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CONCEPTUAL DESIGN STUDY OF A V/STOL LIFT FAN COMMERCIAL SHORT HAUL TRANSPORT

by Ronald G. Knight, William V. Powell, Jr., and Jerome A. Prizlow

Prepared by
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16. Abstract

Conceptual designs of V/STOL Lift Fan Commercial Short Haul Transport Aircraft for the 1980-85 time period were studied to determine their technical and economic feasibility. The engine concepts included both integral and remote fans. The scope of the study included definition of the hover control concept for each propulsion system, aircraft design, mass properties, cruise performance, noise and ride qualities evaluation. Economic evaluation was also studied on the basis of Direct-Operating Costs and route structure.

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OF A V/STOL LIFT FAN

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SUMMARY

The results of a study conducted by North American Rockwell for the NASA Ames Research Center are documented in this report. This study is one of three V/STOL lift-fan aircraft studies concurrently funded by the Ames Research Center. A number of candidate configurations were investigated within each lift fan propulsion concept, and the best design was selected within each concept for further evaluation. Finally, the selected aircraft were compared to identify the most promising lift fan design.

INTRODUCTION

The potential for implementation of V/STOL aircraft into commercial short haul transportation in the 1980-1985 time period is closely related to the timely identification and advancement of the required V/STOL technology. Past studies have concluded that lift fan propulsion offers a promising approach for the first generation of economically viable and community acceptable V/STOL transportation. The purpose of the present study is to develop conceptual designs of 100 passenger V/STOL lift-fan commercial transports based on three NASA furnished advanced second generation lift-fan propulsion concepts. The propulsion systems considered were integral lift fans, and remote fans driven by ducted hot gas generator exhaust or by cold turbofan gas generator exhaust with duct burning at the lift fan.

The scope of the study included definition of the hover control concept for each propulsion system, aircraft design, aircraft mass properties, cruise performance, noise and ride qualities evaluation. Aircraft performance was also evaluated on a multiple stop route structure to a trip distance of 800 nautical miles to develop an economic evaluation of the selected designs. All propulsion data used in the study were furnished by General Electric under contract to NASA Lewis, with the exception of one cruise engine cycle which was selected by this study contractor.

Early study results established that cruise performance imposed an additional thrust requirement over the cruise thrust available from engines sized by hover alone. This additional cruise thrust is attained from either the lift gas generators or from a larger size cruise engine resulting in hybrid type propulsion systems. The study results show that both the remote fan turbojet gas generator aircraft and the integral lift fan cruise engine aircraft have the same performance and direct operating cost when a two engine development program is included in the latter aircraft buy. Although slightly heavier, the remote fan aircraft is identified as the preferred propulsion approach because of reduced technical risk. It is concluded that an improved V/STOL commercial transport would result from a propulsion system combining the remote fan performance for the V/STOL flight mode through transition and an efficient cruise engine cycle for the conventional flight mode.

The direct operating cost was evaluated as most sensitive to the aircraft buy size, initial aircraft cost, and the amount of composite materials used in the structure. The guideline goals for aircraft noise characteristics appear to be achievable with additional development work. Ride qualities in turbulence at the design speeds below 20,000 ft. require additional design effort.

NOMENCLATURE

BCA	Best Cruise Altitude	Ft.
BCM	Best Cruise Mach Number	
BLM	Best Loiter Mach Number	
CA	Cruise Altitude	Ft.
C_{DL}	Drag Due to Lift coefficient	
C_{DO}	Zero Lift Drag Coefficient	
C_L	Lift Coefficient	
ETC	Energy Transfer Control	
F_g	Gross Thrust	Lbs.

F_N	Net Thrust	Lbs.
F_R	Ram Drag	Lbs.
$\dot{h}$	Rate of Change of Altitude	Ft./Sec.
I_{xx}	Roll moment of Inertia	Slug Ft.^{2}
I_{yy}	Pitch Moment of Inertia	Slug Ft.^{2}
I_{zz}	Yaw Moment of Inertia	Slug Ft.^{2}
I_{xz}	Product of Inertia	Slug Ft.^{2}
M_{CR}	Cruise Mach number	
M_{MO}	Max. Operating Mach Number	
n_{LIM}	Limit Normal Load Factor	g's
NP	No Penetration Surface	
n_x	Longitudinal Acceleration	g's
n_y	Lateral Acceleration	g's
n_z	Normal Acceleration	g's
PNdB	Perceived Noise Level	Decibels
SF	Scale Factor	
S_W	Wing Area	Ft.^{2}

T_2	Time to Double Amplitude	Sec.
V_{AP}	Approach Speed	KTS
V_{CR}	Cruise Equivalent Airspeed	KTS
V_{MO}	Max. Operating Equivalent Airspeed	KTS
V_{TD}	Touchdown Speed	KTS
V_S	Stall Speed	KTS
V_2	Obstacle Speed	KTS
W	Takeoff Gross Weight	Lb
W_S	Structural Weight	Lb
α_{AP}	Approach Angle of Attack	Deg.
α_{CL}	Climb Angle of Attack	Deg.
α_S	Stall Angle of Attack	Deg.
β	Lift Fan Gross Thrust Angle from Fan Vertical Axis, Positive Aft	Deg.
Θ	Segmented Hood Gross Thrust Angle from Engine/ Fan Centerline, Positive Down	Deg.
θ_i	Aircraft Attitude Angle from Horizontal	Deg.
$\dot{\theta}$	Rate of Change of Pitch Attitude	Deg./Sec.
μ	Rolling Coefficient of Friction	
ω_n	Undamped Natural Frequency	Rad/Sec.
$2\xi\omega_n$	Damping Parameter	1/Sec.

DESIGN ASSUMPTIONS

The significant design requirements and study ground rules for the V/STOL Lift Fan Commercial Short Haul Transport are summarized in this section. This summary generally follows the format of the Study Guidelines and Design Criteria, Reference 1, as furnished by NASA at the beginning of the program. The referenced document should be consulted for detail discussion, basis for, and additional reference material used to develop these design requirements. As stated by NASA, these design assumptions have no official status outside the present study, and are therefore not to be interpreted as statement of NASA policy.

Design Criteria and Guidelines Summary

The design criteria and guidelines are summarized in Table 1 under the following main sections:

1. Flight Safety Criteria - which includes safety margins, control characteristics, and handling qualities.

2. Performance - which deals with airfield lengths, cruise altitudes, and payload range.

3. Operating Economics - which outlines DOC methodology and economic yardsticks.

4. General Design Guidelines - specifies noise criteria, number of passengers, design life and special equipment.

5. Passenger Comfort Criteria and Guidelines - specifies passenger environmental factors.

Design Missions

Details of the design mission profiles are shown in Figure 1 for both the VTOL and the STOL missions. The VTOL and STOL missions differ only in the time and corresponding fuel allowances at the beginning and end of each trip, and in the reserve cruise distance allowance to an alternate landing field. Mission profile legs (11) through (18) represent the total reserve fuel on board at arrival at the original trip destination, leg (10).

TABLE 1

DESIGN CRITERIA AND GUIDELINES SUMMARY

1. Flight Safety and Operating Criteria

Failure Philosophy	Safe flight with single failed gas generator, remote fan, or integral lift fan/engine.				
Handling Qualities	Speeds below V_{con}, AGARD-R-577-70 except as below.				
Attitude Control	Speeds to V_{con}, Trim most critical c.g. S.L., ISA + 31°F, Aircraft response following step input				
		Max. angular accel. rad/sec^2		Attitude angle in 1 sec., deg.	
	Axis	VTOL	STOL	VTOL	STOL
Level 1, cond. (a) No failures Zero crosswind	Roll	0.6	0.4	10	6
	Pitch	0.33	0.3	6	5
	Yaw	0.25	0.2	5	3
Level 1, cond. (b) No failures 25 kt crosswind	Roll	0.4	0.3	6	4.5
	Pitch	0.33	0.3	6	5
	Yaw	0.17	0.15	3	3
Level 2, cond. (b) Single failure 25 kt crosswind	50% of requirements for Level 1, cond. (b)				

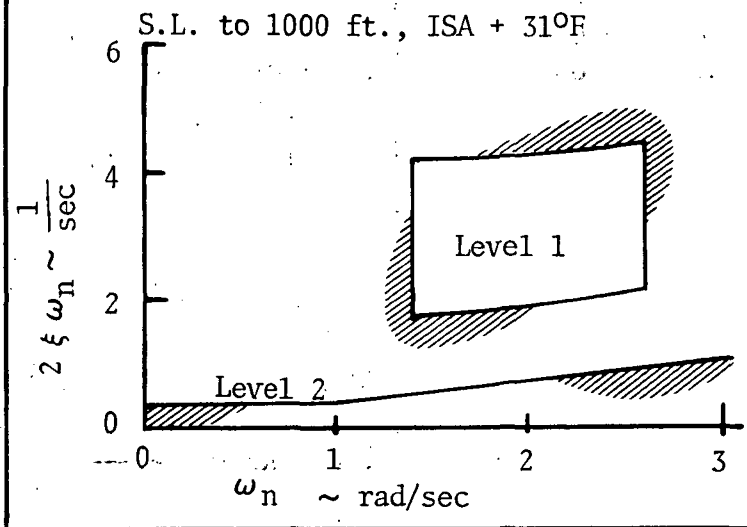
TABLE 1 - continued					
1. Flight Safety and Operating Criteria (cont.)					
Combined Attitude Control	Simultaneously meet 100% on most critical axis and 50% on each remaining two axes.				
Flight Path Control		VTOL		STOL	
below 40 kts	Level	Free Air	Wheels off ground		
Normal accel. ~ g's	1	± 0.1	- 0.1 + 0.05		
	2	- 0.1 + 0.05	- 0.1 0		
40 kts to V_{con}		VTOL		STOL	
(not simultaneously)	Level	n_x	n_z	n_x	n_z
	1	± 0.15	± 0.2	± 0.15	± 0.25
Accel. ~ g's	2	± 0.1	± 0.1	± 0.1	± 0.15
Approach Path	Max Angle	20° in 25 kt crosswind			
Control System Lags		VTOL & STOL, 0 to 1000 FT ISA + 31°F			
		Time constant ~ sec. to 63% final value after step pilot input.			
	Level	Control Moments		Control Forces	
	1	0.2		0.3	
	2	0.4		0.6	
General	Transition reversible. Conversion speed ≥ 1.3 V_S poweroff.				

TABLE 1 - Continued

1. Flight Safety and Operating Criteria (cont)

Stability

Hovering.



Low Speed

	Oscillatory Modes		Unstable
Level	Dominant	Other	Aperiodic Modes
1	Same as Hover	Damped	$T_2 \trianglerighteq 20$ sec.
2		$\omega_n < .84$ $T_2 \trianglerighteq 12$ sec	$T_2 \trianglerighteq 12$ sec.

V/STOL Safety

Level 2
Single failure
25 kt crosswind

S.L., ISA + 31°F,
Mil - F8785B (ASG) gust
Aircraft shall not enter NP (no penetration) surface, except primary surface. (NP surface is 35 ft. above V/STOL approach surface).

STOL Takeoff Safety Field Length

Greatest distance of ~

(a) 100% accelerate stop (1 eng. failed)
(b) 115% all engine takeoff
(c) 100% one engine failed takeoff

TABLE 1 - Continued

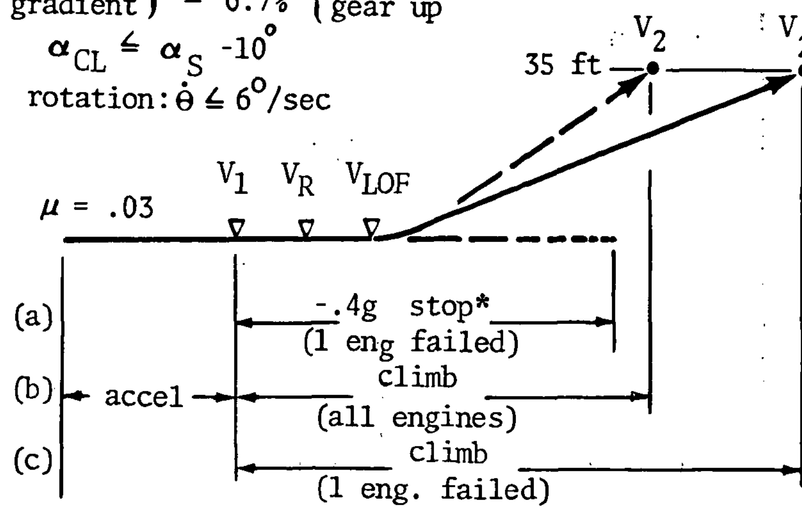
1. Flight Safety and Operating Criteria (cont.)

STOL Takeoff Safety (cont)

climb gradient $\geq$ 6.7% {gear dn, gear up}

$\alpha_{CL} \leq \alpha_S - 10^{\circ}$

rotation: $\dot{\theta} \leq 6^{\circ}$/sec



*lag ~0.5 sec. auto or 1.0 sec. manual.

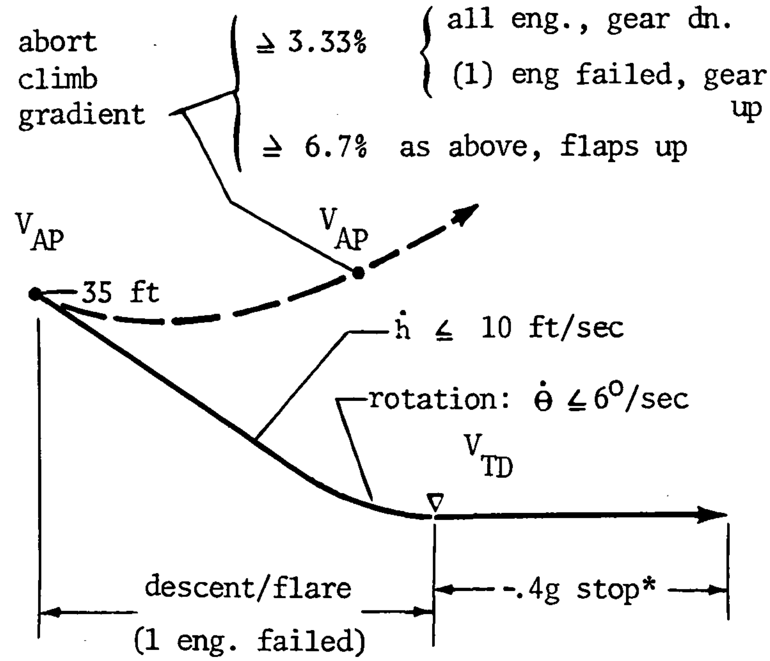
Definition	FAR
$V_{LOF} \geq V_R \geq V_1 \geq 1.05$ (V_{MOG} and V_{MCA})	
V_{MOG} ~ min control ground speed	XX.149
V_{MCA} ~ min control climb speed	"
V_1 ~ critical decision speed	XX.53
V_R ~ rotation speed	
V_{LOF} ~ lift off speed	XX.53
$V_2 \geq V_{LOF}$ $\geq 1.15\ V_{MCA}$ $\geq V_{MCA}$ + 10 kt $\geq 1.2\ V_{MIN}$	
V_{min} ~ min flying speed,	XX.49

Pilot emergency reaction time: 2 sec. excl. system response

TABLE 1 - Continued

1. Flight Safety and Operating Criteria (cont)

STOL Landing Safety



*lag ~ 0.5 sec. auto or 1.0 sec. manual

Definition

$V_{AP} \geq 1.15\ V_{MCA}$

$\geq V_{MCA} + 10$ KT

$\geq 1.2\ V_{MIN}$

$\alpha_{AP} \leq \alpha_s - 10^{\circ}$

Field Length

$\frac{1}{0.7}$ (Descent/Flare + Stop Dist.)

Fuel Reserves

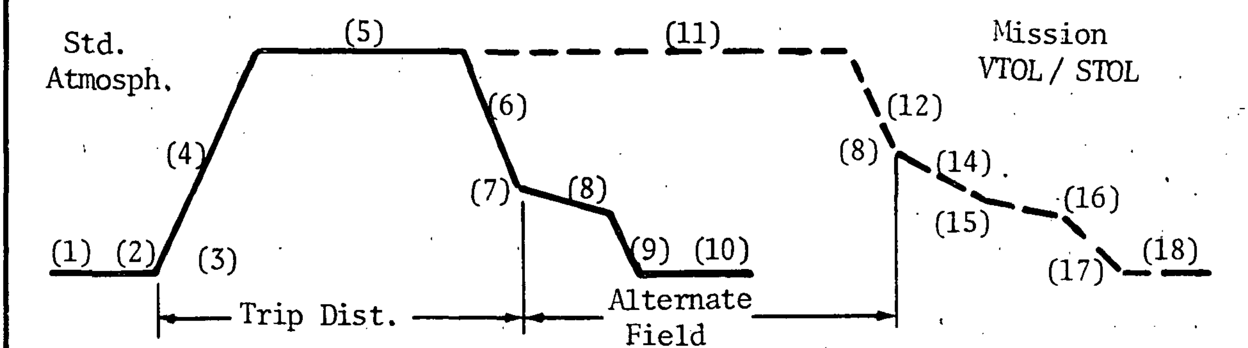
Smaller of ~	VTOL	STOL
Hold at 5000 ft. and best loiter speed	20 min.	30 min.
Flight to alternate at BCA and BCM	50 n.mi.	100 n.mi.

TABLE 1 - Continued			
2. Performance			
		VTOL	STOL
Field Dimensions	Normal Length	200 ft.	1500 ft.
	End Extens.	100 ft.	100 ft.
	Width	100 ft.	-
Obstruction Boundary Slope	Length	4:1	15:1
	Width	4:1	4:1
Field Cond.	S.L., ISA + 31°F		
Design Payload	100 passengers at 200 lb. each (incl. 40 lb. bags)		
Range (Max. Payload)	VTOL: 400 n.mi.		STOL: 800 n.mi. (target)
Cruise Altitude	Smaller of ~ a) Min DOC or acceptable ride b) Cruise dist. ≥ 50% total dist.		
Cruise Speed (Minimum)	Smaller of ~ a) 0.75M b) 350 KEAS		
Propulsion G.E. Data	(1) Integral lift fan (2) Remote fan/Turbofan GG/Duct burners (3) Remote fan/Turbojet gas generator		

TABLE 1 - Continued				
3. Operating Economics				
Environment	1980-1985 Economic & technical 1971 Dollars			
DOC formula	Reference 2 with modified block time and fuel, reserves definitions NASA furnished engine maint. costs.			
Equip. Costs & Weights	300 unit, 600 unit production NASA furnished data for Wheels, tires brakes, Instruments, Elect., Electronics, APU, Seats, Lavatory, Galley, Food.			
4. General Design Guidelines				
Noise Levels	95 PNdB at 500 ft. sideline at take off power.			
Accommodations	Number	Weight (Incl. bags)	Cargohold	
Passengers	100	200 lb. ea.	420 ft^3 total	
Crew	2	190 lb. ea.		
Cabin attendants	2	140 lb. ea.		
Design Life	Airframe	Landing Gear		
	40,000 hr.	80,000 cycles		
Ground Handling	APU, Airstair			
All-Weather	Zero-Zero Capability			
C.G. Limits	Indiscriminate Passenger Seating			

TABLE 1 - Concluded

5. Passenger Comfort Criteria and Guidelines			
Attitude Changes	Angular in normal operation Fuselage deck $\theta_i = +20^\circ$ nose up $\theta_i = -10^\circ$ nose down		
Force Changes	Accelerations in normal operation $n_x = \pm 0.4g$ $n_y = \pm 0.1g$ $n_z = + 0.4g, - 0.2g$		
Rates of Descent	At altitude (max) Decelerating approach Landing touchdown		5000 fpm 1000 fpm 10 fps
Ride Qualities	Formula for gust sensitivity MIL A 8861 (ASG)	Altitude 10,000 ft 20,000 ft 30,000 ft	g/ft/sec $\leq .018$ $\leq .029$ $\leq .036$
Cabin Requirements	Dimensions	Aisle width Seat width Seat pitch	19 in. 21 in. 34 in.
	Storage Space	Overhead bag Underseat case Coat racks for 80% Magazine racks (2) Folding table (1)/seat	
	Service	Galley Lavatories (2) Ticket center Beverage Airvent (1)/seat Attendants seats (2)	



Leg	Operation	Alt.	Speed	Power	Min.	N.Mi.
(1)	Taxi	S.L.	0	Idle	1/2	0
(2)	T.O./Trans.	S.L.	0	Max	0.5/0.5	0
(3)	Air Maneuv.	S.L.	BLM	Max	0.5/1.0	0
(4)	Climb/Accel.	to CA	to M_{CR}	Inter	-	↑
(5)	Cruise	CA	M_{CR}	As Reqd	-	Trip Distance
(6)	Descend	to 2K	Var.	Idle	-	↓
(7)	Air Maneuv.	2K	BLM	As Reqd	1.5/3.0	0
(8)	Approach	1K	-	50% Max	0.5	0
(9)	Trans./Land.	S.L.	0	80% Max	1.	0
(10)	Taxi	S.L.	0	Idle	1/2	0
(11)	Res. Cruise	CA	M_{CR}	As Reqd	-	50/100
(12)	Res. Descend	to 5K	Var.	Idle	-	0
(13)	Res. Loiter	5K	BLM	As Reqd	20/30	0
(14)	Res. Descent	to 2K	Var.	Idle	-	0
(15)	Res. Air Man.	2K	BLM	As Reqd	1.5/3.0	0
(16)	Res. Approach	1K	0	50% Max	0.5	0
(17)	Res. Land	S.L.	0	80% Max	1	0
(18)	Res. Taxi	S.L.	0	Idle	1/2	0

Figure 1. Design Mission Profiles

PROPULSION CHARACTERISTICS

Propulsion systems considered for the V/STOL Commercial Transport Study were integral fan systems and remote fan systems. The General Electric Company, under contract to NASA Lewis, has provided propulsion data for these systems.

Integral Fan Systems

General Electric supplied propulsion data for the GE ILF 1A1 integral engine. This engine is essentially designed to be a high thrust-to-weight ratio lift engine; however, sufficient data were made available to also consider it for lift/cruise purposes. Additionally, the GE 13/F6A1 integral turbofan engine was selected for lift/cruise study purposes. It is noted that the GE 13/F6A1 engine is intended for application to advanced military transport aircraft studies, and is not a part of the contracted propulsion data for the V/STOL Commercial Transport study. This engine was considered, however, because it provides typically good cruise performance which can be expected from an engine designed for cruise applications.

Description/Cycle. - The GE ILF 1A1 integral engine is a high bypass ratio (12.6), twin-spool turbofan engine which features a 1.25 fan pressure ratio, an overall compression ratio of 10 , and a maximum turbine inlet temperature of 2500° F. This engine, with acoustic treatment, is intended to provide low aircraft noise levels consistent with the objective of the study. The reference 100% size engine is shown in Figure 2 .

The GE 13/F6A1 integral engine is a mixed-flow, high bypass ratio (6.2), 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. All data for this engine are presented in reference 3 . The reference 100% size engine is shown in Figure 3 .

Engine Performance. - Both the GE ILF 1A1 and GE 13/F6A1 engines are flat rated so that the takeoff thrust level stays constant at sea level static conditions with a variation in ambient temperature from 59°F to 90°F.

GE ILF 1A1 performance: The reference 100% size GE ILF 1A1 engine produces a maximum nominal uninstalled sea level static thrust of 10,000 lb. without the use of an emergency rating. This 10,000 lb. thrust rating is defined to be Military Power Setting for convenience. This thrust level is intended to be the maximum permissible nominal (neutral control) value during normal Level 1 operation in which no engine failure occurs. During Level 2 operation, in which an engine failure occurs, the remaining operating engines may use an emergency rating that increases the nominal uninstalled thrust

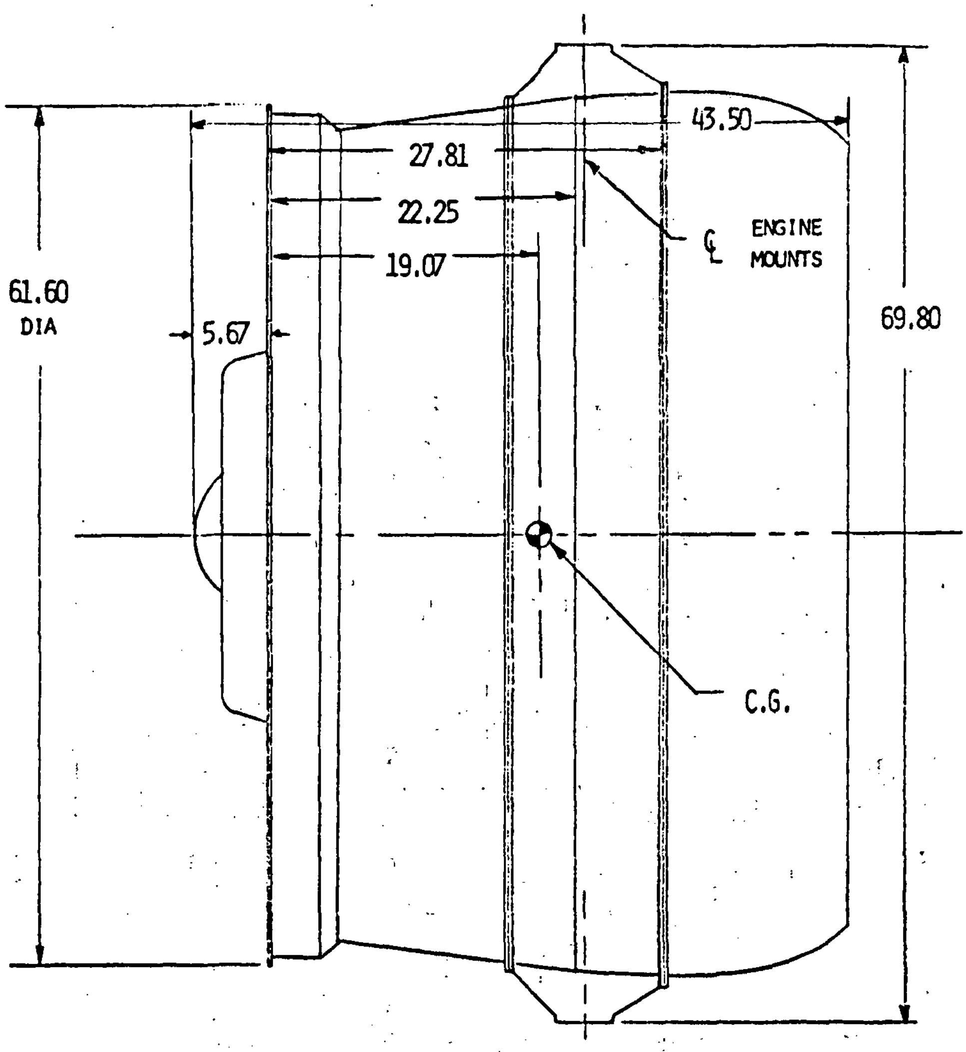


Figure 2. General Electric GE ILF 1A1 Integral Engine

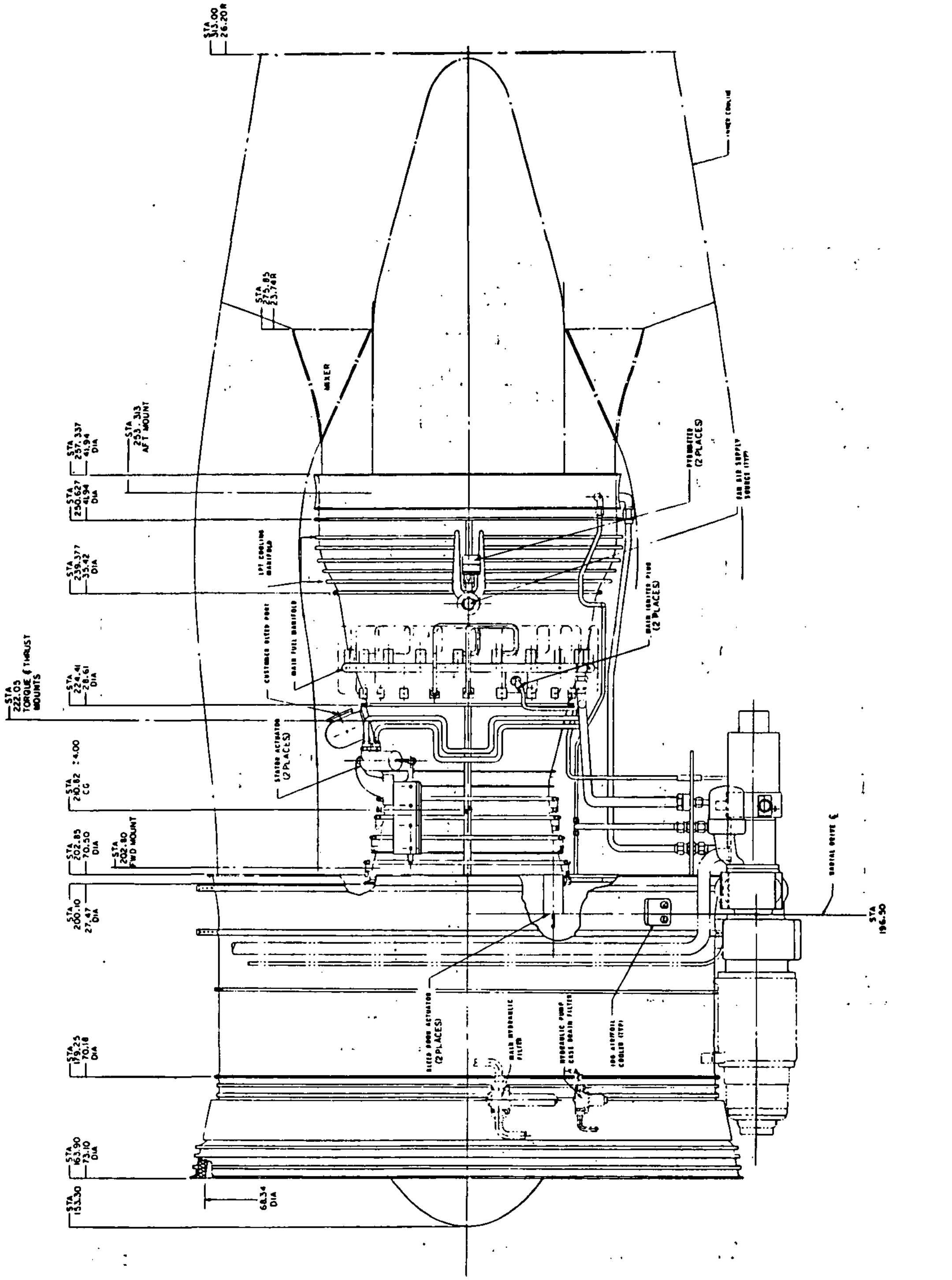


Figure 3. General Electric GE 13/F6A1 Turbofan Engine

level to any value desired between 10,000 to 13,000 lb. These emergency ratings are provided so that air vehicle thrust-to-weight ratio requirements can be met in the case of an engine failure without the necessity of using excessively large engine sizes.

During hover/transition flight conditions where differential thrust between engines are required for attitude control, the thrust of certain engines may be increased above the nominal level while the thrust of others are decreased below the nominal level in such a manner as to maintain air vehicle thrust-to-weight ratio constant. This control excursion is obtained by engine throttle manipulation, and is considered to be permissible short time thrust variation about a required nominal level. The maximum uninstalled engine thrust permitted during maximum control excursion is considered to be 13,000 lb. for both Level 1 and Level 2 operation. It is noted, therefore, that during Level 2 operation with an engine failure, the use of the emergency ratings is obtained at the expense of a decreased attitude control capability. It is evident that if a nominal 13,000 lb. emergency rating were used, no further thrust increase for attitude control would be permissible.

General Electric supplied two packages of tabulated uninstalled engine performance data. One package contains data for VTOL/transition flight conditions covering a range in power settings for flight speeds from 0 - 0.3 Mach number and altitudes from sea level to 1000 feet. The other package presents data for climb/cruise/descent including a range in power settings for flight speeds up to 0.9 Mach number and altitudes up to 40,000 feet.

GE 13/F6A1 performance: The reference 100% size GE 13/F6A1 engine produces an uninstalled sea level static thrust of 22,000 lb. at Maximum Power Setting. This engine has no provisions for emergency power ratings, and the intended use of this engine does not require emergency ratings. In general, scaled lift/cruise versions of the GE 13/F6A1 are considered so that the study air vehicle requires the use of only two cruise engines. With these two engines sized to produce adequate cruise thrust, they are substantially oversized during hover/transition conditions when they are used in the lift mode. As a result, their nominal power setting is substantially less than Maximum Power in order to produce the required lift, and, consequently, the noise generated by these engines are significantly reduced. Differential thrust for attitude control purposes is obtained by means of throttle manipulation.

All uninstalled engine performance data are presented in reference 3 . Climb/cruise data includes a range in power settings for flight speeds up to 0.9 Mach number and altitudes up to 45,000 feet.

Engine weight. - The reference 100% size GE ILF 1A1 engine with acoustic treatment weighs 1064 lbs.

The reference 100% size GE 13/F6A1 engine with no acoustic treatment weighs 3375 lbs. This is the basic weight of the engine and does not include the weight of an exhaust nozzle, mixer, or ducting required to obtain a mixed-flow engine configuration.

Engine dimensions. - Dimensions for the reference 100% size GE ILF 1A1 and GE 13/F6A1 engines are given in Figures 2 and 3 .

Engine scaling data. - Weight and dimensions of the reference 100% size GE ILF 1A1 engine may be scaled in accordance with the following equations:

$$\text{Weight (scaled)} = \text{Weight (ref)} \left[\frac{\text{Thrust (scaled)}}{\text{Thrust (ref)}} \right]^{1.25}$$

$$\text{Diameter (scaled)} = \text{Diameter (ref)} \left[\frac{\text{Thrust (scaled)}}{\text{Thrust (ref)}} \right]^{0.5}$$

$$\text{Length (scaled)} = \text{Length (ref)} \left[\frac{\text{Thrust (scaled)}}{\text{Thrust (ref)}} \right]^{0.5}$$

It is assumed that the weight and dimensions of the reference 100% size GE 13/F6A1 engine may be scaled in accordance with the above equations except that the 0.5 exponent for length scaling should be changed to 0.47.

Remote Fan Systems

General Electric supplied propulsion data for the GE Remote Lift Fan Systems A and C. Both remote fan systems utilize the same 1.25 pressure ratio, tip-turbine driven lift fan design. Remote Lift Fan System A uses hot exhaust gas flow from advanced turbojet gas generators to drive remotely located lift fans. Remote Lift Fan System C uses bypass airflow from advanced turbofan gas generators as the tip-turbine working fluid. Heat is added to this cold bypass airflow in duct burners prior to expansion through the tip-turbine.

Description/cycle. - The General Electric remote lift fan design, which is used in GE Remote Lift Fan Systems A and C, is shown in Figure 4 . This lift fan design features a design pressure ratio of 1.25, a three-strut front frame arrangement, a single bubble double entry scroll (each entry supplying 50% of the fan gas flow), and four fan discharge acoustic splitters. It is considered that this fan can be converted into a lift/cruise fan installation to provide cruise thrust.

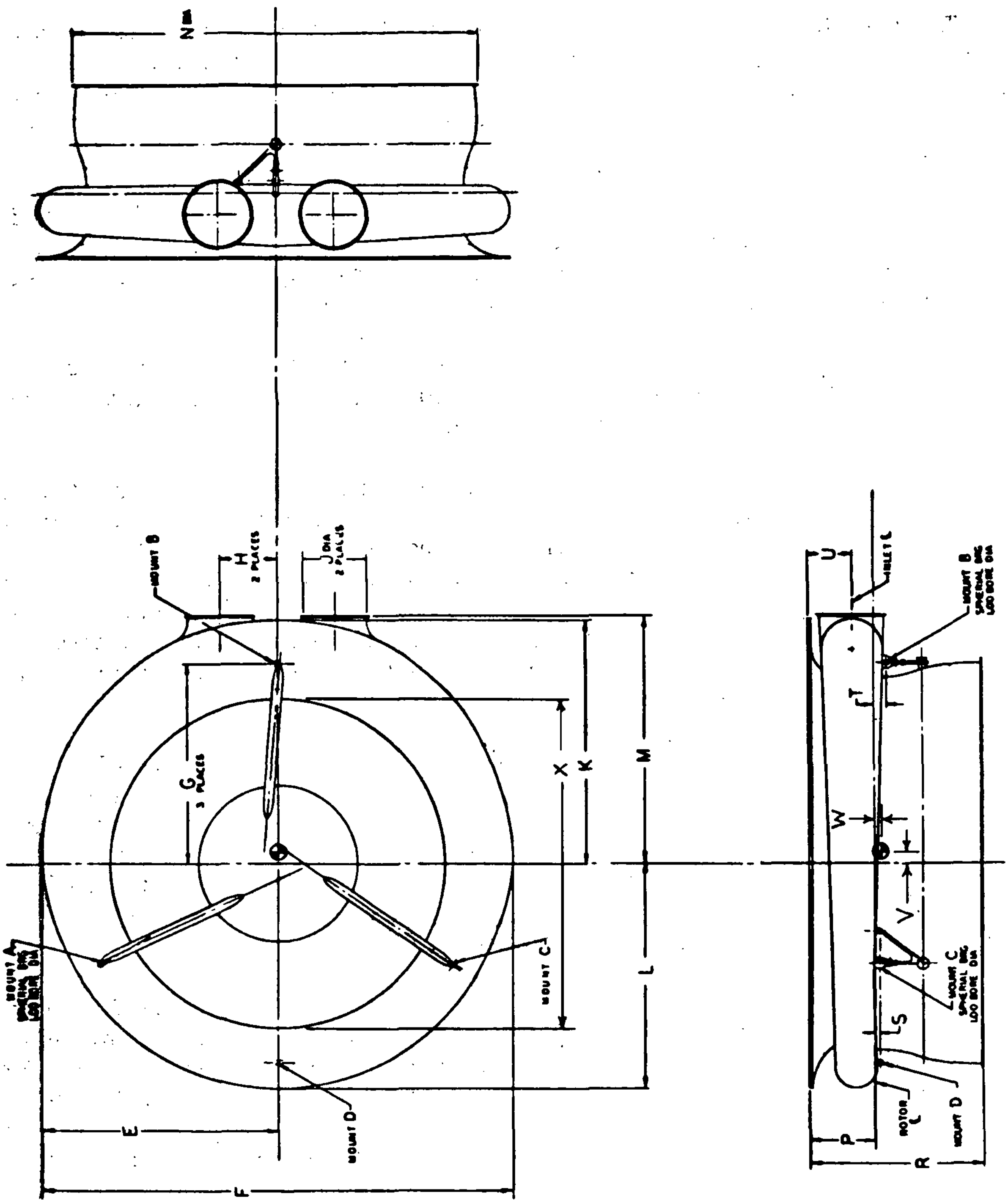


Figure 4. General Electric Remote Lift Fan

The turbojet gas generator used in Remote Lift Fan System A is shown in Figure 5 . This gas generator has an overall compression ratio of 12.17, a nominal turbine inlet temperature of 1921°F, and a nominal turbine discharge temperature of 1793°R. System A operates at nominal conditions with a bypass ratio (fan airflow/gas generator airflow) of 10.

The turbofan gas generator used in Remote Lift Fan System C is shown in Figure 6 . This gas generator has a bypass ratio of about 1.9 and a fan pressure ratio of 3.6. System C operates at nominal conditions with a lift fan airflow/gas generator bypass airflow ratio of 10.

Remote fan system performance. - Remote Lift Fan Systems A and C are flat rated so that the thrust level stays constant at sea level static conditions with a variation in ambient temperature from 59°F to 90°F.

The reference 100% size lift fan produces a maximum nominal uninstalled sea level static thrust of 10,000 lb. without the use of an emergency rating. This 10,000 lb. thrust rating is defined to be Military Power Setting for convenience. As in the case for the GE ILF 1A1 integral engine, the 100% size lift fan may attain a maximum uninstalled thrust of 13,000 lb. during maximum control excursion. Additionally, emergency nominal uninstalled thrust levels between 10,000 - 13,000 lb. are permissible in the event of either a gas generator or fan failure.

A variation in fan thrust above and below a nominal thrust level is required for air vehicle attitude control purposes. For Remote Lift Fan System A, this variation in fan thrust between pairs of fans in the system is obtained during control excursion by means of an energy transfer control concept. For Remote Fan System C, control thrust variation is obtained by a pressure/temperature control concept. These concepts are described in a subsequent section.

General Electric supplied two packages of tabulated uninstalled performance data for each remote fan system. In each case, one package contains data for VTOL/transition flight conditions covering a range in power settings for flight speeds from 0 - 150 knots and altitudes from sea level to 2000 feet. The other package presents data for climb/cruise/descent including a range in power settings for flight speeds up to 0.9 Mach number and altitudes up to 36,000 feet.

Fan/gas generator weight. - The reference 100% size lift fan for Remote Lift Fan Systems A and C weighs 805 lbs.

The reference 100% size turbojet gas generator for Remote Lift Fan System A is sized to drive two 100% size lift fans. This gas generator weighs 1015 lbs.

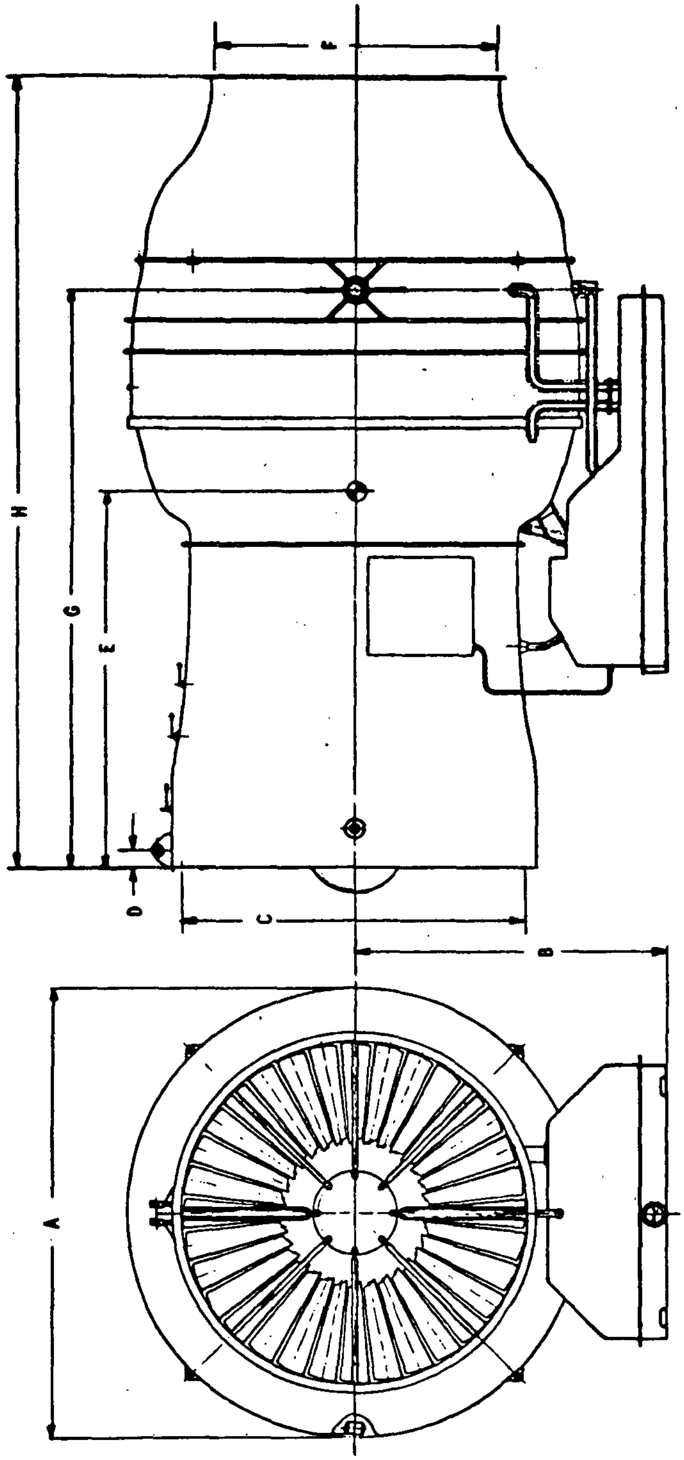


Figure 5. General Electric Turbojet Gas Generator

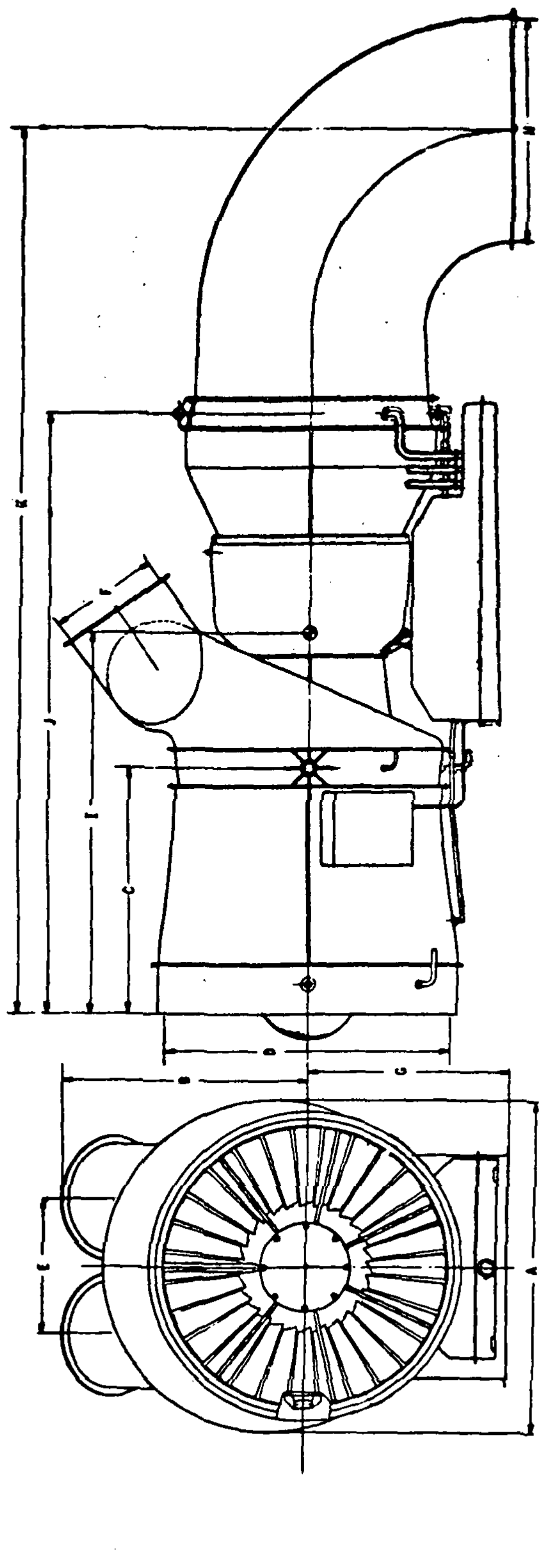


Figure 6. General Electric Turbofan Gas Generator

The reference 100% size turbofan gas generator for Remote Lift Fan System C is also sized to drive two 100% size lift fans. This gas generator weighs 1110 lbs.

Fan/gas generator dimensions and scaling data. - Lift fan dimensional scaling data are presented in Figure 7. Each lettered fan dimension shown is a function of lift fan scale factor. Each letter corresponds to the lettered dimensions given in Figure 4. The lift fan scale factor is defined to be the uninstalled Military Power nominal rated lift $L_{NOM\ MIL}$ of a scaled fan divided by the corresponding value of $L_{NOM\ MIL}$ for a 100% size fan. The following equation applies:

$$SF_{FAN} = \text{Lift Fan Scale Factor} = \frac{L_{NOM\ MIL}\ (\text{scaled})}{L_{NOM\ MIL}\ (\text{ref})} = \frac{L_{NOM\ MIL}\ (\text{scaled})}{10{,}000}$$

Lift fan weight scaling data are shown in Figure 8. A Weight Scale Factor corresponding to a computed value of SF_{FAN} is obtained from this Figure. The following equation applies:

$$\text{Fan Weight (scaled)} = (805)\ (\text{Weight Scale Factor})$$

The above lift fan data/procedure applies directly for Remote Lift Fan System A. In the case of Remote Lift Fan System C, SF_{FAN} is multiplied by 0.946 to obtain a new lift fan scale factor to use with Figure 7. Also, SF_{FAN} is multiplied by 0.947 to obtain a new value to use with Figure 8.

Turbojet gas generator scaling: Dimensional scaling data for the turbojet gas generator are presented in Figure 9 as a function of the gas generator scale factor SF_{GG}. The lettered dimensions in this Figure correspond to those shown in Figure 5. SF_{GG} is a function of SF_{FAN} as follows:

1. One gas generator is sized to drive one lift fan:

$$SF_{GG} = (0.91)\ (0.5)\ (SF_{FAN}) = 0.455\ SF_{FAN}$$

2. One gas generator is sized to drive two equally-sized lift fans:

$$SF_{GG} = (0.91)\ (1.0)\ (SF_{FAN}) = 0.91\ SF_{FAN}$$

The factor 0.91 is used in the case for attitude control thrust variation being obtained by means of an Energy Transfer Control (ETC) System. With this type of attitude control system, a 9% smaller size gas generator is required. The factor 0.5 applies for the case of using one gas generator

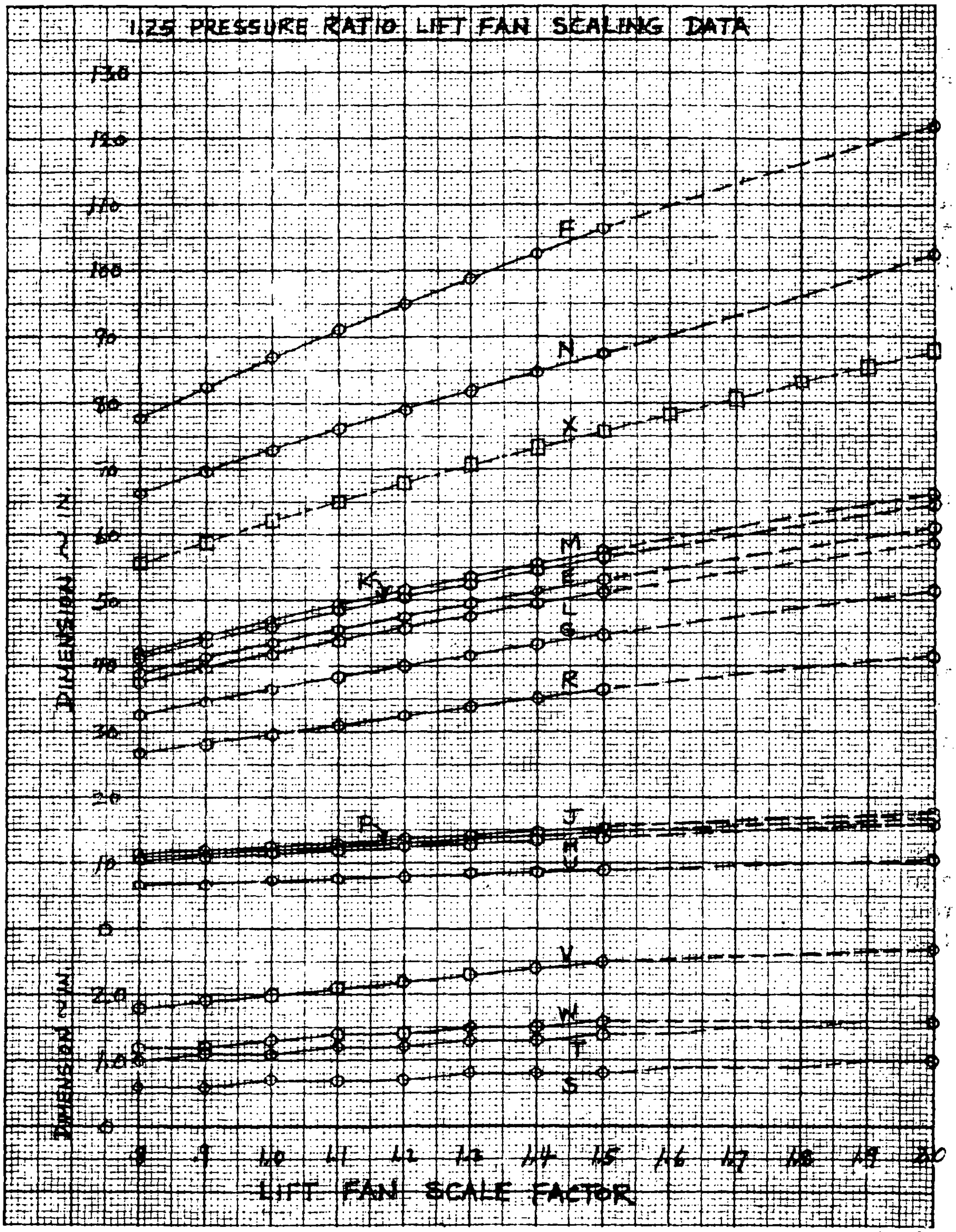


Figure 7. Lift Fan Dimensional Scaling Data

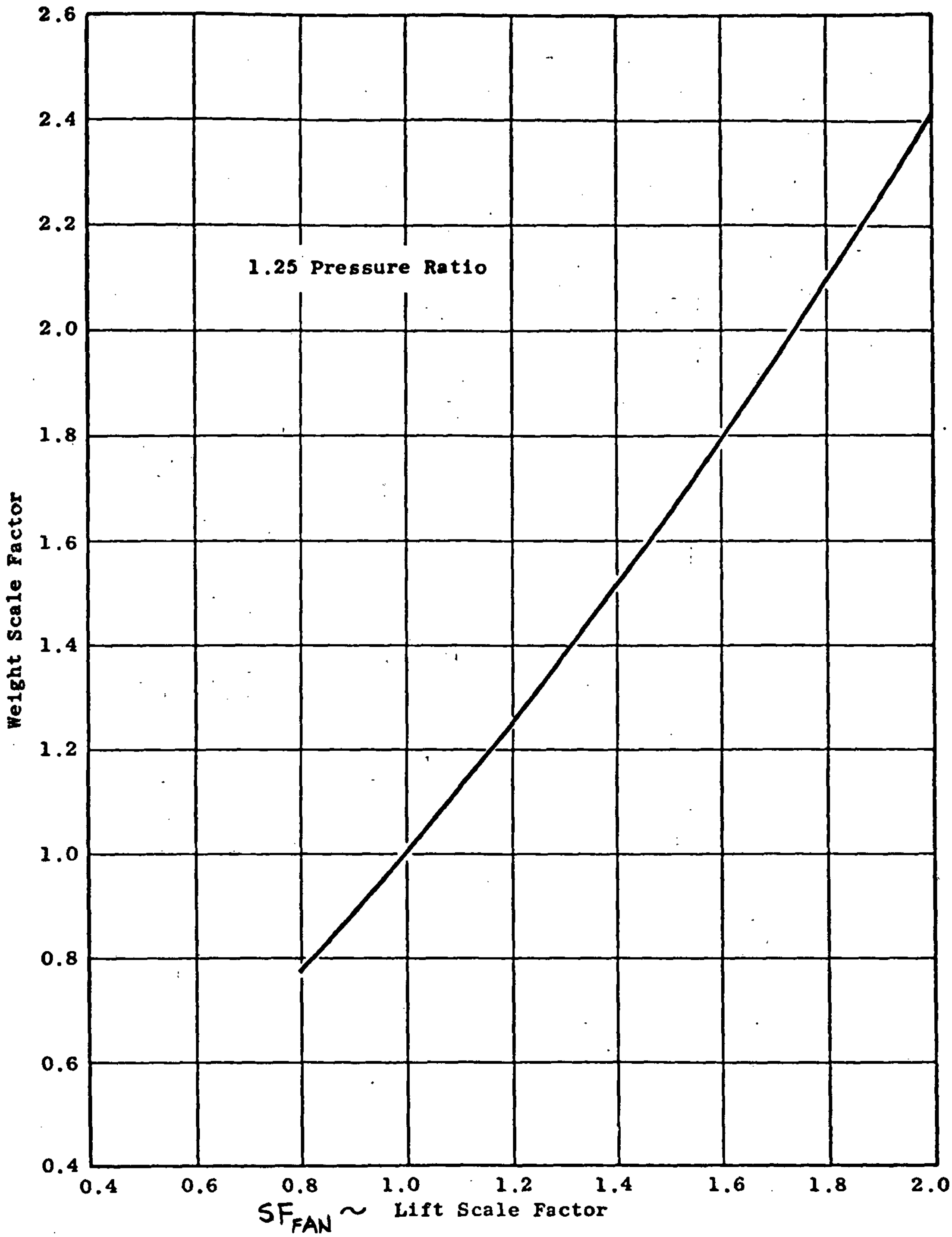


Figure 8. Lift Fan Weight Scaling Data

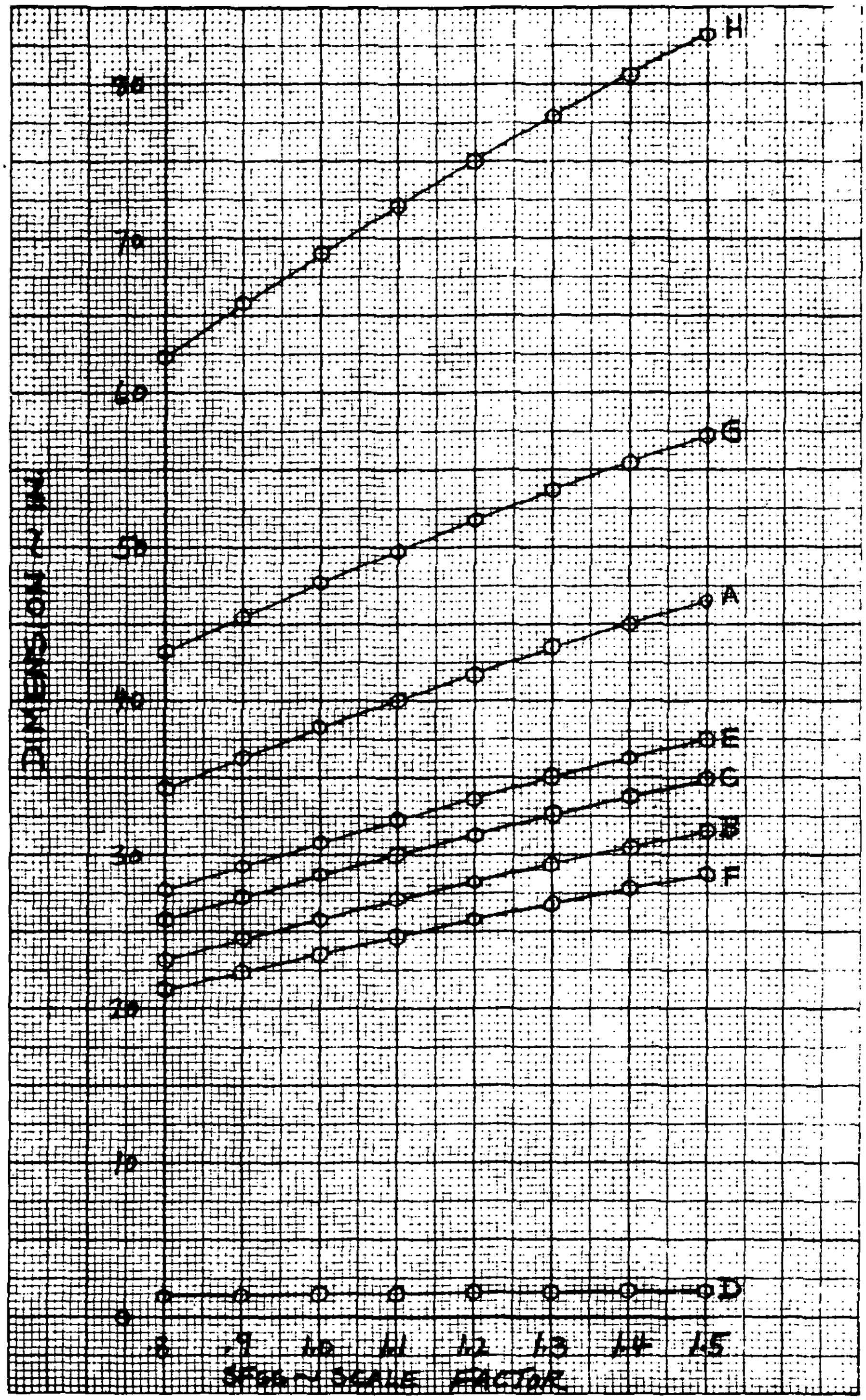


Figure 9. Turbojet Gas Generator Dimensional Scaling Data

per fan, and the factor 1.0 applies for the case of using two equally-sized fans per gas generator.

Weight scaling data for the turbojet gas generator are shown in Figure 10 A Weight Scale Factor corresponding to a computed value of SF_{GG} is obtained from this Figure. The following equation applies:

Turbojet Gas Generator Weight (scaled) = (1015) (Weight Scale Factor)

Turbofan gas generator scaling: Dimensional scaling data for the turbofan gas generator are presented in Figure 11 as a function of the gas generator dimensional scale factor SF_{TGG}. The lettered dimensions in this Figure correspond to those shown in Figure 6 . SF_{TGGW} is the gas generator weight scale factor. Both SF_{TGG} and SF_{TGGW} are functions of SF_{FAN} as follows:

1. One gas generator is sized to drive one lift fan:

$$SF_{TGG} = (1.099)\ (0.5)\ (SF_{FAN}) = 0.55\ SF_{FAN}$$
$$SF_{TGGW} = (1.29)\ (0.5)\ (SF_{FAN}) = 0.565\ SF_{FAN}$$

2. One gas generator is sized to drive two equally-sized lift fans:

$$SF_{TGG} = (1.099)\ (1.0)\ (SF_{FAN}) = 1.099\ SF_{FAN}$$

$$SF_{TGGW} = (1.129)\ (1.0)\ (SF_{FAN}) = 1.129\ SF_{FAN}$$

The factors 1.099 and 1.129 were supplied by General Electric. The other factors are the same as those used in scaling the turbojet gas generator.

Weight scaling data for the turbofan gas generator are shown in Figure 12 . A Weight Scale Factor corresponding to a computed value of SF_{TGGW} is obtained from this Figure. The following equation applies:

Turbofan Gas Generator Weight (scaled) = (1110) (Weight Scale Factor)

Lift fan combustors. - GE Remote Lift Fan System C requires the use of two combustors (duct burners) for each lift fan. These combustors are located just upstream of the two fan scroll entries. General Electric provided reference dimensional and weight data for a combustor design. Additionally, combustor dimensional and weight scaling data were provided.

Attitude Control Systems

The V/STOL Commercial Transport propulsion system is required to provide the entire lift for the VTOL mode, thrust for forward flight, and differential thrust for attitude control purposes during the V/STOL/transition flight modes.

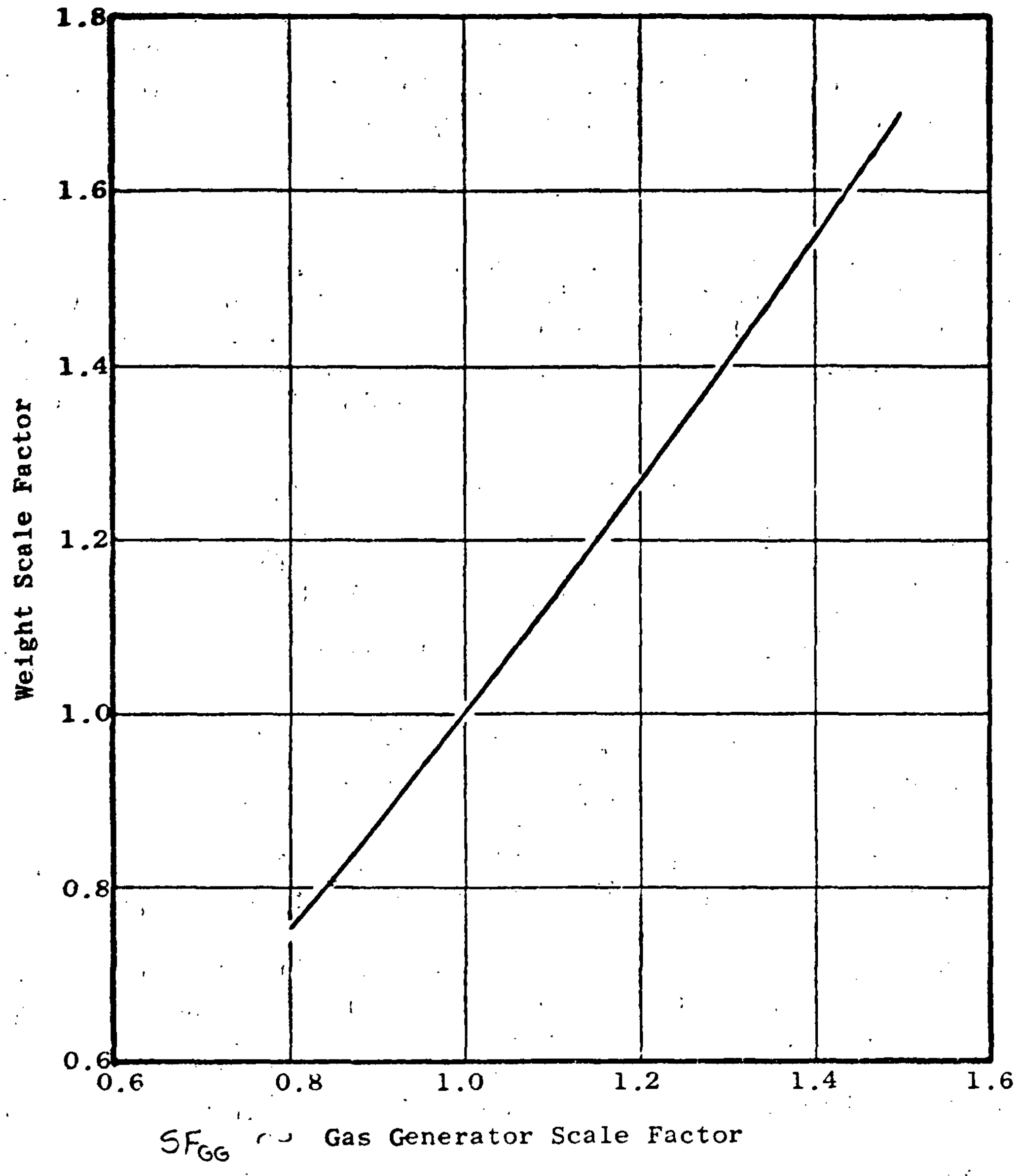


Figure 10. Turbojet Gas Generator Weight Scaling Data

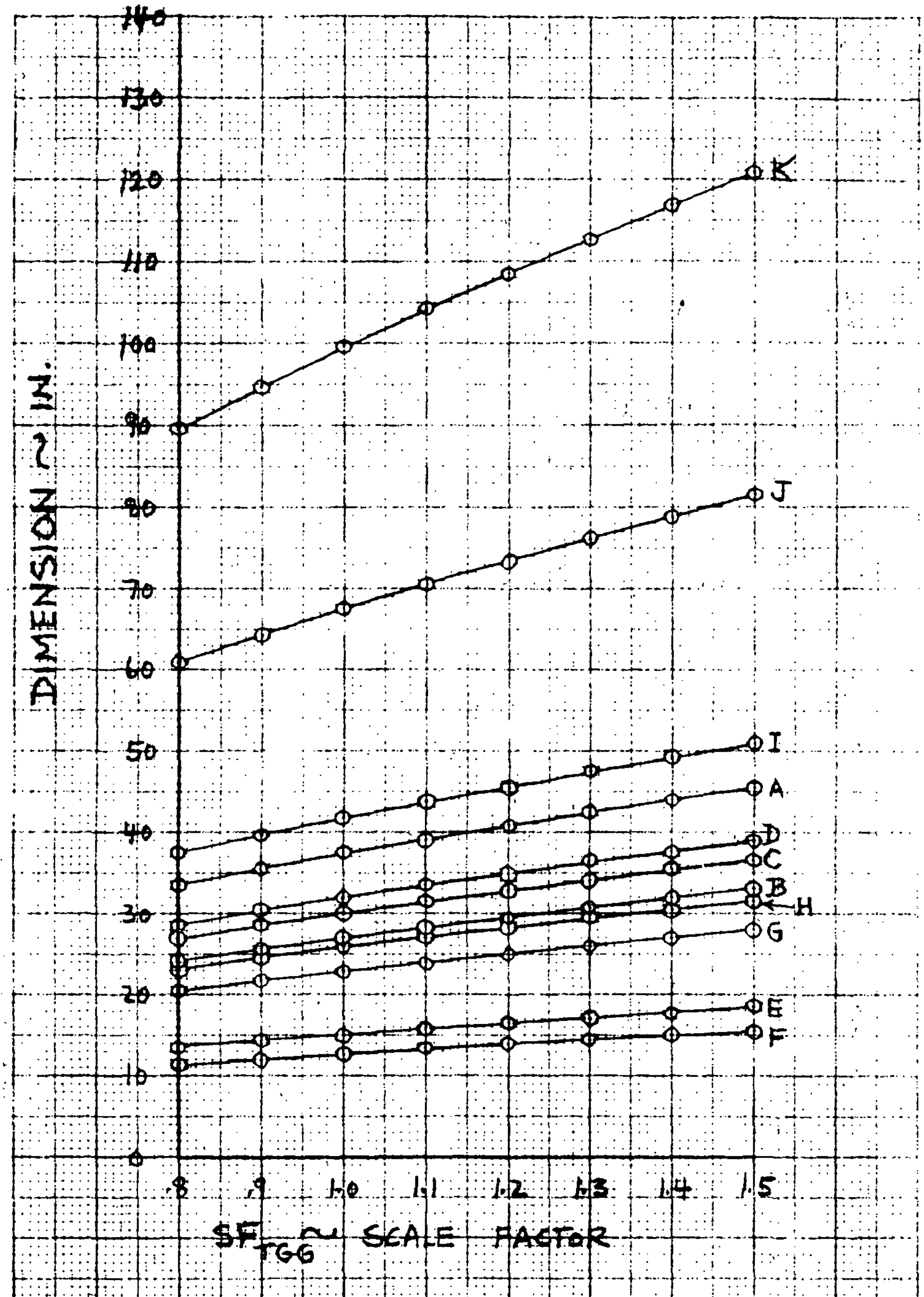


Figure 11. Turbofan Gas Generator Dimensional Scaling Data

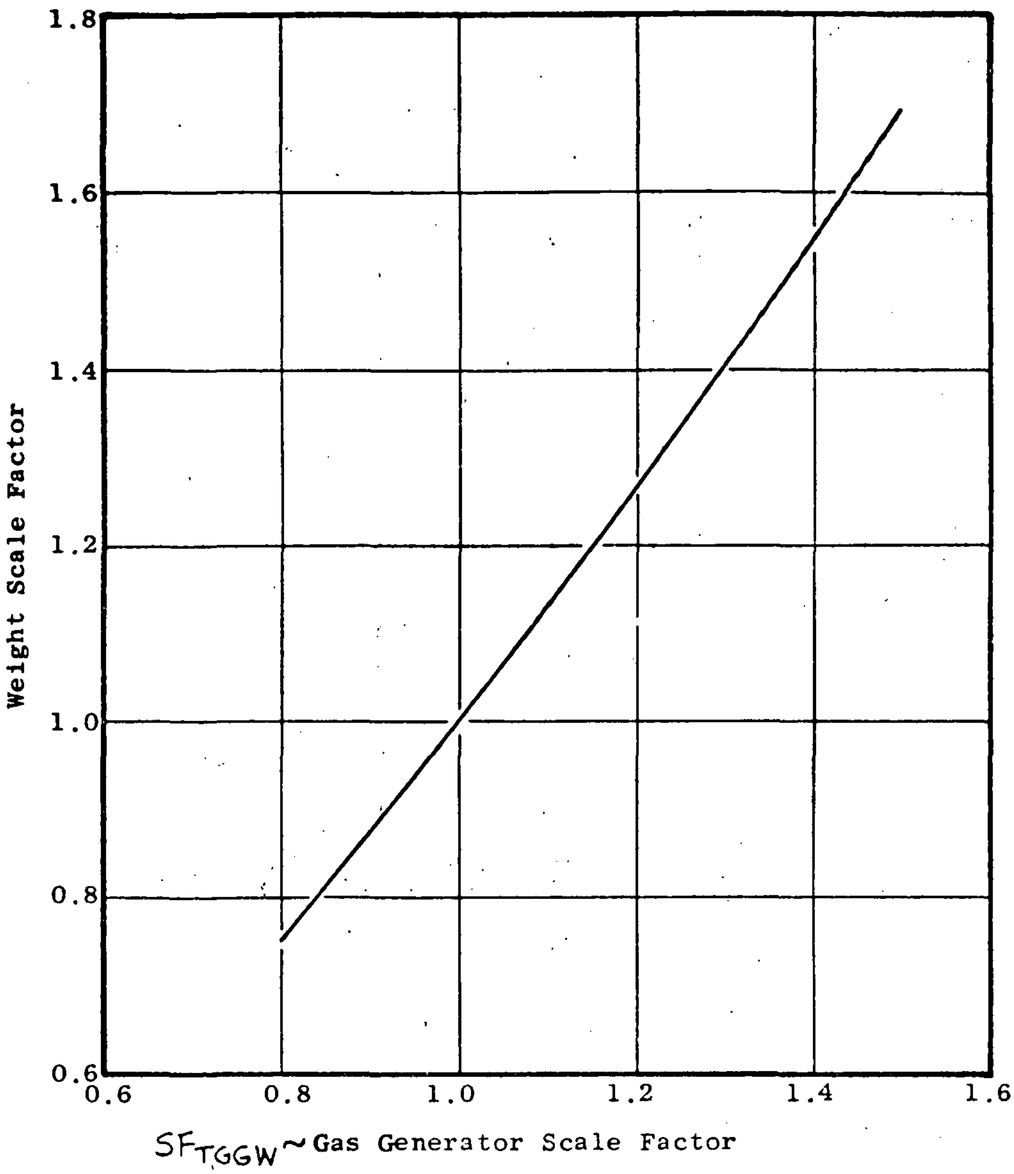


Figure 12. Turbofan Gas Generator Weight Scaling Data

Additionally, it is considered that the propulsion system will provide adequate hover control capability during both normal (Level 1) operation, and operation (Level 2) with the failure of an engine, fan, or gas generator. The propulsion system, therefore, incorporates an attitude control system. The attitude control system concepts used for the remote fan propulsion systems, however, are entirely different from that required for the integral fan propulsion system.

Low-speed attitude control system concepts. - The function of the attitude control system is to provide a short time thrust variation as required between pairs of engines/fans in the propulsion system during control excursions. This variation in thrust, above and below a nominal thrust level, provides the differential control thrust required for attitude control of the aircraft.

In the case of integral fan systems, different thrust levels between pairs of engines are obtained by engine throttle manipulation, resulting in operation at different power settings. Generally, a thrust increase of one engine above the nominal thrust level requires a corresponding thrust decrease of a diametrically opposite engine so that the total air vehicle thrust level stays unchanged.

For the remote fan system which uses turbojet gas generators, attitude control thrust is obtained by means of an energy transfer control concept. An attitude control system which uses this concept is shown schematically in Figure 13 . This system is referred to as a simple separate duct system which provides control thrust between a pair of fans, and requires that these fans be connected together with a common hot gas interconnect duct. Either one full or two half-size gas generators are usually considered to drive the two fans. Each fan requires a butterfly-type fan control valve. The operation of the system is described as follows:

1. During neutral control, both fan control valves remain fully open (aligned with the hot gas flow direction) and each fan produces the same nominal thrust.

2. During control excursion in which Fan 1 increases thrust above the nominal level, Control Valve 1 remains fully open while Control Valve 2 is deflected a certain amount. This deflection of Control Valve 2 induces a total pressure loss in the downstream flow path resulting in a reduced Fan 2 tip-turbine nozzle entry total pressure. The tip-turbine nozzle throat area is constant and operates with choked flow conditions. The effect of the reduced tip-turbine nozzle total pressure is to proportionally reduce the amount of hot gas flow which can pass through the tip-turbine nozzle. This, in turn, results in back pressurization of

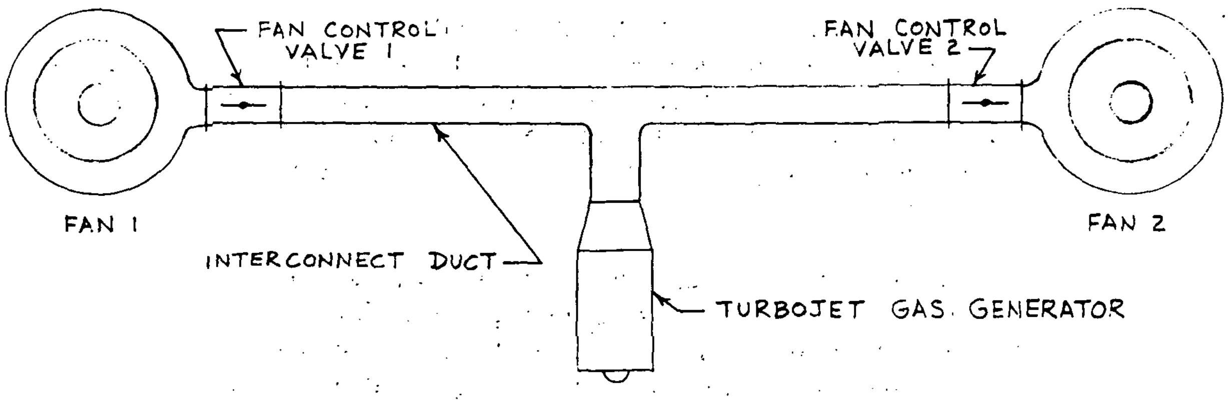


Figure 13. Attitude Control System with an Energy Transfer Control Concept

the gas generator. This, in turn, results in a flow back up which causes a back pressurization of the gas generator. The net result is that the gas generator, in order to maintain constant RPM, is forced to effectively increase its power setting, resulting in an increase in hot gas flow supplied at a higher energy level (increased total temperature and pressure). Fan 1 then increases its thrust level above nominal by virtue of its tip-turbine receiving an increase in gas flow at the higher energy level, thereby causing an increase in fan RPM. The resulting thrust level of Fan 2 does not decrease much below the nominal level because, with Control Valve 2 deflected, the increased energy level of the gas flow is counterbalanced by the control valve induced pressure loss. It is considered, however, that the thrust level of Fan 2 may be reduced below nominal by the same increment that Fan 1 increased above nominal by means of fan thrust spoiling. This thrust spoiling may be accomplished by differential movement of the fan exit louvers.

For the remote fan system which uses turbofan gas generators with duct burning, attitude control thrust is obtained by means of a pressure/temperature control concept. An attitude control system which uses this concept is shown schematically in Figure 14 . This system provides control thrust between a pair of fans which are driven by hot gas discharge flow from duct burners. The turbofan gas generator supplies bypass airflow to the duct burners. Either one full or two half-size gas generators may be used to drive the two fans. Each fan requires a butterfly-type fan control valve located upstream of the duct burner. The operation of the system is described as follows:

1. During neutral control, both valves remain in the same neutral deflected position, both duct burners operate with the same nominal fuel flow, and each fan produces the same nominal thrust.

2. During control excursion, one fan increases thrust above the nominal level while the other fan decreases thrust a corresponding amount below the nominal level. The control valve for the fan which increases thrust is moved toward the open (undeflected) position to increase tip-turbine pressure, while increased fuel flow is added to its duct burner to increase the gas discharge temperature. The resulting tip-turbine pressure/temperature increase is in accordance with maintaining the same constant tip-turbine nozzle flow function while operating with the same duct burner airflow rate from the gas generator. Thus, the operation of the gas generator is not affected and it continues to operate at a constant nominal power setting. Control

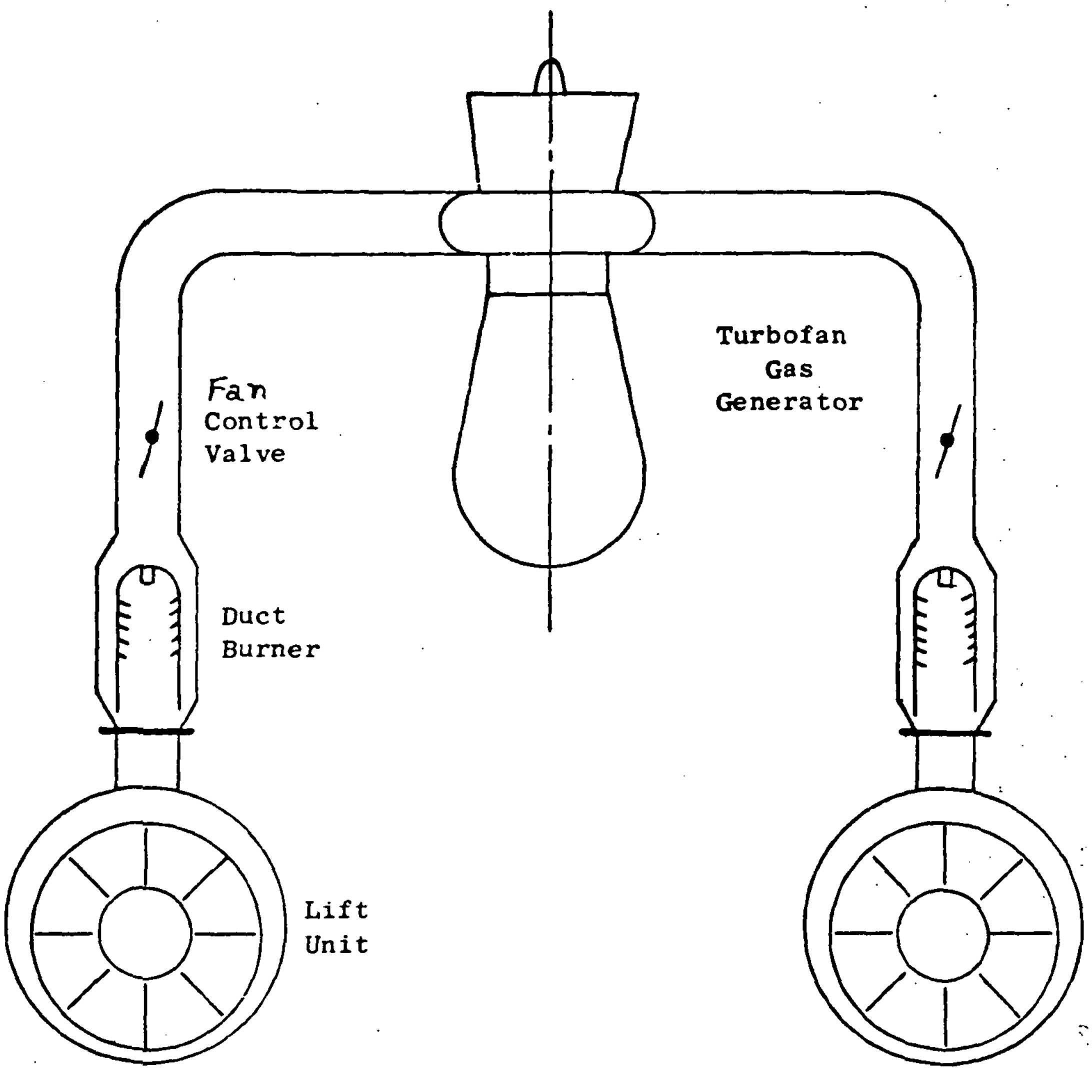


Figure 14. Attitude Control System with a Pressure Temperature Control Concept

valve/duct burner operation for the fan which decreases thrust is similar but opposite to the above operation. In this case the control valve deflection is increased to a position greater than neutral, while the duct burner fuel flow rate is reduced below its normal level. It is noted that another method of obtaining decreased fan thrust is by thrust spoiling from the nominal thrust level. This thrust spoiling may be accomplished by differential movement of the fan exit louvers.

Attitude control system performance. - Performance capability, considered applicable for all of the foregoing integral and remote fan attitude control system concepts, is summarized in Figure 15. The uninstalled thrust levels permitted for a single 100% size integral engine/remote fan are given in this Figure for both normal (Level 1) and emergency (Level 2) operation during neutral and maximum control excursion conditions. As previously indicated, the maximum nominal (neutral control) uninstalled thrust permissible without the use of an emergency rating is $L_{NOM_{MIL}}$ = 10,000 lb. This thrust rating is defined to be Military Power Setting.

In order to determine the hover control capability of specific aircraft configurations, the thrust level of each engine/fan in the system must be established during maximum control excursion conditions. The available percent lift control (%LC), as defined in Figure 15, is a convenient parameter to use in order to determine the thrust levels L_{MAX} and L_{MIN} for emergency (Level 2) operation after $L_{NOMEMERG}$ has been determined. L_{MAX} and L_{MIN} are functions of %LC and the nominal thrust level, $L_{NOMEMERG}$, as shown by the equations in Figure 15. %LC is plotted as a function of $L_{NOMEMERG}/L_{NOM_{MIL}}$ in accordance with the equation shown. The derivation of this equation for %LC is presented in NA-72-444 Volume IV. During normal (Level 1) operation at nominal thrust levels at or below Military power setting, %LC is considered to be 60%. This results in the following values for L_{MAX} and L_{MIN} in terms of L_{NOM}:

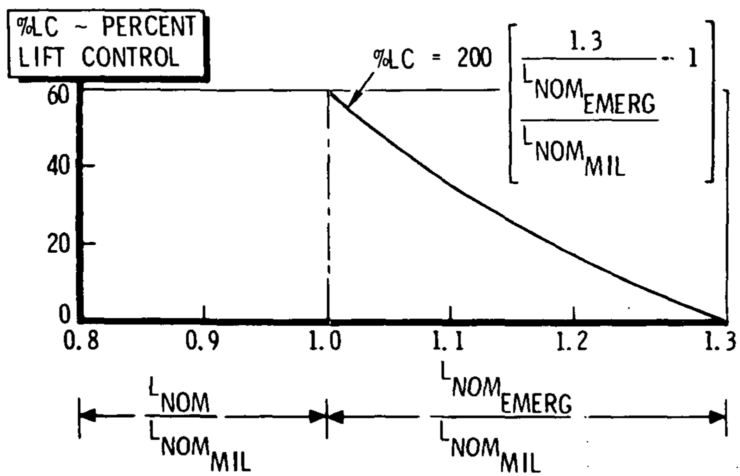
$$L_{MAX} = 1.3\ L_{NOM}$$

$$L_{MIN} = 0.7\ L_{NOM}$$

GENERAL ELECTRIC REMOTE & INTEGRAL FAN SYSTEMS

100% SIZE

OPERATION	CONTROL	THRUST ~ LB
NORMAL	NEUTRAL	10,000
	MAX CONTROL EXCURSION	13,000
EMERGENCY	NEUTRAL	10,000 - 13,000
	MAX CONTROL EXCURSION	13,000



$$\% LC = \left[\frac{L_{MAX} - L_{MIN}}{L_{NOM_{EMERG}}}\right] 100 = \left[\frac{2\Delta L}{L_{NOM_{EMERG}}}\right] 100$$

$$L_{MAX} = \left[1 + \frac{\%LC}{200}\right] L_{NOM_{EMERG}}$$

$$L_{NOM} = L_{NOM_{EMERG}}$$

$$L_{MIN} = \left[1 - \frac{\%LC}{200}\right] L_{NOM_{EMERG}}$$

Figure 15. Attitude Control System Performance Capability

CANDIDATE CONFIGURATIONS INVESTIGATED

Propulsion Arrangement Considerations

The design of a 100 passenger V/STOL Commercial Transport utilizing the specified propulsion systems (integral lift fan, or remote fan gas duct coupled to a gas generator) primarily involves the identification of configuration arrangements which satisfy the design requirements at the lowest total aircraft cost. The propulsion system size (in terms of thrust to weight ratio) and number of units determines directly the relative aircraft cost for a fixed takeoff gross weight. Until engine cruise performance data became available, it was estimated on the basis of previous NR experience that a 100 passenger VTOL aircraft will satisfy the 400 N.Mi. design mission requirement with reserves at a VTOGW of 100,000 lbs. Thus, all preliminary configuration development effort was accomplished at an assumed VTOGW of 100,000 lbs., with weight refinements made as configuration drag characteristics and engine cruise performance data became available.

Engine sizing in the VTOL made is dependent on the propulsion arrangement with the related effect on configuration inertia, and the assumed control concept for both normal and emergency operation. Configuration arrangements having 6, 8, or 10 integral lift engines or remote fans were considered with the propulsion lift and lift/cruise units located alongside the fuselage (tucked), in wing mounted pods (podded) or positoned in the fuselage nose and tail and in wing tip pods (aircraft extremeties), as shown in Figure 16. The six fan/engine arrangement at the aircraft extremities is deleted due to loss of VTOL roll control in the fan failure mode, and the ten fan/engine arrangement at the aircraft extremities was considered less attractive than the eight fan/engine arrangement and was not evaluated. The podded eight fan/engine arrangements were configured with three lift units per pod forward of the wing combined with an aft fuselage mounted lift/cruise propulsion unit, and with an alternate close coupled lift pod (two lift units forward of the wing structure plus one unit aft of the wing structure) combined with a forward shifted aft fuselage lift/cruise propulsion unit.

Evaluation of the propulsion arrangement matrix is illustrated with the integral engine concept in Figures 18 through 21 . For each propulsion system arrangement, the engines are sized to meet the hover control and engine failed trim requirements in accordance with the preliminary engine scaling data shown in Figure 17 . The engine weights corresponding to the various propulsion arrangements are used in an iterative process to calculate the total aircraft inertia characteristics required for hover control analysis.

A comparison of the total propulsion system weight for the propulsion arrangement matrix of Figure 16 is shown in Figure 18 . These data are shown for the following configurations:

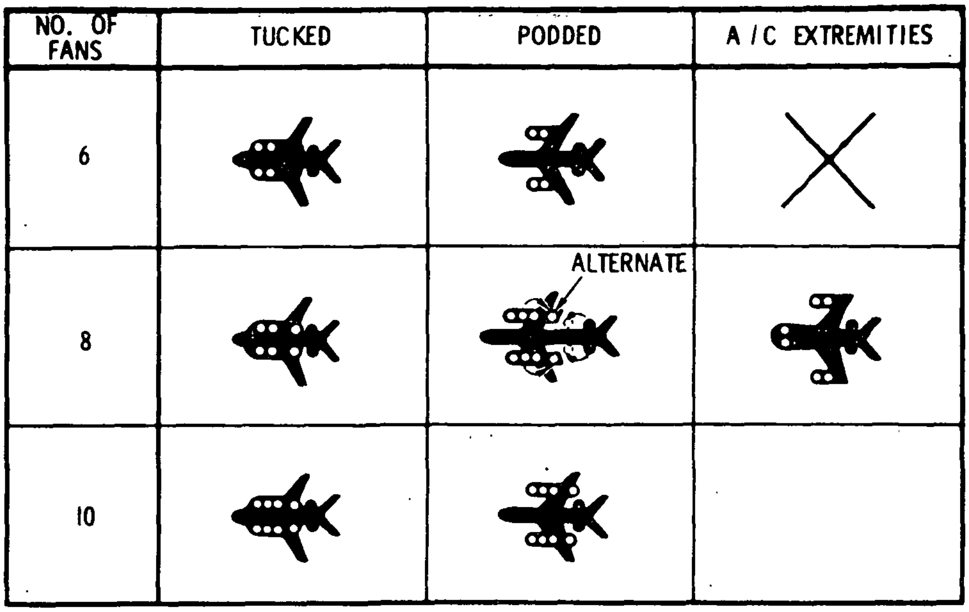


Figure 16. Propulsion Arrangement Matrix,
Intégral Engines or Remote Fans

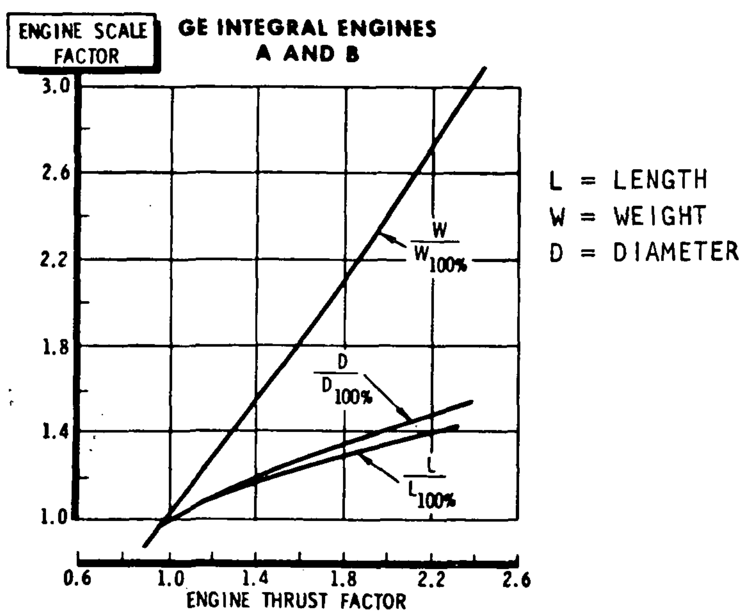


Figure 17. Preliminary Engine Scaling Data

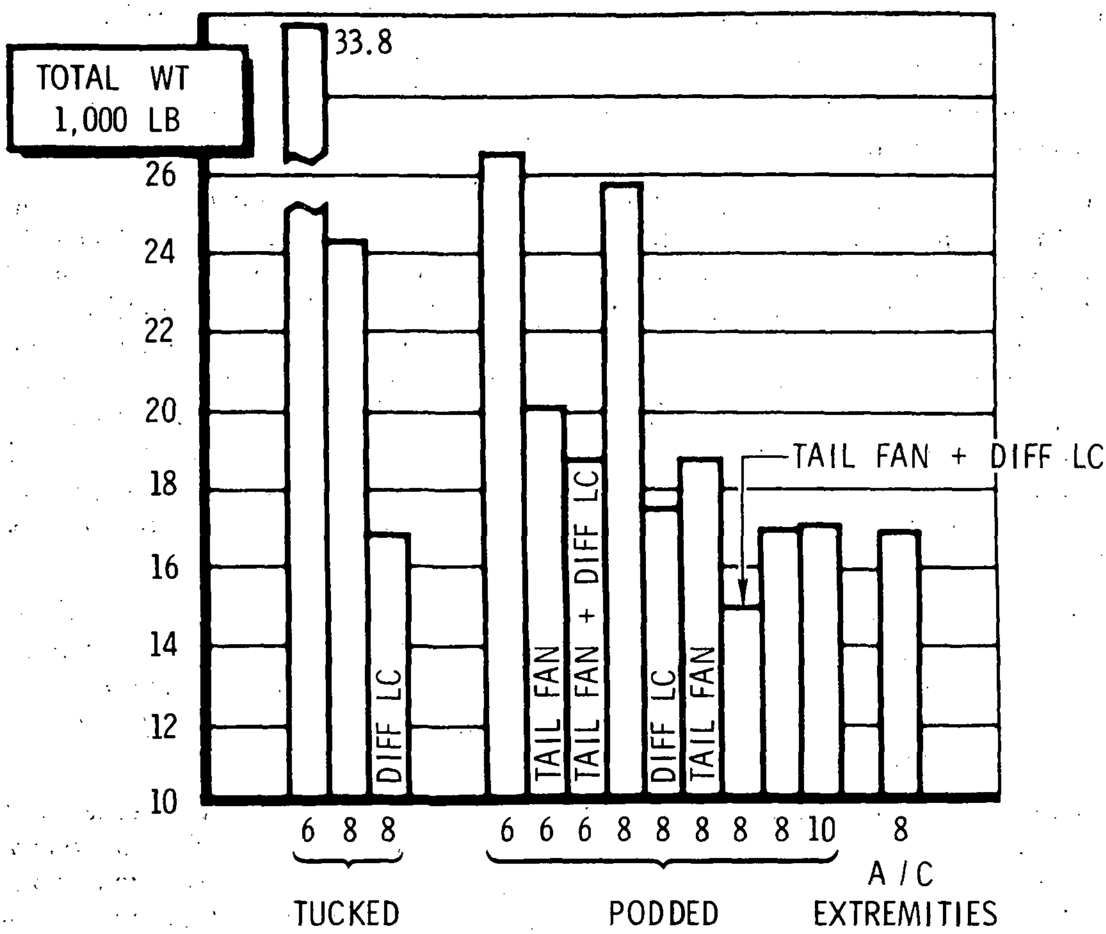


Figure 18. Total Propulsion System Weight
Integral Engine Concept

(a) one size integral engines (unmarked bar),

(b) one size integral engines in combination with aft fuselage pitch fan (tail fan),

(c) one size lift engines in combination with larger lift cruise engines (diff LC), or

(d) one size lift engines in combination with larger lift cruise engines and a pitch fan (tail fan + diff LC)

The 8 engine podded configuration is shown for both the basic and the close coupled alternate arrangements.

For a given control concept, these results show a decrease in the propulsion weight as the number of propulsion units increases from 6 to 10 due to the corresponding decrease in propulsion unit size as required by the failure condition, as well as because the thrust/weight ratio of a given engine increases as the engine size decreases. For a fixed number of engines, the propulsion weight also decreases as the engines are spread from the tucked configuration to the aircraft extremity location. Within each arrangement a reduction in propulsion weight is attained by utilizing different sized lift cruise engines for hover control, or the addition of an aft fuselage pitch fan, or a combination of these concepts if the corresponding development costs can be justified.

These results indicate that if the use of different sized lift cruise engines or tail fans is not considered, the 8 engine close coupled pod arrangement (alternate) is the most attractive from the weight/cost standpoint (minimum number of engines) and best structural arrangement (mid-span pod rather than wing tip pod).

The effect of integral engine arrangement on the inertia characteristics of the aircraft are summarized in Figure 19 . These results show a general trend of increasing inertia as the propulsion arrangement is expanded from the tucked to the extremities location with the associated reduction in engine size. The inertia characteristics within each propulsion arrangement appear to be configuration oriented such that no general trends can be identified.

Design layouts of the 8 integral engine configurations were evaluated for comparison of the effect of propulsion arrangement on the configuration wetted area hence relative skin friction drag. Common wing, tail and fuselage components are used except where modifications are required to include the propulsion system. For example, an increased fuselage length is included to incorporate the fixed forward fuselage lift engines, but no attempt is made to adjust the relative tail volumes to account for differences in the destabilizing input of the various engine pod/fairings. Figure 20 shows that the total airplane wetted areas are essentially related to the sum of the

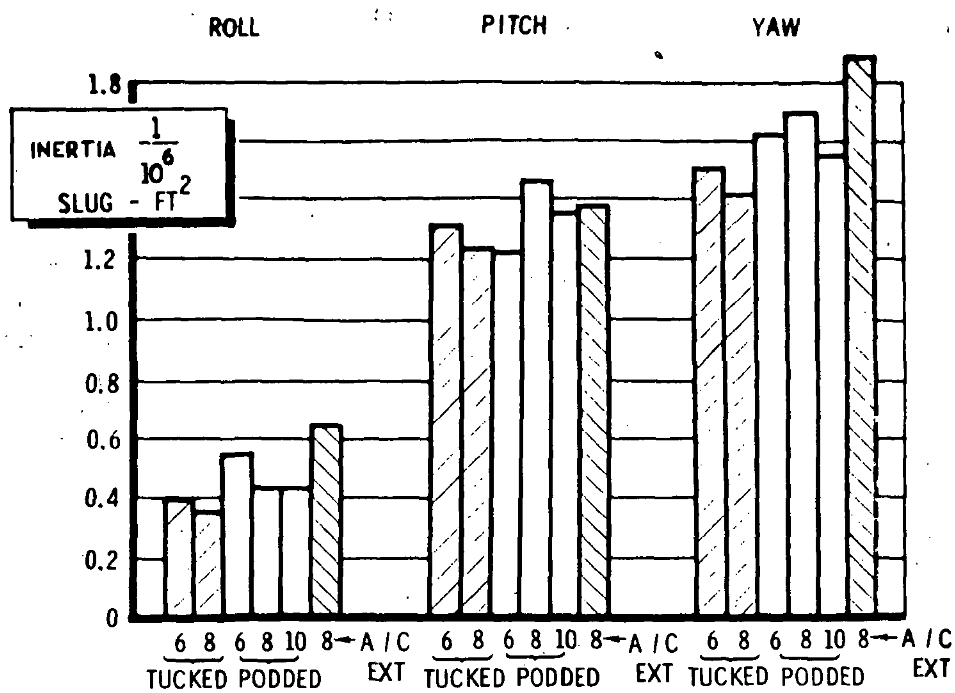


Figure 19. Moments of Inertia, Integral Engine Concept

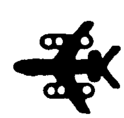
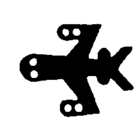
INTEGRAL ENGINES				
FUSELAGE	5,050	3,790	3,790	4,645
VERTICAL	578	578	578	578
HORIZONTAL	572	572	572	572
LC ENGINES	674	458	520	458
INBOARD WING	995	608	465	1,258
OUTBOARD WING		542	650	
LIFT ENGINE PODS	-	2,170	1,735	1,612
LC ENGINE PYLON	118	85	85	102
TOTAL	7,987	8,830	8,395	9,225

Figure 20. Wetted Area Comparison

fuselage plus lift engine pod wetted area, with approximately a 16% penalty for the largest value (aircraft extremities propulsion arrangement) as compared to the lowest value (tucked propulsion arrangement). The wing podded configurations add approximately 1/6 to 2/3 of the aircraft extremities configuration wetted area penalty depending on engine arrangement within the wing pod.

Further comparison identifying the relative engine cost per aircraft as a function of engine size (total installed air vehicle thrust to weight ratio) is shown for the propulsion matrix aircraft in Figure 21. Preliminary engine cost data on file at the beginning of this study were used assuming a 300 aircraft buy to generate the curves for 6 through 12 engined aircraft. The thrust to weight ratio of the 2 lift cruise engines is listed for each configuration identified. Several configurations were sized with different lift cruise and lift engines as identified by the asterisk. These configurations show a sizeable reduction in relative propulsion cost per air vehicle since the development cost of the lift cruise engines is assumed to have been covered by another program, and the lift engine size is reduced. From the minimum cost standpoint and without the benefit of a lift cruise engine from a parallel program, the wing podded and extremity located configurations (lift cruise T/W = .34) are the most attractive propulsion arrangements.

Preliminary Conceptual Designs

The preceding configuration selection process indicated that the wing podded lift engine arrangements are most attractive with the aircraft extremities arrangement as a second choice approach providing the forward fuselage engine installation penalty can be minimized. Although the preliminary propulsion arrangement considerations were concerned primarily with the integral lift engine systems, the results are also applicable to the remote fan systems as well with the added complexity of the interconnecting ducting. Detailed layouts of these two propulsion arrangements were next developed for both the integral engine and remote fan systems such that more realistic evaluations could be made and in particular comparisons between the integral and the remote fan systems where the latter included the effects of cross ducting and gas generator location.

Within both the remote fan systems and the integral engine systems, three different eight fan/engine arrangements are identified as configurations (1) through (6) Figure 22. In addition, configuration (7) was sized as a 6 remote fan system for comparison with the 8 remote fan aircraft. Except for the 6 fan configuration, each 8 remote fan propulsion arrangement has an integral engine counterpart for direct comparison. It will also be noted that the remote fan configuration (5), is developed in two basic versions; (5a) with 8 remote fans (RF) driven by 4 gas generators (GG), and (5b) with 8 remote fans driven by 8 gas generators. Configurations (5a) and (5c) differ only in that (5c) represents the only turbofan with duct burning remote fan

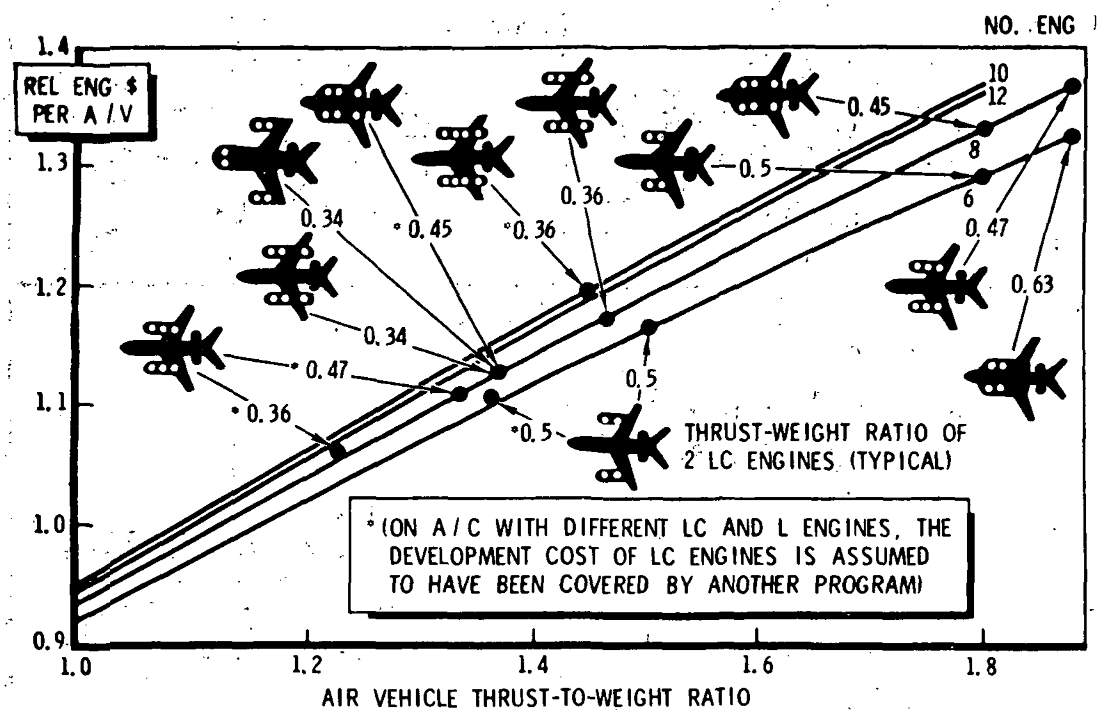


Figure 21. Relative Cost and Thrust to Weight Ratio Comparison

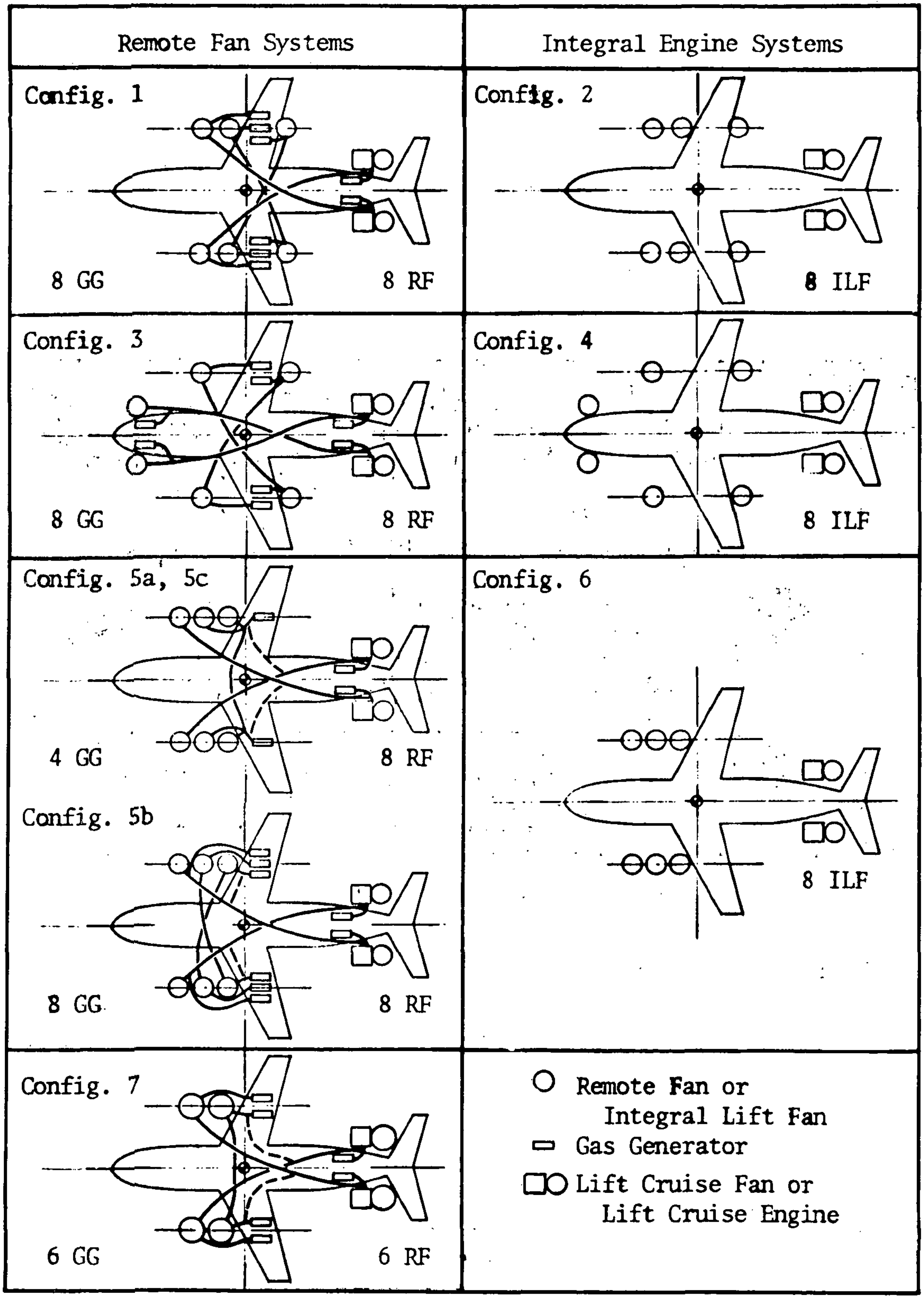


Figure 22. Propulsion System Configurations

system developed prior to deletion of this propulsion concept from further study. All other remote fan configurations represent a turbojet gas-generator-remote fan pair cross-ducted to a diametrically opposite gas-generator-remote fan pair. The interconnecting cross-ducting for the remote fan systems is shown schematically by solid lines in Figure 22 , but the emergency nozzles located near certain fans for failed fan operation have been omitted for clarity. Cross ducting in use only during failed gas generator operation is indicated by a dashed line.

Hover Control Evaluations

A hover control study was conducted for the candidate V/STOL Commercial Transport configurations shown schematically in Figure 23 . The odd numbered configurations utilize a remote fan system with turbojet gas generators, and the even numbered configurations use an integral engine system. All configurations except configuration (7) use eight engines/fans in the propulsion system. Configuration (7) uses six fans. The engines/fans are numbered for each configuration so that the lift/cruise engines/fans are always numbers 2 and 3.

Attitude control system definition. - The attitude control system for each configuration is defined in terms of the engines/fans used for roll, pitch, and yaw control as follows:

Configuration	Engine/Fan Number		
	Roll	Pitch	Yaw
(1), (2) and (6)	1-8	1-8	1,4,5,6,7,8
(3) and (4)	5-8	1-4	5-8
(5)	5-8	1-4	1,4,5,6,7,8
(7)	1-6	1-4	1,4,5,6

Hover control requirements. - The primary hover control requirements of the V/STOL Commercial Transport are summarized in Tables 2 and 3 . These height control and angular acceleration requirements were used in the hover control study made for the candidate configurations.

Installed engine/fan performance assumptions. - The following assumptions were made in order to determine installed engine/fan performance required for the hover control study:

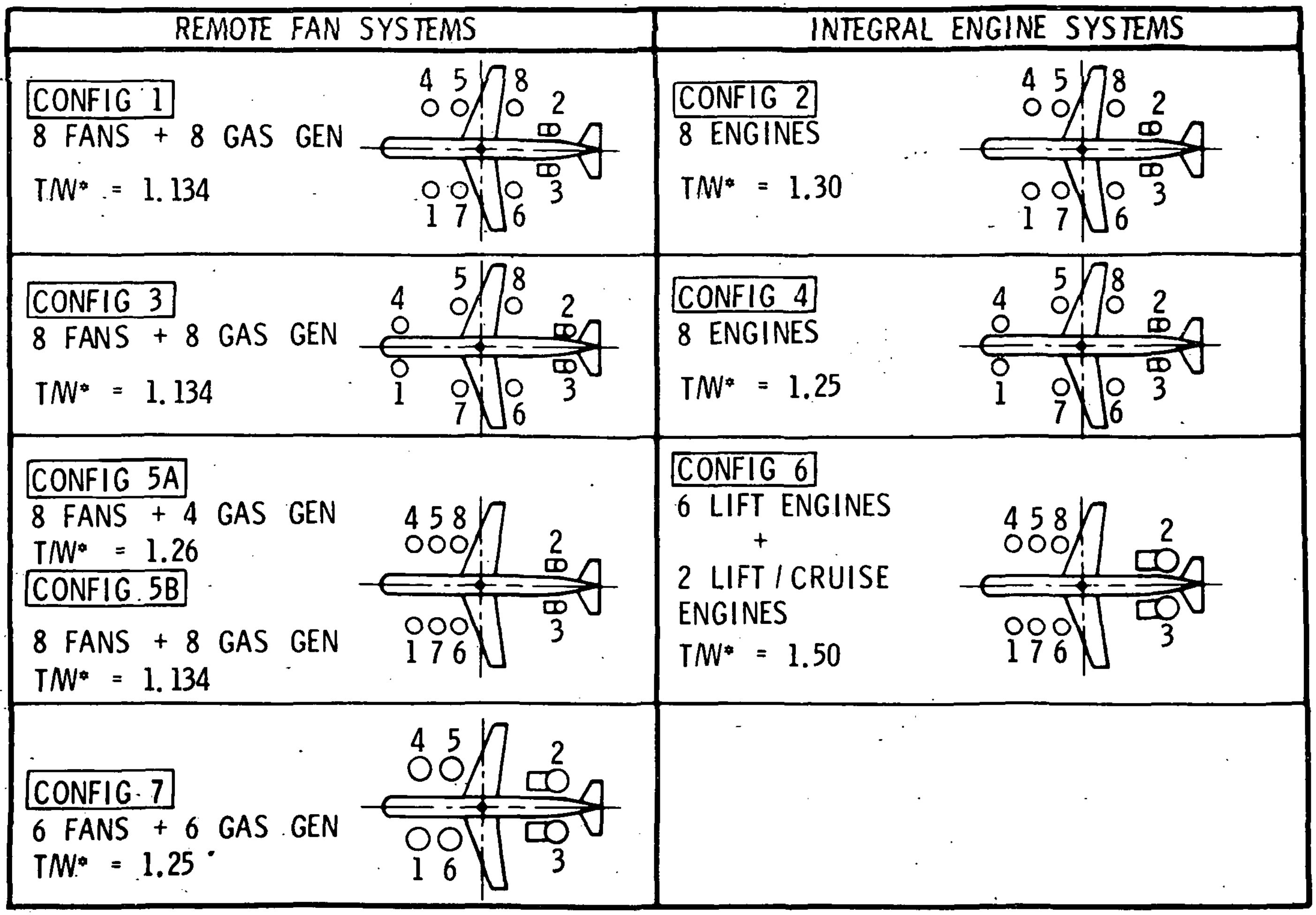


Figure 23. V/STOL Commercial Transport Candidate Configurations

TABLE 2

V/STOL COMMERCIAL TRANSPORT HEIGHT CONTROL REQUIREMENTS

(S.L., 90°F AMBIENT TEMPERATURE)			
Level	Failure	Incremental Acceleration	$\frac{T}{W}$
1	None	$\pm$0.1g	1.10 and 0.90
2	Engine, Gas Generator, or Fan	+0.05g, -0.1g	1.05 and 0.90

TABLE 3

V/STOL COMMERCIAL TRANSPORT ANGULAR ACCELERATION REQUIREMENTS

(S.L., 90°F AMBIENT TEMPERATURE)				
Level	Failure	Angular Acceleration rad/sec^2		
		R/P/Y 100/50/50	R/P/Y 50/100/50	R/P/Y 50/50/100
1	None	.60/.165/.125	.30/.33/.125	.30/.165/.25
2	Engine, Gas Generator, or Fan	.20/.083/.043	.10/.165/.043	.10/.083/.085

1. The total installation thrust loss for each lift engine/fan in the system during hover conditions is estimated to be 10%. Therefore, the following general equation applies:

   Installed Thrust = (0.90) (Uninstalled Thrust)

2. In the case of a lift/cruise engine/fan installation, which incorporates a segmented hood thrust-vectoring exhaust system, an additional 12% thrust loss was assumed when the segmented hood was deflected 90^{o} during the hover mode.

3. For an integral engine configuration, a failure of one engine requires that a diametrically opposite engine be shut down. Therefore, two engines are considered to be out during emergency (Level 2) operation.

4. For a remote fan configuration which uses one turbojet gas generator per fan, each pair of fans are driven by two gas generators in a separate duct system with a common interconnect duct. The failure of one of these gas generators requires that the other supply 50% of its gas flow to each of the two fans. The resulting thrust of each fan, then, is considered to be 54% of the thrust obtainable with 100% gas flow. In the case of a fan failure, the remaining fan in the separate duct system is shut down and the gas flow from each gas generator is diverted to a separate emergency nozzle. The thrust of each emergency nozzle is considered to be 40% of the fan thrust obtainable with 100% gas flow.

5. For a remote fan configuration in which each separate duct system uses one turbojet gas generator to drive its two fans, the failure of the gas generator results in the thrust loss of the two fans. In the case of a fan failure, the remaining fan is shut down and the total gas flow from the gas generator is diverted equally to two separate emergency nozzles. The thrust of each emergency nozzle is considered to be 40% of the thrust of one normally-operating fan.

Hover control study results. - A hover control analysis of each candidate configuration was made consistent with the foregoing attitude control system definition, hover control requirements, installed engine/fan performance assumptions, and the following:

1. A given gross weight.

2. Proper sizing and location of engines/fans/gas generators.

3. Proper center-of-gravity location.

4. Proper values of aircraft roll, pitch, and yaw inertia.

The results of the study indicated an aircraft thrust-to-weight ratio T/W* required to meet all requirements and conditions of the study. These values of T/W* are presented in Figure 23 for each candidate configuration. The explicit definition of T/W* is given below:

$$T/W^* = \frac{\underset{\text{(Lift Fan with } \beta = 0^o)}{\sum L_{NOM_{MIL\ INST}}} + \underset{\text{(Lift/Cruise Fan with } \theta = 0^o)}{\sum L_{NOM_{MIL\ INST}}}}{\text{Aircraft Gross Weight}}$$

where: $L_{NOM_{MIL\ INST}}$ (Lift Fan with $\beta = 0^o$) is the installed Military Power thrust for one lift engine/fan with the thrust vectored in the vertical direction.

$L_{NOM_{MIL\ INST}}$ (Lift/Cruise Fan with $\theta = 0^o$) is the installed Military Power thrust for one lift/cruise engine/fan with the thrust vectored in the forward horizontal direction.

In general, the above thrust definitions include all installation effects except the thrust loss associated with a 90^o deflection of the lift/cruise engine/fan segmented hood exhaust system. For an eight engine/fan configuration that uses eight equal-size engines/fans, the above equation for T/W* reduces to:

$$T/W^* = \frac{(8)\left[\underset{\text{(Lift Fan with } \beta = 0^o)}{L_{NOM_{MIL\ INST}}} \right]}{\text{Aircraft Gross Weight}}$$

The true aircraft thrust-to-weight ratio T/W includes all installation effects. It is noted that for normal (Level 1) operation with a required T/W = 1.10, the minimum possible size engines/fans would be obtained because emergency (Level 2) operation may dictate the use of larger size engines/fans. With a 12% additional thrust loss of each of two lift/cruise engines/fans for an eight equal-size engine/fan configuration, T/W is related to T/W* by the following equation:

$$T/W^* = 1.031\ T/W$$

Using this equation, the value of T/W* which corresponds to the minimum possible size engines/fans for the eight equal-size engine/fan case is:

$$T/W^* = (1.031)\ (1.10) = 1.134$$

This value of T/W* may be compared to those values of T/W* obtained for each candidate configuration to gain an appreciation of the relative engine/fan sizes required for each candidate configuration except configuration (6). Configuration (6) does not use equal-size lift and lift/cruise engines.

Conceptual Design Evaluation and Selection

This section of the report describes the results of the candidate configuration analysis which identifies the best aircraft configuration within each propulsion concept. Table 4 lists the remote fan and integral lift fan configurations described in the preceding paragraphs with identifying sketches of the fan arrangements.

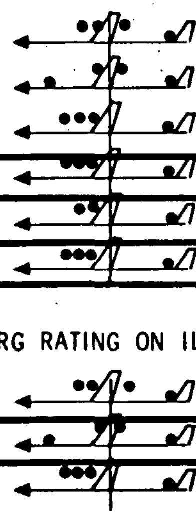
The installed thrust to weight ratios (T/W) required to meet Level 1 (normal) and Level 2 (emergency) hover control are listed for each configuration in the center portion of Table 4 with the critical (maximum) condition underlined. In the remote fan systems, Level 2 operation with a failed gas generator results in the two cross-ducted fans on the failed GG circuit producing 54% of the nominal fan thrust, or zero thrust where one gas generator drives two fans, configuration (5c). Level 2 operation with a failed fan requires the shut down of a diametrically opposite fan with the gas generator flow diverted to convergent nozzles which produce approximately 40% of the nominal fan thrust. In the integral lift fan systems, loss of one engine requires shut down of a diametrically opposite engine. The Level 2 sizing requirements for the integral lift fan configurations are shown for both the pitch and roll axes where separate engines are used for pitch and roll control. For integral lift fan configuration (6), the aft engine out hover control requires substantially larger size lift cruise engines than the lift engines. In the normal Level 1 hover mode these oversize lift cruise engines are operated at approximately half power. To preclude the development costs of two sizes of integral lift fans for this configuration and to achieve improved cruise performance over the integral lift fan, an alternate cruise engine (GE 13/F6A1) was selected from the AMST program.

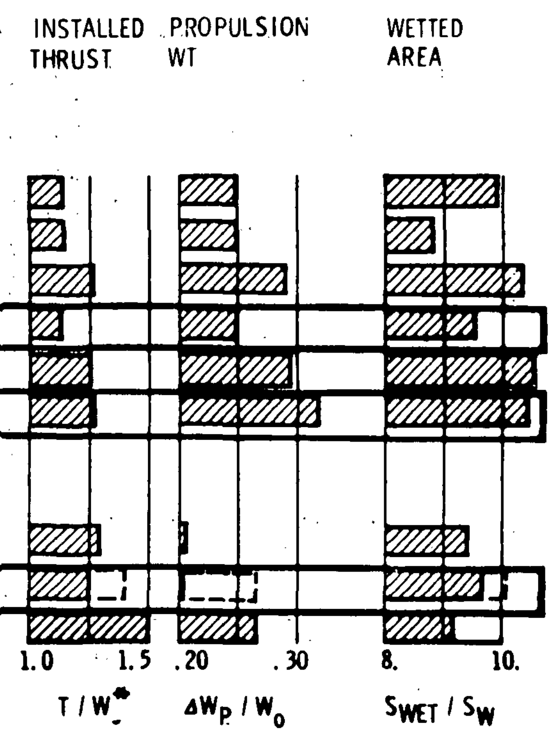
It was evident early in the study, Figure 24, that an 8 equal engine size aircraft would have marginal cruise speed performance for cruise on 2 engines when hover control requirements alone size the engines. In addition, preliminary data indicated that if the 0.75M cruise speed requirement is just met at 20,000 ft., Figure 25, the altitude cruise performance is extremely

TABLE 4

CANDIDATE CONFIGURATION COMPARISON

REMOTE FAN	PROPULSION FANS / GG	ARRANGEMENT	INSTALLED T/W* LEVEL 1	LEVEL 2 G/G OUT	LEVEL 2 FAN OUT	LEVEL 2 ENG OUT
CONFIG 1	8 / 8 T/J		1.14	1.06	1.08	-
3	8 / 8 T/J		1.14	1.06	1.15	-
5a	8 / 4 T/J		1.20	1.27	1.10	-
5b	8 / 8 T/J		1.14	1.06	1.08	-
7	6 / 6 T/J		1.14	1.25	1.19	
5c	8 / 4 T/F		1.20	1.27	1.10	-
INTEGRAL L/F + L/C	EMERG RATING ON ILF ONLY					P / R
2	8		1.14	-	-	1.30 / 1.24
4	8		1.14	-	-	1.23 / 1.25
6	6 + 2 L/C		1.14	-	-	1.50





T/J Turbojet Gas Generator
T/F Turbofan Gas Generator
L/F Lift Fan
L/C Lift Cruise Engine
P/R Pitch Control/Roll Control

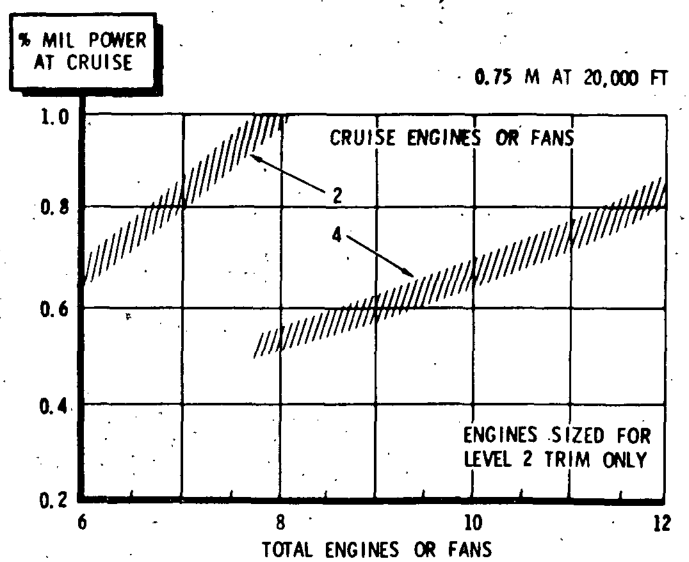


Figure 24. Power Required for Cruise

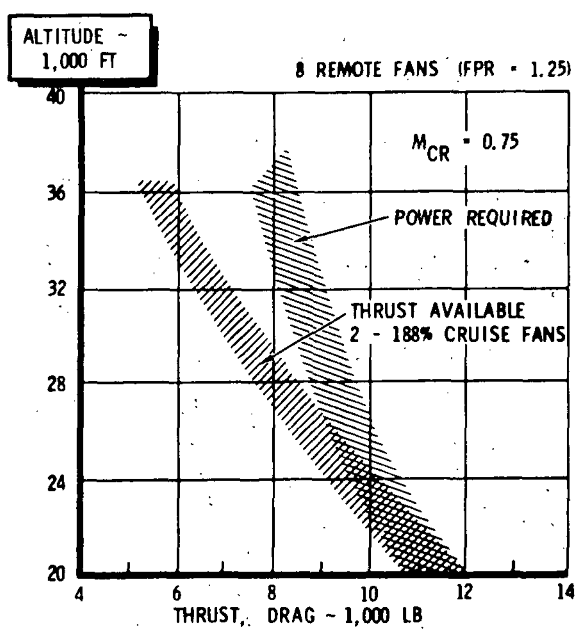


Figure 25. Cruise Requirements at Altitude

limited as represented by the remote fan characteristics. To retain the equal size, and single engine cycle propulsion concept for the remote fan configurations, these aircraft cruise on 2 lift cruise fans plus the additional thrust of 2 convergent nozzles using gas generator flow diverted from the lift fans. Integral lift fan configurations (2) and (4) with equal sized engines, Table 4, have marginal cruise performance, hence an increased size lift cruise engine of an alternate cycle similar to configuration (6) is required for these aircraft.

The bar graphs of Table 4, compare the critical sizing T/W ratios for each propulsion arrangement, the corresponding propulsion system weight fraction, and the total airplane wetted area to wing area ratio. The effect of increasing the lift cruise engine size of configuration (4) is shown by the broken line bar as a T/W* increase from 1.25 (sized for hover) to 1.40 (sized for cruise) with a corresponding increase in propulsion weight fraction. Approximately the same T/W* ratio and propulsion weight fractions will apply also to configuration (2). The effect of increased lift cruise engine size of configuration (4) on the wetted area ratio is negligible, but a broken line bar shows the wetted area penalty due to a fuselage extension if fixed forward fuselage lift engines are considered a more realistic arrangement than the swing out forward lift fan configuration evaluated.

The three candidate configurations selected to represent each of the propulsion concepts for detailed evaluation are emphasized by the outlines on Table 4. Configuration (5b) is selected for the turbojet remote fan system over configuration (3) to minimize hot gas ducting within the fuselage and due to the aversion for hot gas ducting routed to a swingout fan. The evaluation of one configuration, (5c), was initiated for the turbofan driven remote fans with duct burning, before this propulsion concept was deleted from the study by the NASA program office. The integral lift fan propulsion concept is represented by configuration (4) as having the lowest T/W and propulsion weight fraction, except that an increased size (T/W* = 1.4) alternate lift cruise engine cycle is incorporated to provide the desired cruise performance.

SELECTED DESIGN EVALUATION

This section of the report presents the design philosophy and a general description of each of the aircraft selected to represent the three study propulsion system concepts. Design layouts are shown with a brief description of the propulsion system operation in hover, transition and cruise. Each configuration is further described with tabulated dimensional data, inertia characteristics, and a weight summary.

Configuration Design Considerations

The aircraft are designed with a common wing, tail and fuselage configuration modified as required for the specific propulsion concept. The cabin is sized to seat 100 passengers plus 2 attendants in 3 pairs of seats in each row separated by 2 aisles 19 in. wide. The seat pitch is 34 in. The cabin also includes space for 2 lavatories, closets, and a galley. For purposes of clarity, these cabin details are not shown on the selected design layouts. The wing geometry is selected on the basis of previous NR V/STOL studies (References 6 and 7) as a compromise between the sweep, aspect ratio and thickness desired for optimum cruise performance, and the structural considerations required to support podded lift engines or fans and the associated cross ducting. A brief wing loading tradeoff analysis for the cruise condition was the basis for sizing the wing area with consideration given to the associated effect on passenger ride qualities. The tail volumes were sized to give satisfactory stability and control characteristics in the critical low speed flight regime based on detailed analyses performed on previous NR V/STOL aircraft. The conceptual design nature of these configurations did not include sufficient depth of analysis to identify differences in the horizontal tail sizing due to the destabilizing inputs of the wing mounted lift pods. Tail sizing to develop consistant configuration weight and balance evaluations were considered of primary significance within the scope of this study.

The physical and weights descriptions of the selected configurations are presented in the following section of the report succeeded by comparison and substantiation data and aircraft performance.

Integral Lift Fan V/STOL Transport

Configuration arrangement. - Although initial integral lift fan aircraft configurations were sized with all engines at one scale factor, the selection of an eight engined arrangement identified the probability that two of these engines as sized for hover had insufficient thrust for cruise. The penalties of scaling all engines up or cruising on four engines appeared less attractive than sizing the aircraft with two engine sizes, one for lift only, and a larger scale factor for the lift cruise engine. Further, if two engine sizes are to be used in the same aircraft, then the integral lift fan lift/cruise engines (and the inherent higher specific fuel consumption during cruise) can be replaced by cruise engines of a different engine cycle designed for efficient cruise. This is the approach used.

The integral lift fans and lift cruise engines for this aircraft are arranged symmetrically about the center of gravity as shown in Figure 26 such that for one engine failed, the aircraft is trimmed by shut down of the diametrically opposite engine. In the hover mode, the large lift cruise engines are operated at approximately half power, and a 12% thrust loss is assumed with the segmented hood deflected at 90 degrees. The partial power operation of the lift cruise engines reduces the noise levels of these engines and is discussed in a subsequent section of this report. Attitude control in roll and pitch is achieved by thrust modulation of the wing lift pod engines and the fuselage mounted lift and lift cruise engines respectively. The lift pod mounted engines are swiveled for yaw control. Thrust vectoring in accelerating and decelerating transition and steep descent flight is attained by swiveling all integral lift fans (including the swingout forward fuselage fan), and deflecting the segmented hood nozzle on the lift cruise engine.

The swingout forward fuselage integral lift fan arrangement is selected over a fixed fan configuration to avoid the weight and drag penalty of a fuselage extension. The retractable lift engine is located below a level cabin floor, and its nozzle is approximately 95 percent of the nozzle diameter above the ground. The length of the wing lift pod is determined by the aft wing spar-aft lift engine clearance. The resulting location of the aft engine from the airplane center of gravity thereby locates the forward lift pod engine.

General Characteristics. - The physical description, design conditions, and inertia characteristics are listed in Table 5. The center of gravity location and moments of inertia are calculated for a vertical takeoff gross weight of 111,100 lbs.

Propulsion system. - The propulsion system for the selected V/STOL transport configuration which uses an integral engine system consists of eight integral engines is schematically shown in Figure 27 . Lift/cruise engine installations 2 and 3 each use a 144.6% size GE 13/F6A1 turbofan engine. The other six engines shown are 192.8% size GE ILF 1A1 lift engines. With these engine sizes, the aircraft thrust-to-weight ratio T/W* is 1.40 (see section dealing with Hover Control Evaluations for definition of T/W*). All eight engines are in operation during the V/STOL transition flight modes, but the six lift engines are shut down during the conventional flight mode above transition speeds.

Each lift/cruise engine installation consists of a horizontally-mounted nacelle configuration in which the inlet, engine, and thrust-vectoring segmented hood/exhaust nozzle system are contained. This segmented hood

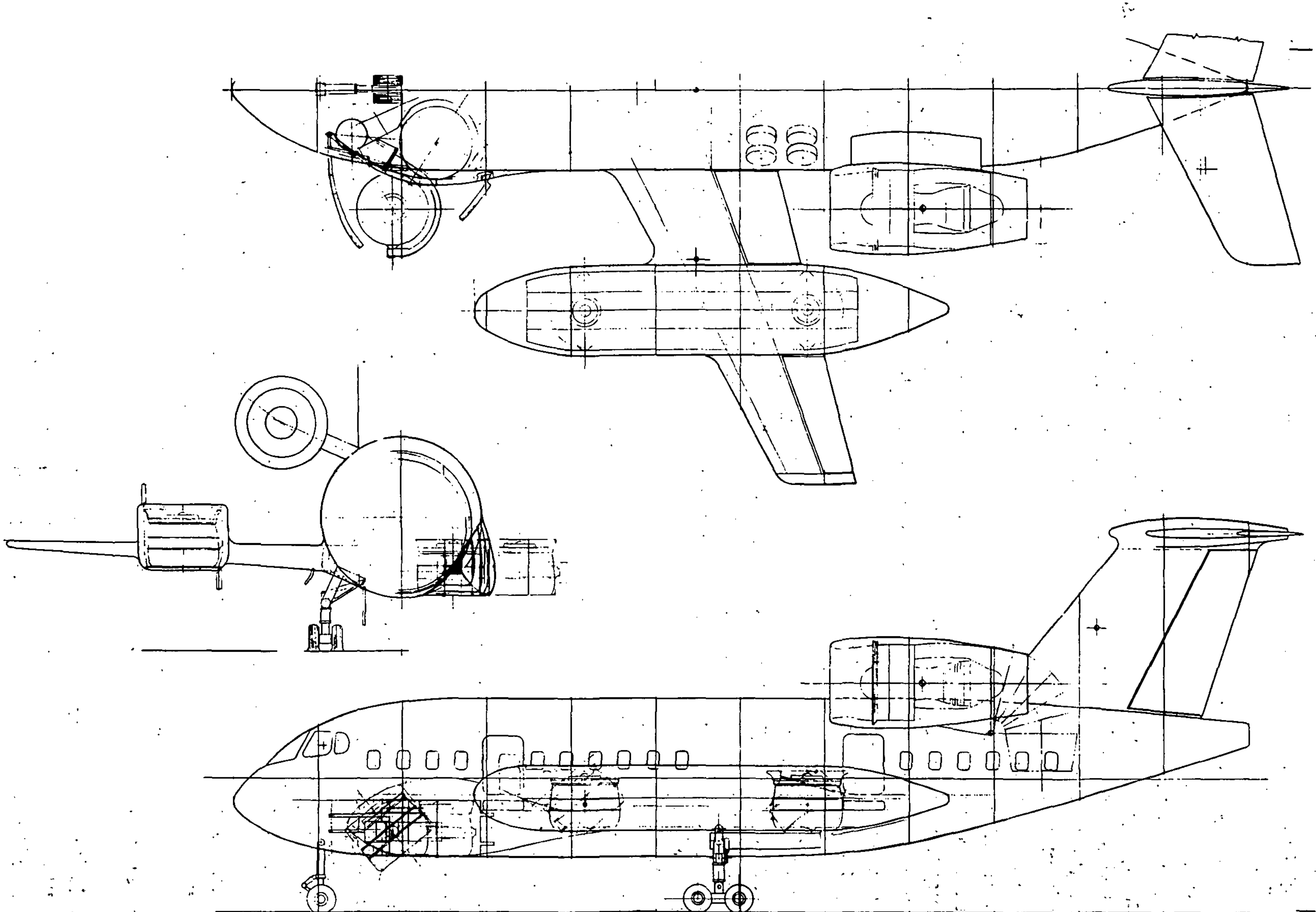


Figure 26. Integral Lift Fan/Cruise Engine V/STOL Transport

TABLE 5

PHYSICAL CHARACTERISTICS

INTEGRAL LIFT FAN & CRUISE ENGINE CONCEPT

Airframe	Wing	Horizontal	Vertical
Area (sq. ft.)	935	282	276
Aspect Ratio	6.0	4.0	1.0
Taper Ratio	0.4	0.6	0.6
Span (ft.)	74.9	33.6	16.6
Mean Aerodyn. Chord (ft.)	13.2	8.6	17.0
Sweep back c/4 (deg.)	25.	25.	35.
Root Section	64A012	64A010	64A010
Tip Section	64A010	64A012	64A010
Tail Length	-	50.0	39.4
Tail Volume	-	1.10	0.15
Fuselage Length (ft.)	100.0		
Fuselage Dia. (ft.)	15.8		

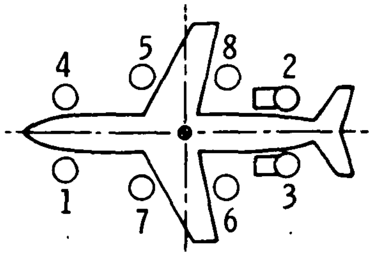
Propulsion	Lift	Lift/Cruise
Number/Designation	(6) GE ILF 1A1	(2) GE 13/F6A1
Scale Factor	192.8%	144.6%
Fan Pressure Ratio	1.25	-

Structural Limits	
V_{MO} (kts EAS)	400
M_{MO}	.85
n_{LIM}	2.5
Design Cruise Conditions	
M_{CR}	.75
V_{CR} (kts EAS)	400
Cruise Altitude (ft.)	36,000
Mass Properties	
Weight VTO (lbs.)	111,100
Center of Gravity X, Z (in.)	556.0, 1.0
I_{xx} (slug ft.^{2})	673,390
I_{yy} (slug ft.^{2})	1,520,996
I_{zz} (slug ft.^{2})	1,923,636
I_{xz} (slug ft.^{2})	210,630

• GENERAL ELECTRIC

- 6 LF1A1 LIFT ENGINES
- 2 GE13/F6A1 LIFT/CRUISE ENGINES

PROPULSION SYSTEM DESCRIPTION



ENGINE FAILURE

ENGINE FAILS	SHUTDOWN ENGINE	RESULT IS THRUST LOSS OF ENGINES
1 OR 2	2 OR 1	1 & 2
3 OR 4	4 OR 3	3 & 4
5 OR 6	6 OR 5	5 & 6
7 OR 8	8 OR 7	7 & 8

Figure 27. Integral Lift Fan V/STOL Transport Propulsion System

system provides gross thrust vectoring from horizontally forward ($\theta = 0^{o}$) to a position which provides an aft thrust component with the gross thrust vector rotated 40^{o} forward of the vertical direction ($\theta = 130^{o}$).

Referring to Figure 27 , lift engines 5 and 8 are mounted in a right wing pod and lift engines 6 and 7 are mounted in a left wing pod. These engines may be swiveled in the fore and aft direction inside each pod so that the gross thrust vector of each engine may be rotated between 40^{o} aft to 40^{o} forward of the vertical direction. Lift engines 1 and 4 are mounted in a swing-out type of configuration. These engines are normally stowed in the lower forward fuselage when not in use. Prior to operation, they are swung out to the position shown. During operation, each of these engines may be swiveled in the fore and aft direction the same amount that the podded lift engines are swiveled.

If an engine failure occurs during the V/STOL transition flight modes, a diametrically opposite engine is shut down to prevent the occurrence of large unbalanced moments. This results in the loss in thrust of two engines as shown in Figure 27.

Attitude control system: Referring to Figure 27 , attitude control of the aircraft during V/STOL/transition conditions is obtained by the following engines:

1. Engines 5-8 provide the entire roll control.

2. Engines 1-4 provide the entire pitch control.

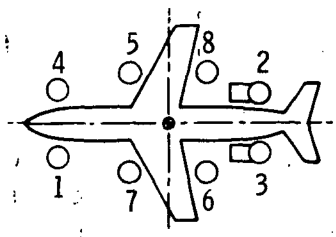
3. Engines 5-8 provide the entire yaw control.

The attitude control system is operated by engine throttle manipulation so that as the thrust of engine 1 is increased above the nominal thrust level, the thrust of engine 2 is correspondingly decreased, and vice versa. This control thrust change for engine pair 1 and 2 also applies for engine pairs 3 and 4, 5 and 6, and 7 and 8.

Installed propulsion system performance: The nominal installed engine thrust $L_{NOM\ INST}$ of each integral lift engine is tabulated in Figure 28 for Level 1 and 2 hover operation at Sea Level Static conditions. The corresponding nominal installed engine thrust of each of the two lift/cruise engines is 88% of that for each lift engine because of the additional 12% thrust loss associated with a 90^{o} deflection of the segmented hood exhaust system. These nominal installed thrust levels are consistent with attaining the aircraft thrust-to-weight T/W requirements shown during Level 1 and 2 operation.

6 GE ILF1A1 LIFT ENGINES PLUS 2 GE13/F6A1 LIFT/CRUISE ENGINES

SLS INSTALLED PERFORMANCE



OPERATION	FAILURE	T/W*	POWER SETTING	L_{NOM} INST PER ENG (LB)	AVAILABLE % LC
LEVEL 1	NONE	1.10	90.7% MIL THRUST	15,749	60.0
LEVEL 2	ENG 5, 6, 7, OR 8	1.05	EMERG	20,253	22.85
LEVEL 2	ENG 1, 2, 3, OR 4	1.05	EMERG	19,839	27.50

*REQUIRED

Figure 28. Sea Level Static Installed Performance For The Integral Lift Fan V/STOL Transport

It is noted that for the Level 1 operating case shown, each 144.6% size GE 13/F6A1 lift/cruise engine operates at a nominal thrust level which is 55% of its Maximum Power thrust level. This is because the lift/cruise engines were sized to obtain adequate cruise thrust levels; consequently, they are effectively oversized during the hover mode where they are restricted to nominal thrust levels appreciably below their maximum thrust capability.

The available Percent Lift Control (%LC) is also shown in Figure 28 for Level 1 and 2 operation at Sea Level. This parameter is a measure of the available control thrust during maximum control excursion as previously indicated in the section dealing with Propulsion Characteristics. It is noted that during Level 2 operation with an engine failure, the use of Emergency Power Settings are allowed for the lift engines in order to obtain a nominal thrust level required to meet aircraft T/W requirements. As the nominal emergency thrust level required increases above that corresponding to Military Power Setting, the available control thrust (as reflected by the value of available Percent Lift Control) decreases. The values of available Percent Lift Control shown are adequate for control of the aircraft.

Installed propulsion data for a 100% size GE ILF 1A1 integral lift engine and a 100% size GE 13/F6A1 integral turbofan engine are presented in Appendix B. These data include installed VTOL performance for the GE ILF 1A1 lift engine and installed climb/cruise performance for the GE 13/F6A1 turbofan engine.

Remote Fan/Turbofan V/STOL Transport

Configuration Arrangement. - Preliminary evaluations of the remote fan fan propulsion concept utilizing one gas generator to drive two remote fans (two-on-one) show weight and wetted area penalties, Table 4, over the one gas generator driving one remote fan concept (one-on-one). However, the use of two gas generators to cruise with the two-on-one system appeared attractive compared to four cruise gas generators in a one-on-one system such that the initial remote fan/turbofan with duct burning aircraft was designed for more detailed evaluation with the two-on-one concept. The design layout of this aircraft configuration is shown in Figure 29, for an assumed TOGW of 100,000 lbs.

The equal sized remote fans and lift cruise fan (with segmented hood nozzle deflected) for this aircraft are located such that the center of lift and the airplane center of gravity and coincident at the maximum VTOL gross weight. A 12 percent thrust loss is assumed with the segmented nozzle deflected 90 degrees for VTOL operation. Each lift cruise remote fan and turbofan gas generator is cross-ducted to the diametrically opposite (forward) lift fan. The mid and aft lift fans in each wing lift pod are driven by the adjacent gas generator and cross-ducted to the opposite lift pod fans for

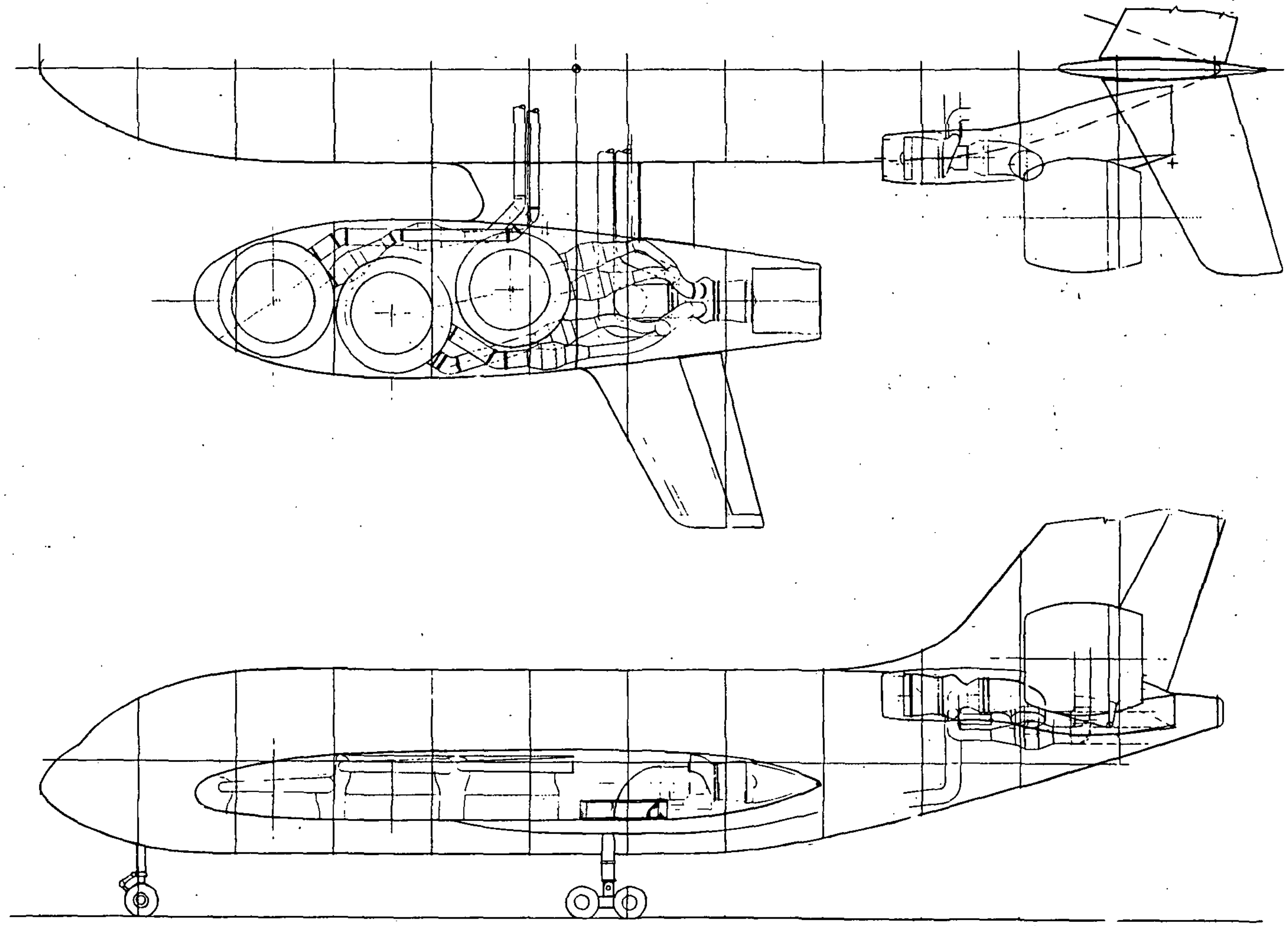


Figure 29. Remote Fan/Turbofan with Duct Burning V/STOL Transport

control. Roll and pitch attitude control in hover is achieved by thrust increase at the desired fans and an equivalent thrust decrease at the diametrically opposite fans. Asymmetrical louver vane deflection between the right and left lift engines is used to provide yaw control. In the event of lift gas generator failure, one fan in each lift pod is shut down and the remaining lift gas generator drives the two remaining pod lift fans. Failure of one of the cruise gas generators also requires shut down of both aft lift remote fans, and diversion of the corresponding gas generator flow to drive the cruise fan and form a lift fan on the failed circuit. Fan failure requires shut down of the other fan in the same circuit and diversion of the gas generator flow to convergent nozzles adjacent to the failed fans. Symmetrical forward or aft louver deflection on all fans and deflection of the segmented hood lift cruise nozzle provides the required thrust vectoring for transition and steep descent flight. In the cruise mode, one half the cruise gas generator fan flow powers the lift cruise fans, and the other half of the flow is diverted aft to duct burners and convergent nozzles (see Figure 30).

The configuration layout, Figure 29 shows that although the interconnecting turbofan ducting has 50% of the cross-sectional area of a corresponding turbojet remote fan system, the added volume required for the duct burners adjacent to the driven remote fans presents a difficult layout problem with a consequent increase in lift pod size. The design arrangement of the lift pod shows all propulsion components external to the wing torque box with the exception of the gas generator core flow nozzle and the relatively cold interconnecting ducting in the wing center section. This design layout also illustrates another inherent disadvantage of the two-on-one remote fan system: the interconnecting ducting between the single gas generator and each of the driven remote fans is of considerably unequal lengths as in the case of the lift cruise fan and the diametrically opposite forward lift fan. The gas conditions at the inlet to the two remote fans will be different, and symmetrical control thrust excursions may be difficult to achieve.

The increased complexity and volume of the remote fan/turbofan/duct burning propulsion concept over the remote fan/turbojet concept completely defeated the advantages of the smaller cold cross ducts such that the approach became unattractive. In accordance with a directive from the NASA V/STOL Program Office, work on this propulsion concept was stopped as soon as it became clear that the system was not competive with the alternate propulsion systems.

General characteristics. - Table 6 summarizes the physical description, design conditions and inertia characteristics of this preliminary aircraft configuration. The center of gravity location and moments of inertia are estimated for a vertical takeoff gross weight of 100,000 lb which is somewhat smaller than required to accomplish the design mission.

TABLE 6

PHYSICAL CHARACTERISTICS

REMOTE FAN/TURBOFAN/DUCT BURNING CONCEPT

Airframe	Wing	Horizontal	Vertical
Area (ft.^{2})	1,000	301.5	295
Aspect Ratio	6.0	4.0	1.0
Taper Ratio	0.4	0.6	0.6
Span (ft.)	77.4	34.6	17.2
Mean Aerodyn. Chord (ft.)	13.7	8.9	17.5
Sweep back c/4 (deg.)	25.	25.	35.
Root Section	64A012	64A010	64A010
Tip Section	64A010	64A010	64A010
Tail Length	-	50	39.4
Tail Volume	-	1.10	0.15
Fuselage Length (ft.)	100.0		
Fuselage Dia. (ft.)	15.8		

Propulsion	Gas Generators	Lift Fans
Number/Designation	(4) G.E. Turbofan	(8) G.E. Lift Fans
Scale Factor	193.9%	176.4%
Fan Pressure Ratio	-	1.25

Structural Limits	
V_{MO} (kts EAS below 17,500 ft)	400
M_{MO} (above 17,500 ft)	.85
n_{LIM}	2.5

Design Cruise Conditions	
M_{CR} (Above 18,000 ft)	.75
V_{CR} (Kts EAS below 18,000 ft)	350
Cruise Altitude (ft.)	36,000
Mass Properties	
Weight VTO (lbs)	100,000
Center of Gravity (F.S.)	548
I_{xx} (slug ft.^{2})	442,130
I_{yy} (slug ft.^{2})	1,400,000

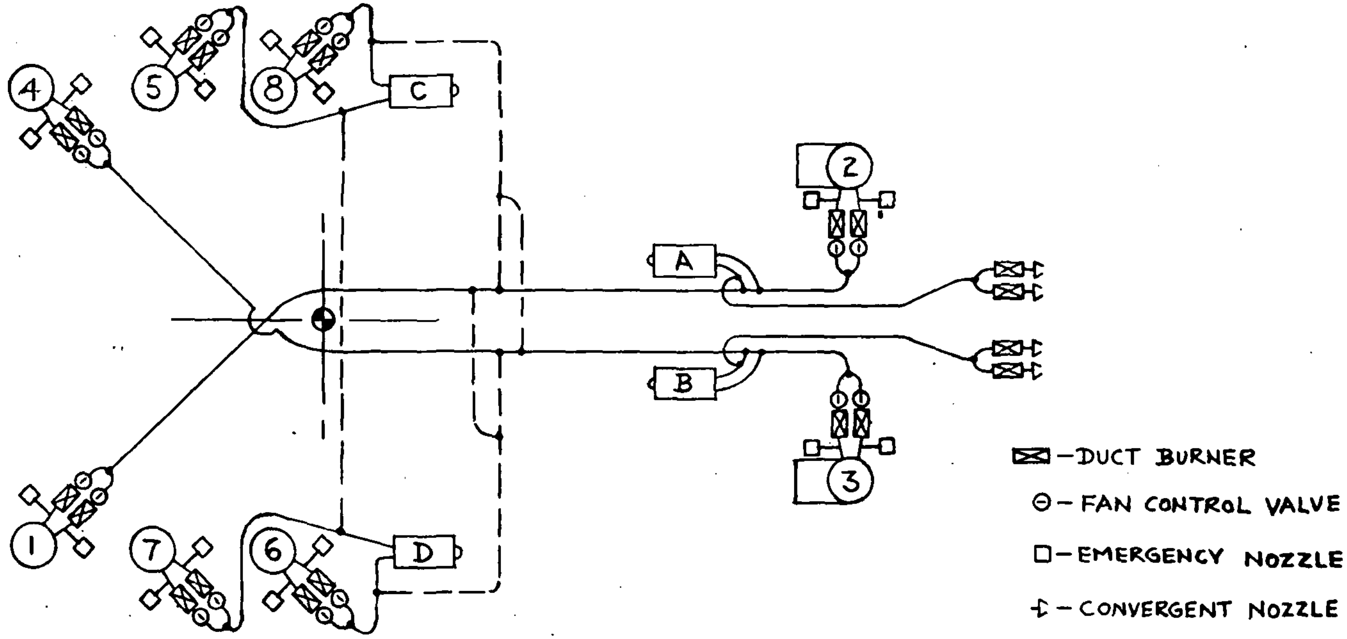
VTOL Mission Fuel lbs.	16,000

Propulsion system. - The propulsion system for the selected V/STOL transport configuration, which uses a General Electric remote fan/turbofan gas generator system, consists of eight equal-size fans driven by four equal-size gas generators as schematically shown in Figure 30 . All fans are 176.4% size and all turbofan gas generators are 193.9% size. These sizes of components were the result of a preliminary aircraft layout study for a 100,000 lb. gross weight aircraft. With the above fan size, the aircraft thrust-to-weight ratio T/W* is 1.27 (see section dealing with Hover Control Evaluations for definition of T/W*). All fans and gas generators are in operation during the V/STOL transition flight modes. During conventional flight conditions. the six lift fans are shut down and the aircraft operates with the thrust provided by lift/cruise fans 2 and 3 plus the thrust obtained from four convergent exhaust nozzles which use the airflow (from gas generators A and B) that is normally used to drive lift fans 1 and 4. During this conventional flight mode, gas generators C and D are shut down. Gas generators A and B are each provided with a forward-facing, nacelle-type inlet.

Each lift/cruise fan installation consists of a horizontally-mounted nacelle configuration in which the inlet, fan, and thrust-vectoring segmented hood/exhaust nozzle system are contained. This segmented hood system provides vectoring of the gross thrust from the horizontal forward ($\theta = 0^o$) to a position which provides an aft thrust component with the gross thrust vector rotated 40^o forward of the vertical direction ($\theta = 130^o$).

Referring to Figure 30 , lift fans 4, 5 and 8 along with turbofan gas generator C are mounted in a right wing pod. Lift fans 1, 6 and 7 along with turbofan gas generator D are mounted in a left wing pod. Each of the six lift fans contained in these two wing pods is provided with an exit louver system. The exit louvers are hinged so that they may be swiveled in unison in a fore and aft direction about their hinge line to produce gross thrust vector directional changes from 40^o aft to 40^o forward of the vertical direction.

The propulsion system incorporates the components necessary to produce the required nominal thrust levels and provide attitude control capability during normal (Level 1) system operation and emergency (Level 2) operation with a fan or gas generator failure. The solid lines of Figure 30 represent interconnecting airflow ducts which supply cold gas generator bypass airflow to the fan duct burners during normal operation of the system. The dotted lines also represent airflow supply ducts which are used, as required, to accommodate a gas generator failure. Two fan control valves and two duct burners are used per fan. The fan control valves are used to provide the attitude control function in accordance with the pressure/temperature control concept previously described in the section dealing with Propulsion Characteristics.



GAS GENERATOR FAILURE

GAS GEN FAILS	FLOW REPLACED BY GAS GEN	RESULTS IN THRUST LOSS OF FANS
A	D AND C	6 AND 8
B	D AND C	6 AND 8
C	D	7 AND 8
D	C	5 AND 6

FAN FAILURE

FAN FAILS	SHUTDOWN FAN	DIVERT GAS FLOW TO EMERG NOZZLES
1 OR 2	2 OR 1	FOR FANS 1 AND 2
3 OR 4	4 OR 3	FOR FANS 3 AND 4
5 OR 6	6 OR 5	FOR FANS 5 AND 6
7 OR 8	8 OR 7	FOR FANS 7 AND 8

Figure 30. Remote Fan/Turbofan Gas Generator V/STOL Transport Propulsion System

Propulsion system operation with a gas generator or fan failure is also summarized in Figure 30 . A gas generator failure results in the entire thrust loss of two fans. A fan failure is accommodated by shutting down a diametrically opposite fan and diverting the duct burner discharge gas flow, which was driving the two fans, to appropriately located overboard-discharge emergency nozzles.

Attitude control of the aircraft during V/STOL/transition conditions is obtained by the following fans:

1. Fans 5-8 provide the entire roll control.

2. Fans 1-4 provide the entire pitch control.

3. Fans 1, 4 and 5-8 provide the entire yaw control

The attitude control system is operated by inputs to the fan control valves and fan exit louver system. Although sufficient differential thrust for control purposes may be obtained without fan spoiling, it is likely that differential exit louver movement (fan spoiling) will be required in order to minimize response rates. Yaw control is effected by means of the fan exit louver system whereby the louvers of fans in the right wing pod are moved to a different position than those in the left wing pod.

Remote Fan/Turbojet V/STOL Transport

Configuration arrangement. - The remote fan concept employing one gas generator for each lift fan unit (one-on-one) interconnected to a second gas generator lift unit combination is identified in the preliminary analyses as the most attractive remote fan propulsion system. Four such independent propulsion systems in the arrangement shown in Figure 31 form the total propulsion package of the 8 remote fan turbojet aircraft. The wing pod mounted lift fans and the aft fuselage lift cruise fans with the extended segmented hood exhaust nozzles are located such that the center of lift is coincident with the airplane center of gravity at the maximum VTOL gross weight condition. The thrust loss with the segmented hood deflected 90° for VTOL is assumed as 12 percent. Each remote fan gas generator combination is cross ducted to its diametrically opposite remote fan gas generator combination for minimum trim change in the event of a gas generator failure. The lift fan pod also contains two emergency nozzles and the aft fuselage has one pitch nozzle for use with a failed fan condition. Attitude control in roll and pitch is provided between diametrically opposite fans by a thrust increase on one with an equivalent thrust spoiling on the other by means of fan exit louver vanes. Forward and aft louver deflections of the right and left lift fans provides the required yaw control. Thrust vectoring during transition and steep decelerating approaches is provided by a combination of exit louver and segmented hood deflection. In the cruise mode, the aft fuselage gas

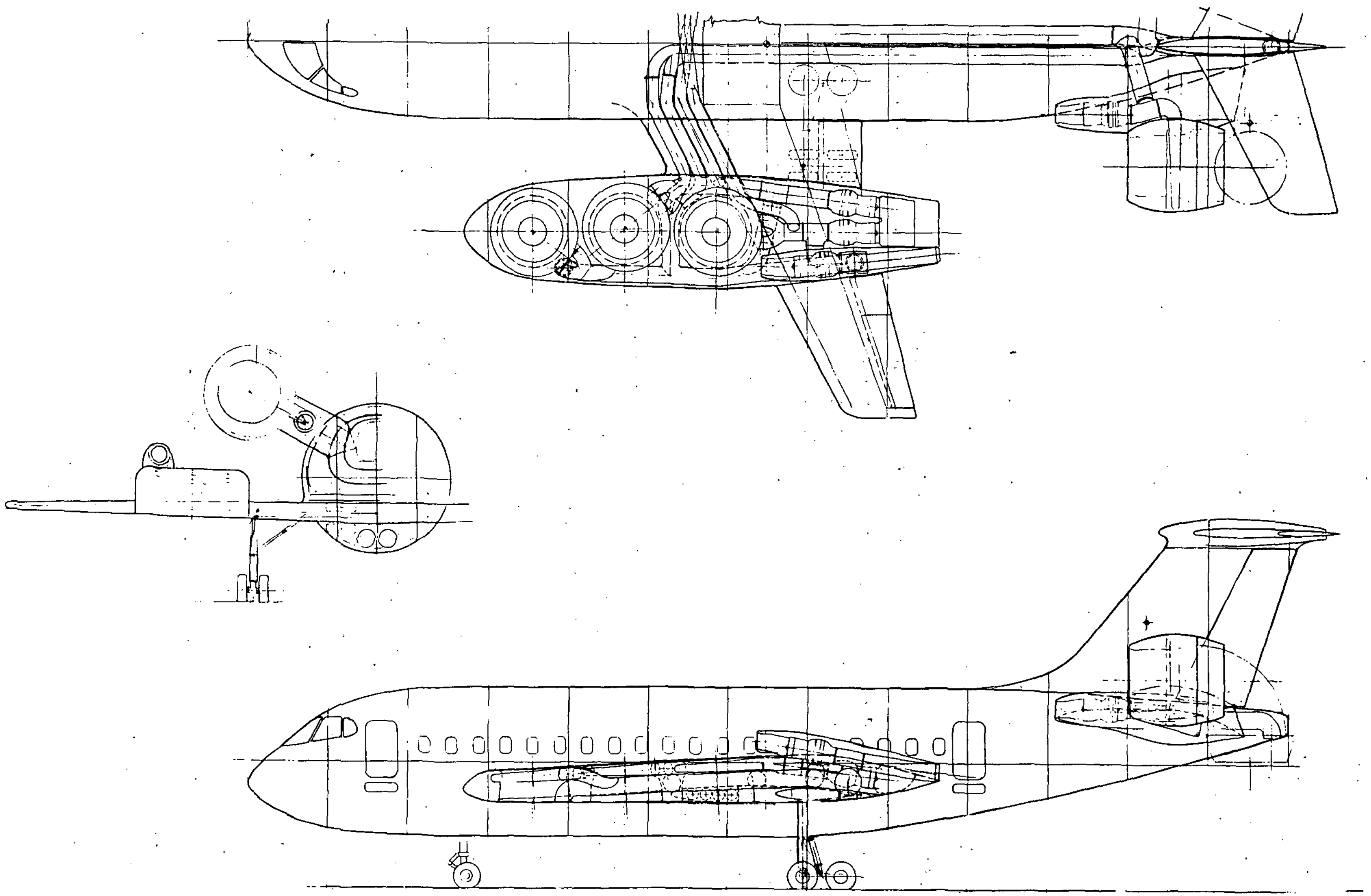


Figure 31. Remote Fan/Turbojet V/STOL Transport

generators drive the adjacent lift cruise fans, and the outboard lift pod gas generators are operated through a diverter valve to provide additional cruise thrust through a convergent cruise nozzle. All propulsion system components in the lift pod are located external to the wing torque box, and the wing center section glove forward of the front spar contains the hot gas cross over ducting. Sufficient fuel volume for the STOL mission is contained within the wing torque box.

General characteristics. - The physical description, design conditions, and inertia characteristics of the remote fan aircraft are listed in Table 7. The center of gravity location and moments of inertia are calculated for a vertical takeoff gross weight of 120,000 lb, the size required to accomplish the design mission.

Propulsion system. - The propulsion system for the selected V/STOL transport configuration, which uses a General Electric remote fan/turbojet gas generator system, consists of eight equal-size fans driven by eight equal-size gas generators as schematically shown in Figure 32 . All fans are 189% size and all gas generators are 86% size. With this fan size, the aircraft thrust-to-weight ratio T/W* is 1.14 (see section dealing with Hover Control Evaluations for definition of T/W*). All eight fans and gas generators are in operation during the V/STOL transition flight modes. During conventional climb and cruise flight conditions, the six lift fans are shut down and the aircraft operates with thrust provided by lift/cruise fans 2 and 3 plus the thrust obtained from gas generators A and D operating as turbojet engines. During these flight conditions, gas generators E, F, G and H are shut down. Gas generators A, B, C and D are each provided with a forward-facing, nacelle-type inlet.

Each lift/cruise fan installation consists of a horizontally-mounted nacelle configuration in which the inlet, fan, and thrust-vectoring segmented hood/exhaust nozzle system are contained. This segmented hood system provides vectoring of the gross thrust from the horizontal forward ($\theta = 0^{\circ}$) to a position which provides an aft thrust component with the gross thrust vector rotated 40° forward of the vertical direction ($\theta = 130^{\circ}$).

Referring to Figure 32 , lift fans 4, 5 and 8 along with gas generators D, E and H are mounted in a right wing pod. Lift fans 1, 6 and 7 along with gas generators A, F and G are mounted in a left wing pod. Each of the six lift fans contained in these two wing pods is provided with an exit louver system. The exit louvers are hinged so that they may be swiveled in unison in a fore and aft direction about their hinge line to produce gross thrust vector directional changes from 40° aft to 40° forward of the vertical direction. Additionally, the exit louvers may be swiveled differentially upon command to effect thrust spoiling when required for attitude control purposes.

TABLE 7

PHYSICAL CHARACTERISTICS

REMOTE FAN/TURBOJET CONCEPT

Airframe	Wing	Horizontal	Vertical
Area (sq. ft.)	1,000	301.5	295
Aspect Ratio	6.0	4.0	1.0
Taper Ratio	0.4	0.6	0.6
Span (ft.)	77.4	34.6	17.2
Mean Aerodyn. Chord (ft.)	13.7	8.9	17.5
Sweep back c/4 (deg.)	25.	25.	35.
Root Section	64A012	64A010	64A010
Tip Section	64A010	64A010	64A010
Tail Length (ft.)	-	50.	39.4
Tail Volume	-	1.10	0.15
Fuselage Length (ft.)	108.3		
Fuselage Dia. (ft.)	15.8		

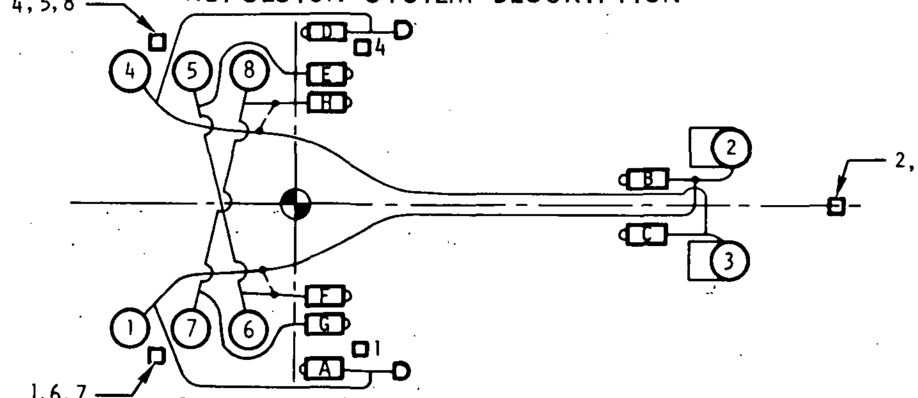
Propulsion	Gas Generators	Lift Fans
Number/Designation	(8) G.E. Turbojet	(8) G.E. Lift Fans
Scale Factor	86%	189%
Fan Pressure Ratio	-	1.25

Structural Limits	
V_{MO} (kts EAS below 17,500 ft.)	400
M_{MO} (Above 17,500 ft.)	.85
n_{LIM}	2.5

Design Cruise Conditions	
M_{CR} (Above 18,000 ft)	.75
V_{CR} (kts EAS below 18,000 ft.)	350
Cruise Altitude (ft.)	30,000

Mass Properties	
Weight VTO (lbs.)	120,000
Center of Gravity X,Z (in.)	650.0, -5.2
I_{xx} (slug ft.^{2})	742,901
I_{yy} (slug ft.^{2})	1,961,369
I_{zz} (slug ft.^{2})	2,501,372
I_{xz} (slug ft.^{2})	184,045

GENERAL ELECTRIC REMOTE FAN SYSTEM A
PROPULSION SYSTEM DESCRIPTION



SEPARATE HOT GAS DUCT SYSTEM

GAS GENERATOR FAILURE

GAS GEN FAILS	ACTION TAKEN	RESULT IS HALF THRUST FOR FANS
A OR B	F REPLACES A OR B	5 & 6
C OR D	H REPLACES C OR D	7 & 8
E OR F	NONE	5 & 6
G OR H	NONE	7 & 8

FAN FAILURE

FAN FAILS	SHUT-DOWN FAN	DIVERT GAS FROM GAS GEN	TO EMERG NOZZLE
1 OR 2	2 OR 1	A & B	1 & 2
3 OR 4	4 OR 3	C & D	3 & 4
5 OR 6	6 OR 5	E & F	5 & 6
7 OR 8	8 OR 7	G & H	7 & 8

Figure 32. Remote Fan/Turbojet Gas Generator V/STOL Transport Propulsion System

The propulsion system (as shown) consists of four separate duct systems, each of which consist of a pair of diametrically opposite fan-gas generator units connected together by means of a single hot gas interconnect duct. Fan-gas generator unit 1-A is interconnected with fan-gas generator unit 2-B, 4-D with 3-C, 5-E with 6-F, and 7-G with 8-H. Also shown by dashed lines are cross connecting ducts from gas generators F and H. The purpose of these ducts is to allow gas generator F to replace gas generator A or B in event A or B fails, and gas generator H to replace C or D in event C or D fails. With this duct arrangement and suitable valving, only the performance of fans 5 and 6 or 7 and 8 is affected if any one of eight gas generators fails.

Each of these four separate duct systems is schematically shown in Figure 33, and incorporates the components necessary to provide attitude control capability during normal (Level 1) system operation and emergency (Level 2) operation with a fan or gas generator failure. Two fan control/shut-off valves are used per fan to provide the attitude control function in accordance with the energy transfer control concept previously described in the section dealing with Propulsion Characteristics. During normal system operation gas flow from the gas generators drives the two fans. In event of a gas generator failure, one control valve of each fan is used as a shut off valve so that each fan is driven by half the gas flow from the remaining gas generator. The back flow valve of the dead gas generator automatically closes to prevent loss of hot, high pressure gas. In event of a fan failure, the remaining fan is shut down and the gas flow from each gas generator is directed to the nearest emergency nozzle by its diverter valve. A shut off valve is provided to isolate the gas generators during the starting process, and, additionally, to isolate a shut down lift fan from an operating cruise fan.

Propulsion system operation with a gas generator or fan failure is summarized in Figure 32. A feature of the system is that only the performance of fans 5 and 6 or 7 and 8 is affected if any one of eight gas generators fails.

Attitude control system: Referring to Figure 32, attitude control of the aircraft during V/STOL transition conditions is obtained by the following fans:

1. Fans 5-8 provide the entire roll control.

2. Fans 1-4 provide the entire pitch control.

3. Fans 1, 4 and 5-8 provide the entire yaw control.

The attitude control system is operated by inputs to the fan control valves and the fan exit louver system. Differential exit luver movement is used to spoil fan thrust during control excursion for the fans which decrease thrust below the nominal level. In general, control thrust is obtained by each separate duct system during control excursion as the thrust increase of one fan is accompanied by a corresponding thrust decrease of the other fan.

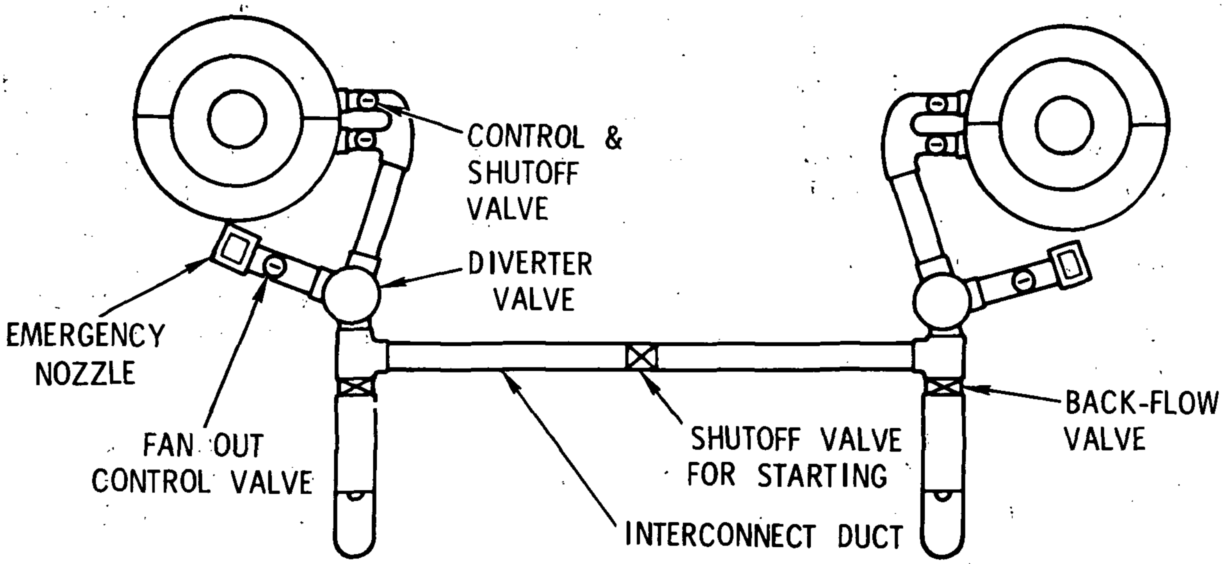


Figure 33 . Separate Duct System

Installed propulsion system performance: The nominal installed fan thrust $L_{NOM\ INST}$ of each lift fan is tabulated in Figure 34 for Level 1 and 2 hover operation at Sea Level Static conditions. The corresponding nominal installed fan thrust of each of the two lift/cruise fans is 88% of that for each lift fan because of the additional 12% thrust loss associated with a 90^o deflection of the segmented hood exhaust system. These nominal installed thrust levels are consistent with attaining the aircraft thrust-to-weight T/W requirements shown during Level 1 and 2 operation.

The available Percent Lift Control (%LC) is also shown in Figure 34 for Level 1 and 2 operation at Sea Level. This parameter is a measure of the available control thrust during maximum control excursion as previously indicated in the section dealing with Propulsion Characteristics. It is noted that during level 2 operation with a gas generator or fan failure, the use of gas generator Emergency Power Settings are allowed for all operating gas generators in order to obtain a nominal fan thrust level required to meet aircraft T/W requirements. As the nominal emergency thrust level required increases above that corresponding to Military Power Setting, the available control thrust (as reflected by the value of available Percent Lift Control) decreases. The values of available Percent Lift Control shown are adequate for control of the aircraft.

Installed propulsion data for the General Electric remote fan/turbojet gas generator system (Remote Fan System A) are presented in Volume IV of NA 72-444 for reference size components. These data include the following:

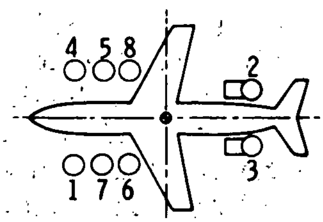
1. Installed VTOL performance data for one 100% size fan driven by one 45.5% size gas generator.

2. Installed climb, cruise, and descent performance data for one 100% size cruise fan driven by one 45.5% size gas generator.

3. Installed climb and cruise performance data for one 45.5% size gas generator which acts as a turbojet engine with a fixed area convergent exhaust nozzle.

4. Installed climb and cruise performance data for a combination system consisting of one 100% size cruise fan driven by one 45.5% size gas generator and 45.5% size gas generator which acts as a turbojet engine.

GENERAL ELECTRIC REMOTE FAN SYSTEM A
SLS INSTALLED PERFORMANCE



OPERATION	FAILURE	T / W*	POWER SETTING	LNOM INST PER FAN ~ LB	AVAILABLE % LC
LEVEL 1	NONE	1.10	MIL	17,010	60.0
LEVEL 2	ANY ONE GAS GEN	1.05	EMERG	18,421	40.08
LEVEL 2	FAN 5, 6, 7 OR 8	1.05	EMERG	19,207	30.26
LEVEL 2	FAN 1, 2, 3 OR 4	1.05	EMERG	18,862	34.47

*REQUIRED

Figure 34. Sea Level Static Installed Performance for the Remote Fan/Turbojet Gas Generator V/STOL Transport

Mass Properties

The mass properties evaluation of the selected remote lift fan and integral lift fan configuration are presented in this section of the report. The characteristics are discussed and compared to identify the weight differences due to the propulsion concepts.

Weight analysis. - The weight evaluation of these configurations is based on analytical, statistical and manufacturers brochure data considered representative of 1980-1985 aircraft technology.

The basic structural wing weights are modified inboard of the lift pods to account for the pod induced bending and torsional moments. The tail weights are based on statistical data indexed on the C-141A tail. Bare fuselage weights are statistically indexed on the C-130A with corrections to account for the added loads due to the swing out lift fan and acoustic treatment on the integral lift fan version. The landing gear weight was determined statistically based on aircraft of less than 200,000 pound takeoff gross weight. The engine section weights include the lift fan pods and the lift cruise nacelles and are based on detailed analyses of similar NR V/STOL aircraft structures. The total structural weight fractions for the remote fan and the integral lift fan configurations are compared on a correlation plot, Figure 35, with statistical data on current operational logistics transports which also represent projected mid 1970 V/STOL study aircraft (NR CX-6 study). The estimated weights of the present study appear to be conservative when compared to NASA CR-743 data for a number of 60 passenger V/STOL aircraft representing current technology. The sensitivity of airplane gross weight for constant performance is shown by the structural fraction design grade curve through the remote fan aircraft data point. The uppermost end of this curve represents a remote fan aircraft (W = 135,000 lbs.) based on C-130A technology as compared to the 1980-1985 remote fan aircraft (W = 120,000 lb.). The latter assumes approximately a 21% weight saving due to composite structures in the wing and tail surfaces, and 5% weight savings due to composite structures in the fuselage which is considered a realistic maximum commercial aircraft usage for that time period. The replacement of twice as much aluminum structure with composite materials would reduce the remote fan aircraft weight to 105,500 lbs. The increased relative fuselage weight and lift cruise nacelle weight account for the higher integral lift fan aircraft structural weight fraction over the remote fan aircraft, despite the higher unit wing weight of the latter.

The propulsion system weights are based on GE data, catalog information and hot gas duct system data developed during NR CX-6 studies. The segmented hood exhaust nozzle weights are based on detail NR V/STOL studies using similar exhaust systems. Comparison of the propulsion weights of the remote fan aircraft, Table 8, and the integral lift fan aircraft, Table 9, show that the propulsion weight fractions are equal.

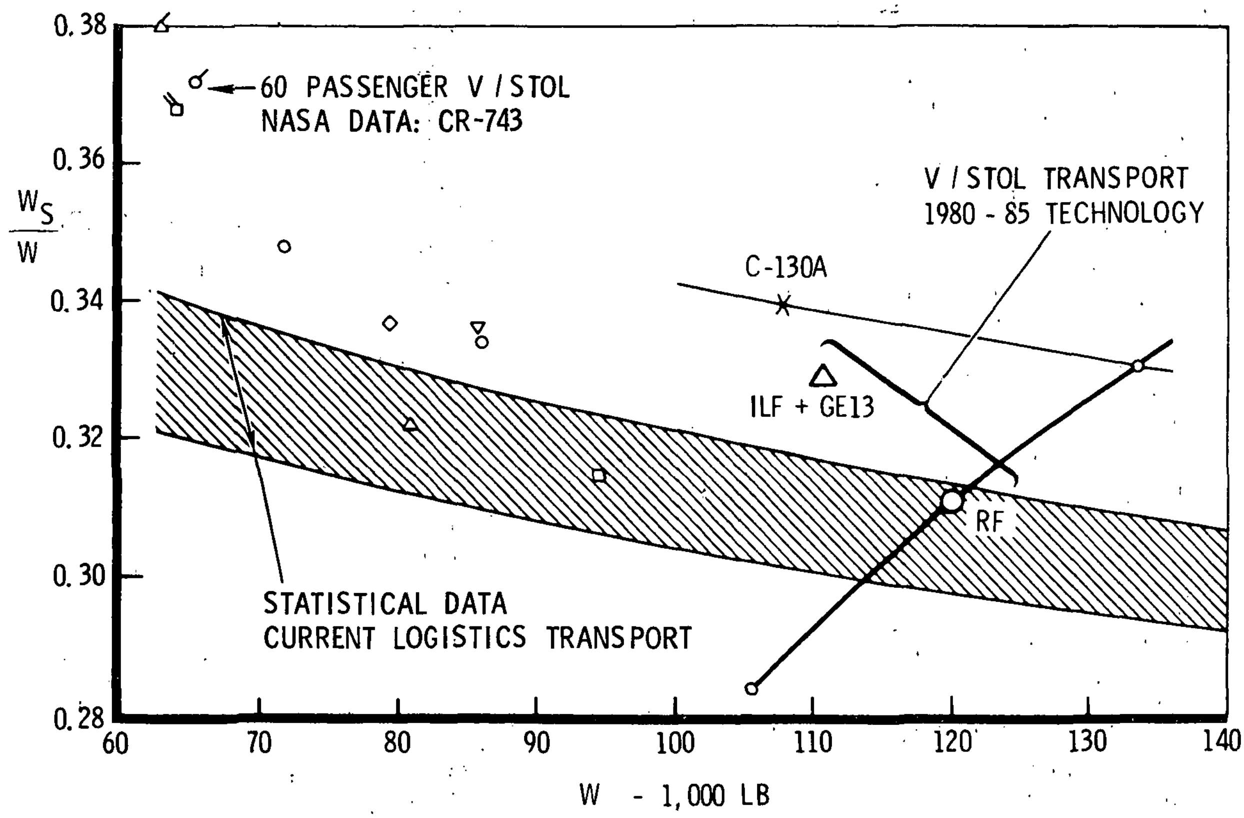


Figure 35. Structural Weight Fraction Comparison

TABLE 8

WEIGHT SUMMARY

REMOTE FAN/TURBOJET CONCEPT

	LBS	Δ W	Δ W/W
Total Structure		(37,370)	(.311)
Wing Group	8,120		
Tail Group - Horizontal	985		
- Vertical	1,020		
Fuselage Group	15,950		
Landing Gear - Main	3,605		
- Nose	900		
Surface Controls	1,785		
Engine/Nacelle Group	5,005		
Propulsion Group		(32,590)	(.272)
Engine	7,160		
Air Induction System	545		
Exhaust System	515		
Cooling & Drain Prov.	95		
Fan	14,000		
Fuel System	385		
Engine Controls	170		
Starting System	335		
Hot Gas Duct	7,185		
Deflection System	1,770		
Aux. Power Unit	430		
Fixed Equipment		(10,410)	(.087)
Instruments	410		
Hydraulic/Pneumatic Group	480		
Electrical Group	1,315		
Electronics Group	805		
Furnishings	5,940		
Air Conditioning Equipment	1,435		
Auxiliary Gear	25		
Total Weight Empty		80,370	
Crew	660		
Fuel	18,600*		
Oil	210		
Passengers	20,000		
Operators Items	160		
Total Useful Load		(39,630)	(.330)
Takeoff Gross Weight (W)		120,000	

*For 400 nmi VTOL Mission.

TABLE 9

WEIGHT SUMMARY

INTEGRAL LIFT-FAN / CRUISE ENGINE CONCEPT

	LBS.	ΔW	ΔW/W
Total Structure		(36,645)	(.329)
Wing Group	6,820		
Tail Group - Horizontal	955		
- Vertical	980		
Fuselage Group	15,865		
Landing Gear - Main	3,555		
- Nose	850		
Surface Controls	1,785		
Engine/Nacelle Group	5,835		
Propulsion Group		(30,735)	(.277)
Engine	25,680		
Air Induction System	775		
Exhaust System	820		
Cooling & Drain Prov.	95		
Fan	-		
Fuel System	385		
Engine Controls	170		
Starting System	470		
Hot Gas Duct	-		
Deflection System	1,910		
Aux. Power Unit	430		
Fixed Equipment		(10,530)	(.095)
Instruments	410		
Hydraulic/Pneumatic Group	480		
Electrical Group	1,315		
Electronics Group	805		
Furnishings	6,060		
Air Conditioning Equipment	1,435		
Auxiliary Gear	25		
Total Weight Empty		77,910	
Crew	660		
Fuel	12,160*		
Oil	210		
Passengers	20,000		
Operators Items	160		
Total Useful Load		(33,190)	(.299)
Takeoff Gross Weight (W)		111,100	

*For 400 nmi VTOL Mission

The only other significant weight differences between the remote fan and the integral lift engine aircraft, Tables 8 and 9 are the fuel loads required to meet the design VTOL mission.

Balance and Inertia Characteristics - The center of gravity locations and inertia characteristics of each configuration are calculated by computer programs with the estimated component weight breakdown and center of gravity as an input. Design changes have been incorporated to the configuration layouts Figures 26 and 31, to attain the desired balance, aft center of gravity location, and center of lift relation shown. The center of gravity locations at the VTOL gross weights of each configuration are listed as distances from the nose of the aircraft and from the longitudinal reference plane in Tables 5 and 7.

Hover control analyses performed prior to the availability of engine cruise performance data assumed preliminary statistical inertia characteristics for 100,000 lb aircraft as shown in Figure 36. Availability of cruise data required resizing the aircraft holding constant installed thrust to weight ratio. The calculated inertia characteristics for the resized remote fan and integral lift fan aircraft are determined by computer integration of the components with component weights, centers of gravity, and corresponding component inertias as inputs. Comparison of these results with the statistical data is shown in Figure 36.

A breakdown of the airframe weights (AMPR weight), and a materials breakdown as used for costing purposes is presented in Volume IV of NA 72-444.

Cruise Performance

Cruise Drag Characteristics. - The drags of all the configurations were estimated by standard NR aerodynamic procedures. The friction drag estimate is based on references 4 and 5, and correlated test data are used to account for the aft fuselage upsweep drag. A 10 percent increase in skin friction drag is included to account for miscellaneous drag items. Drag due to lift is calculated using an airplane efficiency factor of 0.67 to include the effect of the lift pods on the wing. The estimated zero lift compressibility drag rise Mach number is assumed to be 0.65 for both aircraft. A comparison of the calculated cruise drag characteristics for both aircraft is shown on an ASD correlation relating the maximum subsonic lift drag ratio to the wing span divided by the square root of the wetted area. These results, Figure 37, show that the remote lift fan (RLF) and integral lift fan aircraft (ILF + GE13) lift drag ratios are represented near the lower boundary of the correlation; an expected result for the conceptual design phase of these aircraft since configuration refinement for optimum cruise performance has not been accomplished to this point.

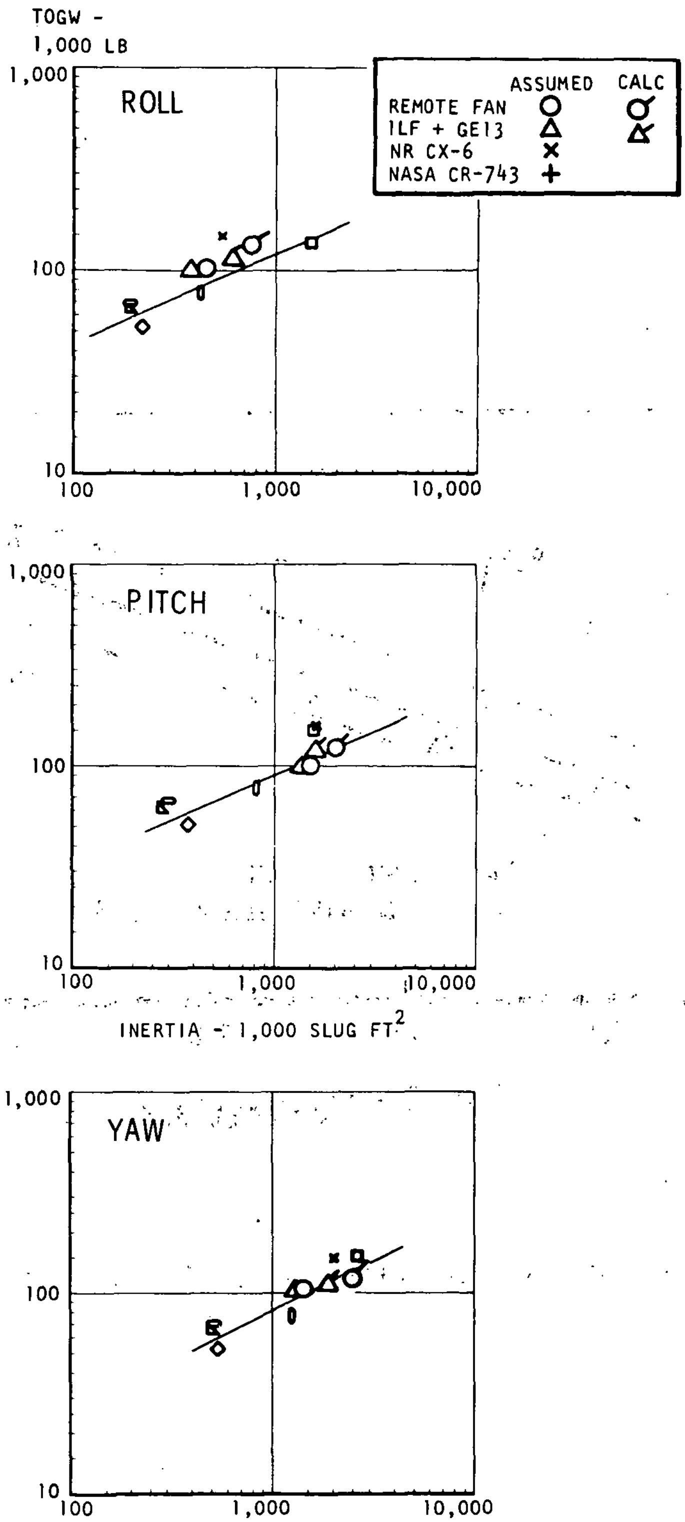


Figure 36. Inertia Characteristics Comparison

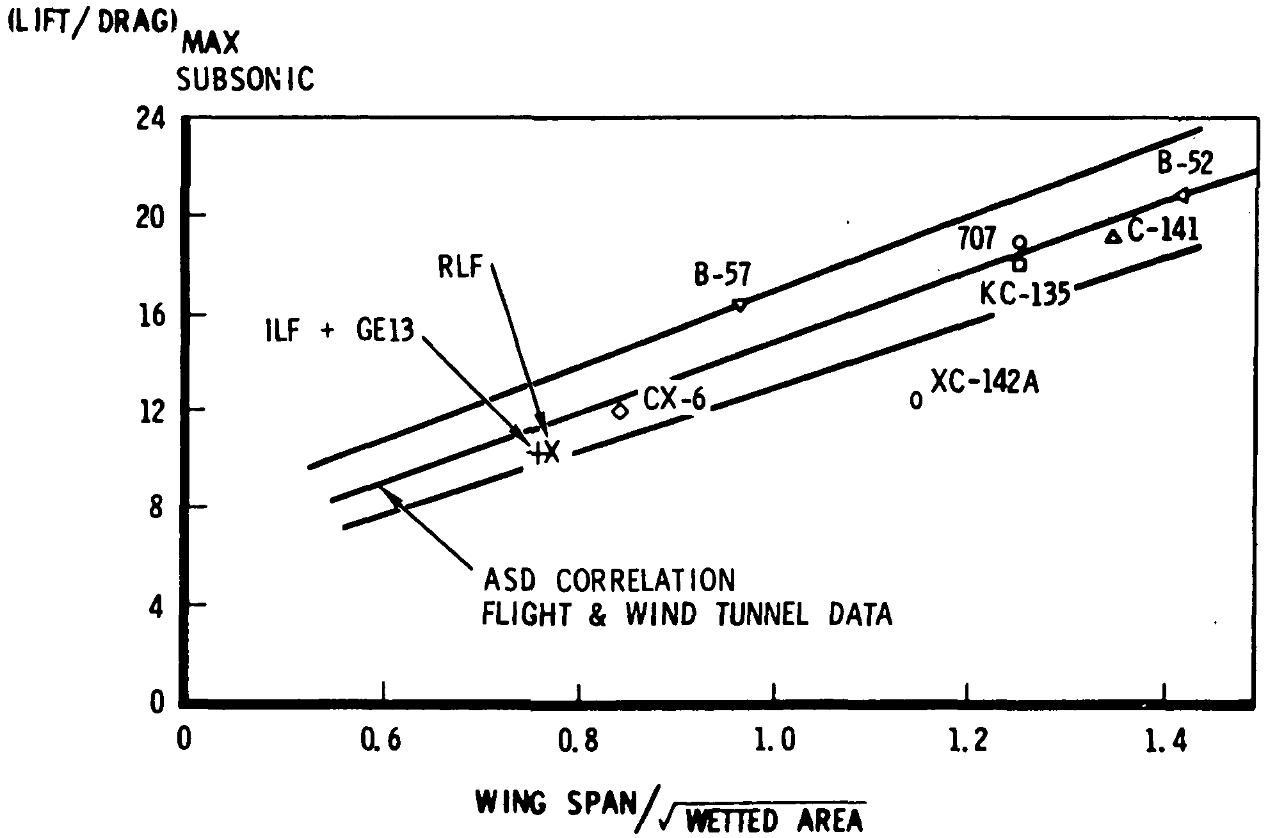


Figure 37. Maximum Lift Drag Ratio Comparison

The complete drag buildup for both aircraft as used to generate the design mission performance trades for the economic analysis is included in Volume IV of NA 72-444.

Cruise speed. - The development of an acceptable operational speed altitude envelope for the representative remote fan and integral lift fan aircraft requires consideration of several factors. A speed margin over the minimum cruise speeds of 350 knots EAS and 0.75M as defined in the study guidelines is desired to provide operational flexibility and establishing direct operating cost sensitivity to cruise speed. Any increases in speed capability are always traded off against the associated aircraft weight penalties. A maximum speed capability of 0.85M and 400 knots EAS are selected as design limits.

The speed altitude profile for the remote fan aircraft is shown in Figure 38 . As discussed in a preceding section, this aircraft with fans sized by the hover criteria did not meet the minimum cruise speed requirement at altitude if only two of the all equal sized fans are used for cruise, Figure 38 . To preclude the development costs of two remote fan system sizes for one aircraft program, the additional cruise thrust is produced from two lift gas generators by the addition of a diverter valve and convergent nozzle in each lift pod. The 0.85M speed capability for the remote fan aircraft as shown in Figure 38 is achieved by cruise with two remote lift cruise fans (2 R/F) plus two lift gas generators operating as turbojets (2 T/J).

Unlike the remote fan system, the independent engine feature of the integral lift fan propulsion concept is adaptible to a combination of propulsion cycles to satisfy more than one design condition of the aircraft operational envelope. Thus, the integral lift fans are sized for hover, whereas the larger lift cruise engine cycle is selected and the engine is sized for cruise. The integral lift fan aircraft is designed to cruise on two GE 13/F6A1 turbofan engines as developed for the military STOL transport application. It is assumed that this engine is available for the 1980-1985 time period such that no additional development cost is charged to the commercial V/STOL transport program. The speed altitude profile for the integral lift fan aircraft with cruise engines is shown in Figure 39 . The maximum speed capability at 20,000 ft. is also shown if this aircraft cruised on two integral lift cruise fans only (2 L/C only) as sized for hover instead of the two larger GE 13 engines. This figure also shows the maximum speed capability of this eight integral lift fan aircraft with an alternate configuration of four integral lift cruise engines (4 L/C only) as sized for hover. The .85M cruise speed capability is attained at 20,000 ft. but the integral lift fan cruise thrust decays rapidly with altitude as compared to the selected GE 13/F6A1 lift cruise engine thrust.

Specific range. - A significant basis for the preference of a good cruise engine over the remote fan-gas generator system for cruise is illustrated by comparison of the results shown in Figures 40 and 41 . These data present the specific range performance of the two aircraft at speeds of 350 knots EAS below 18,000 ft., and at 0.75M above this altitude for a range of cruise

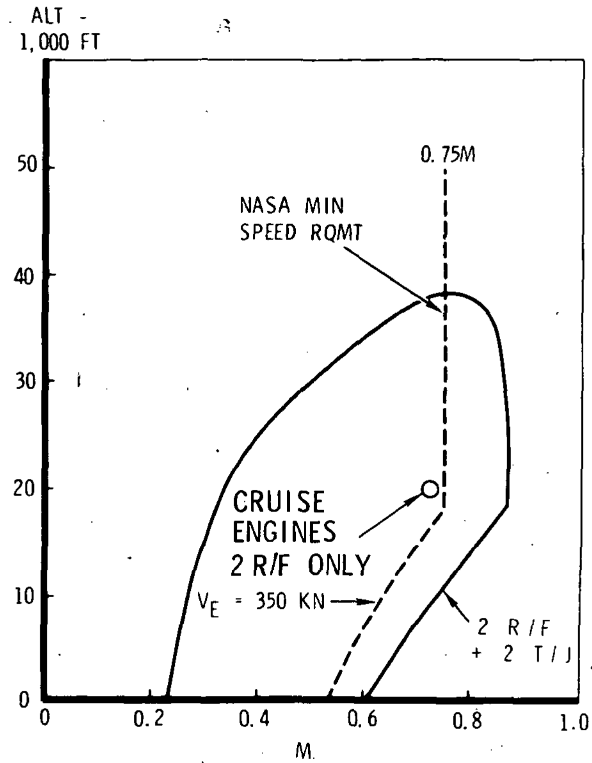


Figure 38. Speed Altitude Profile, Remote Fan Aircraft

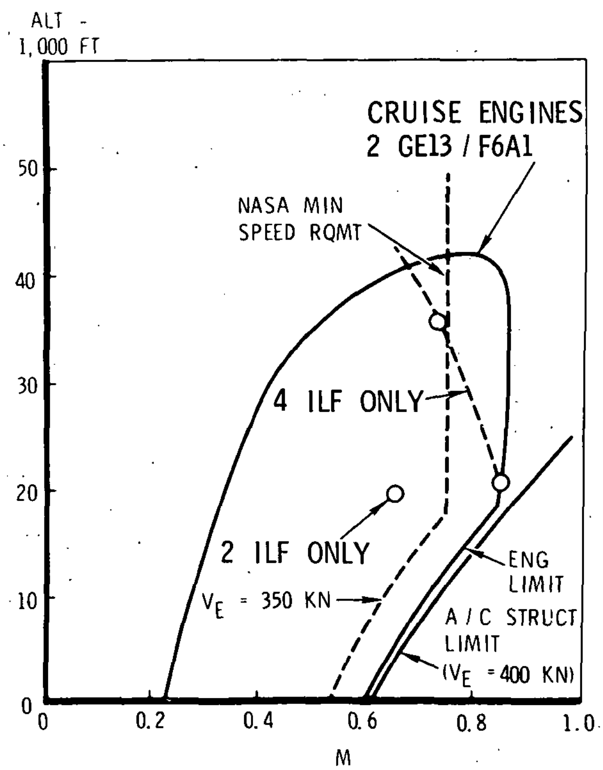


Figure 39. Speed Altitude Profile, Integral Lift Fan Aircraft

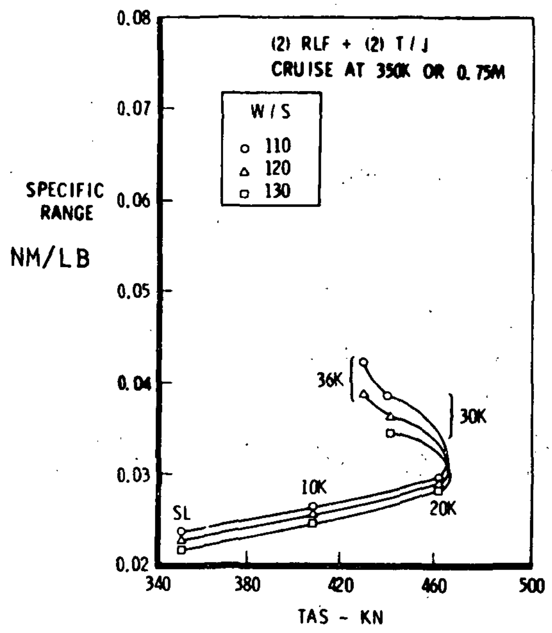


Figure 40. Cruise Performance, Remote Fan Aircraft

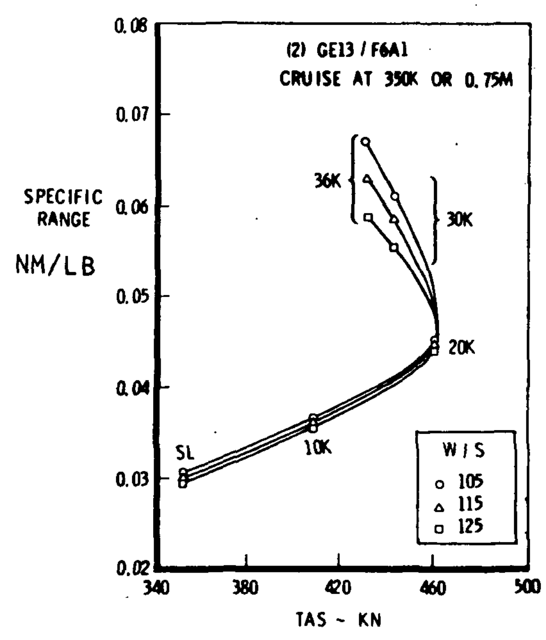


Figure 41. Cruise Performance, Integral Lift Fan Aircraft with Cruise Engines

wing loadings. The remote fan aircraft, Figure 40 cruises on two remote lift cruise fans plus two lift gas generators operating as turbojets. Although the results shown are calculated for all gas generators operating at the same power setting, it is anticipated that operation of the lift cruise gas generators at maximum cruise power and the lift gas generators at reduced power would not achieve a significant improvement in the specific range. The overall specific range level of the remote fan aircraft with this cruise propulsion configuration is poor, Figure 40, as compared to the integral lift fan aircraft which cruises on two GE 13/F6A1 engines, Figure 41. The two aircraft have comparable cruise drags and the cruise specific fuel consumption of the gas generator driven remote fans and the integral lift fans are essentially equal, but the specific ranges differ due to the additional turbojet gas generators for cruise on the remove fan aircraft, and the substitution of efficient cruise engines (GE13/F6A1) on the integral lift fan aircraft. A remote fan engine cycle designed for efficient VTOL operation operated in an off design cruise mode (in combination with a turbojet engine) cannot match the performance of a turbofan engine cycle designed for efficient cruise operation.

The differences in the engine performance of the two aircraft discussed in the preceding paragraph is reflected directly in the fuel fraction differences required to meet the VTOL and STOL design missions as shown in Table 10.

TABLE 10

DESIGN MISSION FUEL REQUIREMENTS

PAYLOAD 100 PASSENGERS		
Mission	VTOL	STOL
Range	400 N.Mi.	800 N.Mi.
Remote Fan Aircraft		
T.O.G.W. (lbs.)	120,000	132,000
Fuel (lbs.)	18,600	30,600
$\Delta W_F/W$	.155	.232
Integral Lift Fan + Cruise Engine Aircraft		
T.O.G.W. (lbs.)	111,100	118,000
Fuel (lbs.)	12,160	19,060
$\Delta W_F/W$	.110	.162

Complete VTOL and STOL design mission summaries are included in Volume IV of NA 72-444.

Operation in the short takeoff and landing mode requires consideration of engine and fan failures, in the event of which the aircraft must be capable of (1) braking to a stop if failure occurs before reaching the critical decision velocity, (2) continuing the takeoff ground roll and climbout if failure occurs on the ground at speeds greater than the critical decision velocity, and (3) continuing the takeoff climbout if failure occurs in the air. This means, then, that the aircraft must meet the specified 1,500-foot field length with a single propulsion system failure. The approach followed is that no change of configuration is to be required following a propulsion failure. Thus, it is necessary to operate normally at lift-fan louver angles and cruise-fan hood angles which permit steady-state flight following a propulsion failure. These settings are determined and used for normal (i.e., no propulsion failure) operation.

In the case of the remote-fan aircraft, the critical failure case is the loss of a fan. In this case, the diametrically opposite fan is shut down and the flow from the gas generators is diverted to emergency nozzles which produce approximately 40 percent of the lift-fan thrust.

The critical failure case for the integral lift-fan aircraft is the case where one engine fails and it becomes necessary to shut down a diametrically opposite engine in order to maintain moment balance.

For both aircraft, the lift-cruise nozzles are in the cruise position during the takeoff ground roll, and are repositioned to the angle for minimum distance at liftoff. The lift-fan system (exit louvers or engine tilt angle) is fixed throughout the takeoff at the angle for minimum takeoff distance.

Results of STOL performance analyses for the remote-fan and integral lift-fan engine aircraft are presented in terms of field lengths as a function of aircraft gross weight in figures 42 and 43, respectively.

The STOL field length for the remote-fan aircraft is set by the failed-fan takeoff distance as shown by the heavy solid curve (figure 42). This aircraft meets the desired 1,500-foot field length for takeoff gross weights up to 127,000 pounds. The lower installed VTOL thrust-to-weight ratio (1.14) combined with the higher fuel load required to meet the STOL range results in a low rate of climb at heavier weights because of the required 10-degree angle-of-attack margin below the stall angle specified by the design criteria. Relaxation of this limit to 6.9 degrees below the stall (lift coefficient is two-thirds of the maximum lift coefficient) achieves the 1,500-foot field length, as shown in figure 42 by the dotted curve. The all-engine takeoff field length is shown by the light solid curve, and the dashed curve shows the landing field length.

The higher installed VTOL thrust-to-weight ratio (1.25) and lesser overload fuel required to perform the STOL range provide STOL field lengths for the integral lift-fan aircraft within the guidelines criteria. The lift-cruise engines of this aircraft are operated at the VTOL reduced thrust levels during STOL for moment balance and noise considerations. Figure 43 shows that the failed engine takeoff performance (heavy solid curve) defines the critical field length for the integral lift-fan aircraft. The landing (dashed curve) and all engine takeoff field lengths (light solid curve) are also presented.

For rejected takeoff (i.e., to accelerate to the critical decision velocity and then brake to a stop), the determining case occurs at the maximum gross weights wherein the critical decision velocity is greatest. At the maximum STOL weights, the accelerate/stop distance is approximately 60 to 70 percent of the all-engine takeoff field length.

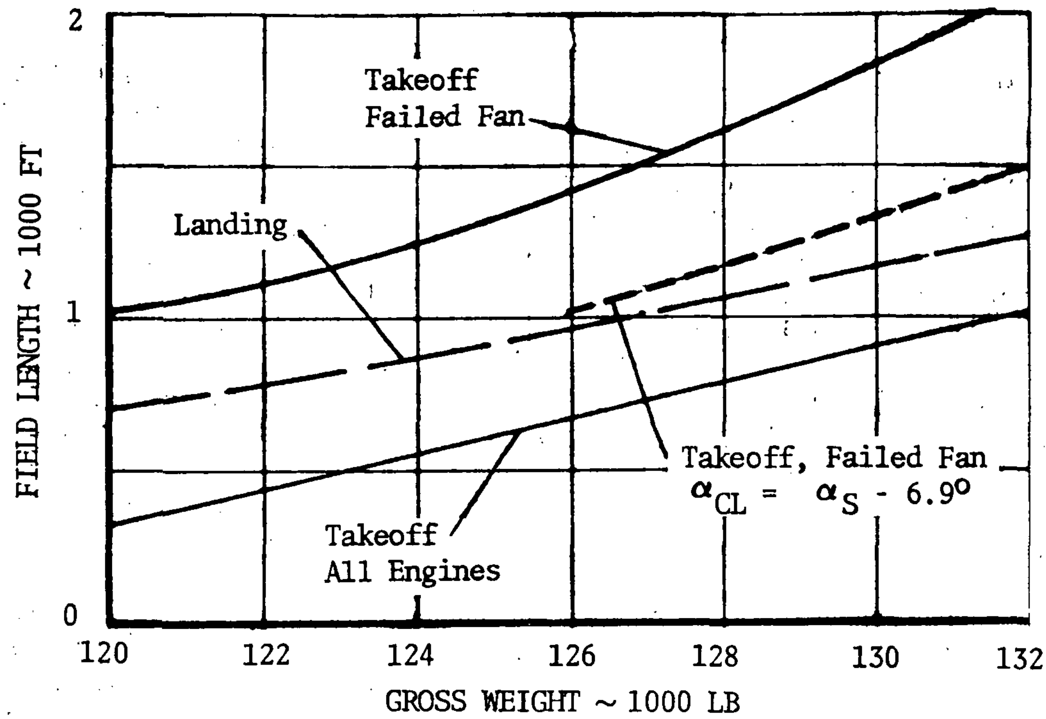


Figure 42. STOL Performance, Remote Fan Aircraft

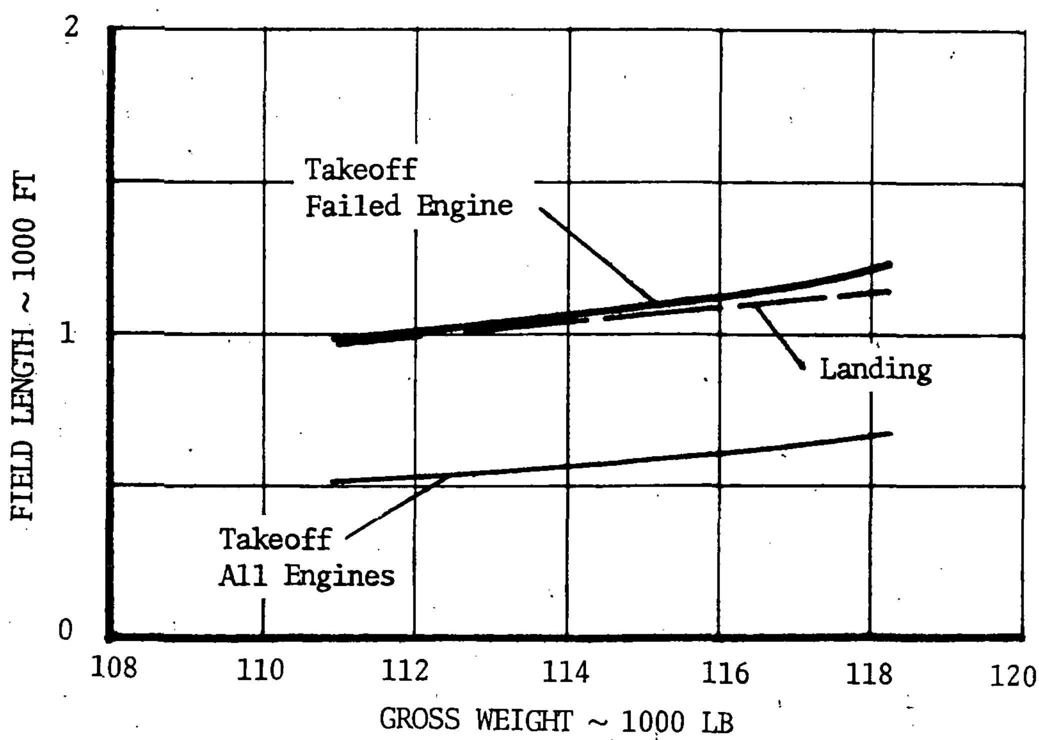


Figure 43. STOL Performance, Integral Lift Fan Aircraft

Ride Qualities

The attainment of acceptable passenger ride qualities on the short haul low altitude trips was recognized as a design problem at the beginning of the study. The NASA Guideline criteria were compared with similar requirements for recent NR studies, and the guideline criteria were found to be considerably more stringent. To meet these ride criteria at low altitude high speed flight conditions requires an increase in wing loading, an increase in wing sweep, a reduction in wing aspect ratio, or any combination of these variables as compared to the configurations shown. Since cruise, STOL, and hover performance, structural weight and DOC are closely associated with any of these changes, design tradeoffs would be required to identify the best compromise solution. It is considered that the study results would not be effected nor the primary objectives be served by diverting the time required to accomplish this refinement, hence the wing geometry has been selected on the basis of engineering judgment.

The data in Figure 44 show the gust sensitivity of both the remote fan and the integral lift fan aircraft at cruise wing loadings of 100 and 114 lb/ft.^{2} when the aircraft is operated along the minimum speed/altitude profile shown in the inset diagram. These results show that the aircraft meet the NASA guidelines at altitudes above 20,000 to 25,000 ft. For comparison, the corresponding ride qualities of the Electra for a range of speeds at 5,000 ft., and the Boeing 737 at 350 knots and 0.75M are shown at cruise wing loadings. If the FAR 91.70 requirement that speeds not exceed 250 KEAS below 10,000 ft. is retained, the gust sensitivity at low altitude is reduced as shown. The analysis is considered conservative in view of the undetermined lift pod effects on the wing lift curve, and the neglect of relieving structural flexibility.

Operational Envelope

For the determination of direct operating cost data, complete aircraft operational envelopes were developed, Figures 45 and 46, which describe the cruise altitudes and number of equal distance trips that can be attained on the initial fuel load for various stage lengths. Time, fuel, and distance data are determined for all mission legs. The aircraft are operated on the VTOL or STOL mission ground rules, Figure 1, transport a maximum 100 passenger payload, and fly successive equal stage lengths unrefueled until only the specified reserve fuel remains on board. The operational envelope for a reduced payload VTOL mission (VTOL offload) is also shown. The VTOL offload mission is initiated with STOL fuel on board; the STOL fuel increment over the VTOL fuel displacing an equivalent payload weight. The trips are flown at minimum cruise speed (350 KEAS or 0.75M), at constant cruise altitude, and such that the cruise distance is at least 50% of the total trip distance. Performance trades were also evaluated wherein the aircraft were operated at maximum cruise speed at altitude, and at 350 KEAS at 5,000 ft.; exceeding the FAR 91.70 limit speed of 250 KEAS at altitudes below 10,000 ft.

The operational envelope for the remote fan aircraft, Figure 45, shows that only 4 multi-stop VTOL offloaded trips of 100 N.Mi. stage length can be completed at a 5000 ft. cruise altitude. For the same trip distance, only 2 VTOL trips or 3 STOL trips can be completed. In summary, this aircraft can achieve single VTOL trips up to the design 400 N.Mi. stage length only at the altitudes shown by the shaded area in Figure 45, whereas both STOL and VTOL

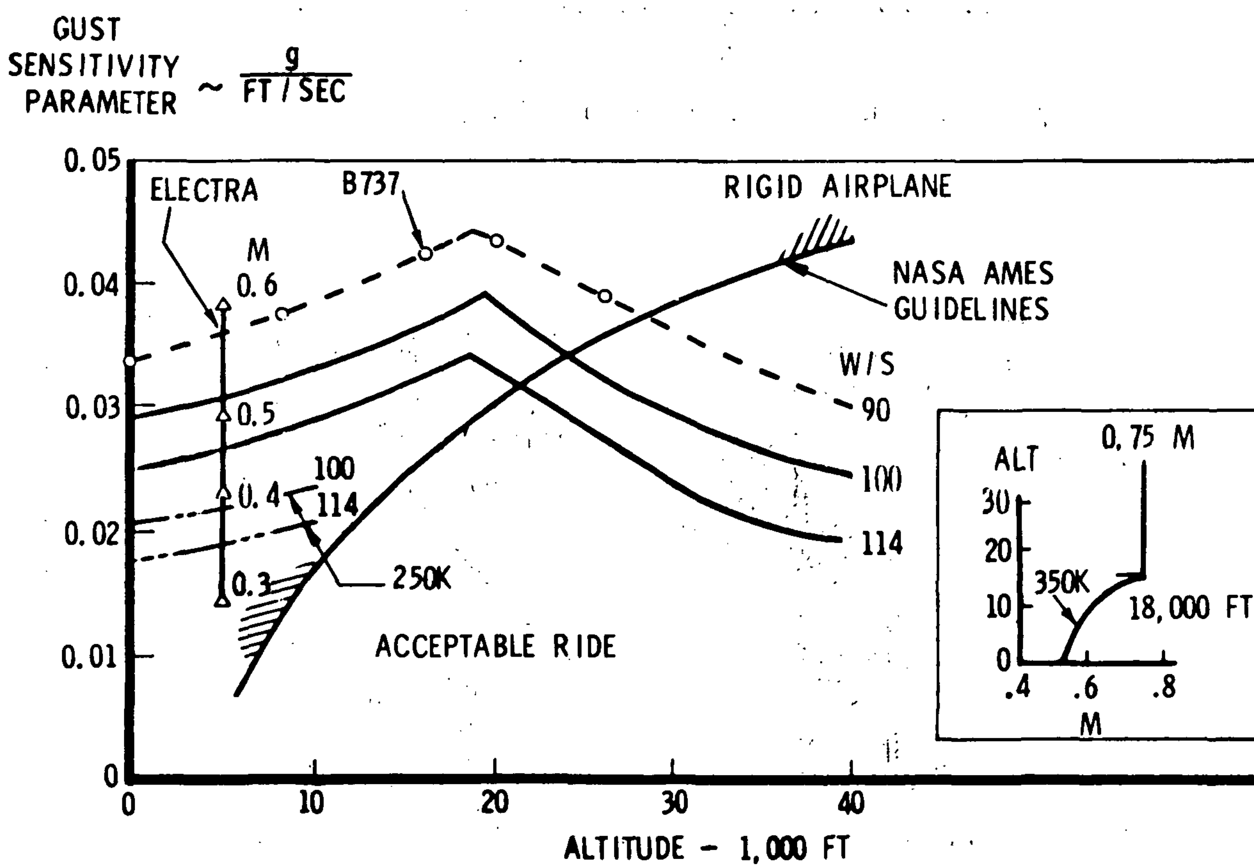


Figure 44. Gust Sensitivity in Turbulence

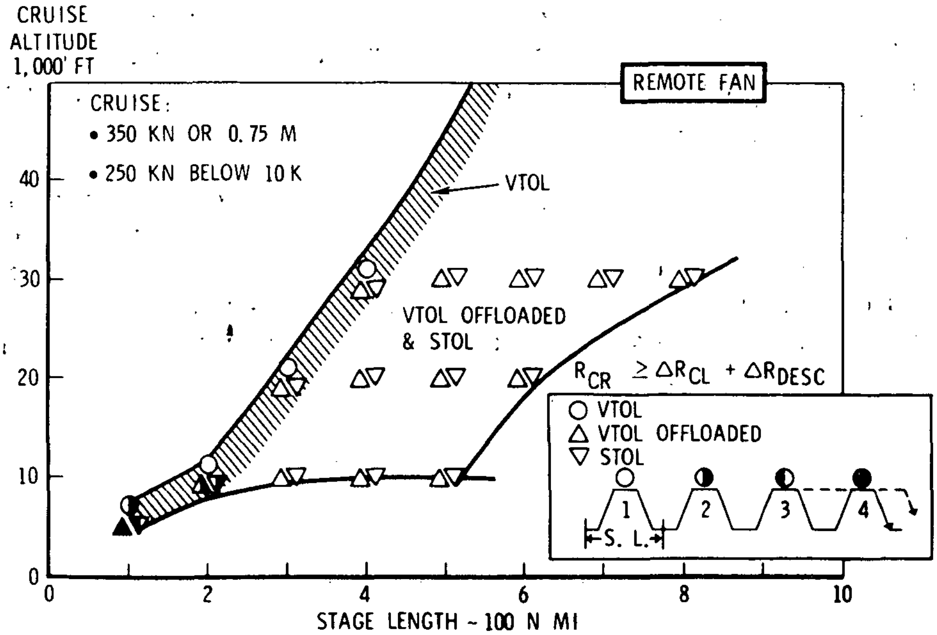


Figure 45. Operational Envelope, Remote Fan Aircraft

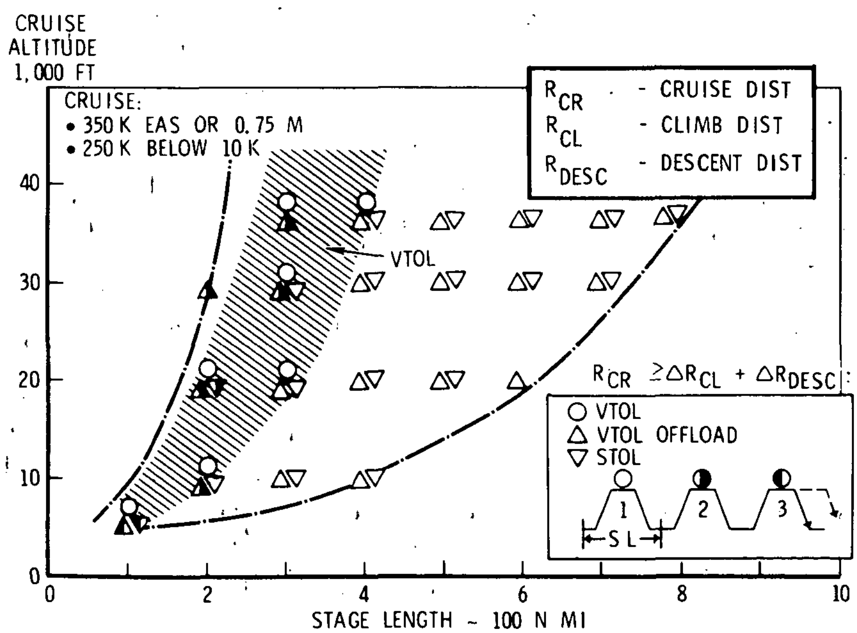


Figure 46. Operational Envelope, Integral Lift Fan Aircraft

offloaded trips are possible within the outlined area to a cruise altitude of 30,000 ft.

The integral lift fan aircraft cruising on GE 13/F6A1 engines shows a considerably expanded operational envelope, Figure 46 compared to the remote fan aircraft. Operation on the VTOL mission (shaded area) is increased to a much greater altitude range, although only 1 VTOL trip or 3 STOL or VTOL offloaded trips can be performed at the 100 N.Mi. stage length. The increased operational envelope provides greater flexibility in utilization and probability of operation at minimum direct operating cost conditions.

Noise Characteristics

Noise characteristics of the selected Remote Fan/Turbojet Gas Generator V/STOL Transport and the selected Integral Lift Fan V/STOL Transport were estimated by the General Electric Company. The characteristics determined were in accordance with a takeoff flight path (altitude) profile provided to General Electric, and assumed flight velocity and thrust vector angle schedules along this flight path. These latter characteristics are shown in Figure 47 as a function of runway centerline distance after takeoff. Angle θ represents the lift/cruise fan segmented hood deflection angle measured from a reference horizontal direction, and β represents the angle between the lift fan thrust vector as measured aft from a reference vertical direction. When θ is zero degrees, the lift/cruise fan thrust vector direction is forward. When β is zero degrees, the lift fan thrust vector direction is vertical.

Noise computations made for the Remote Fan/Turbojet Gas Generator V/STOL Transport resulted in the perceived noise level contours, or noise footprint, shown in Figure 48 . These data are consistent with a gross weight of 120,000 lbs., all gas generators operating at Military Power Setting, and additional installed suppression amounting to -8 db for the lift/cruise fan inlets and -8 db for the lift/cruise fan gas generator inlets. The noise footprint represents the envelope of constant db contours as the aircraft ascends along the assumed takeoff path.

The resulting noise footprint shows that a maximum noise level of 101 PNdb is obtained at a sideline distance of 500 feet. This exceeds the target goal of 95 PNdb for the V/STOL Commercial Transport. The problem of attaining 95 PNdb at a 500 foot sideline distance is the difficulty in adding suppression to the lift fan inlets. These inlets are essentially bell mouth inlets with no place to add splitter rings without upsetting the airflow distribution to the fans during cross flow. An additional 5-10 db suppression of the lift fan inlet noise is required to attain the target goal. It is noted, however, that the 95 db contour line as shown on the noise footprint only encloses an area

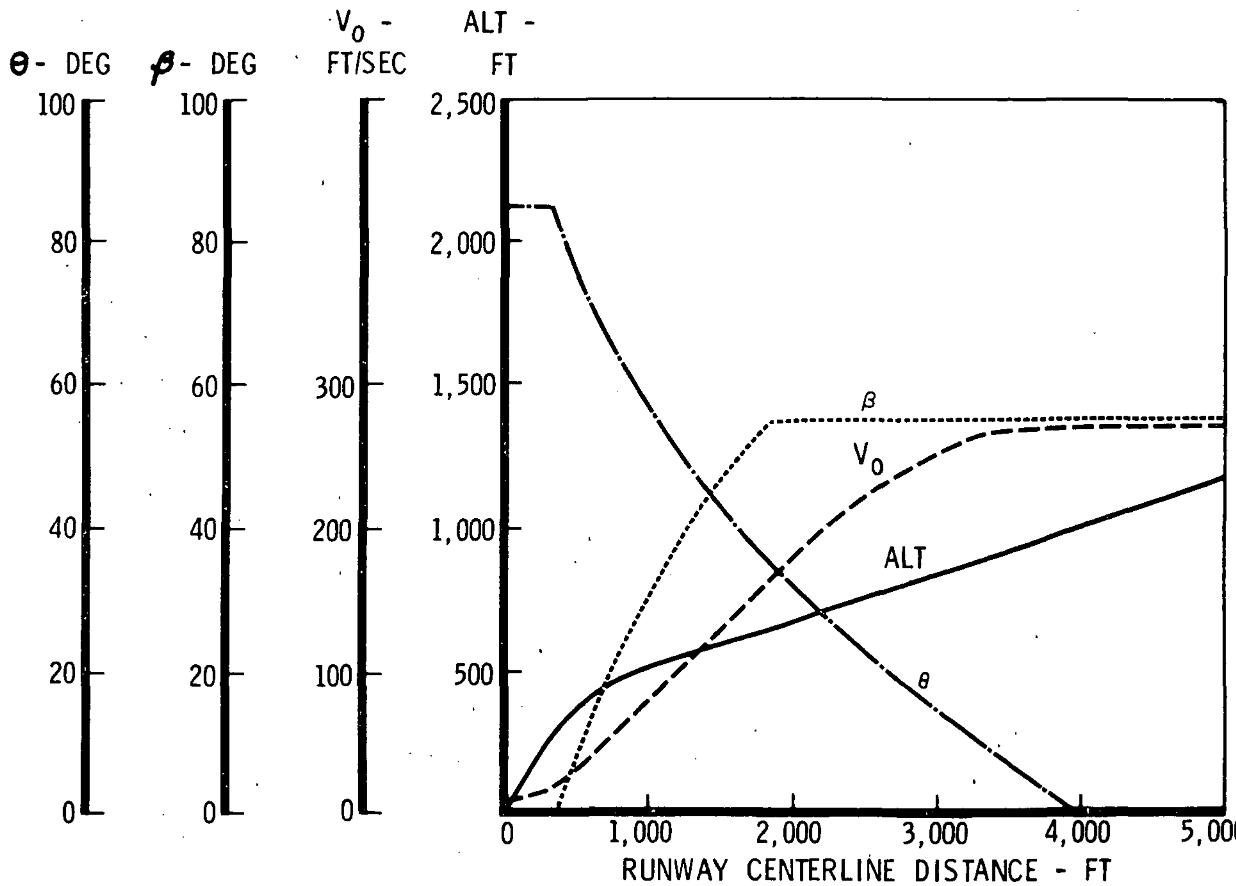


Figure 47. Takeoff Noise Analysis Assumptions

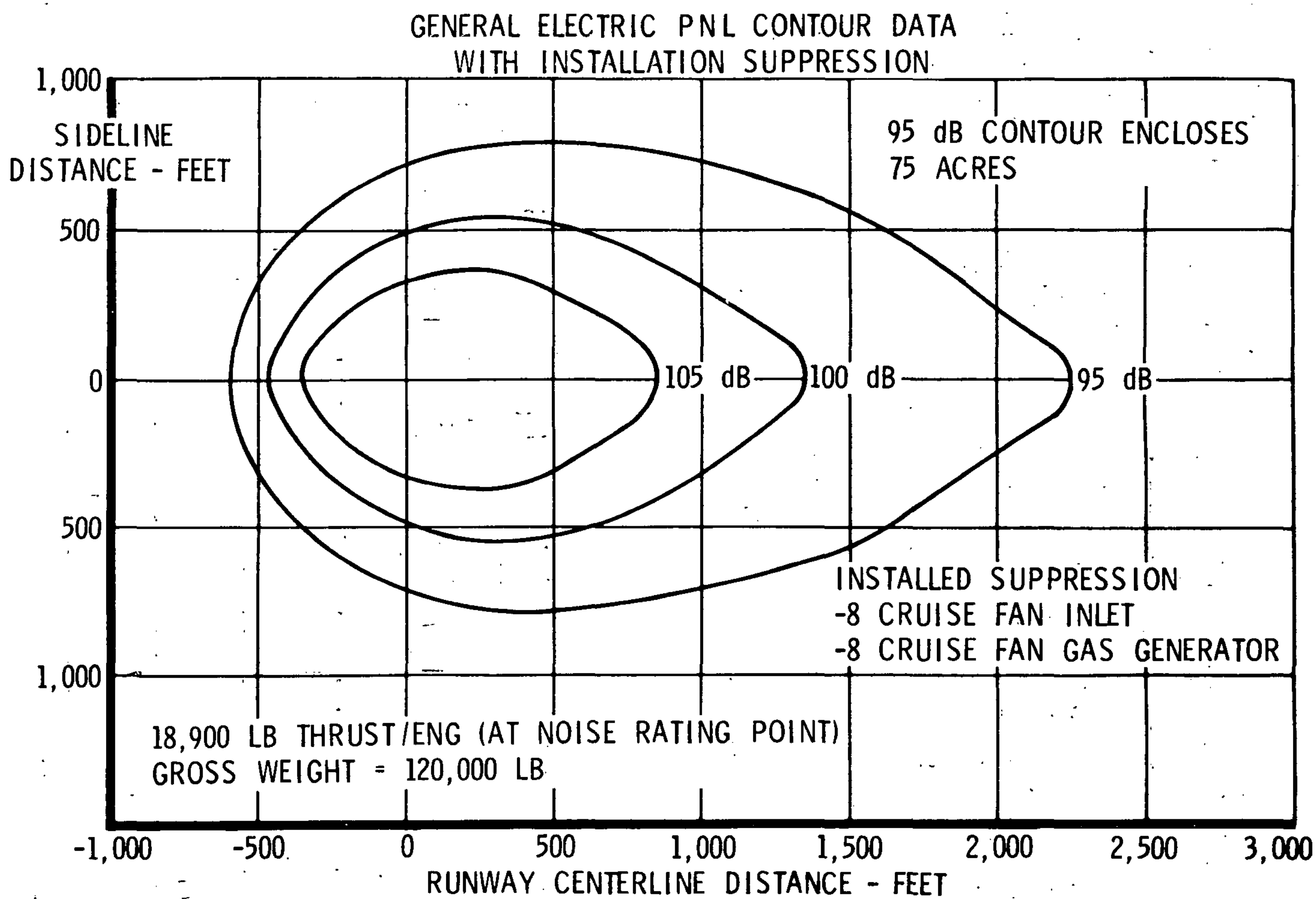


Figure 48. Remote Fan/Turbojet Gas Generator V/STOL Transport Noise Footprint

of 75 acres.

Additional noise computations were made for both the Remote Fan/Turbojet Gas Generator V/STOL Transport and the Integral Lift Fan V/STOL Transport for five specific conditions. The results are compared in Table II. PNdb numbers in the last two columns, corresponding to an additional lift/cruise fan/gas generator/engine inlet suppression of -4 db, generally indicate that the Remote Fan V/STOL Transport is slightly quieter than the Integral Fan V/STOL Transport. The only pronounced difference occurs for the climb through 2000 foot altitude case at Maximum Climb Power Setting. This difference is attributed to both the higher thrust level and engine cycle of the larger size GE 13/F6A1 cruise engines operating at this condition in the case of the Integral Fan V/STOL Transport.

TABLE 11

REMOTE AND INTEGRAL FAN V/STOL TRANSPORT NOISE DATA

POINT	AIRCRAFT NOISE - PNdB		
	REMOTE		INTEGRAL
	L/C FAN + GAS GEN INLET SUPPRESSION		L/C INLET SUPPRESSION
	-8dB	-4dB	-4dB
TAKE OFF 1 MI FROM BRAKE RELEASE	88.0	89.2	90.7
APPROACH 1 MI FROM TOUCHDOWN	86.2	87.4	89.7
TAKE OFF MAX NOISE 500 FT SIDELINE	101.0	101.5	101.7
APPROACH MAX NOISE 500 FT SIDELINE	101.0	101.5	101.7
CLIMB THROUGH 2,000 FT ALT AT MAX CLIMB POWER	76.0	77.5	87.7

ECONOMIC ANALYSIS

Economic Yardsticks

The economic "yardstick" used to evaluate the candidate V/STOL commercial transports consisted of two factors. These were: (1) direct operating costs, and (2) initial investment costs. Both these factors were considered important factors in comparing the economic viability of candidate commercial transports. Consideration of only these two factors is not sufficient to evaluate the economic viability of such a system, but in comparing designs of the same passenger capacity, these measures were considered sufficient to determine the most viable of the designs being compared. Market capture and return on investment evaluations were considered desirable but were outside the scope of this study and are left for future studies of V/STOL commercial transports.

Aircraft Costs

Budgetary and Planning (B&P) cost estimates of the two candidate V/STOL designs are shown in Figure 49 . These are $12.38 million per aircraft for the integral fan plus cruise fan design and $11.35 million per aircraft for the remote fan design at a 300 aircraft buy level. These costs are expressed in 1971 dollars and include development costs for both the airframe and engines, engine manufacturer profit, but not airframe manufacturer profit.

The remote fan engine costs constitute about 43% of the total aircraft cost at the 300 aircraft buy as shown in Figure 50 . The requirement for two separate engine development programs for the lift only and lift cruise engines as well as the relatively small buy size of the GE 13/F6A1 lift cruise engine (two of the eight engines per aircraft) boosts the engines cost to about 52% of the total aircraft cost for the integral fan plus cruise fan design. These data are presented in Figure 51. .

Direct Operating Costs

The direct operating costs (DOC's) for the alternate designs presented herein were determined from a computer program based on "A Standard Method for Estimating VTOL Operating Expense" by the Aerospace Industry Association of America. These direct operating costs consist of the component costs listed in Figure 52. These costing procedures were used to evaluate the relative DOC's of the candidate preliminary designs but do not necessarily reflect a prediction of the absolute value of these DOC's. A detailed description of the inputs and assumptions used in the program as well as a computer printout of the results appear in Volume IV of NA 72-444.

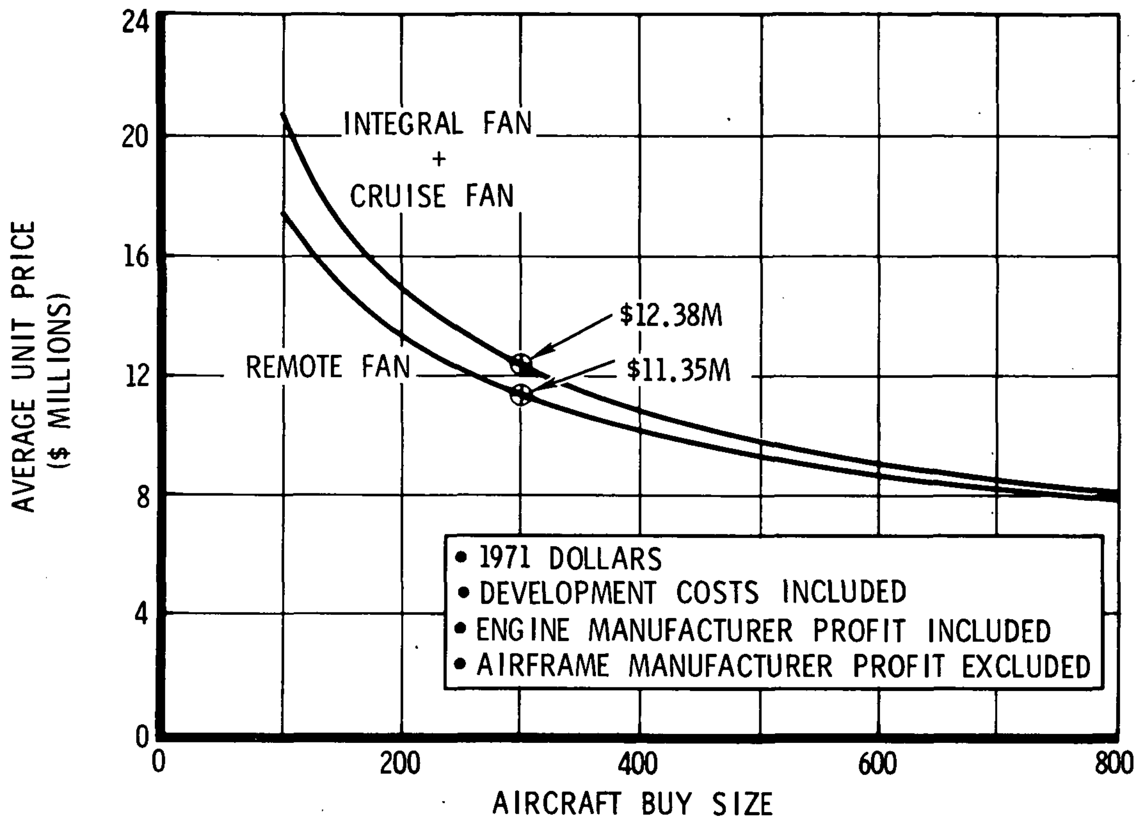


Figure 49. V/STOL Commercial Transport Bugetary and Planning Cost Estimates

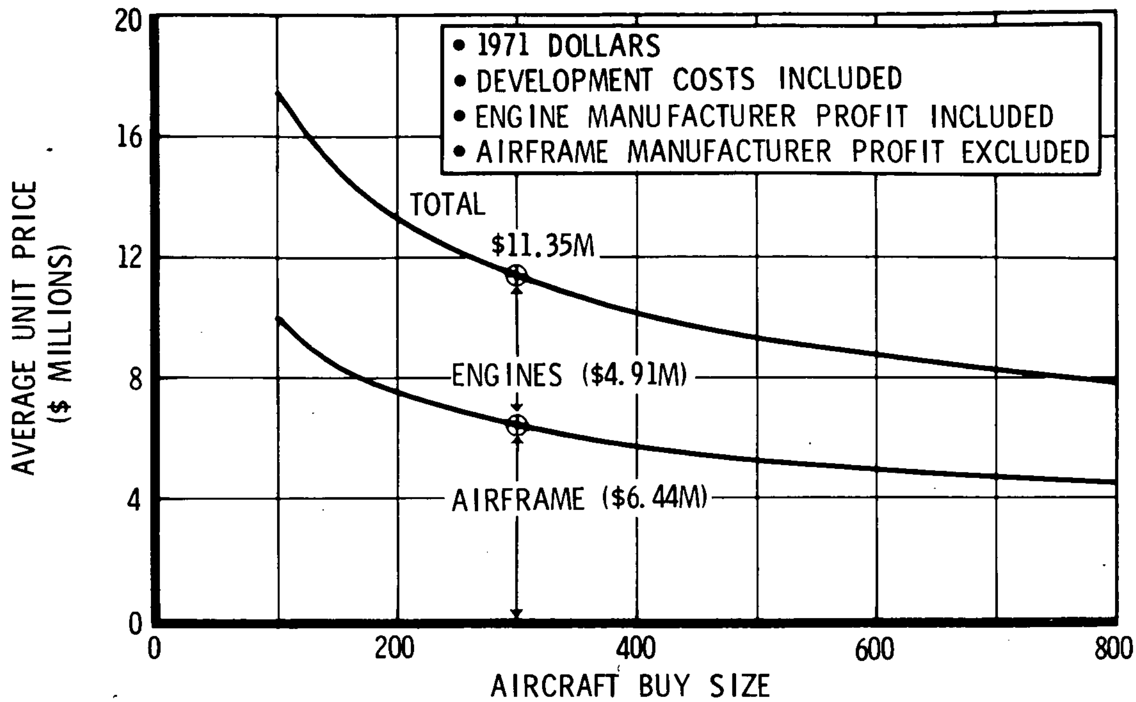


Figure 50. Remote Fan Commercial Transport Cost Components

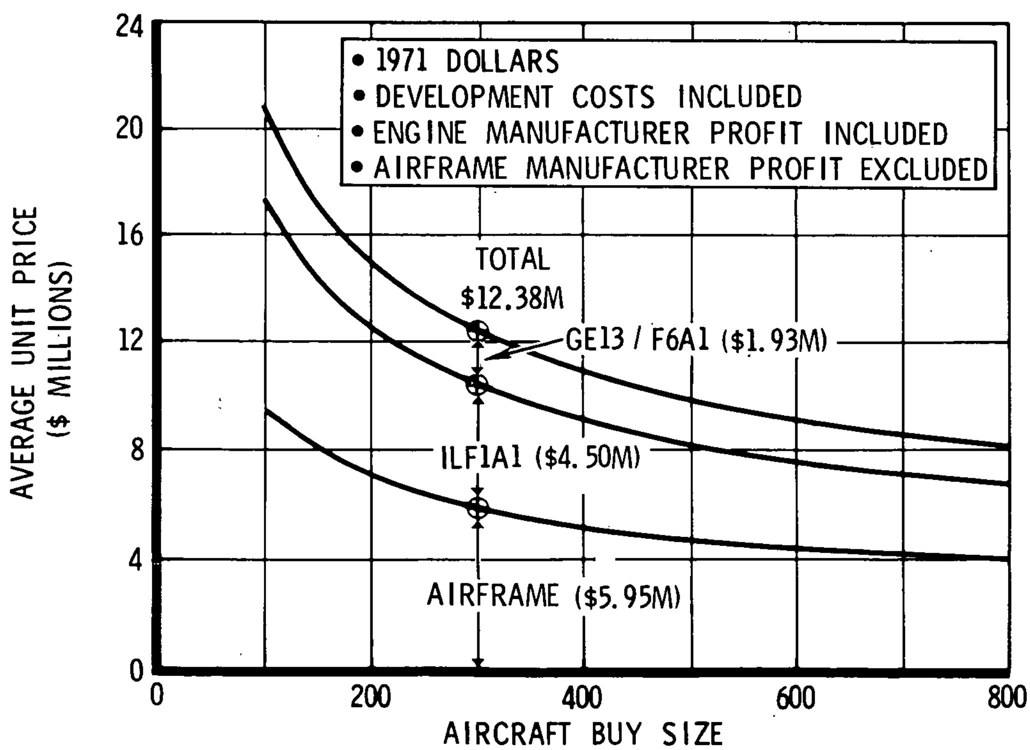


Figure 51. Integral Fan + Cruise Fan Commercial Transport Cost Components

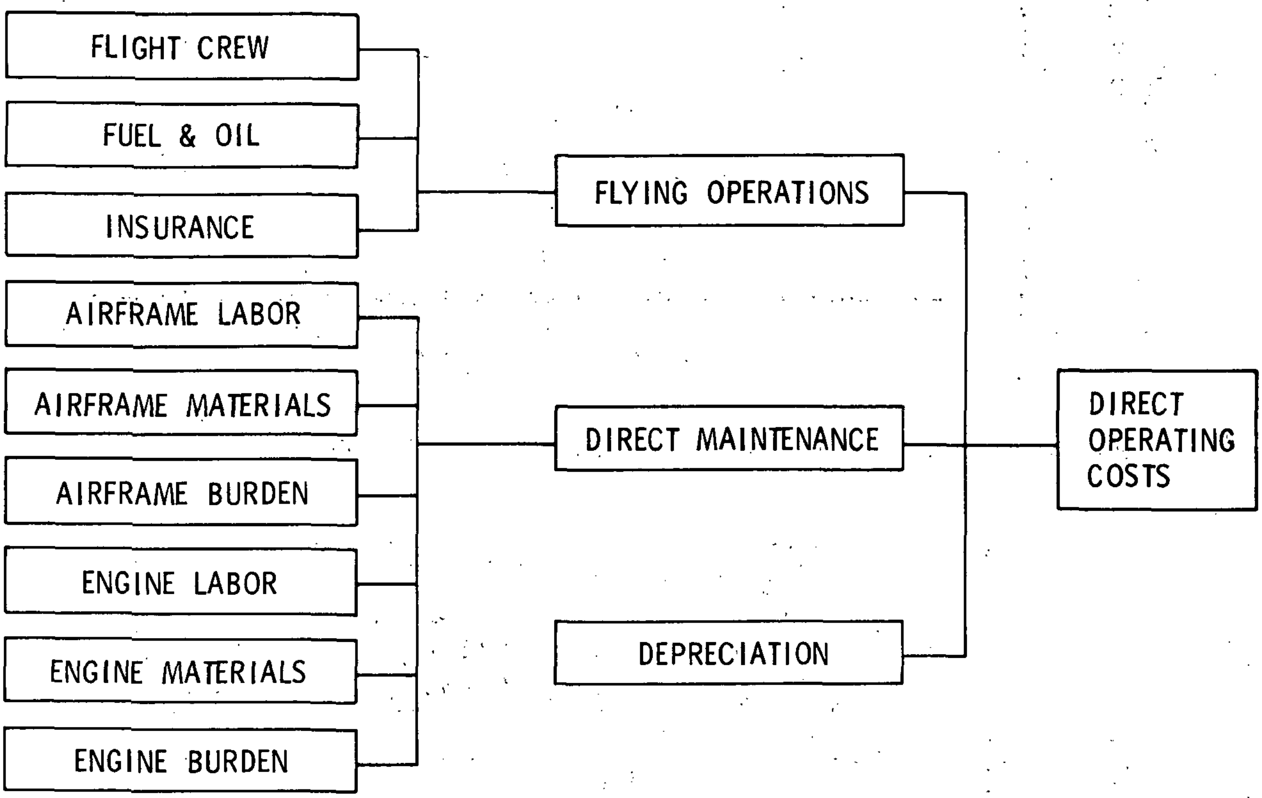


Figure 52. Direct Operating Cost Components

The VTOL DOC's resulting from the above methodology for both the remote fan and the integral fan plus cruise fan design are presented in Figure 53. As shown, the remote fan design has slightly lower DOC's at the shorter ranges while having slightly higher DOC's at the longer ranges. At short trip distances, aircraft utilization is lower with resulting higher amortized depreciation and insurance costs per mile causing the higher integral fan plus cruise fan aircraft cost to increase the DOC's above those of the remote fan design. At longer ranges, increased emphasis is placed on fuel costs in DOC's and the lower fuel consumption rate of the integral fan plus cruise fan design results in somewhat lower DOC's than the remote fan design. The differences in DOC's are on the order of 1% and are considered small except at the very short ranges where the remote fan design is approximately 6% less expensive.

When operating in the STOL mode at design gross weight, the DOC's in Figure 54 are expected. The above comments on the VTOL DOC's apply equally in this case and it is noted the DOC's again are almost equivalent for the two designs.

The components of the above described VTOL and STOL DOC's for the designs under consideration are summarized in Figure 55 . Direct maintenance represents the largest cost category, followed by flying operations and depreciation. Of these first two categories, engine maintenance material and fuel and oil costs represent the largest single cost components in their respective cost categories.

Aircraft Operational Data

The aircraft operational profile used for the DOC computations is shown in Figure 56 . For each trip distance under investigation, each design was flown at the design gross weight as many equal trip distance flight cycles as the fuel supply would sustain, retaining the reserve fuel allowances described in the performance section. This reduced the average stop time below the turnaround stop time that would have been realized if the aircraft were refueled at each stop, and therefore increased utilization and decreased DOC's. The aircraft were flown at a median best cruise altitude and at the minimum design speed described in the performance section of this report for each trip distance, subject to the constraints that cruise distance was at least 50% of the total trip distance and cruise speed would not exceed 250 knots equivalent air speed below 10,000 feet altitude, (FAR 91.70).

A sample of VTOL flight cycle times used in these calculations is shown in Figure 57 . Turnaround stop times were approximately 12 minutes for 100 nautical mile ranges and 16 minutes for 400 nautical mile ranges. The longer of these distances require more time for refueling. These ground times are about 29% and 19% of the flight cycle times for the 100 and 400 nautical mile ranges respectively. As seen in the figure, only small differences in total flight cycle times exist between the two candidate designs.

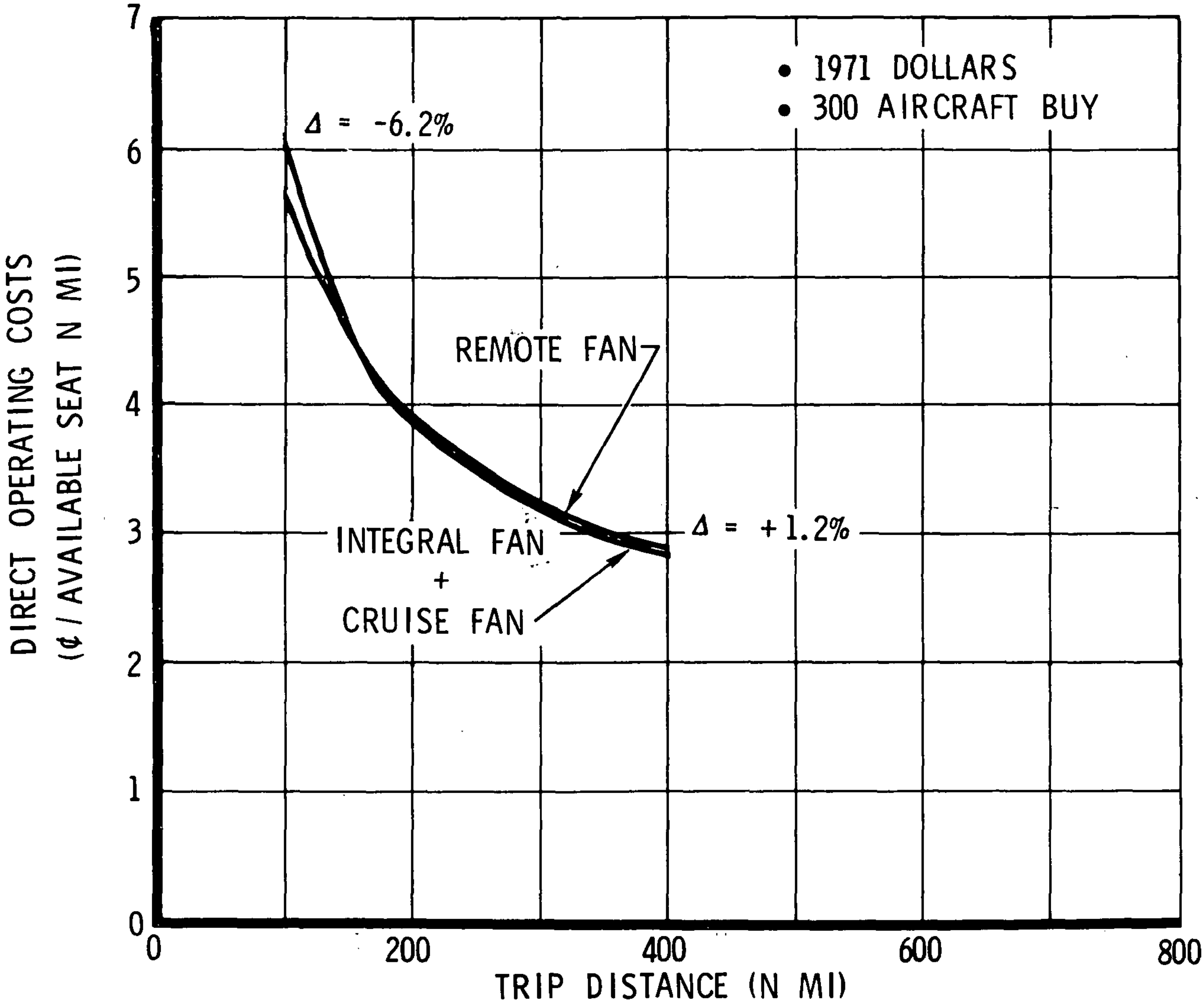


Figure 53. VTOL Direct Operating Costs

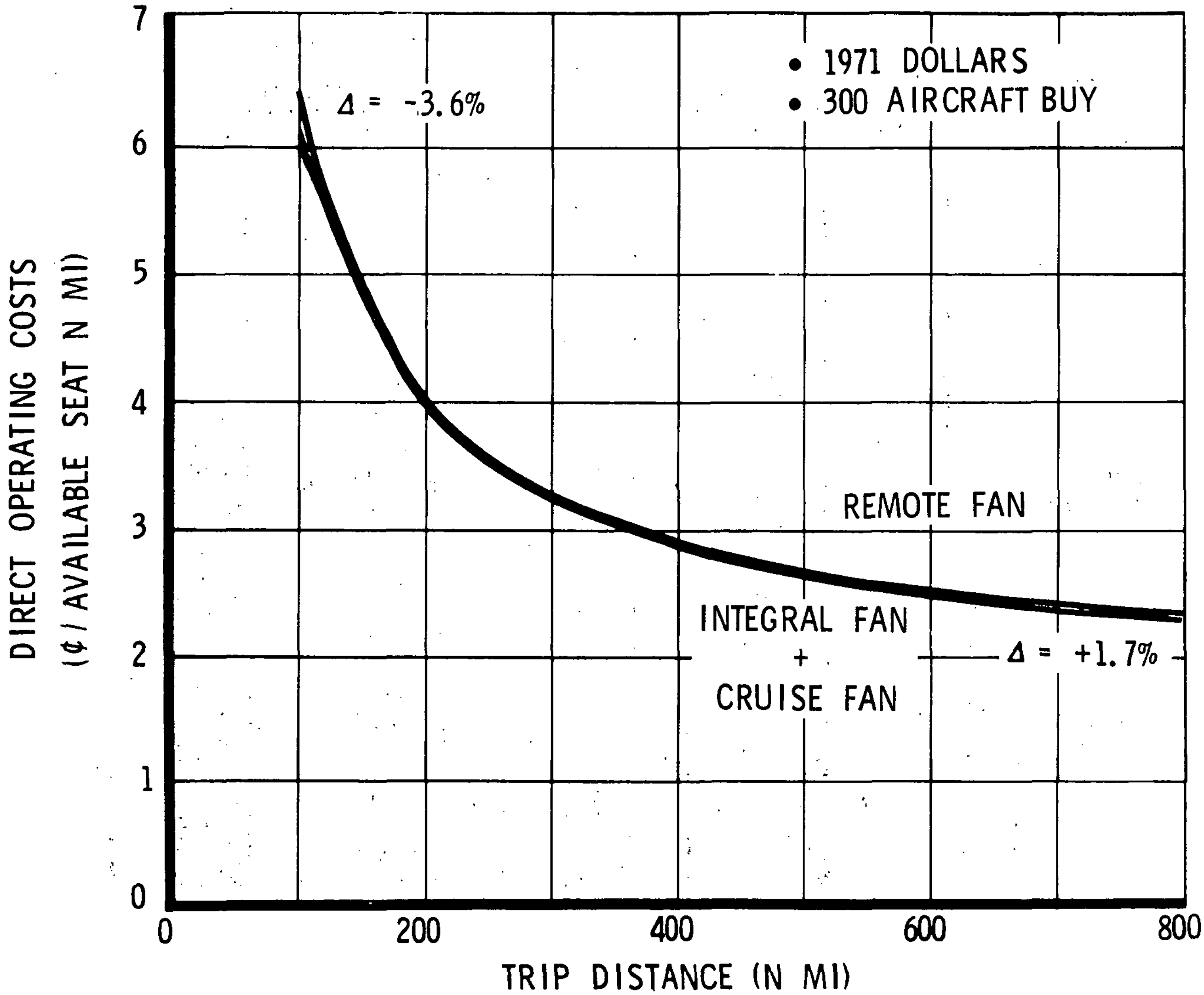


Figure 54. STOL Direct Operating Costs

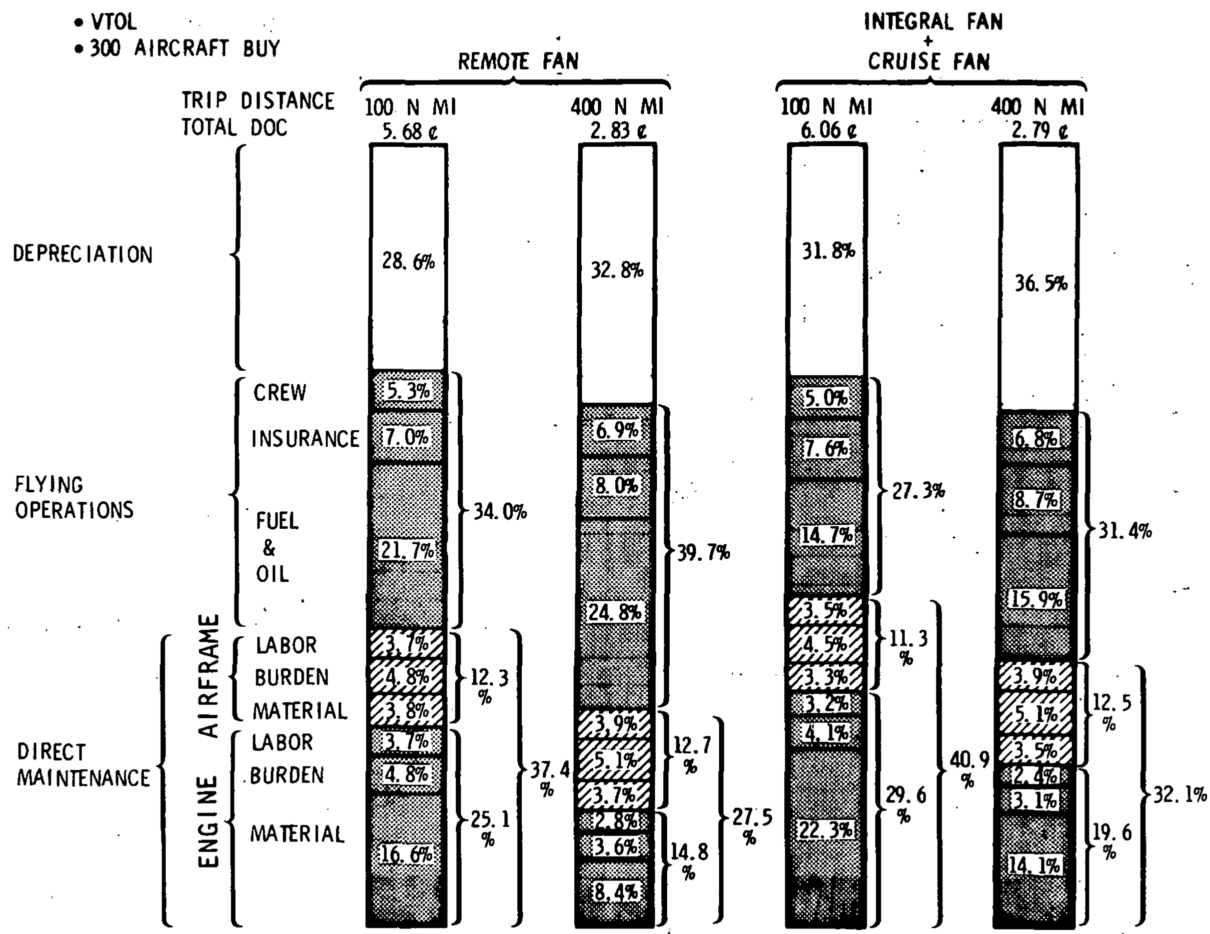
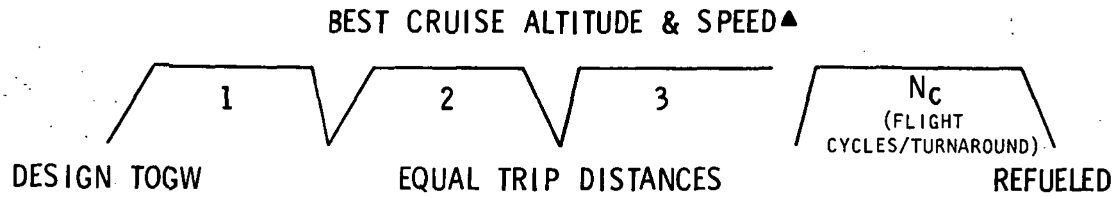


Figure 55. Component Direct Operating Costs



▲ SUBJECT TO THE FOLLOWING GROUND RULES

- CRUISE DISTANCE IS AT LEAST 50% OF TRIP DISTANCE
- CRUISE SPEED IS DESIGN MINIMUM CRUISE SPEED
- CONSTANT ALTITUDE CRUISE
- FAR 91.70 IN EFFECT (SPEEDS $\leq$ 250 KEAS BELOW 10,000 FEET ALTITUDE)

Figure 56. Operational Profile Ground Rules

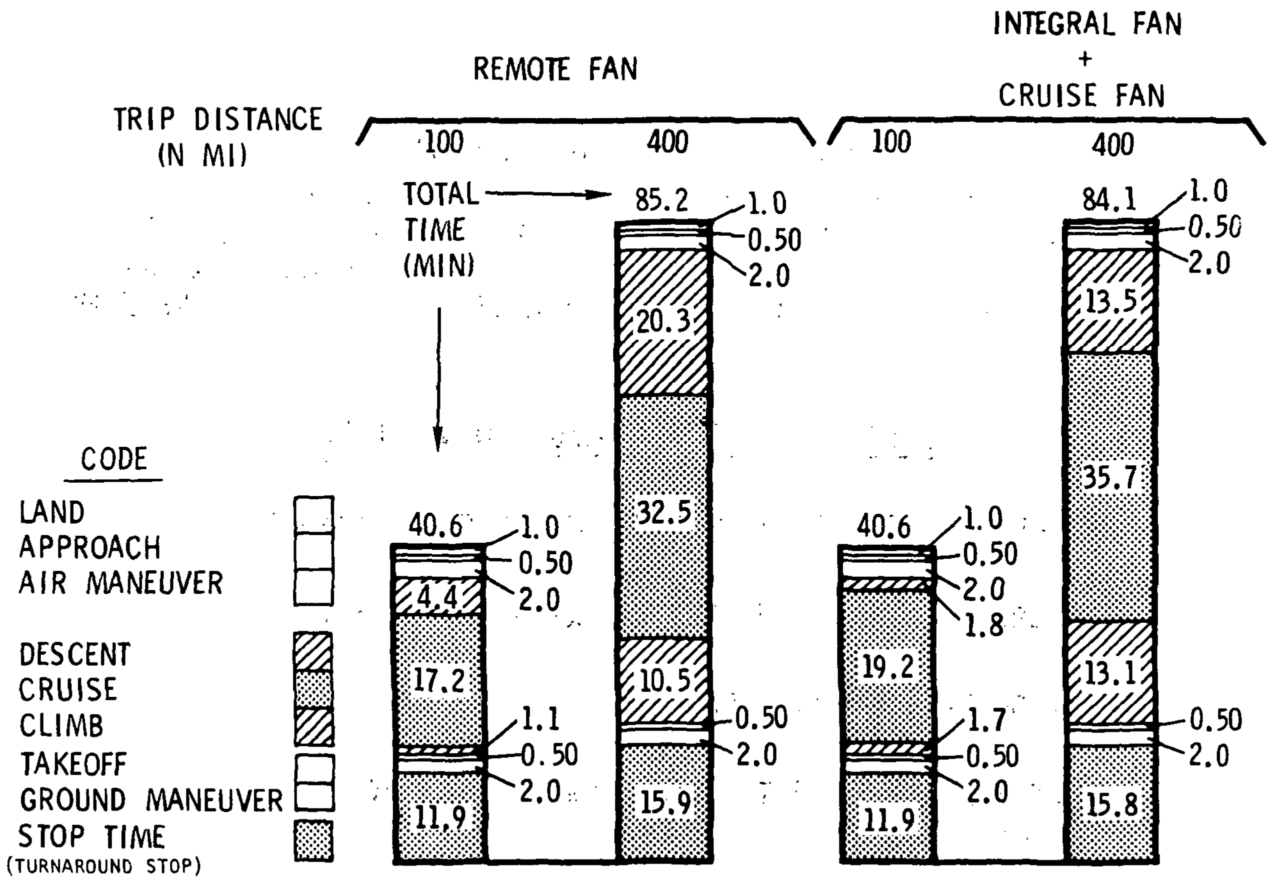


Figure 57. VTOL Flight Cycle Time Components

The operational flight envelopes used in calculating the DOC's are shown in Figure 58 for both VTOL and STOL mode. Best cruise altitude for the remote fan design is about 30,000 feet while the integral fan plus cruise fan deisgn, with the more efficient GE 13/F6A1 cruise engine, cruises at 36,000 feet for the longer trip distances. The corresponding cruise speeds are shown in knots true air speed. Also shown are the number of flight cycles per turn-around (refueling) used in calculating the average ground stop time. The envelopes shown are in compliance with the ground rule that cruise distance be at least 50% of the total trip distance, as mentioned above.

Figure 59 shows the block speeds achieved by flying the operational profiles described in the above paragraph. For the VTOL mode these speeds reach about 250 knots at the maximum design range of 400 nautical miles while the STOL mode block speeds are approximately 375 knots for the longer design range of 800 nautical miles. Very little difference exists between the block speeds of the remote fan and the integral fan plus cruise fan designs.

The aircraft utilization corresponding to the operational profiles above are shown in Figure 60 . The utilizations range from 9 to 10 flight hours per day for the VTOL mode and from about 9.5 to 10 hours per day for the STOL mode. The discontinuities in the Figure occur where the number of flight cycles per turnaround change with a resulting change in average stop time and therefore utilization. Except at isolated points where the number of flight cycles per turnaround differ between designs , the utilizations achieved are almost identical. These utilizations were calculated assuming a 6 hour night stop because of traffic demands and it was assumed that daily maintenance could be performed during this night stop.

DOC Sensitivity Analysis

The sensitivity of DOC's to several parameters was evaluated in this economic analysis in order to identify areas that most strongly affect these costs. These include aircraft buy size, mode of operation, FAR 91.70, ground time, operational cruise speed and aircraft cost. The following section summarizes the results of this analysis.

The effect of increasing the aircraft buy size from 300 to 600 aircraft is shown in Figure 61 . The resultant savings in DOC's is about 13% for the remote fan and about 17% for the integral fan plus cruise fan design. This greater DOC savings for the integral fan plus cruise fan design is due to the fact that the cost of the engines started higher up the cost curve than did the remote fan design, and therefore a greater engine cost savings was realized in this steep portion of the curve than was realized for the remote design.

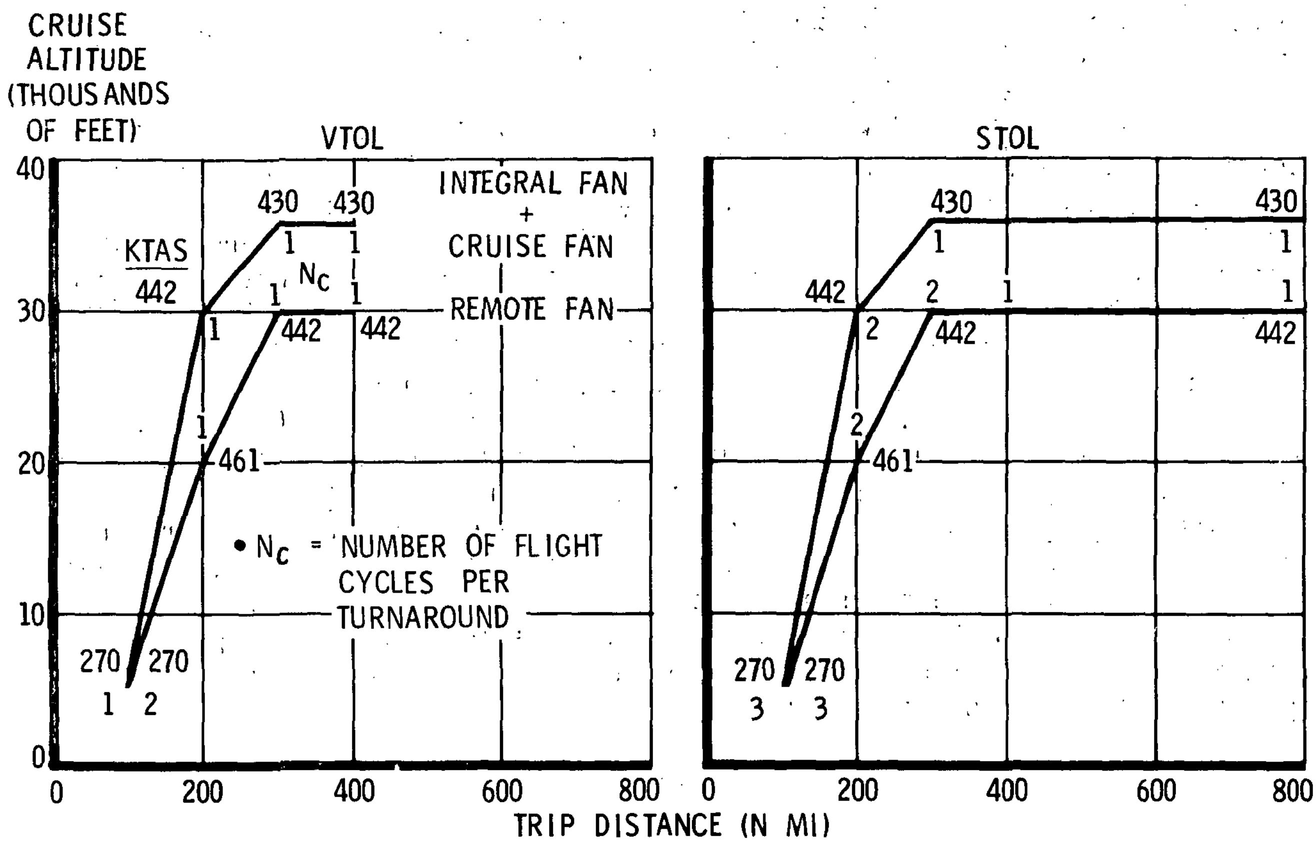


Figure 58. Operational Envelopes for Minimum DOC

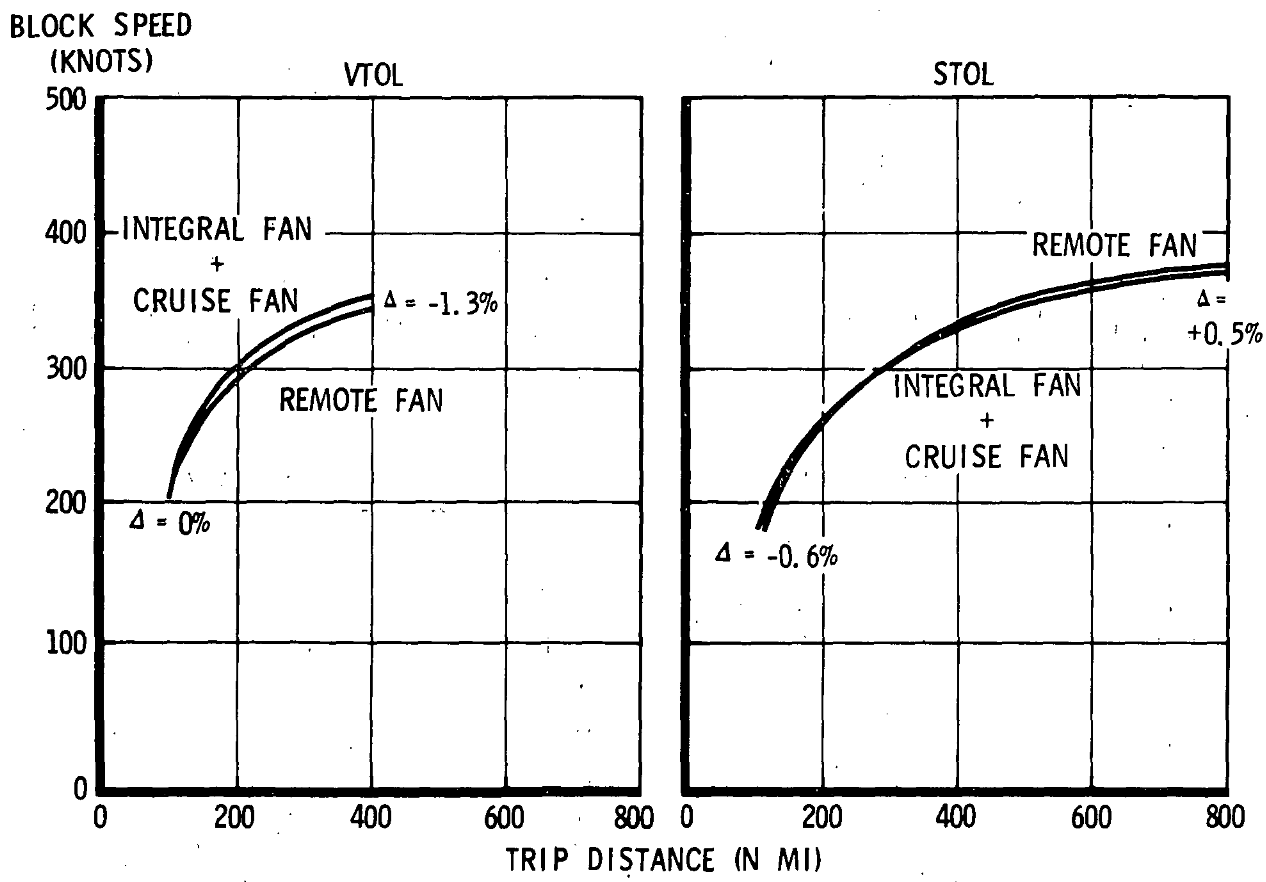


Figure 59. Block Speeds Achieved for Best Cruise Conditions

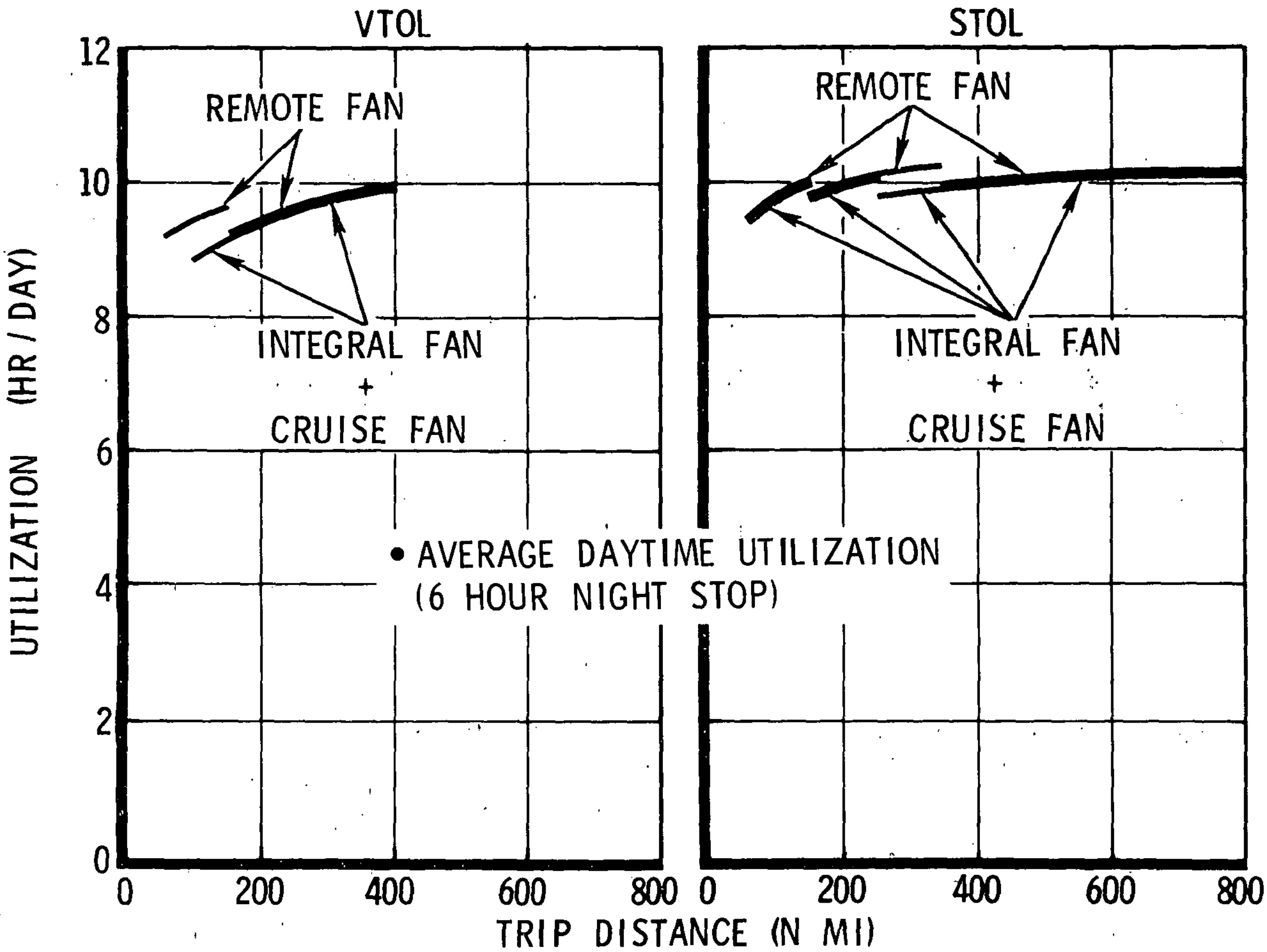


Figure 60. Aircraft Utilization

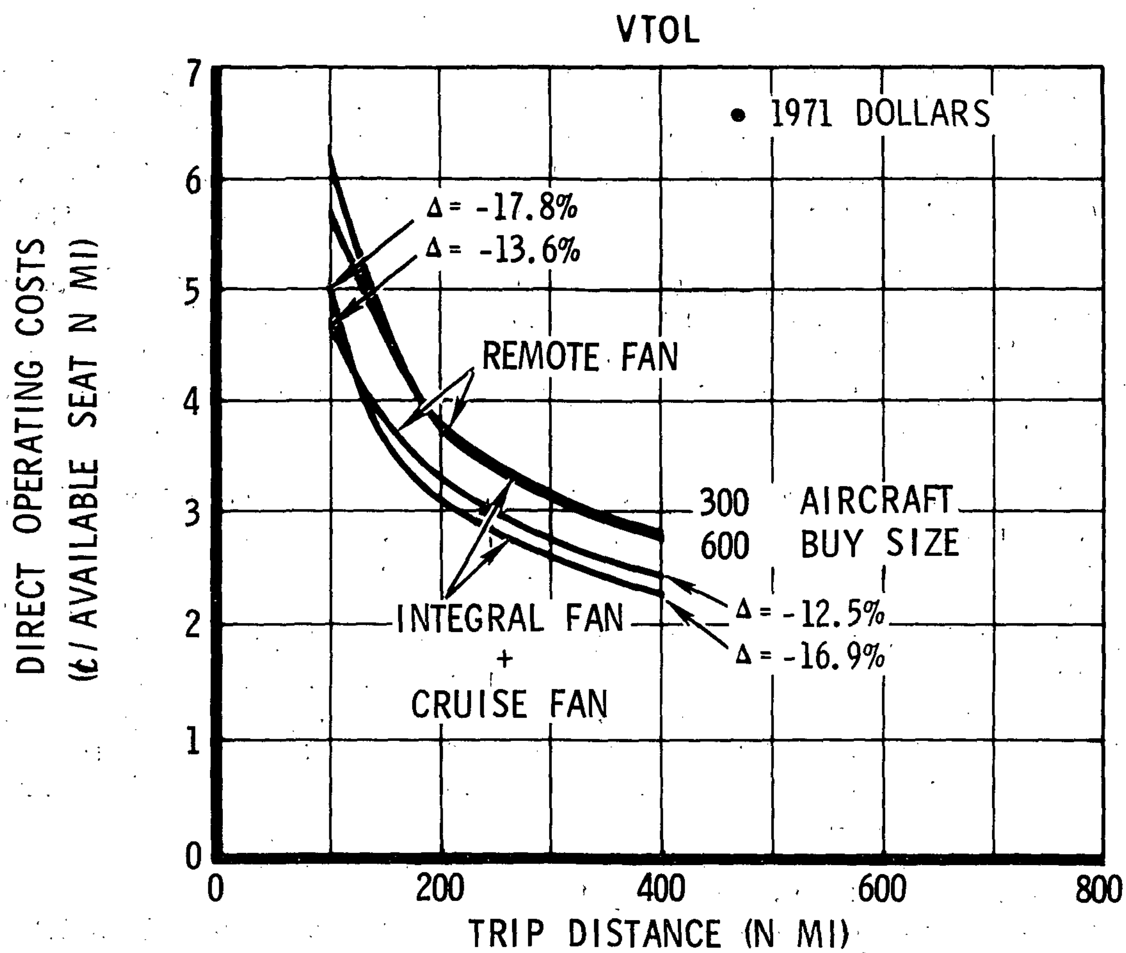


Figure 61. DOC Sensitivity to Aircraft Buy Size

Direct operating cost sensitivity to mode of operation is shown in Figure 62 . These DOC's are for aircraft operating at their design gross weight. Since the STOL design gross weight is substantially higher than the VTOL design gross weight, the additional fuel consumption is reflected in the higher DOC's.

The effect of relaxing FAR 91.70, which requires that speeds not exceed 250 KEAS below 10,000 feet altitude, is shown in Figure 63 . DOC savings of about 7%-8% are realized when cruise speeds are increased to 350 KEAS at the 100 nautical mile trip distance. At ranges greater than 100 nautical miles there was no change in DOC's as this regulation did not effect cruise speeds.

Ground times for a turnaround stop were about 14 minutes and 18 minutes (including a 2 minute ground maneuver time) for 100 nautical miles and 400 nautical miles respectively. If these ground times are reduced by one half, the lower DOC's in Figure 64 result. The savings is about 5%-7% because of the resultant increased utilization.

Flying the two aircraft designs at the maximum speed capability of each was also examined. The speed-altitude profile flown is shown in Figure 38 , and Figure 39 . Increasing operational cruise speed from Mach 0.75 to approximately Mach 0.85 lowered the DOC's as shown in Figure 65 . The savings is rather small except at the 100 nautical mile range where the savings is attributed to the relaxation of FAR 91.70 (increasing cruise speed from 250 KEAS to 350 KEAS) as described earlier. Although the amortized depreciation and insurance costs are lower for the higher cruise speeds, the largest part of this savings is offset by the higher fuel costs, resulting in the rather small DOC savings shown.

The sensitivity of DOC to aircraft cost is shown in Figure 66 . The base aircraft costs were reduced arbitrarily by 20% with a resultant 8% to 11% savings in DOC's, reflecting the rather strong influence of aircraft cost on the DOC's.

In addition to the above described DOC sensitivity analysis, an evaluation was conducted on a more extensive use of composites in a V/STOL design and the effect on DOC's. The structural fraction of 31% for the baseline remote fan design was assumed to be reduced to 28.5% (resulting in a 105,500 pound remote fan design) through more extensive use of fiber glass type composites. The resulting aircraft cost would be $10.04 million, a reduction of 12% from the baseline costs. The DOC's for this high composite design are shown in Figure 67 , and reflect a 10% to 11% DOC savings.

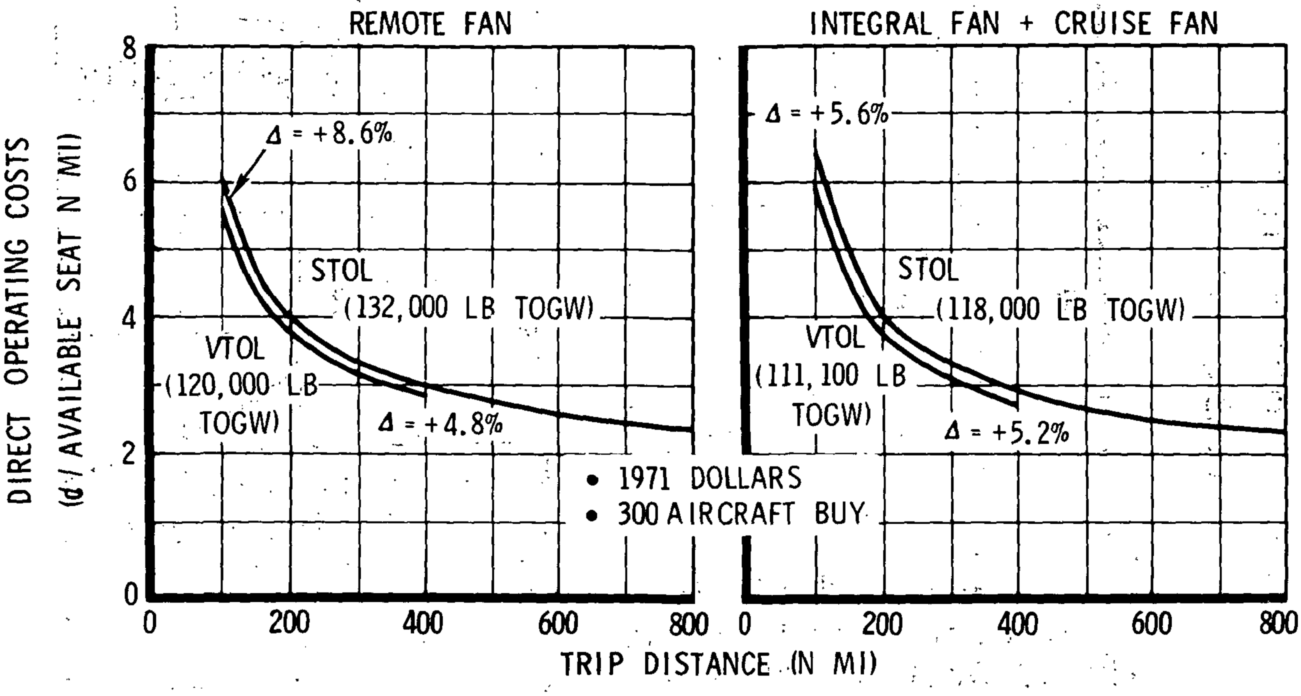


Figure 62. DOC Sensitivity to Mode of Operation

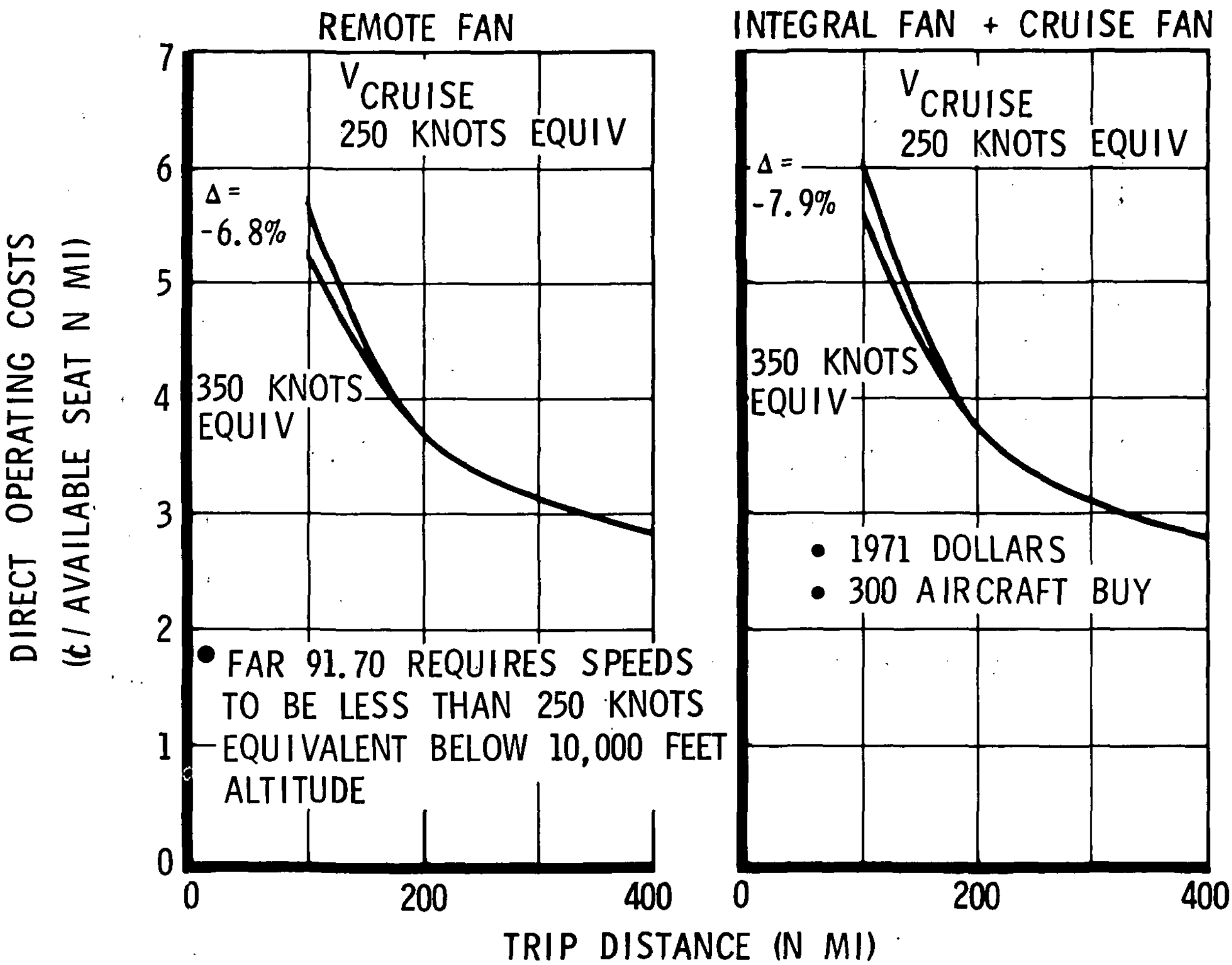


Figure 63. DOC Sensitivity to FAR 91.70

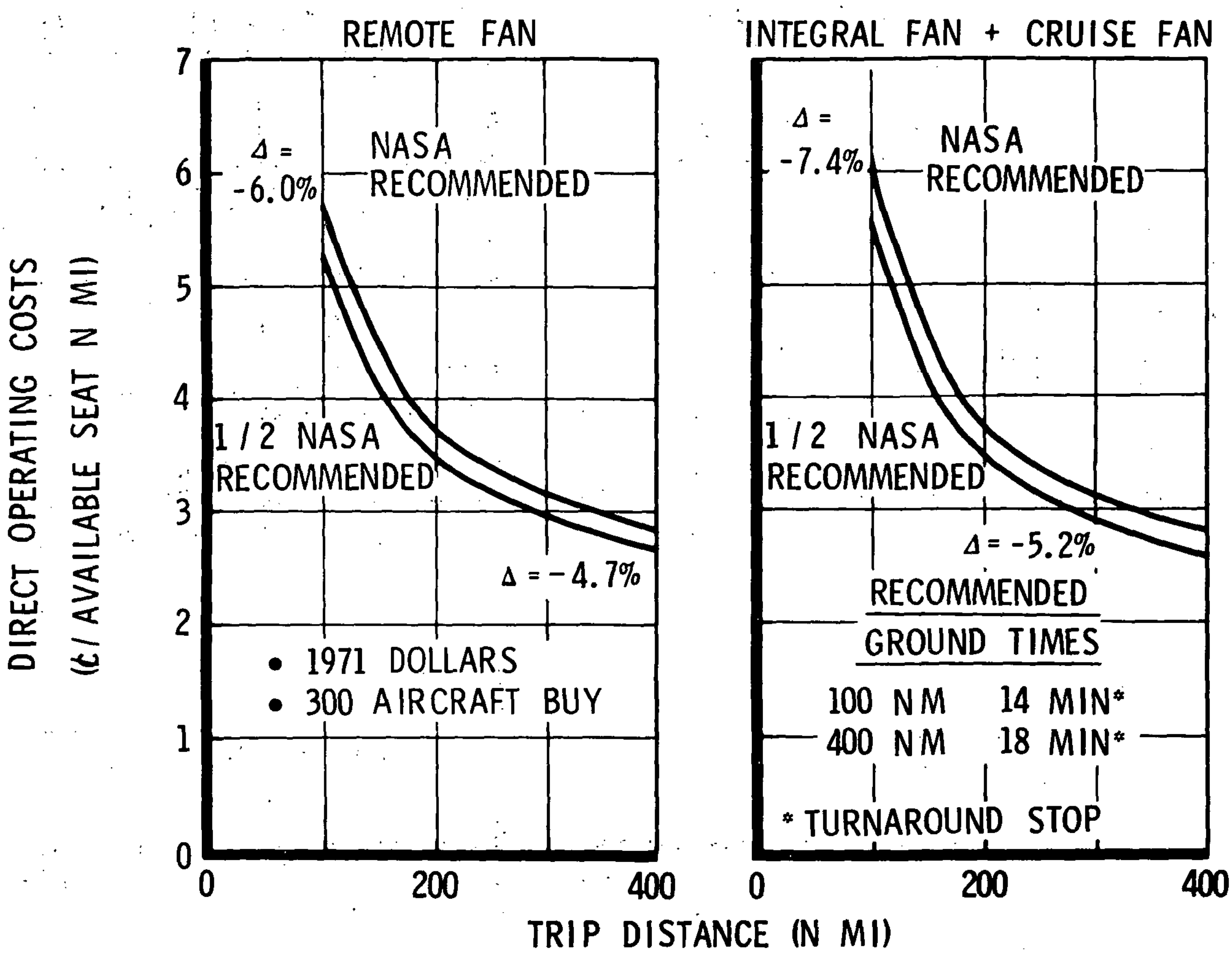


Figure 64. DOC Sensitivity to Ground Time

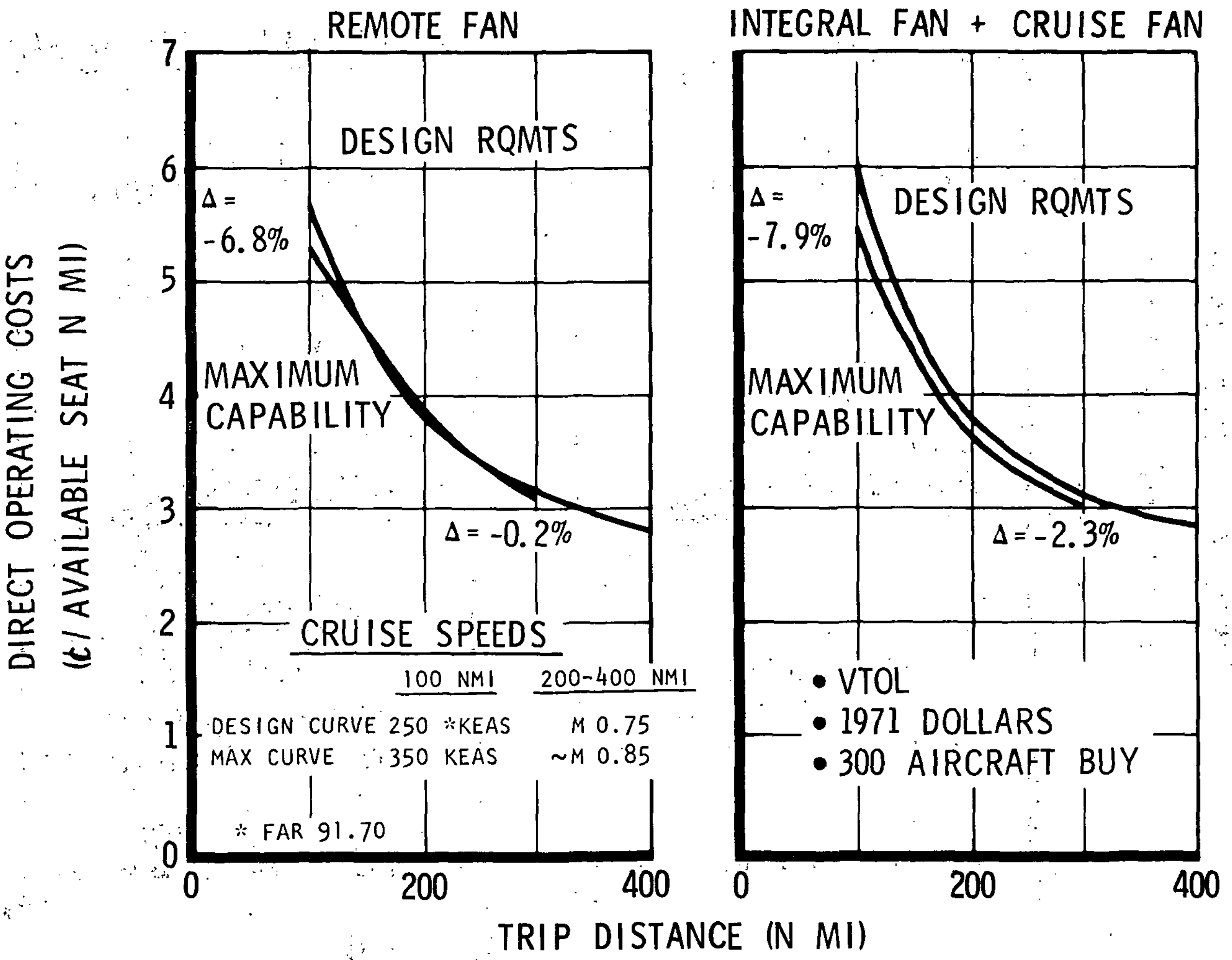


Figure 65. DOC Sensitivity to Operating Cruise Speed

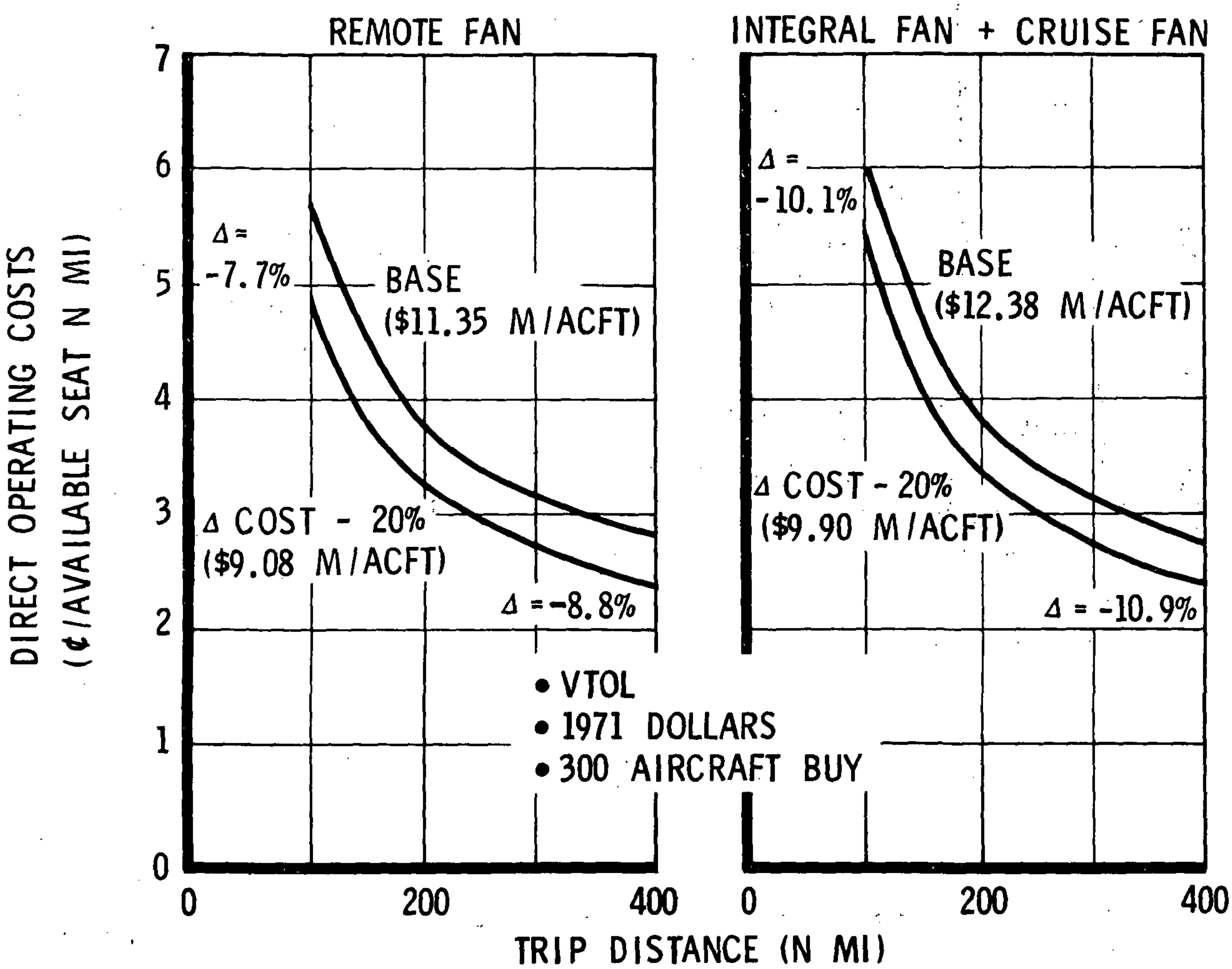


Figure 66. DOC Sensitivity to Aircraft Cost

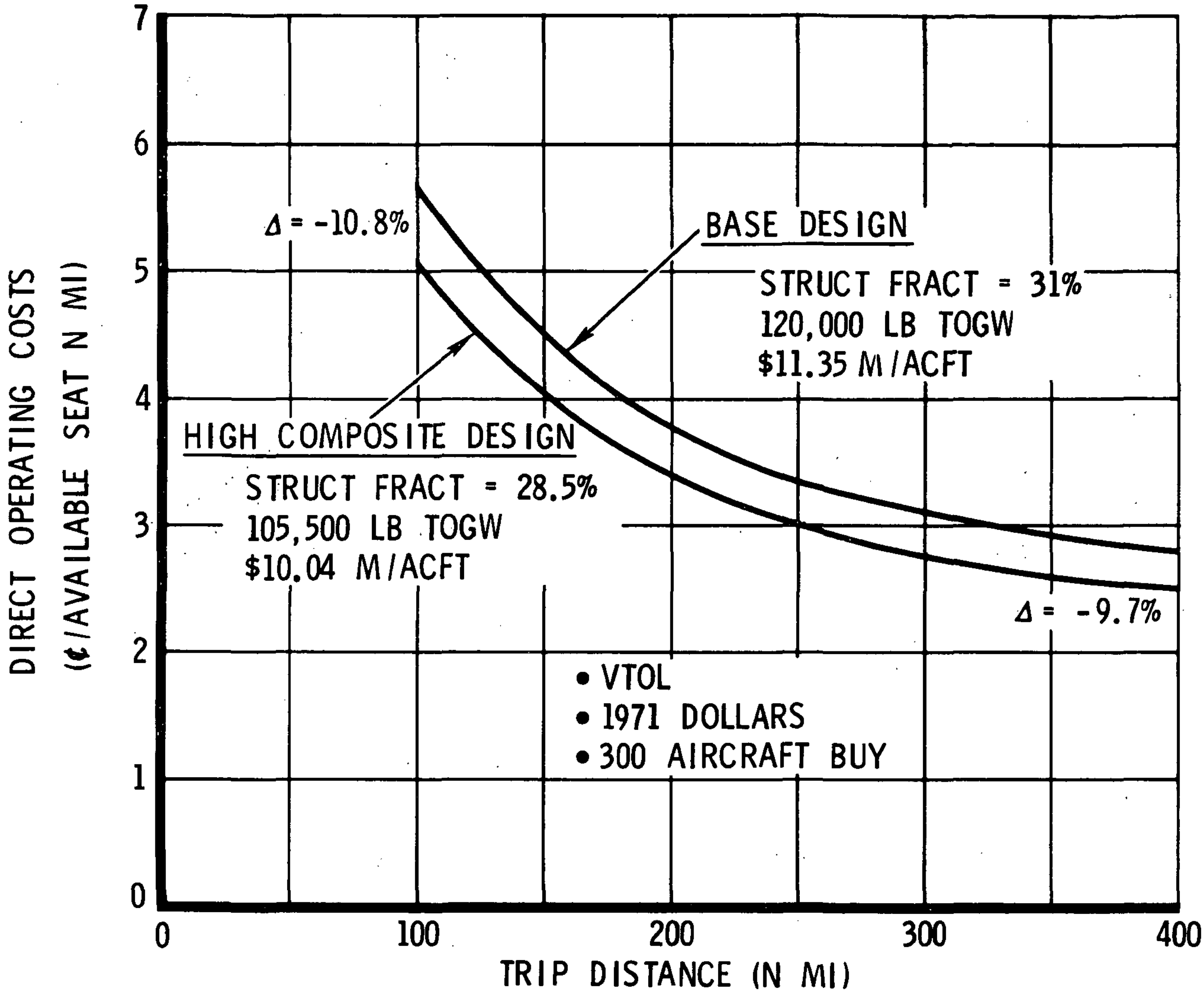


Figure 67. Remote Fan High Composite Design DOC's

Summary

The results of the commercial transport cost analysis are summarized in Table 12 . The $11.35 million cost per aircraft of the remote fan design represents 92% of the $12.38 million cost per aircraft of the integral fan plus cruise fan design. Direct operating costs for the VTOL mode decrease from about 6¢ to about 2.8¢ per available seat nautical mile for both designs for ranges from 100 to 400 nautical miles respectively. In the STOL mode, DOC's decrease from about 6.3¢ to about 2.4¢ per available seat nautical mile for trip distances of 100 and 800 nautical miles respectively for both designs.

Table 13 summarizes the results of the DOC sensitivity analysis discussed in the above section. Aircraft buy size can effect rather large savings in DOC's if the buy size change is appreciable, as reflected by an approximate 16% savings in DOC when buy size is increased from 300 to 600 aircraft. More extensive use of fiber glass type composites than was assumed in the baseline design can yield appreciable savings in DOC's if the design state-of-the-art will sustain this greater use of these materials. Aircraft cost is an important factor in direct operating costs and should methods be discovered to reduce these costs, the DOC's will also be appropriately lower. Reductions in ground time will also yield savings in DOC's as indicated by a 7% savings when reducing the ground times from about 16 to about 8 minutes. Relaxation of FAR 91.70 would result in 6% DOC reduction at short ranges only (100 nautical miles and less). When operating at design gross weight, the STOL mode of the V/STOL aircraft examined is operationally slightly more costly than the VTOL mode. Increasing operational cruise speed from Mach .75 to Mach .85 had very little effect on DOC's.

Conclusions

From the above cost analysis, it is observed that the initial investment cost for the aircraft operator for the remote fan V/STOL design is about 8% less than for the integral fan plus cruise fan design as reflected in the aircraft costs. The DOC's of the two designs are almost identical for the buy size of 300 aircraft examined. It is therefore concluded that the remote fan design is more economically viable than the integral fan plus cruise fan design based on the two criteria of initial investment costs and direct operating costs used in this analysis. Whether either design would be economically successful in the 1980's time period was not determined as this was outside the scope of this study, but in any case the remote fan design should be the more economically viable of the two designs for the above reasons.

TABLE 12

COMMERCIAL TRANSPORT COST SUMMARY

		REMOTE	INTEGRAL FAN + CRUISE FAN	REMOTE / INTEGRAL
• AIRCRAFT COSTS (EACH)		$11.35M	$12.38M	92%
• DIRECT OPERATING COSTS (¢/AVAILABLE SEAT N MI)				
	DISTANCE (N MI)			
VTOL	100	5.68	6.06	94%
	400	2.83	2.79	101%
STOL	100	6.17	6.40	96%
	400	2.96	2.94	101%
	800	2.43	2.39	102%

TABLE 13

DOC SENSITIVITY SUMMARY

PARAMETER	MAGNITUDE OF CHANGE	APPROXIMATE DOC REDUCTION
A/C BUY SIZE	300 → 600	16%
MODE OF OPERATION	VTOL → STOL	6% (INCREASE)
FAR 91.70	APPLIES → DOES NOT APPLY	7% (SHORT RANGE ONLY)
GROUND TIME	~16 MIN → ~8 MIN	6%
OPERATIONAL CRUISE SPEED	M .75 → M .85	1%
A/C COST	DECREASE 20%	10%
HIGH COMPOSITE DESIGN	STRUCT FRACT 31% → 28.5%	10%

SELECTION OF THE MOST PROMISING DESIGN

Selection of the most promising design is based on the relationship of many factors some of which can only be evaluated qualitatively. The following paragraphs summarize primarily the differences between the integral lift fan/cruise engine and the remote fan aircraft attributable to the propulsion system concept and serve as a basis for the selection.

Design Characteristics

Integral Lift Fan Aircraft. - The eight engine aircraft has oversize lift/cruise engines which are sized by the cruise requirement. The use of two engine sizes permits the selection of an efficient cruise cycle for the lift/cruise engine. The forward fuselage mounted integral lift fan is designed with a pivoted swing-out mount located below the cabin floor, but design tradeoffs may show that volume limitations or fan exit ground proximity could require fixed fans in an extended fuselage section. The forward fuselage mounted lift fans combined with the large lift/cruise nacelle structure show approximately a 2% structural weight penalty over the remote fan aircraft. The configuration arrangement is constrained by the inflexibility of the integral lift fan installation. This is discussed in greater detail on the following pages.

Remote Fan Aircraft. - This configuration requires volume for four insulated hot gas cross-over ducts within the wing leading edge between the lift pods, and two ducts to the aft fuselage lift/cruise fans. Short additional ducts connected to emergency nozzles are also provided for use in event of a fan failure. The gas ducts, valves, and other system components must be designed with safety margins comparable to the primary structure. The cruise configuration requires the thrust of two lift gas generators in addition to the two lift/cruise fans, hence a cruise inlet and covergent nozzle are required for one gas generator in each lift pod. The torsional moments due to the lift pod loads impose a small wing weight penalty which combined with the additional cruise fuel required results in a 10% greater TOGW for the remote fan aircraft as compared to the integral lift fan aircraft. Considerable installation design versatility and flexibility is associated with the remote fan systems.

Performance

Integral Lift Fan Aircraft. - This aircraft has superior cruise performance due to selection of a representative engine cycle designed for cruise. The over-size lift/cruise engine is operated at part power on takeoff, hence the 500 ft. sideline noise level is essentially the same as the remote fan aircraft.

Remote Fan Aircraft. - The poor cruise performance of the remote fan aircraft is associated with the one engine cycle concept which forces a cruise mode on lift fans primarily designed for VTOL operation. The comparison shown in Figure 68 indicates that the specific fuel consumption of a remote system (two 189% cruise fans) is no worse than an integral fan system (four 192.8% ILF1A1 engines) except that two remote fans do not provide sufficient cruise thrust. The required cruise thrust is attained for the selected remote fan system by adding the thrust of two lift gas generators operating as turbojets. The resulting cruise performance (two 189% cruise fans plus two 89% turbojets), Figure 68 , shows a substantial SFC penalty. The cruise performance of the selected remote fan system is significantly worse than the selected integral system (two 144.6% GE 13/F6A1 engines), and therefore this aircraft requires a 5 1/2% to 7% larger fuel fraction to meet the VTOL and STOL range requirements.

Propulsion

Integral Lift Fan Aircraft. - The integral lift fan propulsion system is sized by a 23% higher thrust to weight ratio than the remote fan system to meet the cruise requirement. If the cruise condition were not critical for sizing, the integral lift fan thrust to weight ratio would still be 10% greater than the remote fan system to meet the failure condition in hover. The larger throttle controlled integral lift fans have a slower response rate in hover than the ETC/spoiler controls of the remote fans.

The integral lift fans are sensitive to inlet distortion and cross flow effects and may introduce operational problems during transition and steep descent flight.

In the development of an integral lift fan system for a specific application, the unit is difficult and expensive to modify for increased thrust when a change is desired for growth versions.

Due largely to lack of experimental and prototype data, the integral lift system is considered to involve appreciably greater technical risk than the remote fan system.

Remote Fan Aircraft. - The remote fan aircraft propulsion system is sized by the hover requirements to the lowest thrust to weight ratio (T/W* = 1.14).

The remote fans utilizing an ETC/thrust spoiling system for hover control will have a faster response than the throttle controlled integral lift fan system.

The 1.25 fan pressure ratio remote fans are relatively tolerant to flow distortion at the inlet, hence transition and steep descent flight should not present new problems.

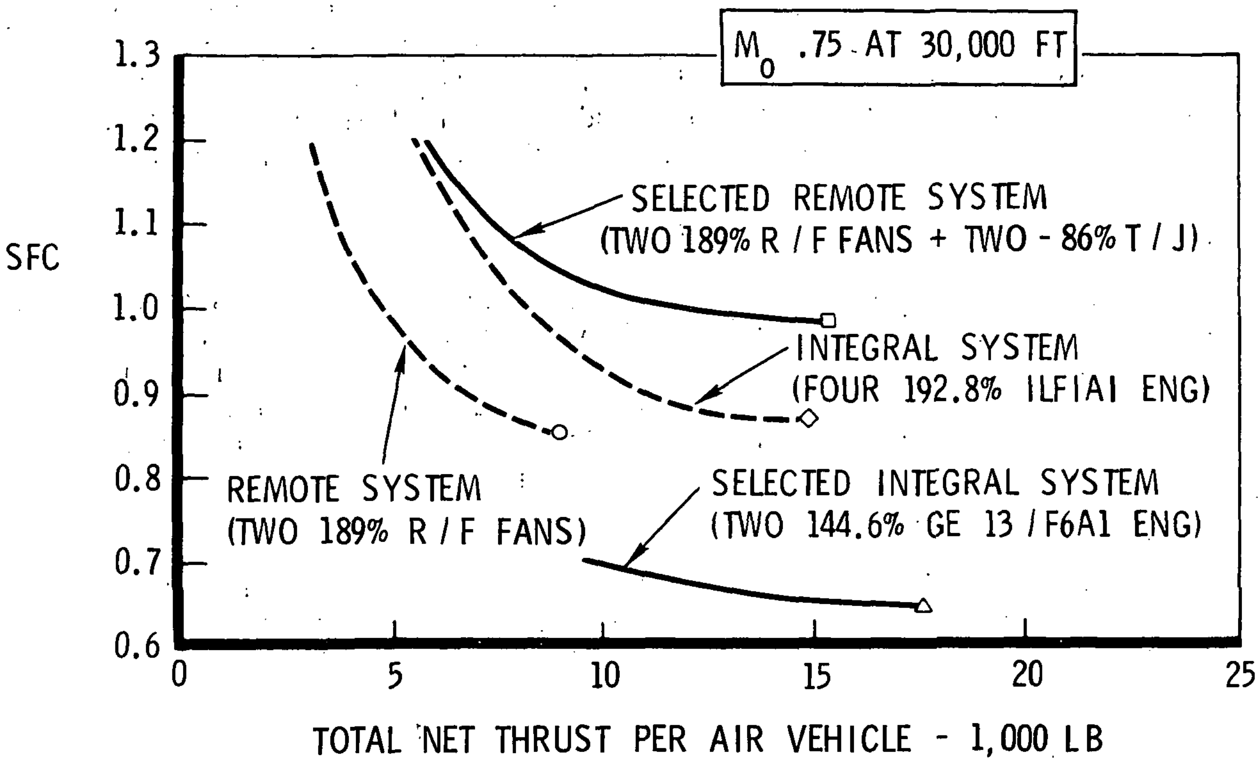


Figure 68. Typical Installed Cruise Engine Specific Fuel Consumption

Separation of the lift unit from the gas generator provides a degree of versatility and flexibility of arrangement as well as easier, more rapid, and less expensive resizing of the system for increased thrust or developing growth capability.

Existing prototype hardware and some flight test experience assures a lower technical risk for the remote fan system.

Economics

Integral Lift Fan Aircraft. - This aircraft is estimated to have a 9% greater initial cost if two engine programs are required. The superior cruise performance of this aircraft results in only a slightly lower (1% to 2%) DOC for the 400 to 800 N.Mi. trip distances, as compared to the remote fan aircraft. An additional 3% to 4% DOC reduction can be realized if the lift cruise fan development costs are reduced from $250 million to $50 million assuming this engine is developed and manufactured for another program but must be resized for the integral lift fan aircraft.

Remote Fan Aircraft. - The single engine concept assures the lower initial cost for the remote fan aircraft. This aircraft also shows 6% and 4% lower DOC than the integral lift fan aircraft when operating over the 100 N.Mi. trip distances on the VTOL and STOL missions respectively.

Selected Concept

All other factors being equal, the propulsion related considerations summarized in the preceding paragraphs indicate that the remote fan concept represents the preferred propulsion system for a 1980-1985 V/STOL lift fan commercial transport. This choice is influenced primarily by the lower technical risk associated with a propulsion concept that has been in development and flight test for at least 10 years. The application of a high bypass ratio turbofan engine to VTOL is still in the feasibility stages of development. The tolerance of the remote fan system to inlet distortion and cross flow effects, and the faster response rate are significant safety features during hover, transition and steep descent operation. The flexibility of propulsion system arrangement provides an additional advantage for the remote fan system.

CONCLUSIONS AND RECOMMENDATIONS

The application of three lift fan propulsion concepts to a 1980-1985 V/STOL commercial short haul transport has been investigated in this study. At an early stage in the study it was established that a remote fan system using turbofan gas generators and duct burning at the lift fan scroll inlet is less attractive than the remote fan/turbojet gas generator system due to complexity and propulsion volume required. The remote fan/turbojet aircraft is slightly heavier than the integral lift fan/cruise engine aircraft due to the additional fuel required by less efficient cruise performance.

It is concluded that the remote fan/turbojet gas generator propulsion concept offers the most promising approach for commercial V/STOL operation. Although this aircraft requires additional cruise thrust from two lift gas generators operating as turbojets with the associated penalty in cruise efficiency, the direct operating costs show only a slight penalty for trip distances over 400 nautical miles as compared to the integral lift fan/cruise engine aircraft. This comparison includes the development cost of two engine programs for the integral lift fan/cruise engine aircraft. The remote fan system is preferred due to flexibility of configuration arrangement and reduced technical risk.

It is also concluded that a V/STOL commercial transport combining the best features of the remote fan system for takeoff through transition, and an efficient cruise engine cycle for the conventional flight mode would provide the best propulsion concept for this application. A suitable cruise engine cycle which could be combined with the remote fan concept is considered to be a feasible and desirable approach, but was not within the scope of the present study. Such a propulsion system could reduce the takeoff gross weight to equal or less than the integral lift fan aircraft.

Reduction in direct operating costs is shown to be sensitive to the amount of composite materials used in the aircraft structure, hence future developments in this discipline have potential payoff.

Aircraft noise levels exceed the guideline requirements, and are comparable for both propulsion concepts, but the goals appear achievable and more development work directed in this area is needed for V/STOL acceptance into commercial operation.

Additional design effort is also required to expand the acceptable ride quality envelope to include higher speeds at the lower altitudes.

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