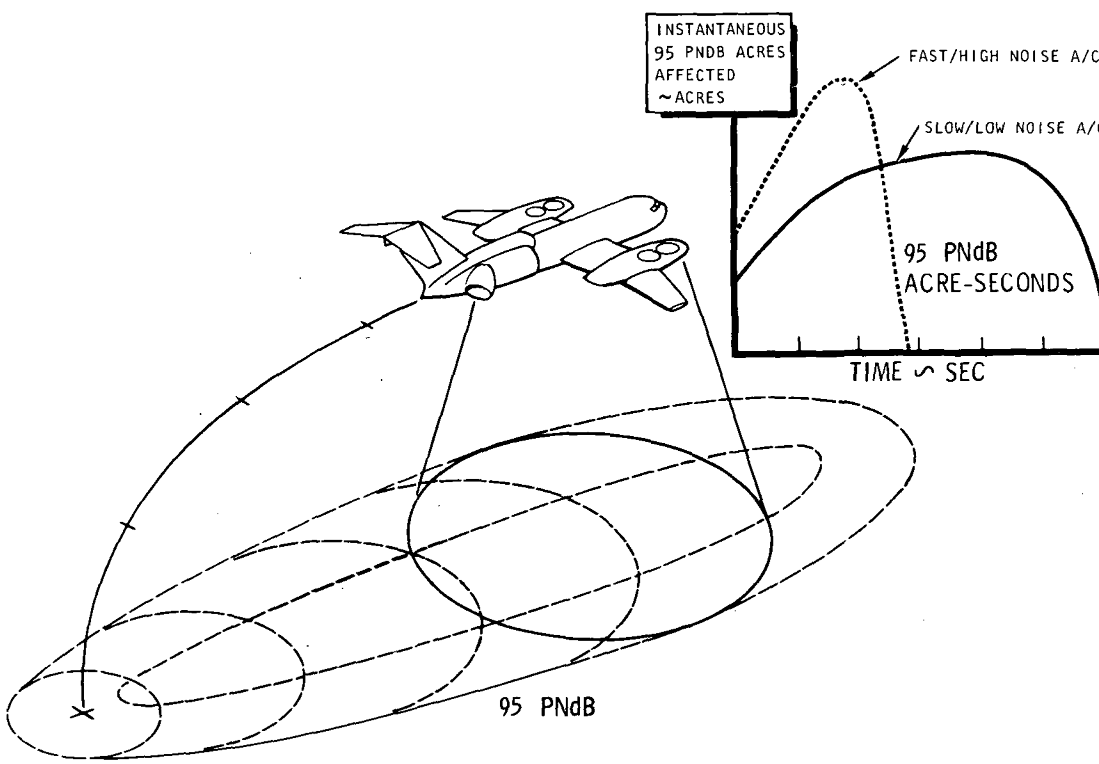


Figure 44. Noise Footprint Analysis with Time Duration Effects

selected level of PNdB, e.g., 95 PNdB, depending on the requirements of a given study. The instantaneous acreage at ground level which is subjected to the selected PNdB level (or higher) is plotted as a function of time in seconds for each point along the aircraft's flyby trajectory. If potential observers are assumed to be uniformly distributed under the aircraft's flight path, an integration of the plotted curve will yield the desired parameter "acre-seconds". This parameter, in a single numerical quantity, defines the area coverage to a selected PNdB level and the time duration characteristics for the noise generated by the passing aircraft. This parameter then is capable of identifying the potential noise annoyance differences of two aircraft that have the same PNdB noise footprints but have different flight times over the trajectories that produce the footprints. The differences in the noise durations would be expected to produce different levels of EPNdB even though the footprints are the same. In the case of "acre-seconds" the integrated area under the curve is modified by the differences in flight times and indicates a higher evaluation number for aircraft whose noise duration is longer due to a slower flyby. Also the "acre-seconds" parameter will provide a consistent numerical evaluation of annoyance for aircraft that vary in both noise footprint and flight time because the parameter is directly proportional to both of these quantities.

The inset of figure 44 illustrates the acre-seconds characteristics comparison of a fast/high noise aircraft and a slower/low noise aircraft. The plots indicate by the ordinate that the ground acreage instantaneously subjected to a 95 PNdB noise level or higher at the altitude for maximum sideline noise will be higher for the high noise airplane than for the lower noise airplane. The plots also indicate that the difference in flight time caused by the aircraft acceleration or speed capability influences the total noise annoyance evaluation by the effect on the duration of the annoyance in seconds. The integrated area under the curves defines the combined effect of the acreage affected and the duration. In the example shown, the slower/low noise aircraft would be expected to be more annoying than the fast/high noise aircraft because of the larger total integrated area (acre-seconds) enclosed by its characteristic curve.

While correlations of the acre-seconds parameter with EPNdB studies have not yet been accomplished to verify the degree to which acre-seconds would predict the outcome of rigorous EPNdB studies, the intrinsic nature of the parameter suggests that such correlation will likely be shown to exist because both acre-seconds and EPNdB respond numerically in the same direction as a function of PNdB noise level and time duration of a noise. EPNdB analysis assumes a single stationary observer while the acre-seconds analysis assumes uniformly distributed observers. Acre-seconds has the advantage of agglomerating the effects of noise level and time duration over the entire footprint in one number whereas EPNdB analysis produces further contour shapes and areas that must be separately evaluated to arrive at a total comparison.

With the above methods available as a basis for the investigation, the test trajectories for the selected 1.25 FPR 6 fan/6 gas generator configuration were developed as illustrated in Figure 45.

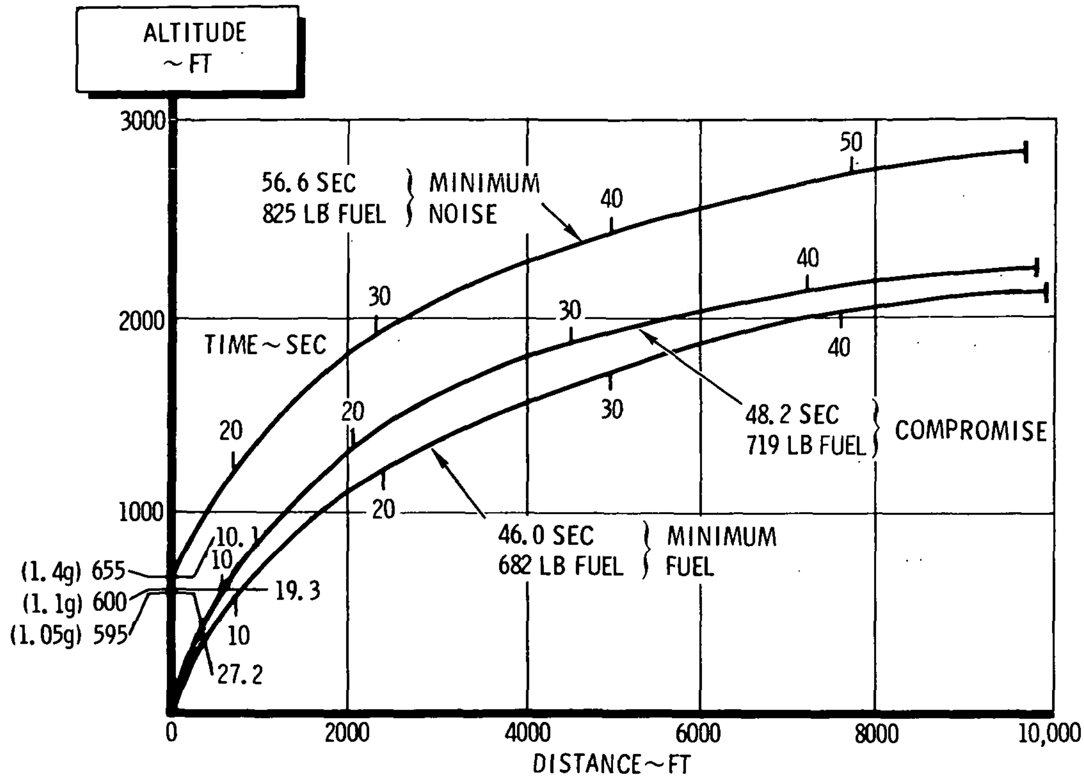


Figure 45. VTOL Trajectories for Selected 1.25 FPR Configuration

The lowest altitude trajectory of Figure 45 is the minimum fuel trajectory and the highest altitude path is the minimum noise trajectory. The compromise trajectory lies between the other two. Three options for the minimum noise trajectory were investigated. These options consisted of three different levels of an accelerating direct vertical rising initial flight path to the point above the takeoff pad where the 95 PNdB footprint contour disappeared above the surface of the ground, followed by a more normal forward accelerating/climbing flight through transition. Investigation of these three options indicated that, while the noise footprint was reduced through the use of the lower power settings associated with the slowly accelerating vertical paths, the time duration noise annoyance parameter (95 PNdB acre-seconds) indicated that these slowly accelerating trajectories would likely be more annoying to persons on the ground because of the prolonged durations of the noise. These slowly accelerating vertical trajectories also consumed more fuel in direct proportion to the longer flight times required. The ultimate minimum noise trajectory was established using the maximum vertical acceleration of 0.4 g as permitted by the study guidelines. This trajectory while producing a slightly larger 95 PNdB footprint produced significantly lower time duration annoyance as indicated by the 95 PNdB acre-seconds parameter. Review of the fuel used data for the various trajectories shown on Figure 45 indicates that there is only about 140 pounds of fuel difference between the minimum fuel and the minimum noise profile trajectories. Figure 46 presents the results of the noise analyses of the trajectories.

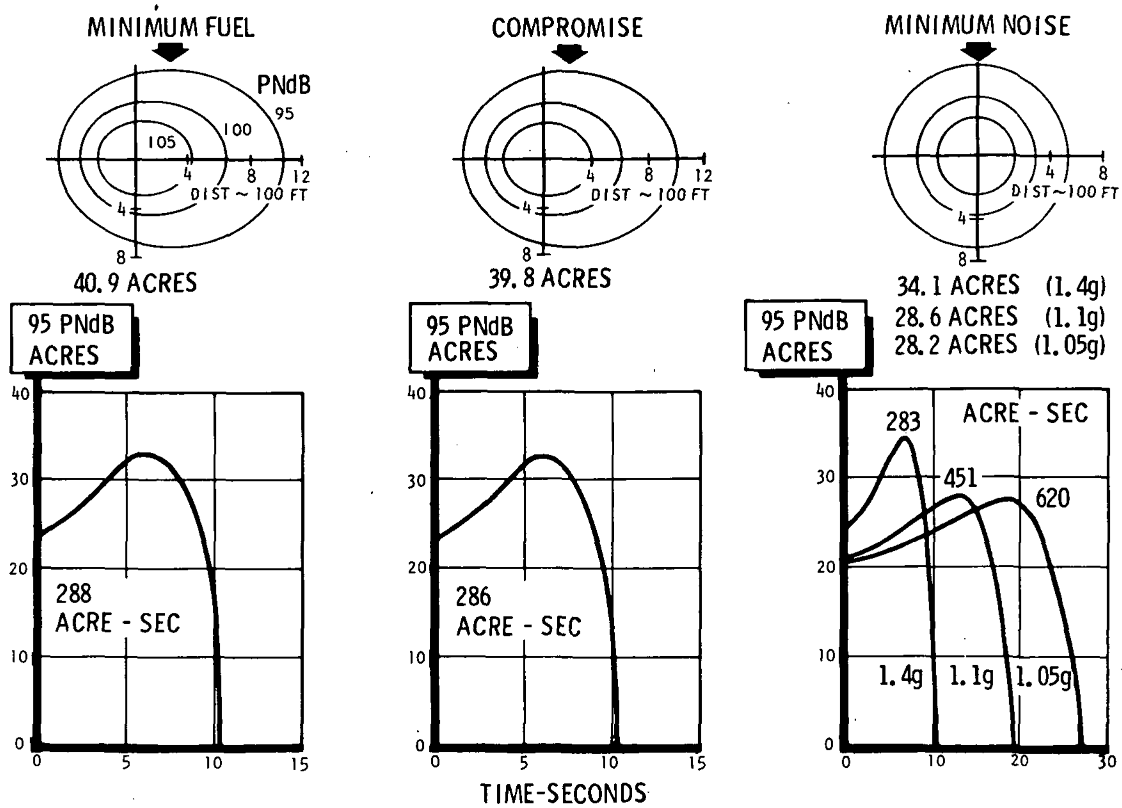


Figure 46. VTOL Takeoff Noise Characteristics for 1.25 FPR Aircraft

The minimum noise trajectory data is presented on the right of Figure 46. The nearly circular noise footprint presented is for the selected 1.4 g vertical accelerating minimum noise profile trajectory. This trajectory consists of a direct rising path to a height of 655 feet where the 95 PNdB footprint contour disappears in about 10.1 seconds. The lower power setting, vertical rising 1.1 g path takes 19.3 seconds to get to the 600 foot altitude point where its 95 PNdB contour disappears; the 1.05 g path requires 27.2 seconds. The ground level acreage enclosed by the 95 PNdB footprint contour for each of these three paths are 34.1, 28.6 and 28.2 acres respectively for the 1.4, 1.1 and 1.05 g paths.

The 95 PNdB acre-seconds plots on the lower right of Figure 46 indicate the acreage exposed to a 95 PNdB noise level or higher for each instant of each trajectory. These curves show that the ground level area affected at first increases, until the aircraft reaches the altitude where its maximum sideline noise is experienced, then, it decreases rapidly as the aircraft continues its accelerated vertical flight. The 95 PNdB acre-seconds data provide a single numerical index of the expected annoyance on the ground due to these trajectories with variable affected areas and time durations. It is most interesting to note that the fast, 10 second/1.4 g flight path that momentarily affects 34.1 acres on the ground is expected to be only about 45 percent as annoying as the slow, 27 second/1.05 g path that affects only 28.2 acres on the ground at its maximum noise impact altitude in terms of 95 PNdB acre-seconds.

The noise characteristics of the minimum fuel and compromise trajectories are also presented on Figure 46. The data for these trajectories indicate that because they begin horizontal translation before the 95 PNdB contour line disappears, they affect larger footprint areas with 95 PNdB level or higher noise. However, because their flight times are short, they register only nominal increases in annoyance relative to the 1.4 g minimum noise profile according to the acre-second parameter. A conclusion that can be reached from this analysis is that, provided that the nominal increase in footprint area affected is not significant, a minimum fuel profile should be relatively little more annoying than the best minimum noise profile.

Review of the footprint data on the top of Figure 46 shows that the 1.25 FPR airplane exceeds the guideline goal of 95 PNdB maximum 500 foot sideline noise. The actual minimum level achieved as calculated on the 1.05 g minimum noise profile was 97.5 PNdB.

Another potentially significant observation of the above analyses is, that with such relatively small areas being affected (35 to 40 acres), the guideline goal of 95 PNdB maximum 500 foot sideline may not be an absolutely essential characteristic of the 1985 V/STOL short haul transport. The larger school yards in many cities are of this size and it is likely that V/STOL ports with arrival/departure areas of this size could be located in cities without prohibitive real estate costs.

It was desired, as a part of the noise analysis trade studies, to investigate the aircraft noise characteristics as a function of design fan pressure ratio. A representative high fan pressure ratio of 1.40 was selected for investigation and comparison with the 1.25 FPR data reported above. Minimum fuel and minimum noise trajectories for the 1.40 FPR airplane of Figure 43 were computed and the noise characteristics estimated using the same approach as described above for the 1.25 FPR aircraft data. Figure 47 presents the results of the 1.40 FPR noise investigations. From the data

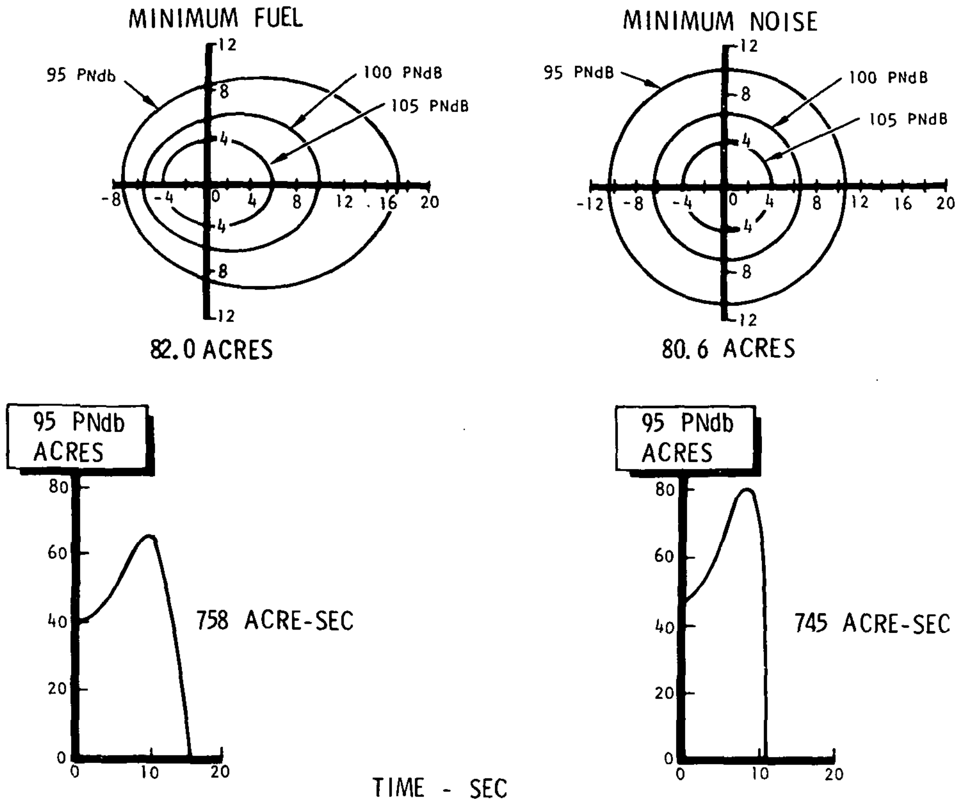


Figure 47. VTOL Takeoff Noise Characteristics for 1.40 FPR Aircraft

of Figure 47, it can be seen that the 1.40 FPR airplane produces noise levels somewhat higher than the 1.25 FPR airplane. The minimum fuel and minimum noise trajectories produced 95 PNdB footprint contour ground coverages of 82.0 and 80.6 acres and 95PNdB acre-seconds of 758 and 745, respectively. The 1.40 FPR minimum fuel profile produced 95PNdB footprint acreage about 2.0 times as large as the 1.25 FPR airplane. The associated 1.40 FPR 95PNdB acre-seconds annoyance factor was approximately 2.6 times as high as for the 1.25 FPR airplane. The maximum 500 foot sideline noise level of the 1.40 FPR airplane during a 1.05 g minimum noise vertical ascent was 102PNdB. The fuel used by the 1.40 airplane on the minimum fuel trajectory is 720 pounds, this compares with 682 pounds used by the 1.25 FPR airplane.

It is noted that the limiting factor in reducing the community noise annoyance, as indicated by the 95PNdB acre-seconds parameter, is the vertical 0.4 g acceleration tolerance of the onboard passengers. Higher power settings were available which would have further reduced the absolute value of 95PNdB acre-seconds noted for either the 1.25 or the 1.40 FPR aircraft but they were not practically usable because of the likely passenger objection to the resulting vertical acceleration.

Review of the noise characteristics of the 1.25 and 1.40 FPR aircraft indicate that the 1.25 FPR airplane has the more desirable characteristics relative to the current guideline goal of 95 PNdB maximum sideline noise, footprint area and time duration noise annoyance characteristics. However, if VTOL ports can be constructed to contain the objectionable arrival and departure noises within their boundaries for either airplane, e.g., 35 acres for 1.25 FPR and 80 acres for 1.40 FPR, the adjacent population would not be expected to be offended by either aircraft. Future V/STOL short haul commercial operations implementation studies might consider these aspects and relate them to both direct and indirect operating cost consequences of the aircraft design FPR selection.

Higher Cruise Mach Number Trade

A trade study was made to determine the impact on the aircraft design of increasing the cruise mach number to 0.85M. An important consideration in

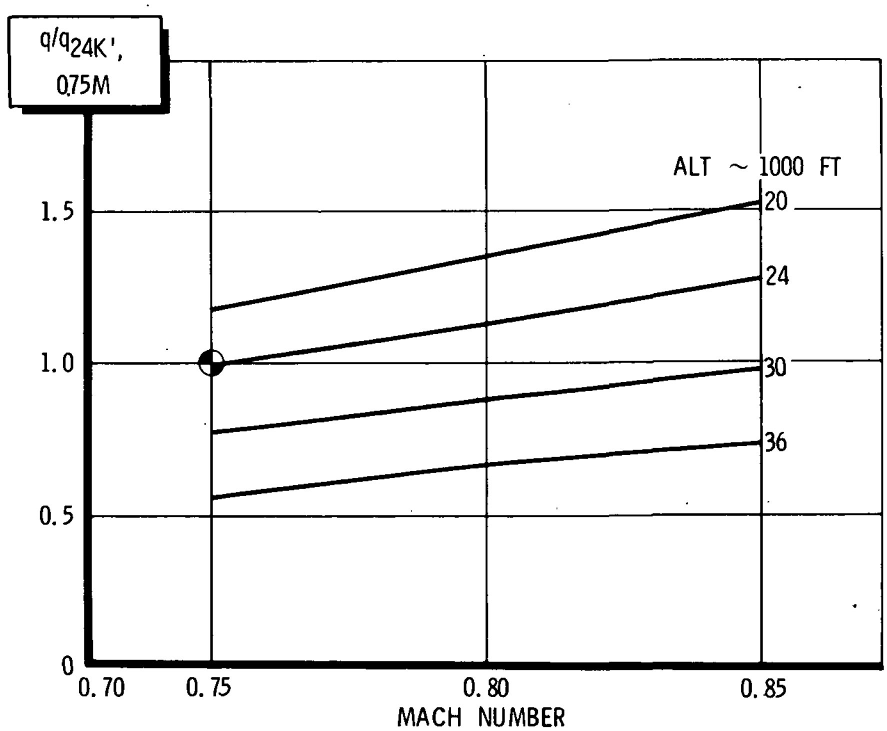


Figure 48. Relative Dynamic Pressures at Selected Altitudes and Speeds

design for higher flight speeds is the relative drag to be encountered. Figure 48 illustrates the relative dynamic pressures, q, that will be noted at the flight conditions for alternate altitudes and higher cruise speeds ratioed to the selected aircraft flight conditions at 0.75M/24,000 feet. The dynamic pressure ratio is an indicator of the relative pressure drag, and hense the propulsive effort to be expended to reach a selected altitude and speed, relative to the reference design condition. The data of Figure 48 are indicative of the relative drag required only if the pressure drag coefficient remains constant over the range of conditions shown. If in proceeding from a lower to a higher speed, a given design drag divergence mach number is exceeded, the drag will be higher than indicated by Figure 48. As illustrated by the data of the figure, the drag build up can be reduced or reversed with increase in speed by a simultaneous increase in altitude. The reduction in drag through use of higher cruising speeds is limited by the practical consideration that the thrust of typical propulsion systems decrease with increased altitude. Another practical consideration is that the aircraft wing size must be increased proportional with design cruise altitude to retain the wing lift coefficient below the critical value where drag divergence would take place for a given design speed. If the wing design is altered to provide a thinner airfoil to provide higher drag divergence mach number, the wing weight rises proportional to the reduction in thickness. From consideration of the above, it can be seen that for any given mission design requirement, propulsion system and air vehicle concept, there will be an optimum design altitude and speed above which the propulsion system and wing design penalties will outweigh the theoretical drag reduction benefits that might accrue from selection of a higher cruise altitude/speed combination.

Computer design syntheses of aircraft using the selected 1.25 FPR propulsion system and aircraft concept were accomplished for various alternate design cruise speeds, altitudes, wing loadings and vehicle thrust-to-weight ratios to determine the impact of these options on the required vehicle takeoff weight to meet the guideline VTOL mission range/payload requirements. Figure 49 illustrates the results of these studies.

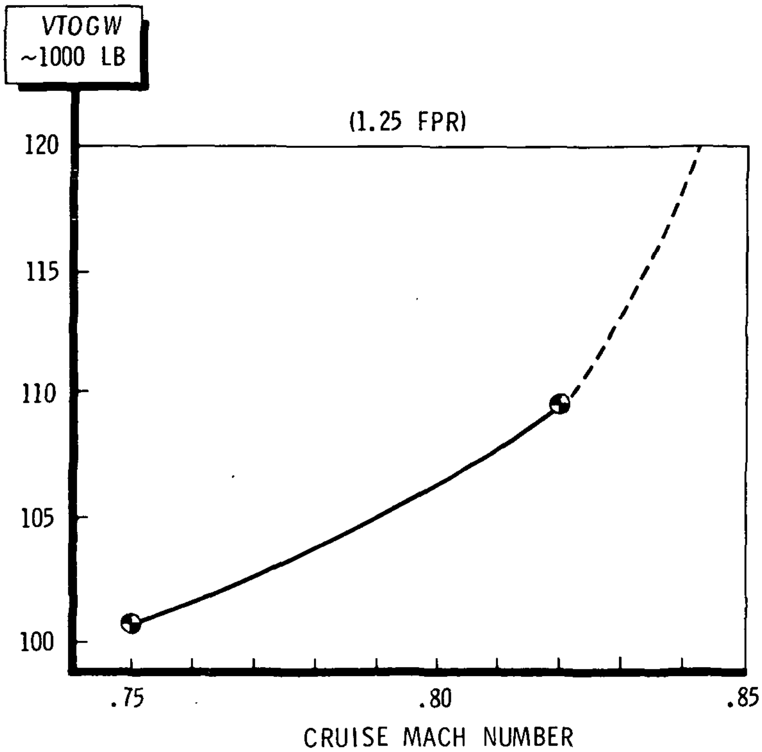


Figure 49. Aircraft Takeoff Weight Required Versus Design Cruise Speed

The data of Figure 49 indicate that even with optimization of cruise altitude, wing loading, thickness and propulsion system size, the takeoff weight required is shown to rise with increases in the design cruise speed. The data of the curve is discontinuous above 0.82 mach number because beyond this speed the drag divergence mach number is exceeded for any practical wing thickness with the unswept inboard wing panel of the selected aircraft concept.

In order to reach a design cruise speed of 0.85 mach number without unacceptably high takeoff weights, the aircraft concept would, as a minimum, have to be changed to eliminate the unswept inboard wing panel. Selection of a higher design pressure ratio propulsion system would also aid in controlling the propulsion system weight growth while providing adequate cruise thrust.

From the trends indicated in Figure 49 and the potential conceptual changes discussed above, it is apparent that an aircraft designed to meet the mission guidelines at a design cruise speed of 0.85 mach number will likely be considerably heavier than the selected 0.75 mach number design and would have poorer noise characteristics due to heavier weight and likely higher pressure ratio propulsion system.

An increase in design cruise speed from 0.75 to 0.85 mach number over one half of the design trip distance amounts to a cruise time saving of the order of 6 to 7 percent. From the DOC sensitivity data of Figure 37, the expected improvement in DOC from the cruise time reduction is less than 2 percent. This DOC advantage could be offset by an airframe weight growth of as little as 8 percent. Thus, unless market capture projections indicate that high cruise speed has beneficial economic impact on V/STOL short haul transport operations beyond those indicated by DOC, an 0.85 mach number cruise speed would not be recommended at this time. Further analyses, including the effects of noise characteristics and market capture effects on indirect as well as direct operating costs and return in investment for the airlines should be made to fully assess the impact of higher design cruise speeds. Because of the expected higher takeoff weights and noise characteristics of higher cruise mach number airplanes, the recommended design cruise speed at this time is 0.75 mach number.

Potential Improvements

During the course of the study, selected design features, operational concept and alternate technologies were identified that were considered to be of potential value as further improvements to a 1985 V/STOL short haul transport system that could not be incorporated into the recommended design. The reasons for non-incorporation included (1) insufficient technical feasibility data availability, (2) incorporation required effort beyond the scope of the current study or (3) conflict with a study guideline. A selection of the potential improvement items identified are presented below with the rationale for their consideration.

<u>Alternate Design Features</u>. - A small group of alternate design features were identified that would likely contribute to the definition of a lighter and therefore less expensive short haul aircraft if certain aspects of the design guidelines were changed to reflect a different operational philosophy for the V/STOL short haul transport. The changes are related to the acceptance of the role of the V/STOL transport as a true means of mass transportation for the general public rather than as a supplementary means of business travel and service to those who value their time and the amenities of current air travel sufficiently to overlook the surcharge involved in trip costs relative to surface transportation. This means that the operating philosophy, furnishings and support facilities provided would have more in common with metropolitan bus operations than with the similar items associated with contemporary airline operations and equipment. There is a trend in this direction already being established by many of the commuter airlines. Some of the larger airlines are also experimenting with express "shuttle" services over their short haul high density routes where many of classic airline check-in and ticketing procedures are being curtailed to provide

somewhat less personalized but faster and less expensive movement of passengers to and from the aircraft. For example, if the current airline seating comfort and inflight services and furnishings were reduced to the level of what is currently considered acceptable for metropolitan bus transportation, significant aircraft weight savings could be made. If the V/STOL short haul transport guidelines were to permit seating of the design currently used in commuter aircraft with commuter seat pitch of about 29 inches instead of the current 34 inch pitch, approximately 4740 pounds of the recommended aircraft takeoff weight could be eliminated. Approximately 2700 pounds of this are saved through the use of 13 pound seat allocations per passenger rather than the current 22 pounds. The remainder would be saved through the removal of the requirement for approximately 7.5 feet of the fuselage because of the seat pitch reduction.

Also, in recognition that short haul flights will likely consist primarily of trip times of an hour or less, the need for inflight restroom and food service facilities could be drastically curtailed. Current guidelines provide for two lavatories at 300 pounds each. If both were deleted, the takeoff weight could be reduced by another 1800 pounds. If a single lavatory of a type now flying in one of the wide body jets were retained, at a weight of 135 pounds including chemicals, the takeoff weight saving would still be about 1400 pounds. Elimination of food and beverage service would save another 2700 pounds. Many metropolitan commuters often encounter trip times of the order of 30 minutes to an hour on a twice a day basis with no expectation of either food or rest stops. Thus adoption of a mass transportation philosophy can remove many of the fixed weight items currently believed to be essential to airline operations. Taken together the takeoff weight savings could be as high as 9240 pounds as indicated above.

Alternate Operational Concept. - A potential operational concept change related to a continuance of the metropolitan bus philosophy idea developed above, would be to conceive the V/STOL short haul terminal facilities to approach the austerity of current bus transportation terminal facilities. For example, main terminals would have shelter, amenities and ticketing facilities and means for rapid loading of many aircraft from specialized docks, etc., as is current bus and airline practice. Many enroute stops however could be made at simple, open area paved V/STOL ports having austere sheltered waiting areas with restroom facilities and basic concession services but without elaborate ticketing or multiple docks, etc. The size of the open area, austere V/STOL port would be established only by the requirements to provide adequate noise isolation of the high noise level arrival and departure operations from the surrounding population and to provide adequate taxi and safety clearance for a minimum of simultaneous aircraft residencies. The main objective of this concept would be to provide essential facilities at minimum cost such that the short haul transportation indirect operating costs (IOC) would be minimized.

New Technology Applications. - Four additional technology applications were identified as having potential merit for future study efforts related to defining more attractive 1985 V/STOL systems.

The first potential new technology application identified was related to the acceptance of the 1985 short haul transport as a VTOL system exclusively, similar to a helicopter, rather than as a transitional system having alternate STOL capabilities for long trips. This switch in operating philosophy would allow the application of the embryonic lightweight air cushion landing gear technology to be applied to the VTOL aircraft design instead of the usual heavy forgings and wheel, brake and tire rolling gear normally associated with CTOL aircraft. If there is no requirement for STOL operations, the air cushion landing gear can be designed to be inflated by available treated bleed air without any need to supply large leakage air supplies to hold ground clearance. Thus the air cushion gear can be designed strictly for landing shock absorption and airframe support on the ground. If such a system could be provided at a weight of only one half the current landing gear system, the airplane takeoff weight saving would be about another 4700 pounds.

Current technology developments in the areas of stored energy devices are also providing potentially attractive alternatives for V/STOL aircraft to the practice of providing additional or significantly larger main propulsion units for the required levels of safety after operational failures. Two areas appear to be particularly worthy of investigation and monitoring: (1) composite material, high energy flywheel developments and (2) hybrid rocket technology. In addition to backup energy, the flywheels might supply a portion of the vehicle attitude stability in gusts, such that overall control power requirements might be reduced. The hybrid rocket technology could use on board fuel in combination with a minimum stored oxidizer to provide the gas necessary to operate the lift fan system normally after gas generator failures. A single centralized hybrid unit could replace the oversizing of all the main propulsive units for the failure design condition.

Advanced composite material and structural technology potentially could allow unique structural advantages for specialized applications such that the normal aircraft design tradeoff procedures would have to be revised. For example, the specific application of composite material technology might encourage the design of a heavier but more efficient aerodynamic wing configuration relative to current metal technology trade off factors because of the higher level of structural efficiency. Also, specific tailoring of the composite material orientations and plying techniques may allow structural weight reductions beyond the percentages now thought practical when all the factors related to flutter, aeroelasticity, ride quality, flexible airloads, etc., as well as strength are discretely handled in an optimum manner for a given set of vehicle requirements. Discrete consideration of composite design factors was not within the scope of the current study, thus more detailed investigations should be made to pursue the latent opportunities through discrete, tailored composite material structural design.

CONCLUSIONS

The major conclusions of the study are:

1. Attractive V/STOL short haul commercial transports are technically achievable by the 1985 time period.

2. A 100-passenger six fan/six gas generator configuration can be built with a takeoff weight of 100,680 pounds for the 400 nautical mile VTOL mission and 110,020 pounds for the 800 nautical mile STOL mission.

3. A 1.25 FPR system has lower noise and lower direct operating costs for trip distances less than 500 statute miles relative to higher pressure ratio systems.

4. A 97.5 PNdB 500 foot sideline noise level is achievable with projected quiet lift-fan technology.

5. The study goal of 95 PNdB maximum 500 foot sideline noise goal may not be essential to practical introduction of a 1985 V/STOL transport system if V/STOL port arrival and departure areas of the order of 50 to 100 acres can be established that will shield the surrounding population from the high level terminal area noise.

6. Cruise speeds higher than 0.75 mach number do not appear attractive from the direct operating cost viewpoint, however, market capture studies should be accomplished to determine the overall effect of higher cruise speed on short haul airline operations profitability.

7. There are additional technology areas and operational philosophies to be explored that could lead to still more attractive and competitive short haul V/STOL systems.

    a. air cushion landing system
    b. stored energy devices for peak and emergency power
    c. discrete tailored composite structure design
    d. reduced onboard passenger amenities
    e. use of austere intermediate stop facilities.

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