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CONCEPTUAL DESIGN STUDIES OF CANDIDATE V/STOL LIFT FAN COMMERCIAL SHORT HAUL TRANSPORT FOR 1980-85 V/STOL LIFT FAN STUDY

by W. M. Eldridge, J. A. Ferrell, J. W. McKee, J. F. Wayne, Jr., and J. M. Zabinsky

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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, aircraft mass properties, cruise performance, noise and ride qualities evaluation. Economic evaluation was also studied on a basis of Direct Operating Costs and route structure.

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CONCEPTUAL DESIGN STUDIES OF CANDIDATE V/STOL LIFT FAN COMMERCIAL SHORT HAUL TRANSPORT FOR 1980-85 V/STOL LIFT FAN STUDY

THE BOEING COMPANY
SEATTLE, WASHINGTON

SUMMARY

Conceptual designs of V/STOL Lift Fan Commercial Short Haul Transport aircraft for the 1980-1985 time period were studied with a view toward determining technical and economic feasibility.

A large family of aircraft were examined using a design payload of 100 passengers, a VTOL mission range of 400 n. mi. and a STOL range of 800 n. mi. Three basic propulsion concepts formed the nucleus around which the configurations were developed. These concepts were: (1) integral lift fan engines; (2) remote (tip driven) lift fans; and (3) variable-pitch shaft driven prop fans.

Examples of each type of aircraft are presented in Figure 1. The first is an integral fan engine design using lift fans for cruise. The second is powered with remote fans requiring four to meet cruise requirements. The third uses shaft connected prop fans for cruise power.

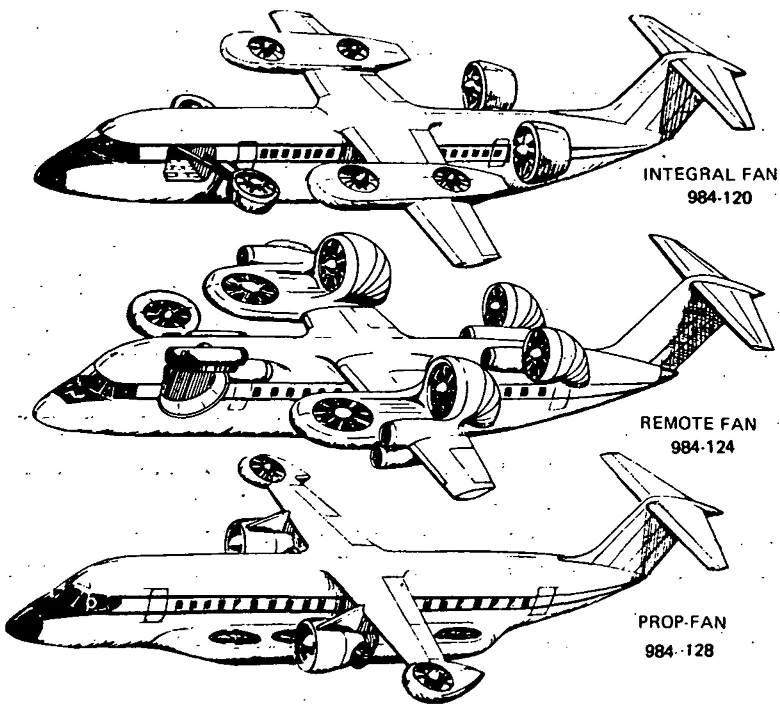


FIGURE 1 1980-85 V/STOL TRANSPORTS

In order to study the effect of engine cycle, a parametric investigation of the integral lift fan was made. The parameter matrix was:

Bypass ratio	6, 8, 10, 12
Fan pressure ratio	1.3
Turbine entry temperature	2800° R, 3000° R
Compressor pressure ratio	8
Overall pressure ratio	10.4

Consideration of overall airplane performance and noise resulted in the integral fan engine parameters presented on Table 1. This table also contains a summary of the characteristics of the other propulsion systems used.

TABLE 1 ENGINE CHARACTERISTICS SUMMARY

	OPERATING CONDITIONS					
	MAX. CONTROL (MC) - FULL POWER TRANSFER SEA LEVEL, M = O				CRUISE M = .75; 25,000 FT.	
ENGINE TYPE	BPR	T & LIMITING CONDITION DEG R	R_F	$R_{OVERALL}$	$\frac{F_n}{F_{G_{MC@SL}}}$	SFC LB/HR/LB
INTEGRAL LIFT FAN (M)	12.7	3000, TURBINE ENTRY	1.31	10.2	0.239	0.75
REMOTE LIFT FAN (RLFA) (TIP TURBINE DRIVE)	10.6	2060, SCROLL ENTRY	1.3	2.0	0.205	0.837
CRUISE FAN (P)	12.0	3000, TURBINE ENTRY	1.33	20.8	0.248	.655
VARIABLE PITCH PROP/FANS						
LIFT/CONTROL	–	–	1.18	–	–	–
LIFT/CRUISE	–	–	1.23	–	0.354	0.649
TURBOSHAFT ENG	0	3000 TURBINE ENTRY	–	20.0	–	–

Ten configurations were selected for comparative purposes. Figure 2 shows the relationship of the designs. An attempt was made to use the basic lift engines for cruise power as well as lift. Since the lift engines are relatively poor cruise devices, some designs require four engines for cruise, other have lift systems sized by cruise thrust requirements, and others are mixed engine designs with lift fan and cruise fan engines. Additional trades led to an evaluation of the merits of interconnecting gas generators (remote fans) and six to eight engine arrangements.

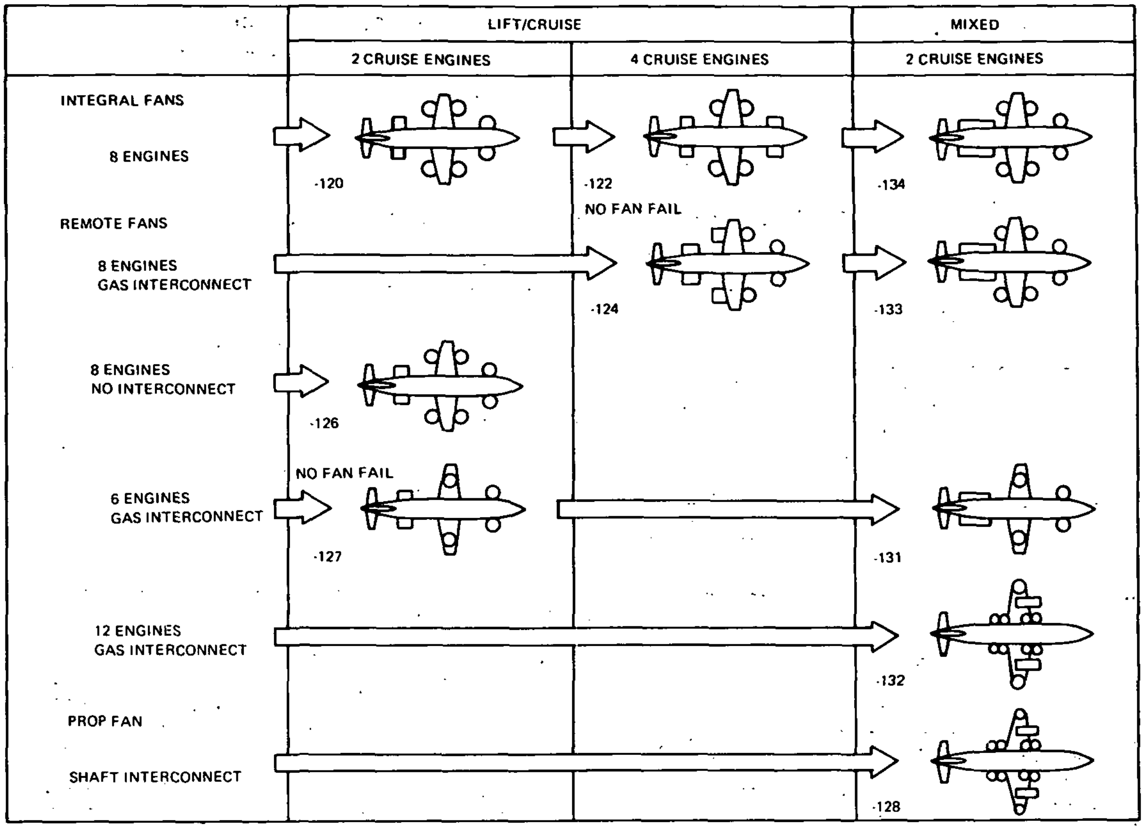


FIGURE 2 DESIGN EVOLUTION

The aircraft were developed based on assumed advancements over present state-of-the-art. Turbine entry temperatures of 3000° R and uninstalled thrust to weight ratio 12:1 were used for the integral fan engines, for example. Airplane weights were consistent with the use of graphite composites and advanced construction techniques such that approximately a 9 percent reduction in OEW over current practice was realized. Advanced airfoil technology allowed use of unswept wings with relatively thick sections for 0.75M cruise.

Table 2 summarizes the major characteristics of each aircraft. The following conclusions can be drawn:

- The prop fan and integral fan aircraft are significantly lighter than remote fan designs.
- The airplane with interconnected remote fans, the 98-124, is 10,000 lb lighter than the airplane with noninterconnected remote fans, the -126. This advantage results, in part, from designing without consideration of fan failure. Designing the interconnect system for fan failure through use of emergency jet nozzles reduces the advantage by about 2000 lb.

- The thrust match for eight-engine airplanes, with two engines for cruise, is dominated in all cases by the cruise requirement. On each of these airplanes, the total installed thrust is greater than that required for takeoff and landing.

TABLE 2 COMPARISON OF SIZED CONFIGURATIONS

COMPARISON OF SIZED CONFIGURATIONS

- 400 N. MI. VTOL MISSION
- 20,000 LB. PAYLOAD
- .75 MACH CRUISE

FAN DRIVE	MODEL 984-	TOGW LB	OEW LB	SIZED BY TAKEOFF REQMT. $(F_n/W)_{T.O.}$ REQ'D	LIFT NO.	LIFT $F_{n\,T.O.}$ ~ LB	CRUISE NO.	CRUISE $F_{n\,T.O.}$ ~ LB	SIZED BY CRUISE REQMT. $(F_n/W)_{T.O.}$ AVAIL	LIFT NO.	LIFT $F_{n\,T.O.}$ ~ LB	CRUISE NO.	CRUISE $F_{n\,T.O.}$ ~ LB	NO. OF GAS GENERATORS
INTEGRAL	120	116,700	82,600	1.47	–	–	–	–	1.67	6	24,400	2	24,400	
	122	113,500	77,300	1.49	4	21,200	4	21,200	–	–	–	–	–	
	134	110,200	78,100	1.47	6	20,300	–	–	1.55	–	–	2	24,900	
REMOTE GAS INTER-CONNECTED (EXCEPT -126)	124	132,400	91,500	1.26	4	20,900	4	20,900	–	–	–	–	–	8
	133	128,800	93,600	1.32	6	21,250	–	–	1.49	–	–	2	32,200	6
	126	142,400	99,900	1.44	–	–	–	–	1.47	6	26,200	2	26,200	8
	127	131,600	92,500	1.26	4	27,600	2	27,600	–	–	–	–	–	6
	131	133,200	97,800	1.38	4	30,700	–	–	1.41	–	–	2	32,500	4
	132	130,600	94,400	1.18	10	12,850	–	–	1.51	–	–	2	34,500	5
PROP FAN SHAFT INTER-CONNECTED	128	110,100	78,200	1.10	10	11,600	–	–	1.38	–	–	2	18,400	5

V/STOL transport initial cost is expected to be twice to three times that of conventional jet transports of about the same size. This increase is almost entirely due to propulsion cost. On conventional aircraft the propulsion system is about 15 percent of the cost and for V/STOL airplanes it is about 50 percent.

Direct operating costs in cents-per-seat mile are plotted on Figure 3. The costs fall into three groups with the prop fan and remote fans being the lowest and highest respectively. A comparison of V/STOL and conventional aircraft direct operating costs shows that at an average range of 240 n. mi., the best of the V/STOL designs (prop fans) are about 30 percent higher than some of the conventional twins.

It may be possible to improve in areas contributing to direct operating costs. Sensitivity studies were accomplished to determine the leverage of items such as maintenance costs, utilization and air maneuver time on direct operating costs. The items of maintenance, initial cost and utilization have the greatest leverage.

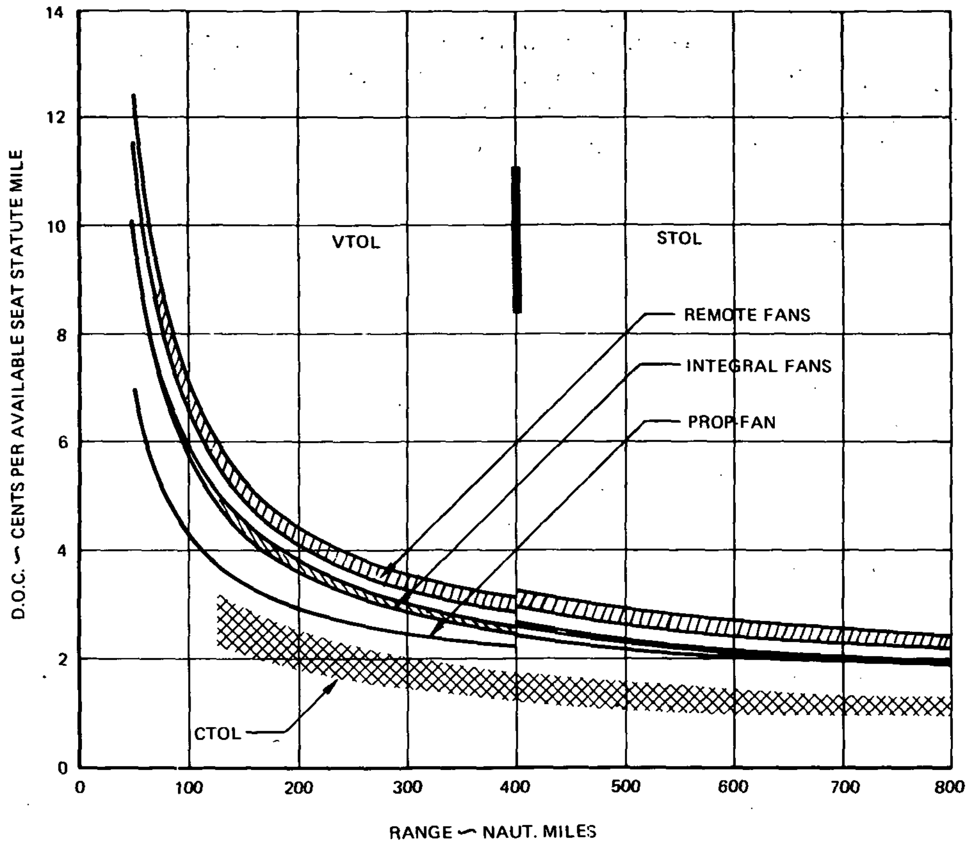


FIGURE 3 DIRECT OPERATING COST SUMMARY

The following conclusions were reached as a result of this study:

- Integral fan and prop fan aircraft are the most promising.
- Integral fans probably require less development.
- V/STOL aircraft can be reasonable in size if structures technology is realized.
- Sideline noise at 500 ft can be about 95 PNdB.

- Aircraft cost will be approximately twice that of similar sized conventional twins.

- DOC's will probably be 30 to 60 percent higher than conventional twins of similar size at an average mission length of 240 n. mi.

- The development of V/STOL aircraft will probably not occur until an economic study, which includes all the factors of the system, (including real estate, access, terminals, navigation aids, fare structure, etc.) shows a favorable situation compared to alternate means of providing transportation.

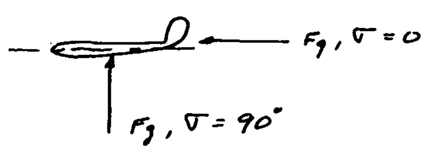
SYMBOLS

A_{DES}	design nozzle area - ft^2
A_F	fan nozzle area - ft^2
A_P	primary nozzle area - ft^2
A_{prim}	primary nozzle area ratio - A_P/A_{DES}
A_{sec}	fan nozzle area ratio - A_F/A_{DES}
AIA	Aerospace Industries Association
ATA	Air Transport Association
BPR	engine bypass ratio - $\frac{W_e}{W_p}$
C_D	drag coefficient - D/q s
C_L	lift coefficient - L/q s
C_{D_M}	drag coefficient increment due to Mach No.
C_{D_O}	zero lift drag coefficient
C_{D_i}	drag coefficient due to elliptical lift distribution
ΔC_{D_p}	drag coefficient due to lift correction for camber and nonelliptical lift distribution
c.g.	center of gravity
CTOL	conventional takeoff and landing
D	drag - pound
DOC	direct operating cost - cents per available seat statute mile
F	thrust - pounds
F_g	gross thrust - pounds
F_{gmc}	gross thrust at max control rating - pounds

F_{mc}	thrust at max control rating - pounds
F_n	net thrust - pounds
F_{net}	net thrust - pounds
F/W	thrust-weight ratio
HP	horsepower
ILF	integral lift fan
Ix, Iy, Iz	moments of inertia - slug ft^2
I_{xz}	cross product of inertia - slug ft^2
L	lift - pounds
$\mathcal{L}$	rolling moment - foot/pound
LRC	long range cruise speed. The higher of two speeds at which 0.99 best NAM/ pound is achieved.
M	Mach number
M	pitching moment - foot-pound
MAC	mean aerodynamic chord
N	number of engines
n	yawing moment
NAM/Lb	nautical air miles per pound of fuel
OEW	operating weight empty - pound
PNL	perceived noise level
PNdB	perceived noise level - dB re 20 micronewtons/$meter^2$

q	dynamic pressure - pound/ft^2
R_F	fan pressure ratio
$R_{overall}$	fan + compressor pressure ratio
S	wing or reference area - ft^2
SAS	stability augmentation system
SFC	specific fuel consumption - $\frac{\text{pound/hour}}{\text{pound}}$
STOL	short takeoff and landing
T	temperature
TAS	true air speed
TET	turbine entry temperature
t/c	thickness - chord ratio
TOGW	takeoff gross weight
V_{AP}	approach speed
V_1	critical decision speed
V_{LOF}	liftoff speed
V_{MCA}	minimum control speed in the air
V_{MCG}	minimum control speed on the ground
V_{MIN}	minimum flying speed
V_R	rotation speed
V/STOL	vertical/short takeoff and landing
VTO	vertical takeoff
VTOL	vertical takeoff and landing

VTOGW	vertical takeoff gross weight - pound
W	weight - pound
W_{AT}	total engine airflow - pound/sec
We	fan airflow - pounds/sec
W_f	fuel flow - pounds/hour
W_p	primary air flow - pounds/sec
W/S	wing loading - pounds/ft^2
α	angle of attack
β	elevation angle between the noise source and a sideline listening point.
γ	flight path angle
θ	pitch angle
$\Lambda_{c/4}$	sweep of the quarter chord line
¢/ASM	cents per available seat statute mile
σ	gross thrust vector angle relative to the horizontal body reference line. When the thrust is horizontal and forward, $\sigma = 0$. When the thrust is vertical and up, $\sigma = 90^o$.



ϕ	roll angle
ψ	yaw angle

1.0 CONCEPTUAL DESIGN AND INTEGRATION

Aircraft representing the commercial V/STOL transport for the 1980-1985 time period are designed to carry 100 passengers, cruise at M = 0.75 or at an equivalent speed of 350K (whichever is less) and use various propulsion types and combinations of these types. They are all designed for a maximum perceived noise level of 95 dB at the 500-ft sideline. The engines used are remote tip turbine driven lift and cruise fans, integral lift and cruise fans and prop fans. Only the remote fans and prop fans could be interconnected to represent a no fan failure case. The interconnection also permitted power transfer in the control loop. These engines all reflect the state of the art as it is expected in the 1980-1985 time period.

The aircraft are all sized to a basic VTO mission of 400 n. mi. The STOL mission at 800 n. mi. was less stringent from a power matching standpoint.

The configuration variations were made to evaluate the various propulsion concepts and arrangements. Variation of the low speed aerodynamics was not pursued in detail; all the airplanes have a similar flap configuration and the lift characteristics vary due to configuration effects and wing-loading. The maximum wing-loading was limited to 150 psf from consideration of maneuver margin and buffet.

It is Boeing's design philosophy that fan failure is sufficiently probable that the design must account for fan failure as completely as for engine failure. For comparison, NASA asked that Boeing design at least one airplane based on the assumption that fans would not fail.

1.1 Technology and State-of-the-Art

The technology level used in designing these aircraft is based on anticipated 1980-1985 state-of-the-art. Specific technology regarding aerodynamics, propulsion, structures and weight, and noise are contained in the following paragraphs.

1.1.1 Aerodynamic Technology

The airplanes are designed to a maximum wing-loading of 150 lb/ft^2. This is estimated as an upper bound at which a buffet-free maneuver margin is available at cruise speed and altitude. The wing and empennage airfoil sections are representative of the supercritical technology expected by 1980-85. Using a straight wing of relatively thick section, the anticipated airplane drag rise characteristics are shown on Figure 4.

The low speed aerodynamic systems are current state-of-the-art. Advanced high lift systems do not greatly benefit V/STOL airplanes.

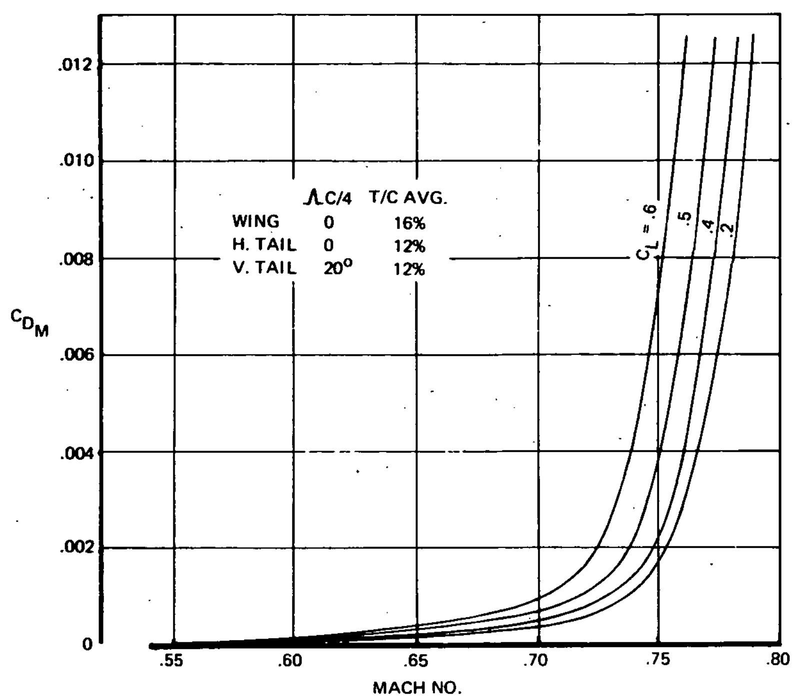


FIGURE 4 DRAG RISE

1.1.2 Propulsion and Noise Technology

The study of 1980-1985 airplane designs considered use of various propulsion concepts. Propulsion concepts included integral lift fans, remote lift fans, prop fans, and cruise fans. Some airplane designs used lift fans for both lift and cruise, and on other designs, cruise engines were added which were also used for lift. A range of cycle variables was investigated. The final selection was influenced by the noise characteristics as much as by performance. The state-of-the-art considered applicable for the 1980-1985 time period is used. To achieve both a cruise capability of M = 0.75 and a 500-ft sideline noise level of 95 PNdB, the following engine systems were selected for the 1980-1985 commercial concepts.

The integral lift fan has a bypass ratio of 12.7 with a fan pressure ratio of 1.31 at the maximum control power setting. At the noise rating point the pressure ratio is below 1.25. The performance, weight, and noise characteristics were coordinated with General Electric.

For the 1980-1985 time period, a turbine entry temperature of 3000° R is used as a nominal standard day sea level maximum. Flat rating to a 90° F day is assumed feasible. Integral lift fans with an overall pressure ratio of about 10:1 will have uninstalled thrust weight ratios as shown on Figure 5.

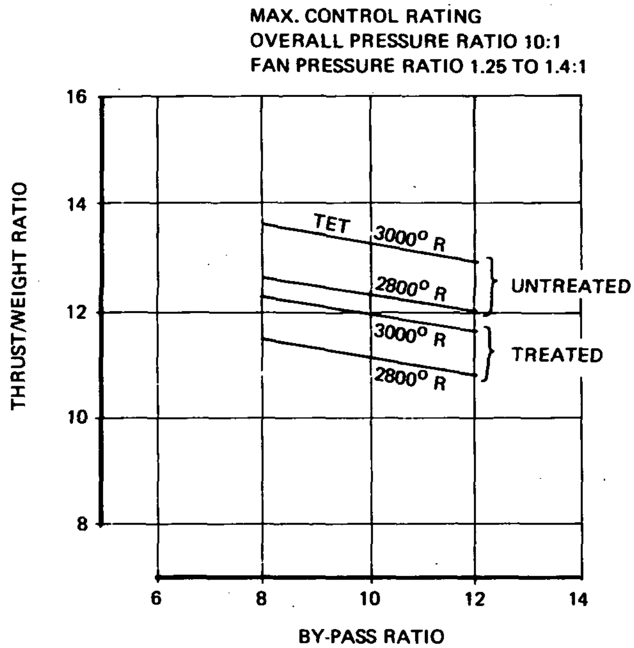


FIGURE 5 INTEGRAL LIFT FANS THRUST/WEIGHT RATIO

Engines with overall pressure ratios of about 20 will have thrust-weight ratios as shown on Figure 6.

The integral lift fan and cruise fan performance is presented in Appendix A.

The remote lift fan system was used as received from General Electric. The fan has a design pressure ratio of 1.25. Under conditions of maximum power transfer, the fan pressure ratio increases to 1.3. These gas driven tip turbine fans have duct and scroll temperature limits of 2060° R. The weights of the fans and gas generators were estimated using the data on Figure 7 which shows uninstalled thrust weight ratios for the fans and fans plus gas generators.

The remote lift fan performance is presented in Appendix A.

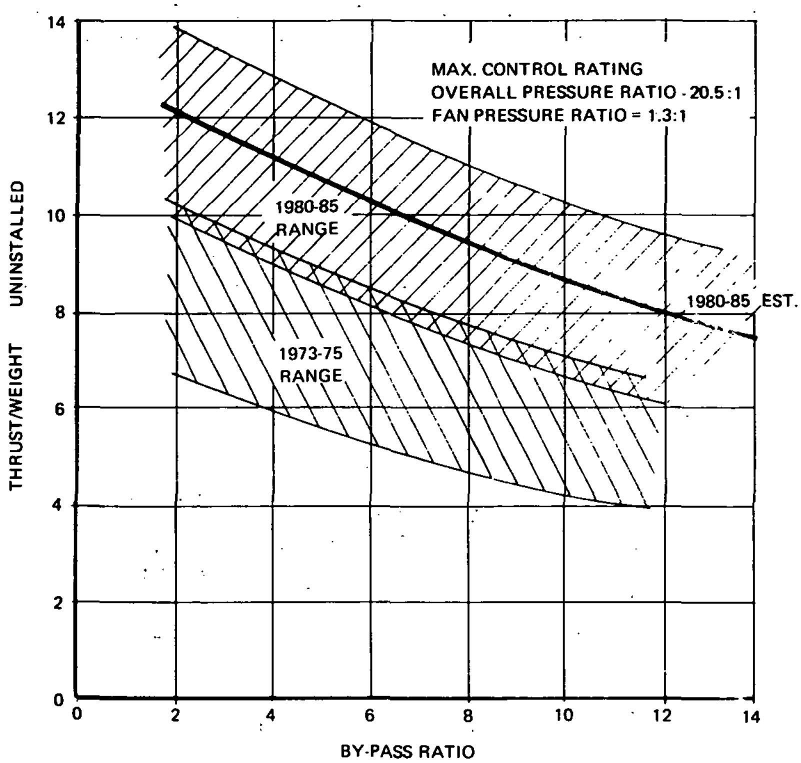


FIGURE 6 CRUISE TURBOFANS THRUST/WEIGHT RATIO-UNINSTALLED

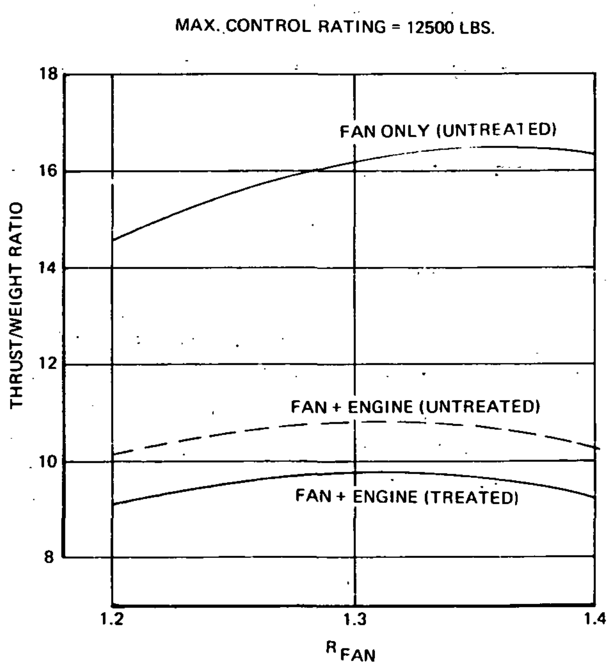


FIGURE 7 REMOTE LIFT FANS THRUST/WEIGHT RATIO

The prop fan performance, weight, and associated data were generated in concert with the Hamilton Standard Company. During takeoff and landing, the prop fans operate at pressure ratios of approximately 1.25 or less. They are designed to operate over a range of power input at constant rpm. These variable pitch fans were developed for configuration -128 and represent specific point designs. Two fans were designed: a lift control fan and a lift cruise fan. A single gas generator size is used throughout the airplane and the fans are designed to absorb a proportionate share of this power.

At maximum control, the lift control fans will operate at pressure ratio 1.18. They are designed to absorb 3/8 of the power of a gas generator with no control.

The cruise lift fans have a double design point. The variable pitch capability permits efficient operation with two power levels; one for takeoff and landing and one for cruise. The arrangement of -128 is such that during takeoff and landing each cruise fan takes 5/8 of the power from a gas generator and during cruise it uses the full power from the same gas generator. During takeoff and landing, the cruise fan has a pressure ratio of 1.23.

The performance characteristics are presented in Appendix A.

Noise technology for the 1980-85 time period assumes the development of suppression treatment techniques which together with good design will permit achievement of the goal of a sideline perceived noise level, at 500 ft of 95 PNdB. To this end, the fans are designed to operate during takeoff, landing, and associated low speed flight at pressure ratios 1.25 or less. In addition, a primary-to-fan exhaust velocity ratio of 1.3 or less is a design feature; this capability is achieved by the use of a two-position nozzle on the fans which are used for cruise as well as lift. When louvers are used in the fan exhaust, they are treated to suppress noise.

1.1.3 Structures-Weight Technology

The weights of these airplanes depend on a structural technology advancement that will occur in three steps or levels. The third level for 1985 is assumed to produce a 16 percent reduction in structural weight with a resulting reduction in operational weight empty of 9 percent from current techniques.

Level 1 technology introduces boron or graphite fibers in an epoxy matrix. This material will have approximately twice the strength of aluminum, stiffness equaling that of steel and a density less than aluminum. The high stiffness-to-density ratio is particularly advantageous in wing structure where weight savings derived from increased strength will not be penalized by the stiffness required to prevent flutter. An operational empty weight reduction of 3 percent is possible and could be available in 1979.

Level 2 technology calls for additional development of the material. It will permit a reduction in operational empty weight of approximately 5 percent in 1981. The introduction of cross-ply reinforcement will allow the tailoring of axial strength and stiffness in relation to shear strength and stiffness according to static or dynamic requirements. This is accomplished by adding more fibers in the direction of required strength or stiffness and allows a more efficient use of structural weight. The metal which is reinforced provides some strength and protects the composite from exposure to damage and weather.

Level 3 technology, which is assumed available for these designs, is another step in the use of fiber-composite material. Composite components are used in all heavily loaded primary structure to take full advantage of light weight, high strength fibers in large areas of sandwich as well as semimonocoque structure. Use of metal, with its lower strength and higher density, can be held to a minimum at this development stage. The ability to vary the quality and direction of fibers in the composite will be highly developed.

This technology development is summarized in Table 3.

TABLE 3 ADVANCED COMPOSITE TECHNOLOGY

TECHNOLOGY	DEFINITION	AVAILABILITY DATE
LEVEL 1	UNIAXIAL REINFORCED PRIMARY STRUCTURE - BORON - EPOXY SECONDARY PANELS - PRD 49 FIBER SECONDARY CONTROL SURFACES - GRAPHITE EPOXY ALL COMPOSITE COMPONENTS	1979
LEVEL 2	ADD MULTIDIRECTIONAL REINFORCEMENT CAPABILITY - BORON - EPOXY ALL CONTROL SURFACES - GRAPHITE - EPOXY ALL COMPOSITE COMPONENTS	1981
LEVEL 3	ADD CAPABILITY FOR ALL COMPOSITE PRIMARY STRUCTURE COMPONENTS - GRAPHITE - EPOXY	1985

Weight reductions of subsystems and fixed equipment for advanced technology are included in the 1985 weight analysis. The primary areas of improvement are expected to be flight controls, electronics, furnishings, secondary power systems and standard and operational items of useful load.

The effect of technology level on airplane weight is illustrated in Figure 8. This figure shows operational empty weight as a function of maximum vertical takeoff weight.

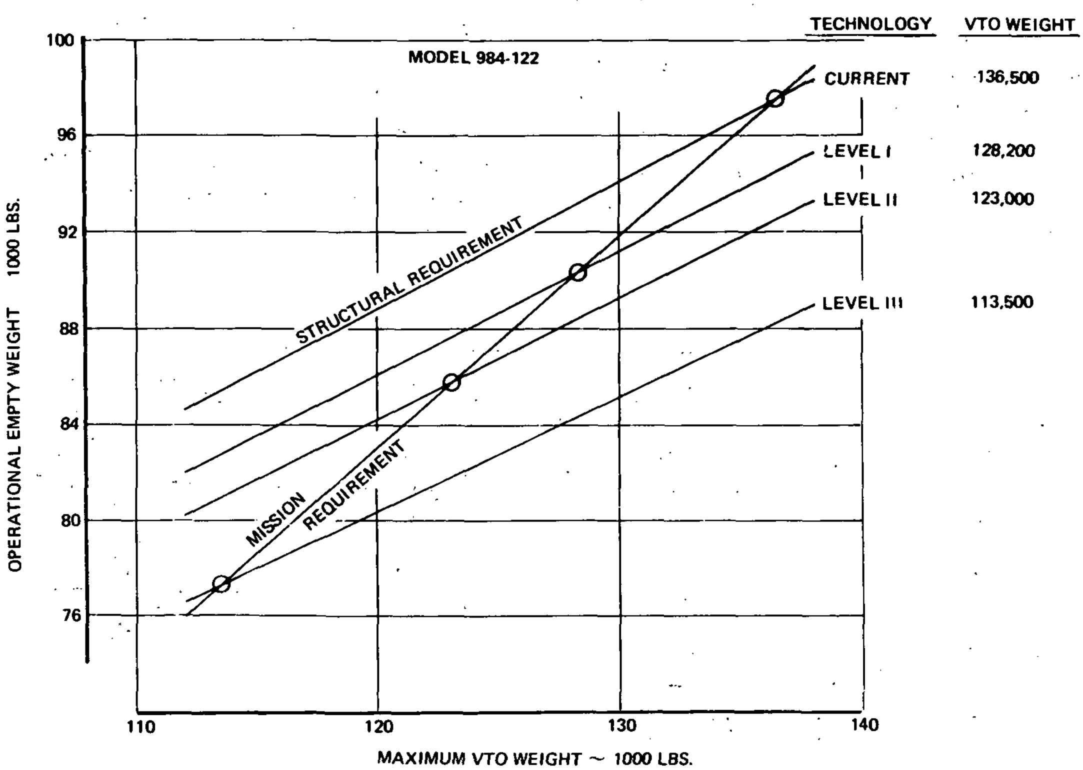


FIGURE 8 WEIGHT TECHNOLOGY

The variation of OEW with VTOGW which characterizes the particular design is shown as the line of mission requirement. Other lines showing the effects of technology on OEW are marked structural requirement. The intersection of these lines defines the matched OEW and VTOGW at a particular state-of-the-art. For this study, the airplane developed to 1985 technology will have a VTOGW of 113,500 lb; whereas with current technology, it would have weighed 136,500 lb.

1.2 Concept Development

The airplanes designed during this study were conceived in terms of the propulsion system. The types of propulsion considered were integral lift fans, remote lift fans, prop fans, and conventional cruise fans. Airplanes were designed using all these propulsion concepts. As the designs developed, ten were chosen for sizing and matching. The relationship among these ten designs is shown on Figure 9.

Development of the designs with a specific propulsion system are arrayed horizontally. The vertical array shows the features that are comparable among the propulsion concepts. For instance, the top line has the integral lift fan designs. These are by their nature not interconnected. The first slot contains an eight-engine airplane of which two are used in cruise. The second position has a similar design with four engines for cruise, and the third is another variation using a mixed engine installation consisting of six integral lift fans and two conventional cruise fans. In the discussion which follows, reference to this figure will help in the comparisons.

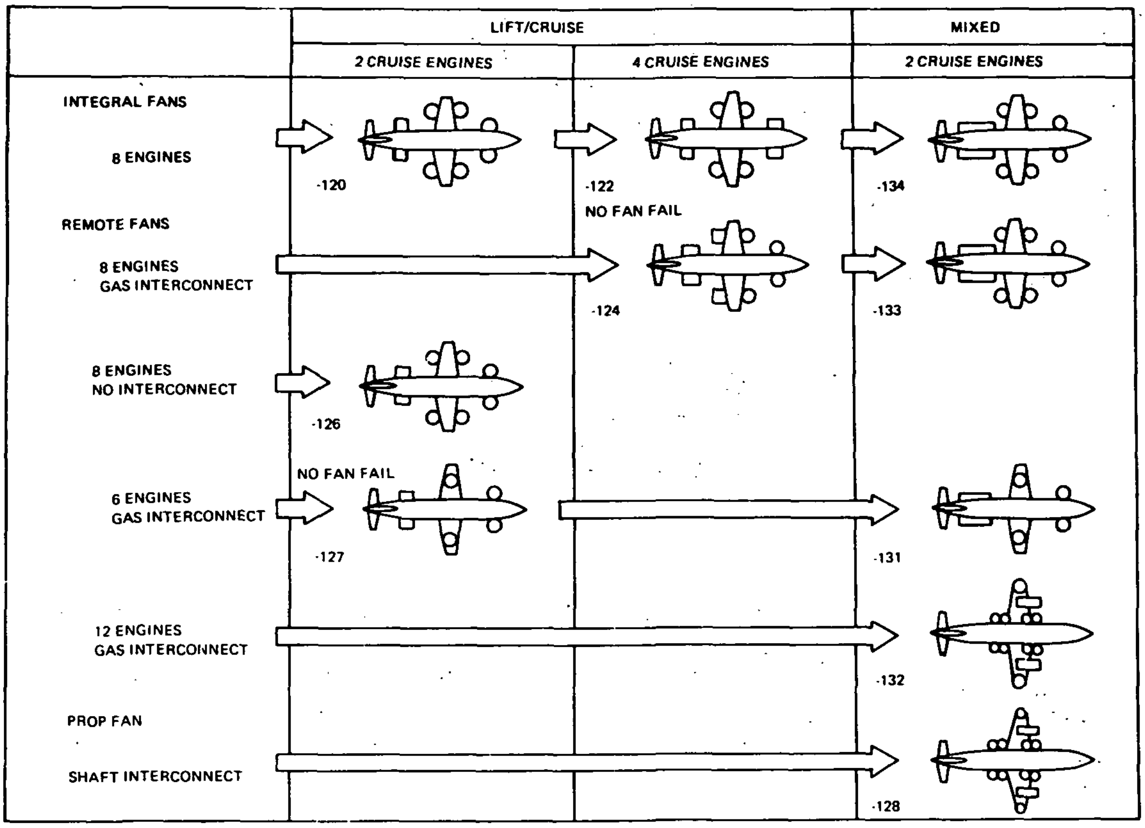


FIGURE 9 DESIGN EVOLUTION

1.2.1 Airplane Sizing and Matching

The configurations were all initially designed for a VTO weight of 115,000 lb. The initial variation in size among these designs stems from the propulsion system installation requirements. This initial or reference design of each concept is then matched to the requirements of takeoff and cruise.

The takeoff thrust required includes margins for both angular and vertical accelerations. The specific criteria are detailed in Appendix B. The cruise thrust criterion is that the airplane be able to cruise above 20,000 ft at M = 0.75. After the propulsion system is matched to the more stringent of these requirements, it is scaled to the VTO mission. The mission is summarized on Figure B-1 in Appendix B.

1.2.2 Configuration Descriptions

Ten configurations are used to represent the design evolutions. These configurations are all conceptual designs. The assumptions leading to weight and size determination are consistent for all the designs. The three basic systems upon which these designs depend are propulsion, flight control and electronic.

The propulsion subsystem contains the engines and associated hardware and is the source of the low speed control moments. The functions of lift and cruise and control link this system to the other two.

The control system contains all the actuators, boosters and associated components necessary to provide the required control. This system is considered fully automatic.

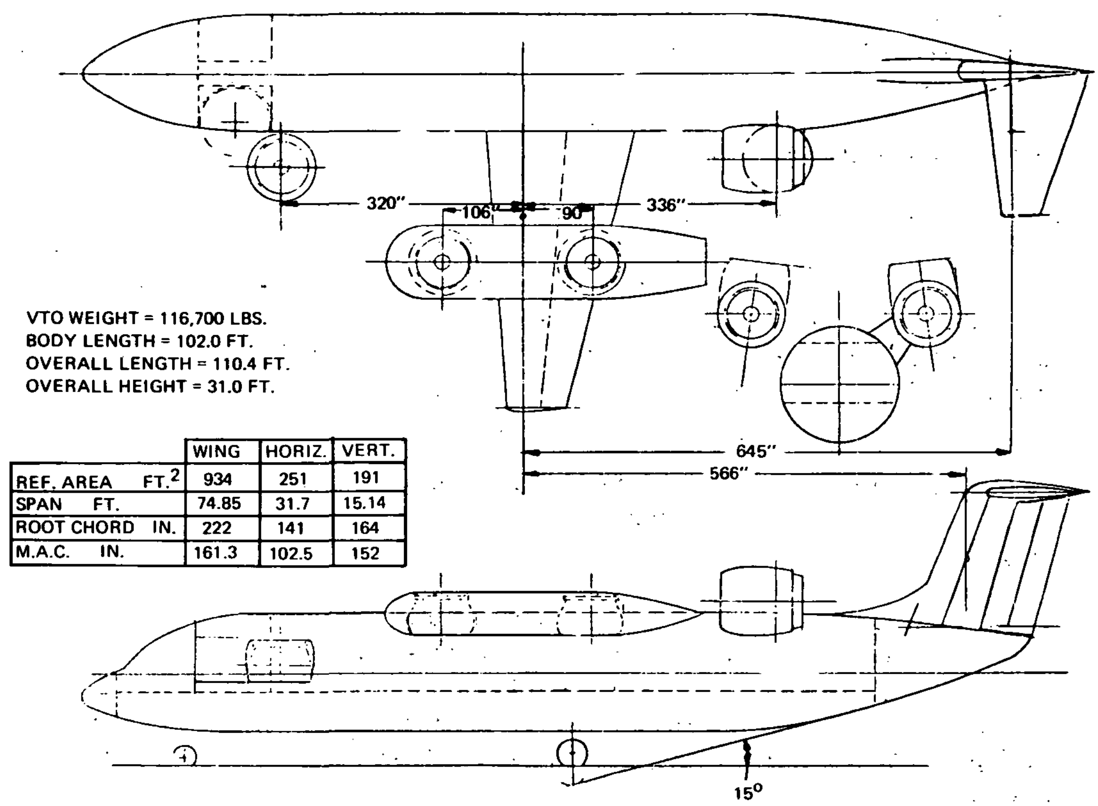
The electronic or avionic system consists of a computer that operates the propulsion and flight control systems and provides for flightpath guidance from takeoff through landing.

In addition, these airplanes have a common passenger compartment and basic airframe from which the variations proceed. The genetic relationship among these ten airplanes as illustrated in Figure 9 will be followed in this discussion.

1.2.2.1 Integral Lift Fan Airplanes

984-120 (Figure 10)

This airplane is the first of the integral lift engine family. It has eight fans which are mounted in pairs around the c.g. Two on the aft body are equipped and mounted for cruise and two on the forward body retract for cruise. Thrust vectoring is achieved by rotating the entire engine. The remaining engines are arranged with the fan axis of rotation vertical. The fans on each wing are approximately at the midpoint of the exposed wing. Thrust vectoring is accomplished with louvers in the exhaust.



	WING	HORIZ.	VERT.
REF. AREA FT.^{2}	934	251	191
SPAN FT.	74.85	31.7	15.14
ROOT CHORD IN.	222	141	164
M.A.C. IN.	161.3	102.5	152

FIGURE 10 MODEL 984-120

All the engines were considered nearly identical with differences in accessories and cowling resulting from location and function. The forward lift engines are packaged differently from the wing engines and the cruise engine package is also different and has accessories for cruise not needed on the other engines. They also have two-position nozzles.

The matching and sizing of this configuration is dominated by the thrust required to cruise and climb on two engines. The thrust weight ratio (F/W) at sea level to achieve this is 0.417 leading to a total F/W of 1.67. The F/W required for VTO and low speed operation is 1.47 and does not dominate.

A plot of the matched and sized VTOGW as a function of wing-loading is shown on Figure 11.

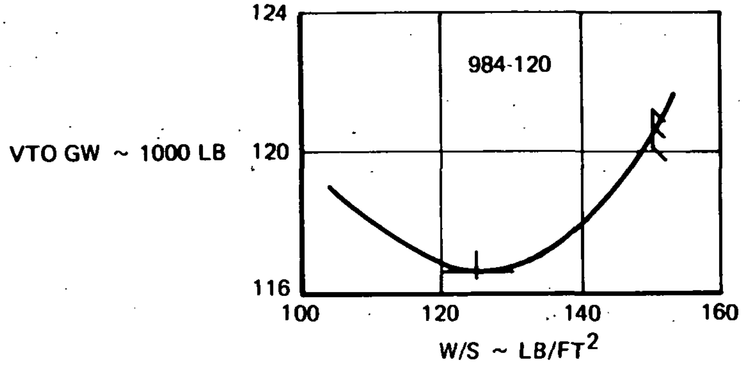
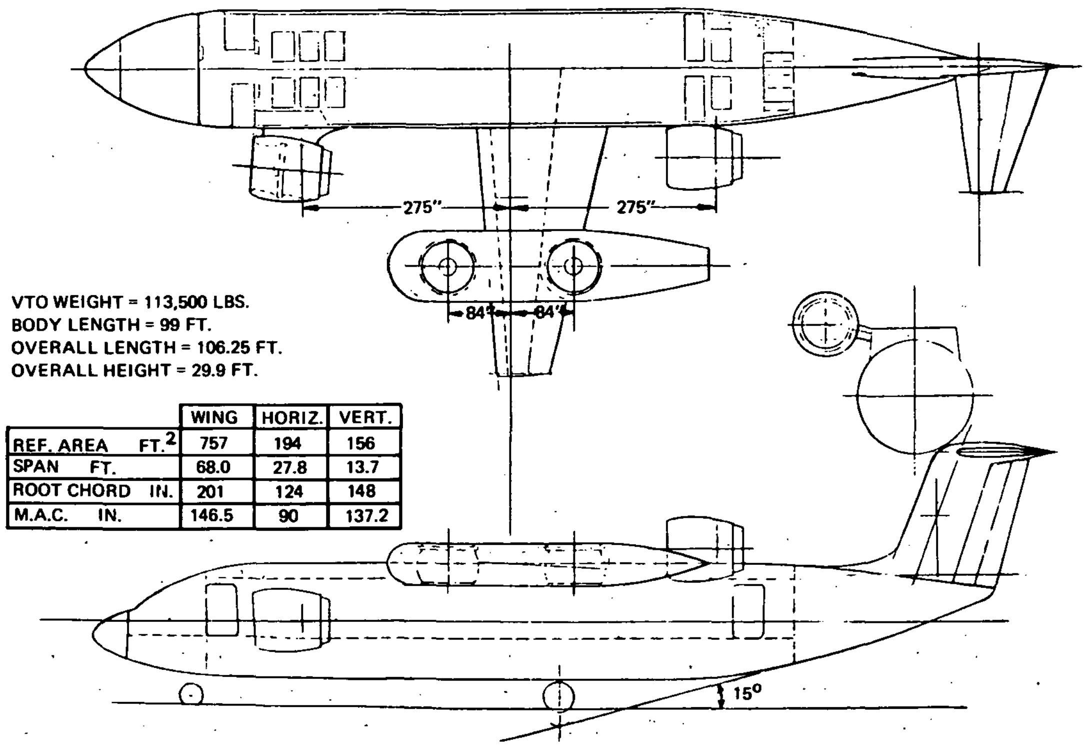


FIGURE 11 VTO GW vs W/S, 984-120

The matched wing-loading is 125 lb/ft^2 and the VTOGW is 116,700 lb.

The characteristics of this configuration are tabluated with all the others on Table 2.

984-122 (Figure 12)



	WING	HORIZ.	VERT.
REF. AREA FT.^{2}	757	194	156
SPAN FT.	68.0	27.8	13.7
ROOT CHORD IN.	201	124	148
M.A.C. IN.	146.5	90	137.2

FIGURE 12 MODEL 984-122

This configuration is a variation of 120 and cruises on four of the eight integral lift cruise fans. The physical effect of this change is the elimination of the cutout in the forward fuselage with a decrease in body weight. The fore and aft engine arms are shortened so that the saving in fuselage length and weight results in an increase in thrust required for pitch control. Accounting for all the requirements the VTO F/W required is 1.49, only 0.02 more than the -120. This provides a cruise F/W of 0.745 which is excessive and results in a mismatch from the sfc standpoint at cruise. The resulting VTO GW is 113,500 lb.

The wing-loading match does not show an optimum and is set at 150 lb/ft^2. The variation of takeoff weight with wing-loading is shown on Figure 13.

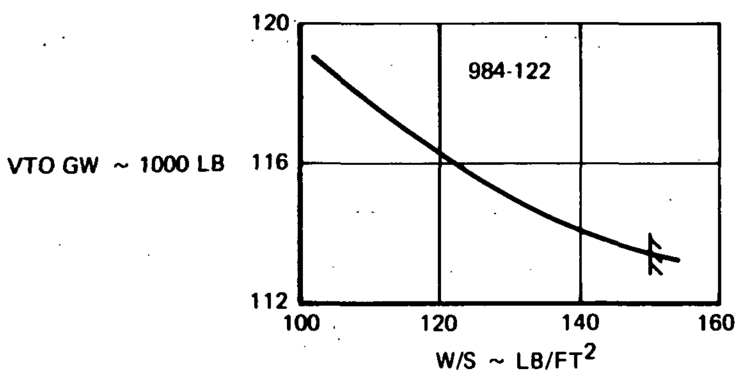
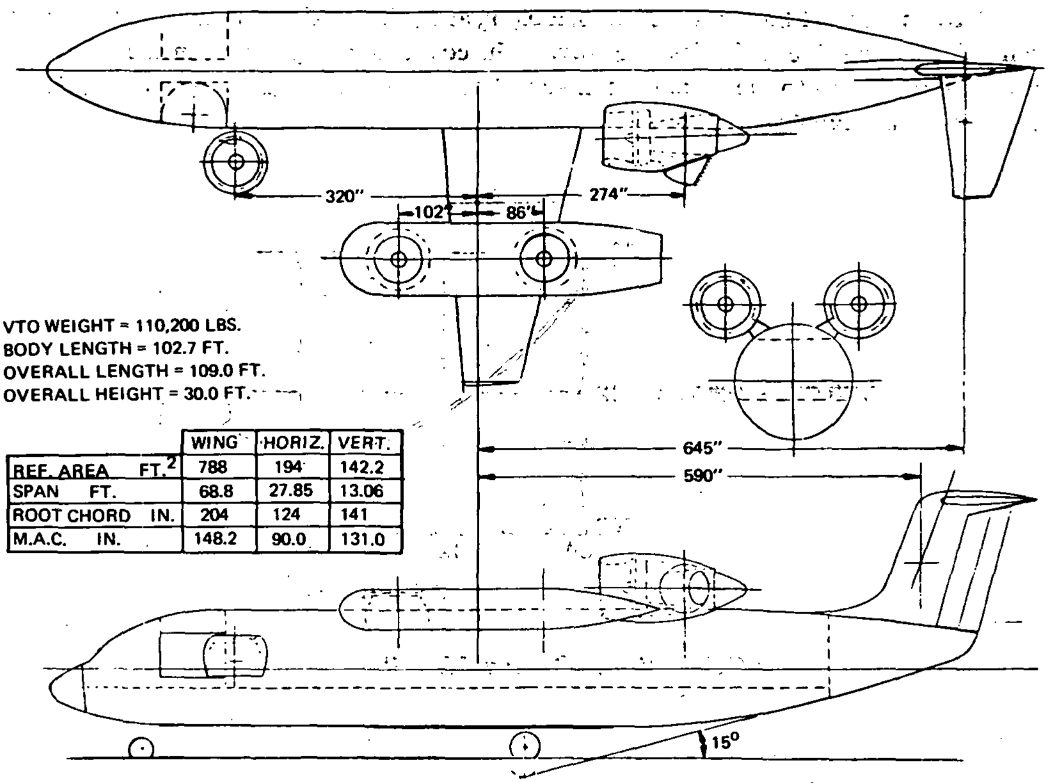


FIGURE 13 VTO GW vs W/S, 984-122

A continued weight decrease is seen to be available with increased wing-loading although the change in slope indicates that this potential advantage will be small.

On Table 2 (page 4) a comparison with the -120 shows a weight reduction of 3200 lb. This results from the effects of reduced weight due to fuselage length and installed thrust. The difference would be even greater except that the use of four-engine cruise results in poorer L/D's and higher SFC's which increase mission fuel requirements.

984-134 (Figure 14)



	WING	HORIZ.	VERT.
REF. AREA FT.^{2}	788	194	142.2
SPAN FT.	68.8	27.85	13.06
ROOT CHORD IN.	204	124	141
M.A.C. IN.	148.2	90.0	131.0

FIGURE 14 MODEL 984-134

This final member of the integral lift fan family is designed to match both the lift and cruise requirements which leads to having two engine sizes and cycles. The cruise fans are fixed on this design and the thrust is vectored through a louvered nozzle similar to those on the Pegasus engine.

An exact match between both the lift and cruise requirements was not achieved due to the desire to keep the cruise engines as far aft as practicable. Moving the cruise system forward would have slightly reduced the size of the lift engines.

The installed F/W is 1.55 and that required for takeoff is 1.47. Use of a cruise turbofan provides for improved sfc in cruise. The cruise thrust weight ratio is 0.488.

The effect of the good cruise match is seen on the plot of VTOGW vs W/S on Figure 15.

The minimum gross weight occurs at a W/S of 140 lb/ft^2. The gross weight is 110,200 lb.

A comparison of these three designs, looking at Table 2, indicates the weight improvements that are possible as the design evolved. The cost of stowing engines in the forward fuselage is secondary to the propulsion match. The cruise thrust match and the takeoff thrust match are equally important.

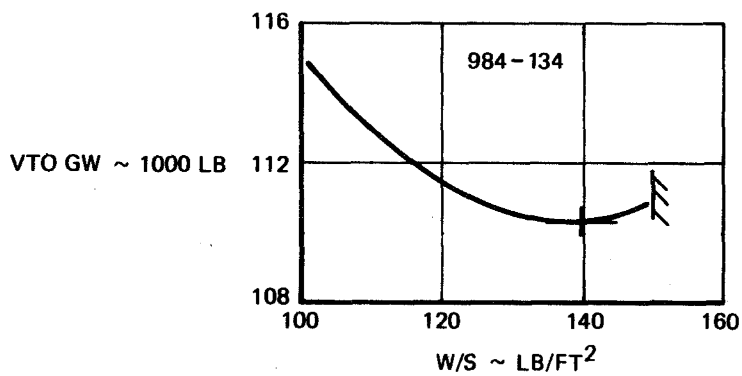


FIGURE 15 VTO GW vs W/S, 984-134

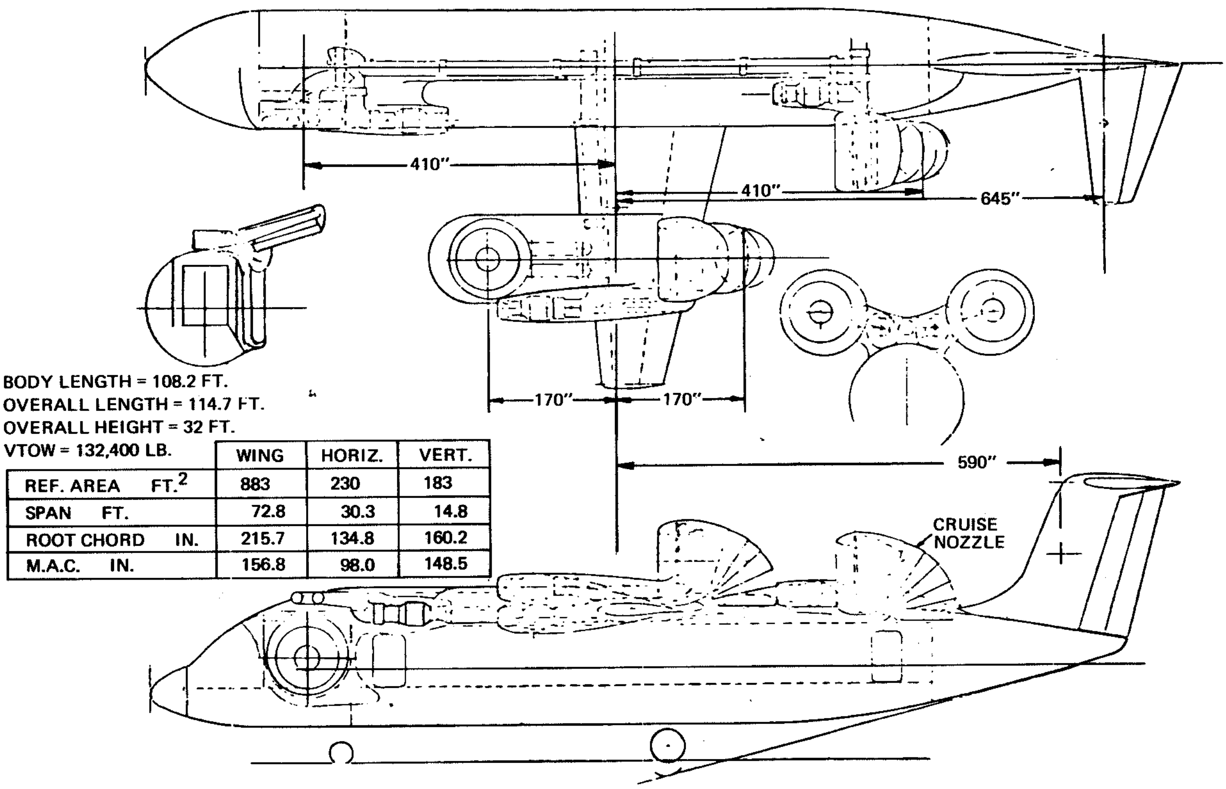
1.2.2.2 Remote Lift Fan Airplanes

Several alternatives of remote lift fan designs were considered (Figure 9). These alternatives include the number of cruise engines, interconnection, lift fan failure, and mixed engines.

984-124 (Figure 16)

This airplane is designed with the assumption that lift fans do not fail. It has eight fans driven by eight gas generators. The system is fully gas interconnected with a multiengine manifold. Four of the fans are used for cruise; the two on the aft body and the rear two on the wing. Thrust vectoring is accomplished by a variable hood nozzle on the cruise engines while the lift fans use louvers. This arrangement retains fuselage cutouts for stowing the forward fans.

The use of a multiengine manifold for interconnect and the assumption of infinite fan integrity minimizes the gas generator size. This airplane is designed to an F/W of 1.26 based on takeoff requirements; however, the complexity and weight of the interconnect and the poor cruise sfc's negate this advantage. The airplane sizes to a gross weight of 132,400 lb. The use of four engines for cruise results in a wing loading of 150 lb/ft^2.



	WING	HORIZ.	VERT.
REF. AREA FT.^{2}	883	230	183
SPAN FT.	72.8	30.3	14.8
ROOT CHORD IN.	215.7	134.8	160.2
M.A.C. IN.	156.8	98.0	148.5

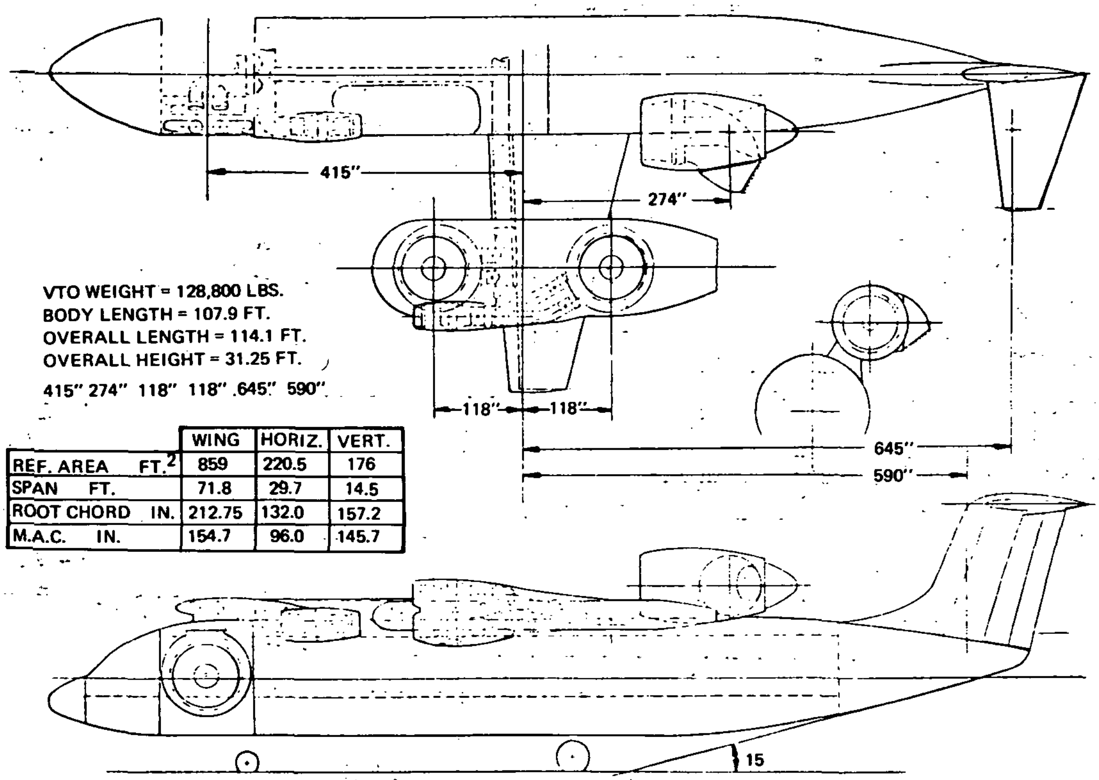
FIGURE 16 MODEL 984-124

984-133 (Figure 17)

A variation of the -124, the -133, has six interconnected remote lift fans and has two integral cruise fans mounted on the aft fuselage. The remote lift fans are used only during takeoff and landing. Design simplification is achieved by removal of the awkward thrust vectoring cruise nozzles and by reducing the interconnect ducting to that needed for the six remote fans. Fuel requirements are reduced through lower drag and SFC's. The F/W required for takeoff is 1.32. (This is required to handle loss of a cruise fan which is the critical failure case.). The thrust required for climb and cruise increase the overall F/W available to 1.49 which exceeds the takeoff requirement. This combination of factors resulted in a VTOGW of 128,800 lb resulting in the lightest of the remote fan aircraft.

The wing loading to best match this installation is shown on Figure 18.

The minimum gross weight occurs at a wing-loading of 150 lb/ft^2.



	WING	HORIZ.	VERT.
REF. AREA FT.^{2}	859	220.5	176
SPAN FT.	71.8	29.7	14.5
ROOT CHORD IN.	212.75	132.0	157.2
M.A.C. IN.	154.7	96.0	145.7

FIGURE 17 MODEL 984-133

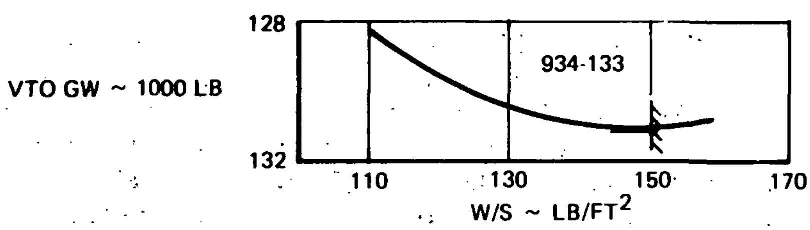


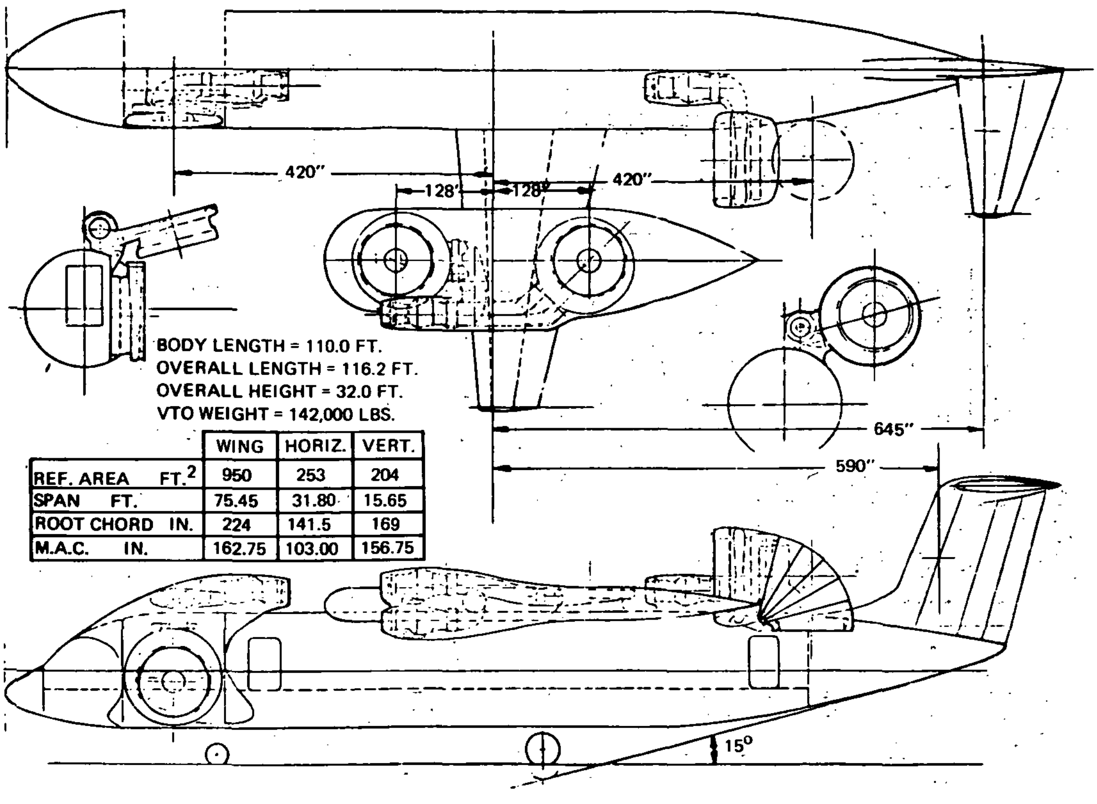
FIGURE 18 VTO GW vs W/S, 984-133

984-126 (Figure 19)

Designed to tolerate fan failure, this eight-engine remote lift fan airplane cruises on two engines. It is the only remote fan design with no interconnecting ducts. The airplane is directly comparable with the integral fan design -120.

The cruise and takeoff thrust requirements are nearly matched. The engine size of 26,200-lb sea level static thrust is set by the cruise requirement. This results in an installed F/W of 1.47. The VTO F/W required is 1.44. The size and awkwardness of the remote fan system leads to a VTOGW of 142,400 lb, at a wing-loading of 150 lb/ft^2.

A comparison of remote and integral fan designs, without interconnection can be made by comparing the remote fan -126 with integral fan -120. The installed F/W of the -120 is 1.67 and is set by the cruise thrust match. The -120 weighs 116,700 lb compared to 142,400 lb for the -126. The penalty for a remote fan, without taking any of the interconnect advantages, is clearly shown.



	WING	HORIZ.	VERT.
REF. AREA FT.^{2}	950	253	204
SPAN FT.	75.45	31.80	15.65
ROOT CHORD IN.	224	141.5	169
M.A.C. IN.	162.75	103.00	156.75

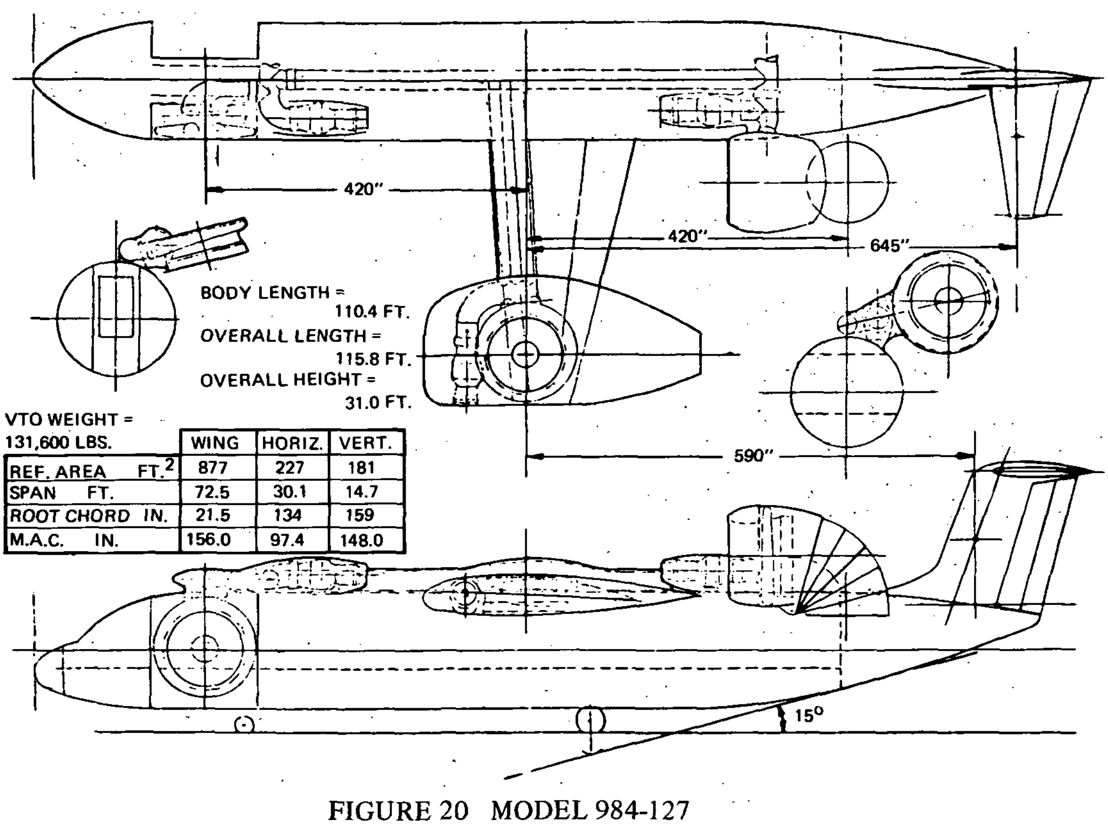
FIGURE 19 MODEL 984-126

984-127 (Figure 20)

Model 984-127 is a six-engine, fully interconnected, no fan failure, design. It cruises on two of the engines. The arrangement is similar to the -124. With no fan failure to account for, one fan on each wing is acceptable. With six engines, the takeoff/cruise thrust match is good. The installed thrust of F/W = 1.26 is matched to the VTO requirements; the cruise F/W is 1/3 of this or 0.415 which is a good match of these requirements.

On the negative side, the fan diameter is large causing a stowage problem for the front fans. The spanwise location of the wing fan is set by the roll control and the fan moves to the wingtip. The wing ducts, which are sized by loss of a wing gas generator, are large and must be installed as multiple ducts.

The wing loading is 150 lb/ft^2 and the VTOGW is 131,600 lb. This is slightly better than the -124.

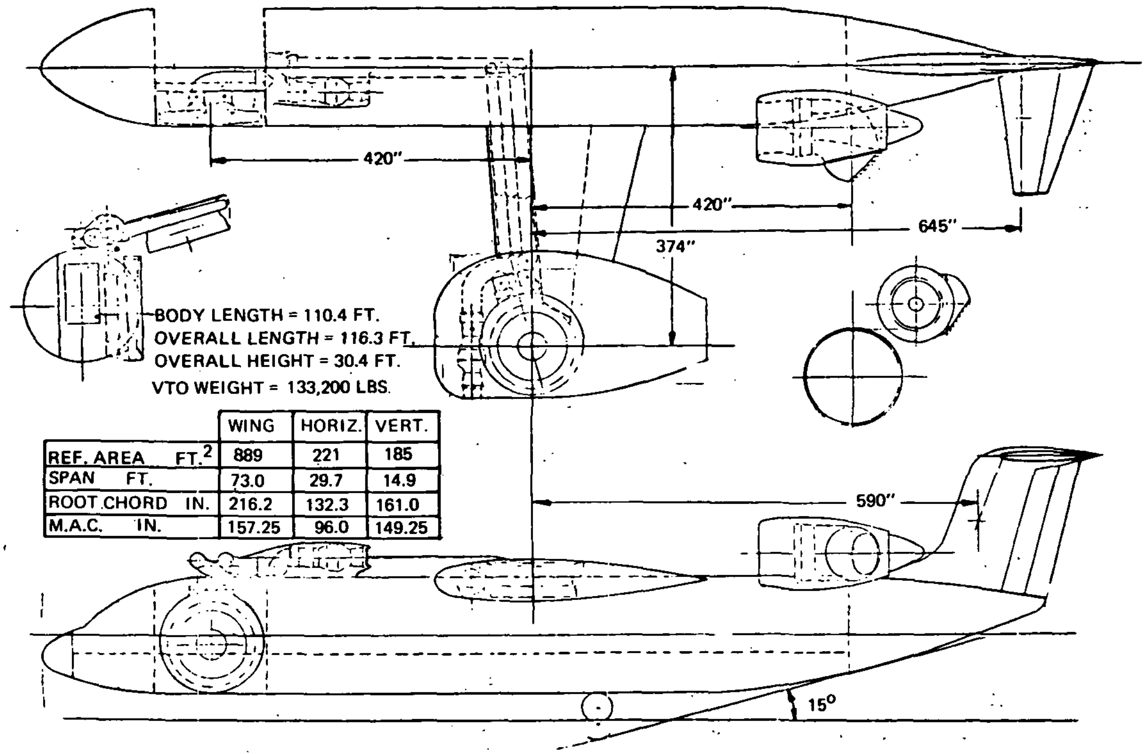


	WING	HORIZ.	VERT.
REF. AREA FT.^{2}	877	227	181
SPAN FT.	72.5	30.1	14.7
ROOT CHORD IN.	21.5	134	159
M.A.C. IN.	156.0	97.4	148.0

FIGURE 20 MODEL 984-127

984-131 (Figure 21)

An attempt to improve the -127 by use of independent cruise engines is represented here. The design was not successful. The F/W required during VTO is set by loss of a cruise fan. In fact there is enough thrust so that fan failure can now be tolerated; only the addition of an emergency jet system is needed. The airplane cruise thrust required increases the total installed F/W from the 1.38 required for VTO to 1.41. For this configuration, the wing-loading for minimum VTOGW is 150 lb/ft^2 and the weight is 133,200 lb. This is 1600 lb heavier than the -127.



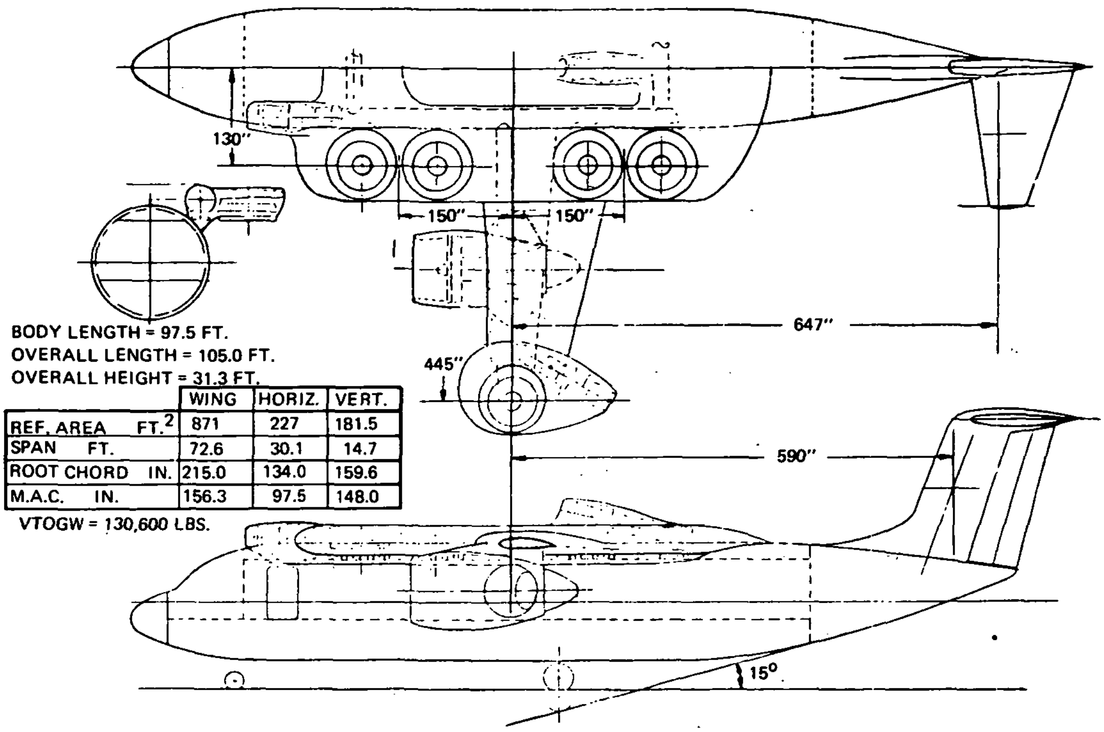
	WING	HORIZ.	VERT.
REF. AREA FT.^{2}	889	221	185
SPAN FT.	73.0	29.7	14.9
ROOT CHORD IN.	216.2	132.3	161.0
M.A.C. IN.	157.25	96.0	149.25

FIGURE 21 MODEL 984-131

984-132 (Figure 22).

This configuration uses a smaller number of gas generators than fans. The design was taken from the prop fan configuration -128 (Section 1.2.2.3). Ten lift fans are driven by five gas generators. Cruise thrust is provided by two wingmounted cruise engines.

The fully interconnected lift system has eight fans and three gas generators mounted on the body and another fan and gas generator at each wingtip. This arrangement minimizes the wing duct area. The installed F/W of 1.51 comes about from the thrust cruise required and the requirement to tolerate a cruise engine failure during VTOL. The VTOGW is 130,600 lb.



	WING	HORIZ.	VERT.
REF. AREA FT.^{2}	871	227	181.5
SPAN FT.	72.6	30.1	14.7
ROOT CHORD IN.	215.0	134.0	159.6
M.A.C. IN.	156.3	97.5	148.0

FIGURE 22 MODEL 984-132

1.2.2.3 Prop Fan Airplane

984-128 (Figure 23)

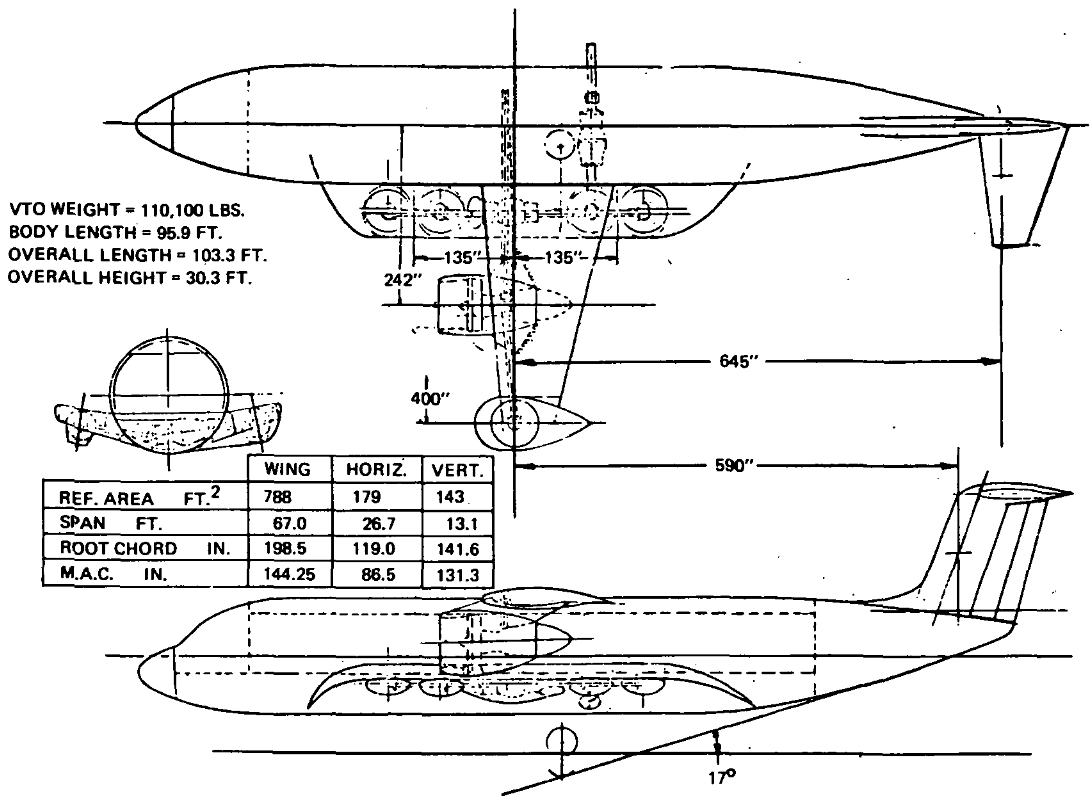
The prop fan design features variable pitch shaft interconnected fans that provide a very rapid control response. The systems used on this design consist of three items: lift fans, cruise fans, and turboshaft power generators. These units are arranged into two separate systems, one for takeoff and landing only and one for both V/STOL and cruise. The low speed system is body mounted, consists of eight lift fans and three power generators. They are fully shaft interconnected. The power generators operate at constant speed and power output and power transfer occurs with variation of prop pitch at constant speed.

The V/STOL/cruise system is mounted in the wing. The cruise fans and power generators are arranged in a cruise position at about midspan. Thrust vectoring is through rotary Pegasus-type nozzles. A control fan is located at each wingtip and the four fans and two generators are connected. During takeoff and landing, the power split in the wing is about 3/8 of a generator output to each control fan and 5/8 to each cruise fan. Under this powerloading, the cruise fan has a pressure ratio of about 1.23.

During cruising flight, the body system is shutdown and the wingtip fans and interconnecting shafting are taken off the line. Each cruise fan now has the power of one gas generator, and operates at an equivalent zero velocity pressure ratio of about 1.4.

This change in loading provides a good match between the cruise and takeoff requirements. The F/W available with controls neutral and all five gas generators at takeoff rating is 1.38. The resulting VTOGW is 110,000 lb.

The minimum gross weight wing-loading is 140 lb/ft^2. This is coincidently the same as the integral design -134 that weighs 110,200 lb.



	WING	HORIZ.	VERT.
REF. AREA FT.^{2}	788	179	143
SPAN FT.	67.0	26.7	13.1
ROOT CHORD IN.	198.5	119.0	141.6
M.A.C. IN.	144.25	86.5	131.3

FIGURE 23 MODEL 984-128

1.2.3 Takeoff and Landing Techniques

The vertical takeoff profile as specified by NASA was used for the commercial airplane configurations. This profile provided the base from which noise estimations were made and is the fuel measure for performance calculations. It has a vertical liftoff, followed by a rapid climbout and acceleration to forward flight. This is an efficient and safe flight profile with low noise under the flight path.

Figure 24 shows the flight profile for a vertical takeoff and transition of the 984-120. The initial rise is along a 1:1 climb gradient. The flightpath angle is rapidly reduced to 9.5°. The airplane accelerates along this path to transition speed at 4000-ft ground distance and 1000-ft altitude. At this point, the lift engines are shutdown and the climb is continued on the cruise engines. This is a moderate maneuver, well within the capability of the pilot and control system. The control deflections are small; the acceleration is moderate (less than 0.3g), and there are no rapid control inputs.

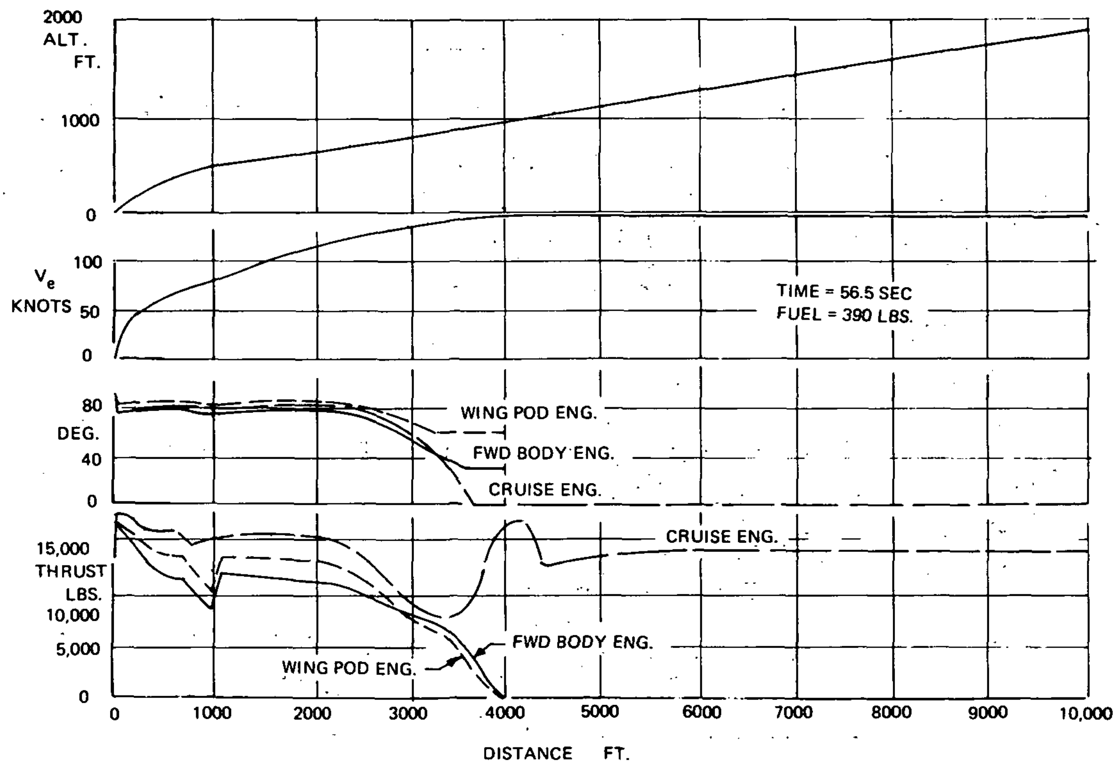


FIGURE 24 984-120 VERTICAL TAKEOFF PROFILE

A vertical landing profile for the 984-120 is shown in Figure 25. The approach and landing follow the same flightpath as the takeoff but takes considerably more time and fuel because the maximum rate of descent is restricted to 1000 fpm below 2000-ft altitude. The airplane control system has the capability to do the approach and landing with much higher descent rates that would reduce the time and fuel.

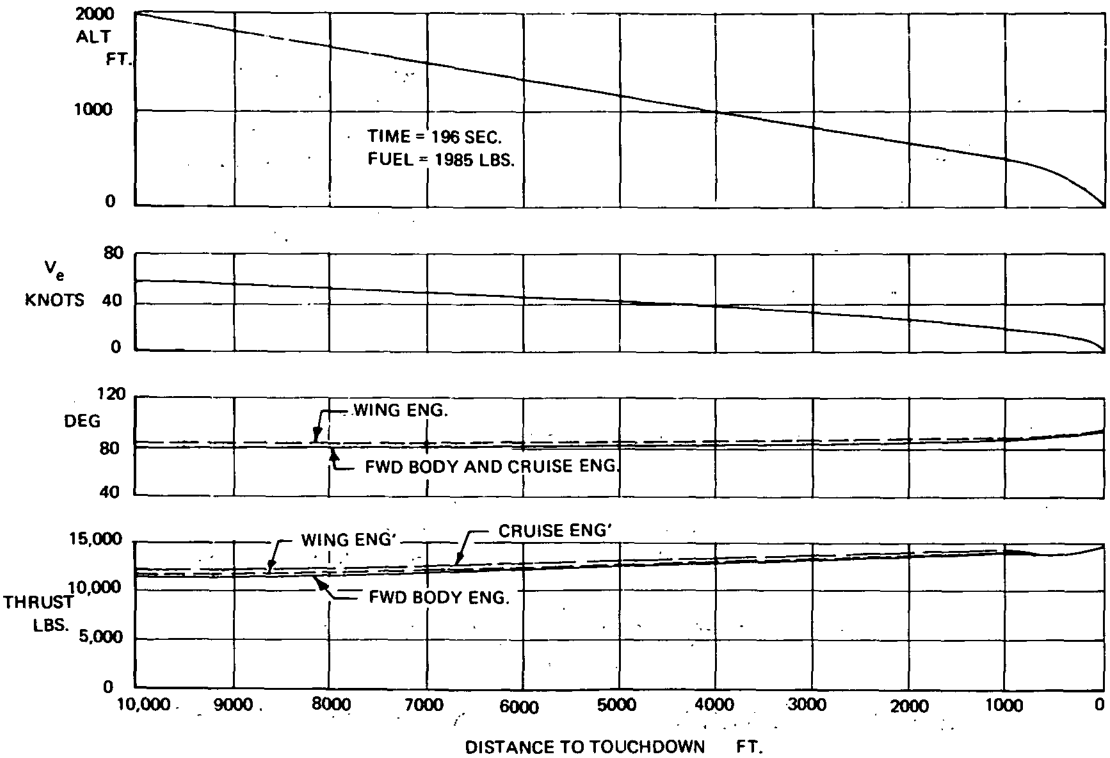


FIGURE 25 984-120 COMMERCIAL V/STOL TRANSPORT VERTICAL LANDING PROFILE

The STOL takeoff and landing are shown for the eight-engine 984-134 in Figure 26. The maneuvers take full advantage of the installed thrust and control to achieve low takeoff and landing speeds. The takeoff ground run is made with the thrust deflected 70°. Liftoff speed is 44 knots. The total ground distance to takeoff and climb to 35 ft is 902 ft. From the study rules, this gives a 1039-ft field length. The thrust level is set so that the full moment and maneuver control are available with fan control alone. No credit has been taken for the aerodynamic controls. The thrust weight ratio at this setting is less than 1.0.

The STOL landing uses a decelerating approach, similar to the vertical landing. The approach speed is reduced to 40 knots at 35 ft to meet the sink rate restriction of 600 fpm. The landing distance is 550 ft which gives a 785-ft field length.

The commercial airplanes have nearly this same VTOL and STOL capability following a failure. They are sized to provide a F/W of 1.05 after a failure and can continue a takeoff or landing with only a small reduction in performance.

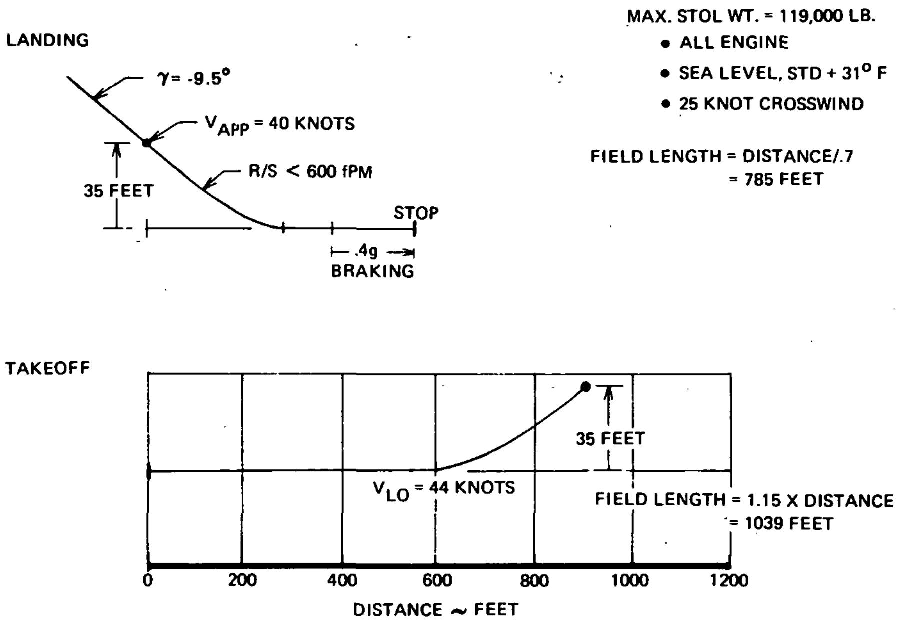


FIGURE 26 STOL TAKEOFF AND LANDING CHARACTERISTICS

1.2.4 Stability and Control

The stability and control at normal flight speeds is conventional. The aerodynamic controls are matched to the minimum conversion speed and the c.g. range and empennage are designed to provide good static stability and maneuver margins in conventional flight.

The primary area of interest for these airplanes is the hover and low speed flight regimes. Control is provided by varying the thrust magnitude and direction on the engines and the stability depends largely on the gyroscopic and flow properties of these engines.

As an example of the dynamic stability of these airplanes, an analysis of configuration 984-122 was made. This is the eight-engine integral lift fan design that uses four of these for cruise (Figure 13). The stability roots are presented in root locus form on Figure 27 and in Table 4.

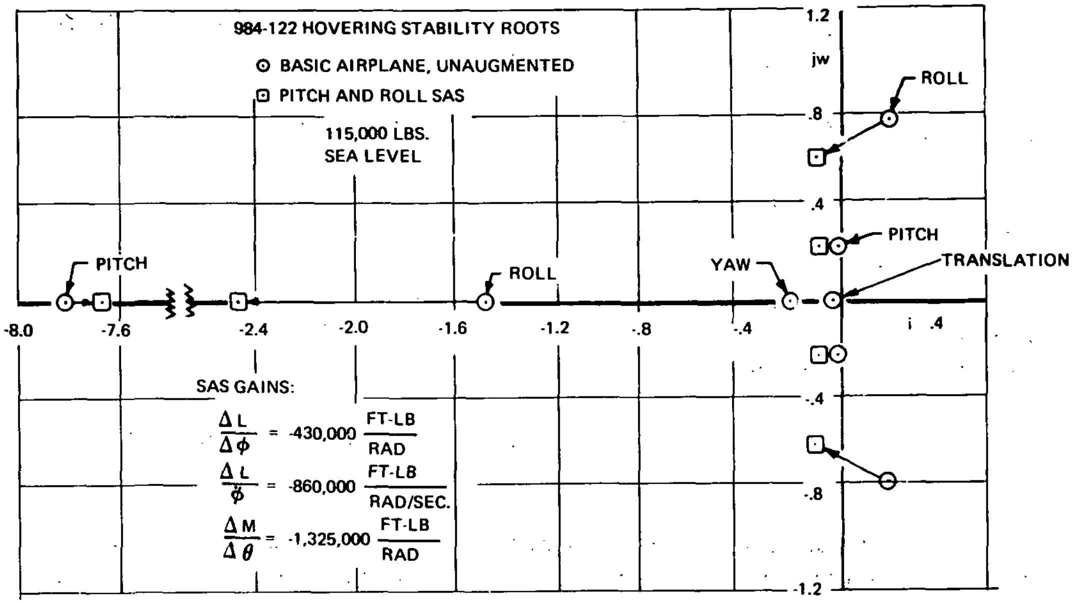


FIGURE 27 984-122 HOVERING STABILITY ROOTS

TABLE 4 MODEL 984-122 COMMERCIAL V/STOL TRANSPORT HOVERING STABILITY

OPERATING MODE	LONGITUDINAL PERIOD SEC.	LONGITUDINAL TIME TO ½ AMP SEC.	LATERAL - DIRECTIONAL PERIOD SEC.	LATERAL - DIRECTIONAL TIME TO ½ AMP SEC.
ALL FLIGHT OPERATIONS	25.9	7.68	10.3	6.5
SAS ON	–	.091	–	.278
	–	18.4	–	3.25
BASIC AIRPLANE	27.5	44.1	8.07	-3.52*
SAS OFF	–	.089	–	.471
	–	18.4	–	3.25

*- VALUE IS TIME TO 2 AMP.

There is a real yaw root and a real translational root with approximately neutral stability. Pitch and roll have oscillatory root pairs. The pitch roots are lightly damped and the roll roots are unstable. This instability results from the interaction of the inlet momentum drag with pitch and roll. The effective point of action of the inlet drag is taken as one diameter above the inlet. Since the airplane has a high wing, this force has a long moment arm.

A full time, fail operational, stability augmentation system is provided. This system provides static and dynamic stability augmentation, makes the control linear, provides pure couple, and eliminates interactions between control functions. The augmentation system is part of the total flight control which operates during all flight modes.

The engines and control systems are designed to give the required control at a F/W = 1.05 on a 90° F day after any single failure. Some of the airplanes, particularly those that cruise on two engines, have the engines sized by the cruise thrust required so that they have more thrust than is required for low speed flight. When an engine or fan fails on a noninterconnected design, the opposite engine is shutoff to balance. The remaining engines must provide the necessary thrust, trim and control.

On the remote fan configurations with gas interconnect, a fan failure could be balanced by shutting off the opposite fan and diverting the extra gas into emergency lift nozzles.

On the prop fan design, a series of clutches will permit taking fans or gas generators off the line and redistributing the power among the remaining units as needed.

1.2.5 Noise

The V/STOL commercial transports are all designed for a perceived noise level of 95 dB at the 500-ft sideline. This low noise level is considered acceptable to a person who hears ten such daytime occurrences each day (Ref. A). Not until there are as many as 64 occurrences per day does the rating reduce to barely acceptable. From the community noise standpoint, the introduction into service of these aircraft will not be obtrusive.

Engine noise characteristics.—The engines used in the study are all designed to meet the noise characteristics. The fan pressure ratios, the exit velocity ratios, and the noise suppression treatment is similar for all the engines.

For the integral lift fan, the estimate of the basic noise generation characteristics followed initial estimates by General Electric for an engine with a bypass ratio of 12.6 and a fan pressure ratio of 1.25 that produces 10,000 pounds of thrust at the "noise rating point." The perceived noise 500 ft to one side of this engine is 85.3 dB. For the various configurations, the airplane noise was estimated from this base. Noise treatment in the lift fan inlet is considered necessary to achieve the 95 PNdB level.

Noise increments for variation in fan pressure ratio and engine bypass ratio are shown on Figure 28. The variation with pressure ratio has 1.25 as the base. The ILF engine design pressure ratio is 1.31 and denotes a noise increase. The bypass ratio increases from 12.6 to 12.7. No noise reduction was taken for this change. The noise generated by eight ILF engines as they are arranged in configuration 984-120 is shown on Table 5. The noise scaling with thrust level is derived from the fundamental relationship that the noise in dB is proportional to the power at the source. The extension to a noise increment equal to the log of the airflow ratio is given in Reference D. For a fixed cycle thrust is proportional to airflow and substituting thrust for airflow:

$$\Delta PNdB = 10 \log \frac{F_2}{F_1}.$$

The noise increment for eight engines is taken from Reference E. The relationship is an extention of that given in Reference D.

$$\Delta PNdB = 5 \left(1 + \sqrt{\sin \beta}\right) \log N$$

where β is the elevation angle between the noise source and the sideline listening point. This angle is 20^{o} when the airplane is at an altitude of 180 feet and the listening point is at the 500-ft sideline. N is the number of engines.

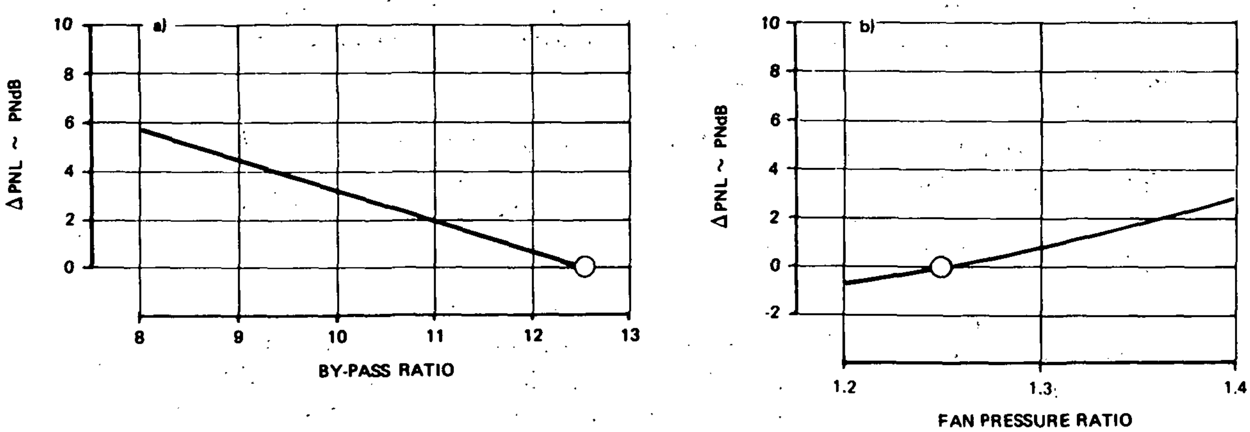


FIGURE 28 NOISE TRENDS FOR 1980-85

TABLE 5 500-FT SIDELINE NOISE, 984-120

ONE ENGINE PERCEIVED NOISE LEVEL		
Δ @ .8 F_{MC} = 10,000 LB.		85.3 PNdB
Δ PNL - R_F = 1.31	0.8 PNdB	
Δ PNL - BPR = 12.7	–	
Δ PNL - .8 F_{MC} = 20,000 LB.		
Δ 10 LOG $\left(\frac{20{,}000}{10{,}000}\right)$	3.1 PNdB	
Δ PNL - EIGHT ENGINES		
$5\left(1+\sqrt{\text{SIN } 20^{\circ}}\right)$ LOG 8	7.1 PNdB	
Δ PNL - CONFIGURATION SHIELDING	-1.3 PNdB	
Δ PNL - TOTAL	9.7 PNdB	
PERCEIVED NOISE LEVEL OF 984-120		95 PNdB

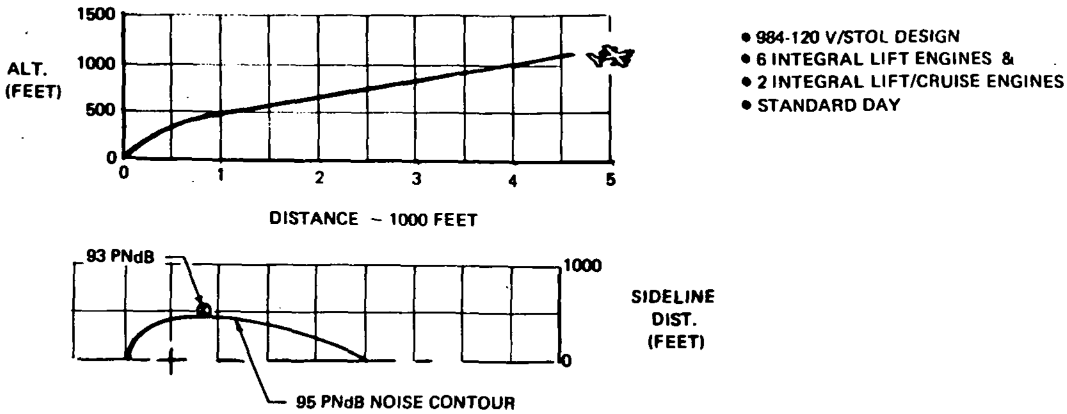
No account is taken for aircraft structural shielding in this equation. The engines are assumed to be suspended in the air. The increment of 1.3 PNdB for shielding is taken to account for this lack and is based on current Boeing estimating techniques. The sideline noise at noise rating thrust is 95 PNdB.

The total installed thrust on the -120 is determined by the cruise criteria. There is excess thrust available during vertical takeoff which cannot be used due to restrictions on acceleration, and the thrust applied is lower than the noise rating point. Under these conditions the noise level is estimated to be 93 PNdB.

All the engines used on the 1980-1985 aircraft were similar from a noise generation standpoint. The pressure ratios, jet velocity ratios, and noise suppression treatment were chosen to provide acceptable noise levels. As a result the noise characteristics of the 984-120 are considered to be typical of the series of designs. The variation due to gross weight could account for a spread of less than 1.5 PNdB and the spread due to cycle differences would be about the same.

Community noise.—The effect on the community of the V/STOL transport is illustrated by the 95 PNdB noise level contour generated during takeoff and landing.

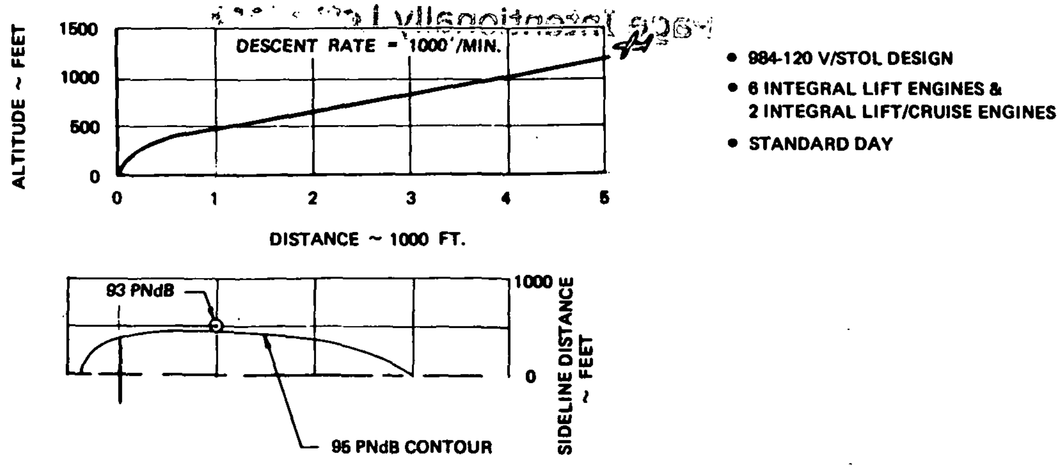
Figure 29 is the noise contour for the vertical takeoff at maximum gross weight. The takeoff path is shown for reference. A description of the takeoff is given in Section 1.2.3. The 95 PNdB contour closes 2000 ft from takeoff and extends to 450 ft at the sideline. The area enclosed within this contour is 35 acres.



AREA ENCLOSED WITHIN 95PNdB = 35 ACRES

FIGURE 29 VERTICAL TAKEOFF NOISE CONTOUR

Noise generated during approach and vertical landing is shown on Figure 30. The noise contour differs from the VTO contour in that the 95 PNdB level extends to 3000 ft before the threshold, the sideline distance remains 450 feet, and the area enclosed is 53 acres. Approach power setting is determined by the requirement that the descent rate be less than 1000 ft/min. Extension to the noise contour ahead of the threshold, in comparison with the takeoff, is due to this limitation.



AREA ENCLOSED WITHIN 95 PNdB = 53 ACRES

FIGURE 30 VERTICAL LANDING NOISE CONTOUR

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2.0 ECONOMICS

The economic analysis of the 1980-85 V/STOL commercial transports is presented in terms of manufacturing or initial costs and operating costs. The sensitivity of operating costs to its various components is analyzed. As a result of this study, it is expected that the initial cost of a V/STOL transport will be about two times higher and the direct operating costs will be approximately 50 percent higher than current aircraft.

2.1 Manufacturing Cost

Manufacturing cost estimates are developed through a detailed component costing analysis of each V/STOL transport configuration. The airframe cost estimates are based on actual component cost experience on Boeing commercial aircraft programs modified to include the effects of new technology and new design features. The engine cost estimates are developed from cost data furnished by General Electric and Hamilton Standard.

Total V/STOL transport costs, defined at the 300 airplane production level and in 1971 dollars, are two to three times greater than the price of equivalent capacity CTOL aircraft. Figure 31 summarizes the relative manufacturing costs at maximum takeoff weight for each configuration. Using the prop fan -128 as reference, the integral fan aircraft are 10 percent to 15 percent more expensive and the remote fan machines cost 30 percent to 35 percent more than the prop fan.

Approximately 50 percent of the airplane cost is directly related to the propulsion system. Figure 32 presents the major components costs normalized to the -128 cost. The cost associated with the propulsion system is identified by the crosshatching. Although formally included in airframe costs, the nacelle and powerpack groups are linked with the propulsion systems here to identify the extent of propulsion system costs. Approximately half of nacelle and powerpack group costs are associated with louver, lobstertail, hot gas duct, shafting, and gearbox systems.

2.1.1 Airframe Cost

Airframe manufacturer's cost estimates are developed, with an airframe component costing model, for V/STOL transport production quantities of 300 units. The model provides costs data for 12 major components of the airframe. The basic estimating relationships for each major airframe component are based on the cost experience of previous Boeing commercial airplane programs. The effects of the technology level anticipated for the 1980-85 time period, as well as specific manufacturing complexity considerations are incorporated in the component costing analysis. A production rate schedule similar to previous turbojet CTOL programs is assumed.

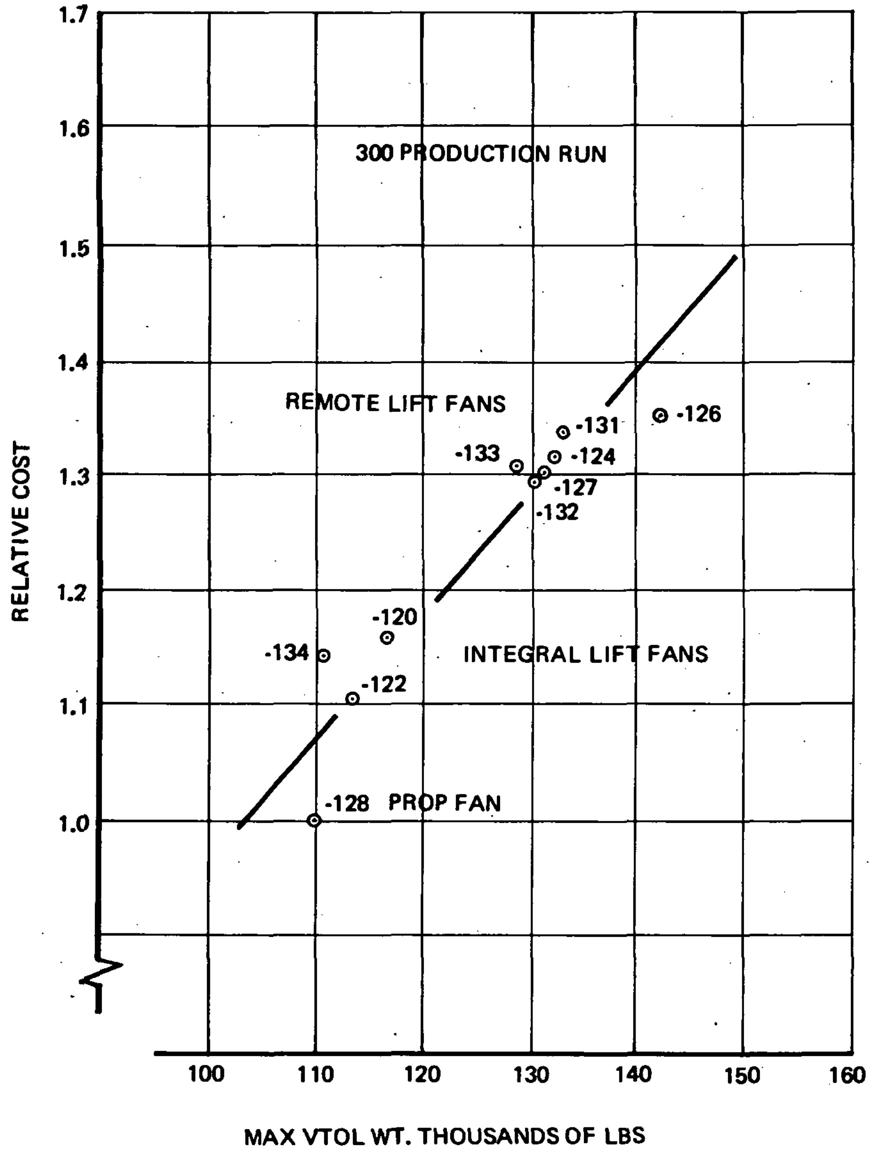

FIGURE 31. 1980-85 V/STOL TRANSPORT MANUFACTURING COSTS

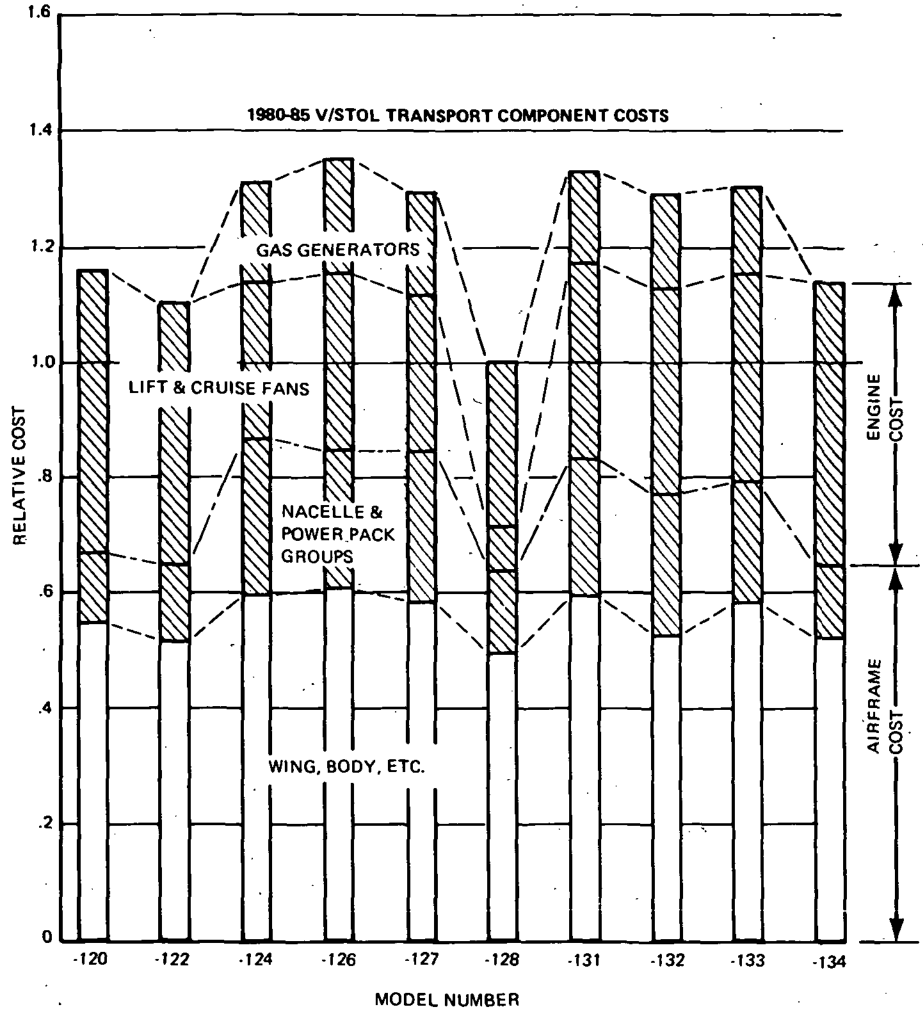

FIGURE 32 1980-85 V/STOL TRANSPORT COMPONENT COSTS

2.1.2 Engine Cost/Price

Parametric engine study prices for 1980-85 integral lift fans, remote lift fans, and gas generators are developed for the V/STOL transport study by General Electric. They are used to calculate the engine costs for a 300-unit production quantity of each V/STOL transport configuration. A 40 percent spares factor is added to the actual engine requirements for 300 aircraft to identify the total engine production requirements for each configuration. Due to basic design differences between configurations, the engine production requirements differed substantially among the ten V/STOL transports. For example, the remote lift fan production requirement for the -127 (six remote fans) is 2520 engines, while for the -131 (ten remote lift fans and two P cruise engines) the remote fan requirement is 4240 engines.

The one exception to the above production quantity groundrule is in pricing the P cruise engines employed in V/STOL transport designs. In the case of these engine configurations, a production requirement of 3500 cruise units more than the number required for 300 V/STOL shipsets, plus spares, is assumed. This assumes that such a cruise engine will be developed for some other use and V/STOL transport application would simply add to the production requirements.

Engine study prices for the prop fan configuration (984-128) were developed using data from Hamilton Standard and Boeing Vertol with the same production quantity and spares ratio applied to the other configurations.

2.2 Operating Costs

Direct operating costs have been developed and used as a figure of merit in comparing the economic characteristics of the ten V/STOL transports. Variations in component operating costs with changes in design philosophy are discussed. The airframe and engine prices for a 300 airplane production run were used in conjunction with the 1968 AIA V/STOL DOC methodology and powerplant maintenance costs from engine manufacturers.

The DOC's of the ten configurations group together in three separate bands corresponding to the three design families. The DOC characteristics of these three families are in order of increasing operating cost: prop fan, integral fan, and remote fan configurations. Figure 33 summarizes the range of DOC's at the 400-n. mi. design point VTOL mission. Direct operating costs range from 2.27 cents/available seat statute mile, for the prop fan configuration to 3.13 cents per available seat statute mile for the 984-126 (remote) configuration.

Airplane cost, a direct function of airplane weight, can be identified as the principal factor in determining this DOC spread.

The direct operating costs for the V/STOL configurations are computed using General Electric and Hamilton Standard engine maintenance data for both cruise and lift engines, and the 68 AIA methodology for all other operating cost components. The variation of DOC with range is presented in Figure 34. These DOC's are computed at minimum cost cruise conditions. Differences in operating costs for the VTOL and STOL missions are primarily due to differences in air and ground maneuver times rather than any significant changes in block fuel or flight profile.

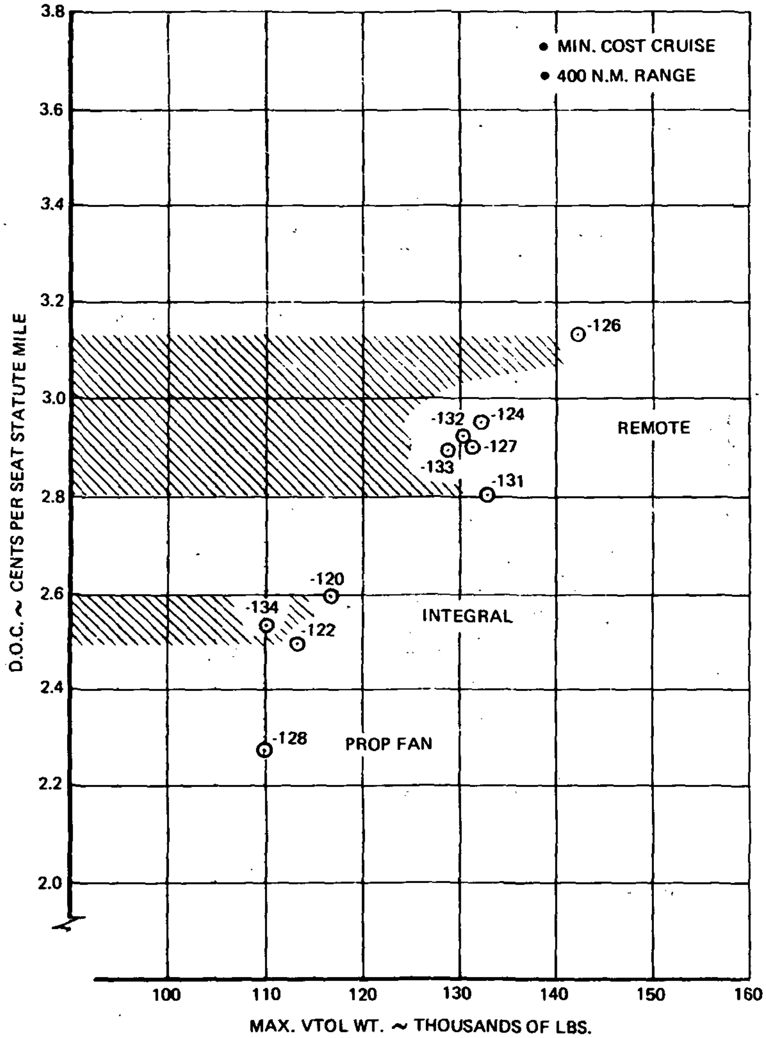

FIGURE 33 V/STOL TRANSPORT DIRECT OPERATING COST

The differences in direct operating costs between configurations, at the range associated with the VTOL market, are of primary interest in any V/STOL concept comparison. To identify the sources of these differences, a component analysis of operating costs is required. An indication of the outcome of such an analysis can be seen in the summary of DOC vs VTOL design weight shown on Figure 33. A 37 percent increase in DOC with a 30 percent increase in VTOL takeoff gross weight is shown.

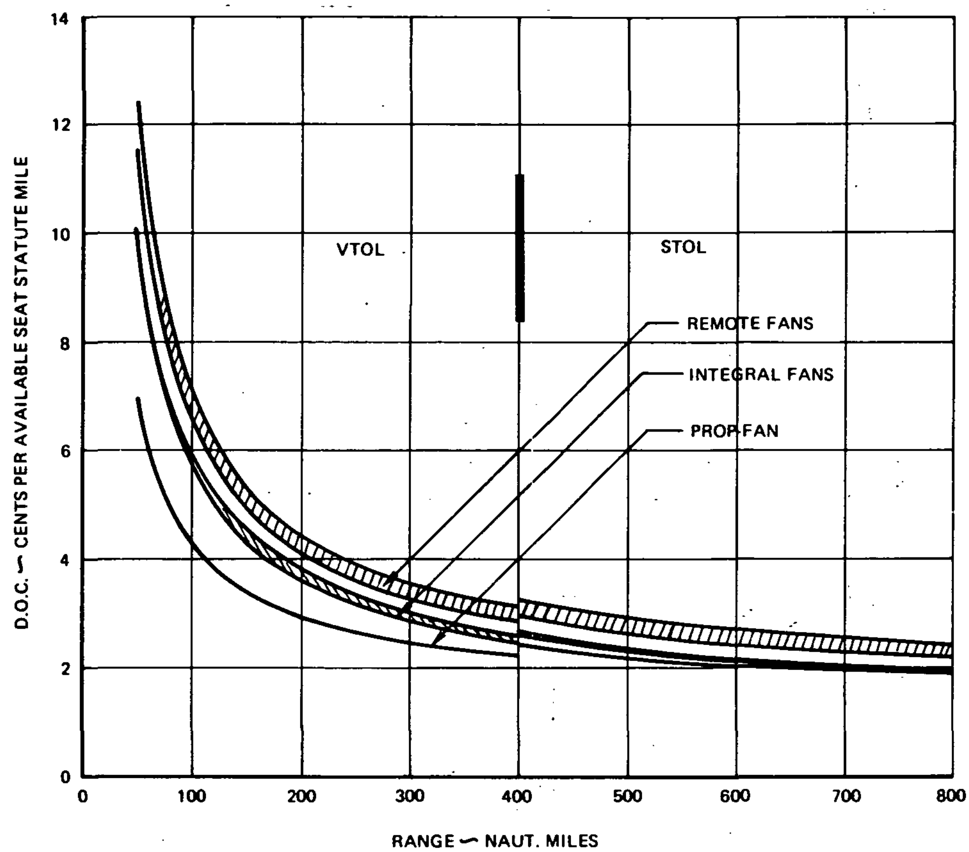

FIGURE 34 DIRECT OPERATING COST SUMMARY

Gross weight affects operating costs primarily through its influence on airplane cost. Since all DOC components, with the exception of crew and fuel costs, are a function of airplane cost, the weight effect dominates direct operating cost trends. The impact of aircraft and engine costs on DOC can be seen in Table 6 which is a breakdown of trip cost for the 400 n. mi. VTOL mission. Variation in cost of insurance, maintenance and depreciation correlate with the airframe and engine costs, whereas crew costs are essentially equal for all configurations while fuel costs vary as a function of gross weight and propulsion system efficiency.

Operating cost changes are not completely described by weight trends. A comparison of cost components of integral and prop fan configurations -122 and -128, with gross weights differing by only 3 percent show similar crew, airframe maintenance, and airframe depreciation costs. The substantially lower engine cost of the -128 produces lower engine insurance and depreciation costs; the prop fans, more closely tailored to cruise requirements, produce lower fuel costs. The overall effect of these propulsion system considerations is a -128 DOC 9 percent lower than that of the -122 integral fan.

TABLE 6 TRIP COST COMPONENTS

		INTEGRAL FANS			REMOTE FANS						PROP/ FAN
CONFIGURATION		-120	-122	-134	-124	-133	-126	-127	-131	-132	-128
CREW	$	106	102	105	102	104	102	103	105	104	105
FUEL	$	162	183	147	237	184	272	223	186	197	152
INSURANCE	$	131	122	129	145	147	150	144	150	145	108
A/F MAINTENANCE	$	165	158	160	202	190	200	200	199	187	161
ENG. MAINTENANCE	$	184	173	184	194	212	216	184	195	225	163
A/F DEPRECIATION	$	229	215	221	287	268	283	284	282	260	216
ENG. DEPRECIATION	$	214	194	215	189	223	215	192	217	226	141
TOTAL TRIP COST	$	1192	1146	1162	1357	1328	1438	1329	1335	1344	1046
DOC	¢/ASM	2.59	2.49	2.53	2.95	2.89	3.13	2.89	2.90	2.92	2.27

In the -134 integral fan design an attempt is made to improve the cruise efficiency characteristics of the -122.

The -134 cruises on two instead of four engines and uses cruise fans in place of lift fans. Both configurations have eight engines and similar gross weights. A substantial reduction in fuel costs is achieved for the -134. However, the associated dilution of engine production quantity by incorporating two different types of engines on the -134 increases engine costs and therefore the cost components sensitive to engine costs such as insurance, engine maintenance, and engine depreciation. These engine cost effects are greater than the fuel cost improvement and the net effect is a 1.5 percent greater DOC for the -134 than the -122.

The -120 integral lift fan cruises on two engines of eight engines that are identical. The thrust is determined by the cruise requirement. This approach has the advantage of maintaining integral fan production levels associated with the -122 while increasing propulsion system cruise efficiency. The requirement that the six engines not used for cruise must be larger than required for the takeoff and landing maneuver is a disadvantage, however. The increased weight and cost associated with these six oversized engines as well as the added complexity of stowing two engines in the fuselage during cruise produce cost and weight penalties greater than the advantages of high engine production levels and improved cruise engine efficiency. The net effect of this design trade is a 4 percent greater DOC for the -120 than the -122 configuration.

The most significant components of DOC are the maintenance and depreciation costs for the engines and airframe. The relative effect of these components is independent of mission range.

2.3 DOC Sensitivities

Sensitivity analyses have been made to identify design and operational parameters which could have a significant impact on the economics of a V/STOL system. Operational changes considered include ground and air maneuver times, climb and descent speeds, and aircraft utilization. Design variations considered include engine price, airframe price, and engine maintenance costs. Unlike the constant cost items such as crew pay and fuel cost, the above parameters are variable and will influence design decisions and overall V/STOL system productivity. Due to the large fraction of total airplane cost in the propulsion system, special attention is given to the effect of engine maintenance costs and selling price.

Sensitivity curves were developed for both the -120 and -122 configurations. They represent two and four engine cruise designs. The results of the analysis on these designs is typical of all the V/STOL transports.

2.3.1 Manuever Time

Operationally the V/STOL transport may need very little air and ground maneuver times compared to conventional aircraft. The economic advantages of reduced maneuver times are important at the short range of V/STOL operation. This advantage is accounted for in the basic DOC analysis to the extent shown on this table.

	TAXI OUT AND TAKEOFF	AIR MANEUVER	LAND AND TAXI IN	TOTAL
VTOL (per guidelines)	1.5 min	2 min	2.5 min	6 min
CTOL (domestic 67 ATA)	10 min	6 min	5 min	21 min

The sensitivity of the DOC to further changes in this portion of the VTOL mission has been investigated. Figure 35 summarizes the effect on DOC of halving the VTOL mission ground and air maneuver times. This 50 percent reduction in air and ground maneuver time does not appear to offer significant DOC improvements. The effect is to reduce DOC by 1 percent at the 400-n. mi. design range and somewhat over 2 percent at the 100-n. mi. range point. This lack of sensitivity results because air and ground maneuver are a small part of the VTOL mission. The sensitivity is in proportion to the total mission time. For the 400-n. mi. mission, the block time is about 1.1 hours, and at the 240-n. mi. range, it is about 0.7 hour. In each case air and ground maneuver time is about 0.1 hour.

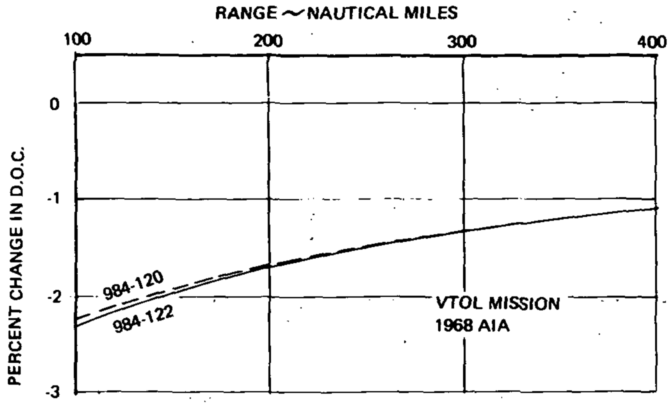

FIGURE 35 EFFECT OF HALVING GROUND AND AIR MANEUVER TIME

2.3.2 Climb and Descent Schedule

The climb and descent is a large part of the short range VTOL mission. The 250-knot IAS airspeed limitation below 10,000-ft altitude could reduce the performance advantages of a high (F/W) aircraft such as a V/STOL transport. Since operating costs are sensitive to block time changes, the impact of this operational restriction on V/STOL direct operating costs is of interest. VTOL missions with varying climb and descent schedules were investigated for the -120 and -122 configurations. The DOC is not very sensitive to increasing the 250-knot speed limit to 325 knots. The DOC is decreased by 1.2 percent at the 400-n. mi. design range.

The sensitivity of DOC to climb speed between 10,000 ft and cruise altitude is also small.

2.3.3 Aircraft Utilization

The utilization characteristics of a V/STOL system will be determined by design features, such as carry-on baggage and by scheduling requirements. The utilization level in this study was established using the 1968 AIA utilization curve. After study of the utilization data of conventional twins (737 and DC-9), it was decided that a V/STOL transport could reasonably expect a utilization rate approximately 20 percent better than predicted by the 1968 AIA curve. At a range of 240 n. mi., the projected improvement could mean a 9 percent reduction in DOC's (Figure 36).

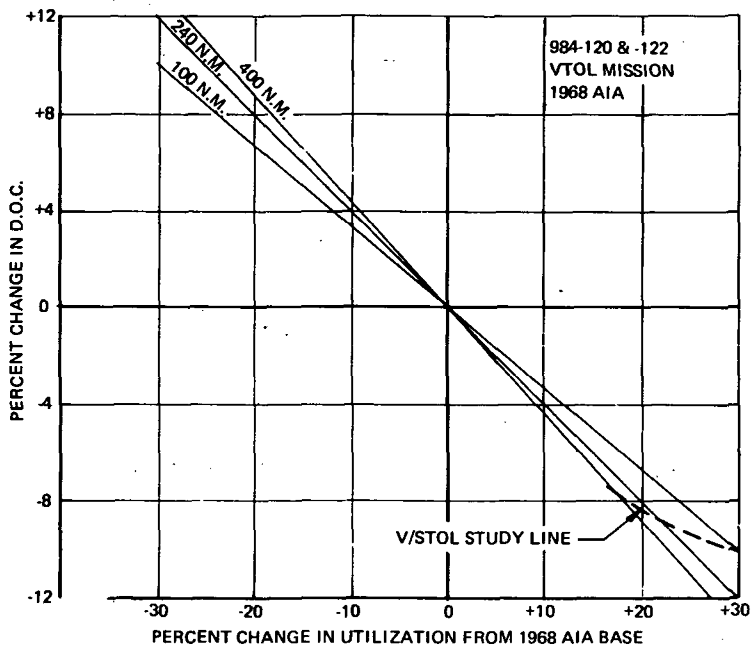

FIGURE 36 EFFECT OF UTILIZATION ON DOC

2.3.4 Engine Costs

V/STOL transport propulsion system costs, which account for approximately 50 percent of total airplane cost, have a significant impact on V/STOL DOC's at all ranges. The three components that reflect propulsion system costs, engine maintenance material, depreciation and insurance, account for as much as 37 percent of total DOC at the 400-n. mi. design point range. Figure 37 summarizes the DOC sensitivity of the 984-120 and -122 configurations to changes in engine price at the 100-, 240- and 400-n. mi. range points. For an engine price change of $100,000 per airplane, DOC changes by 6.3 percent at 100-n. mi. range and 5.4 percent at 400-n. mi. range. An engine price reduction of this order of magnitude could be achieved by increasing the production base and reducing the development costs.

2.3.5 Airframe Costs

The sensitivity of direct operating costs to changes in airframe price is also of interest in an analysis of V/STOL transport economics. Airframe price changes affect airframe maintenance material, depreciation, and hull insurance portions of direct operating cost. Figure 38 shows the overall impact of airframe price changes on the DOC of the -120 and -122 configurations. The effect of a $1,000,000 airframe price change on DOC ranges from 4.6 percent for the -122 to 5 percent for the -120. These changes are independent of flight range.

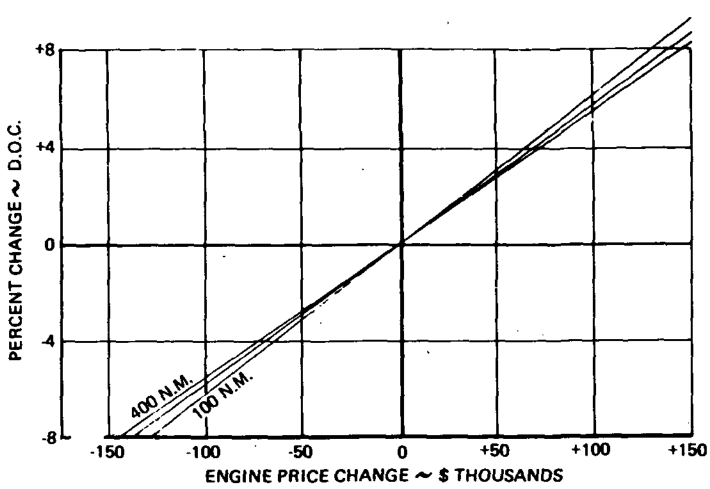

FIGURE 37 DOC SENSITIVITY TO ENGINE PRICE

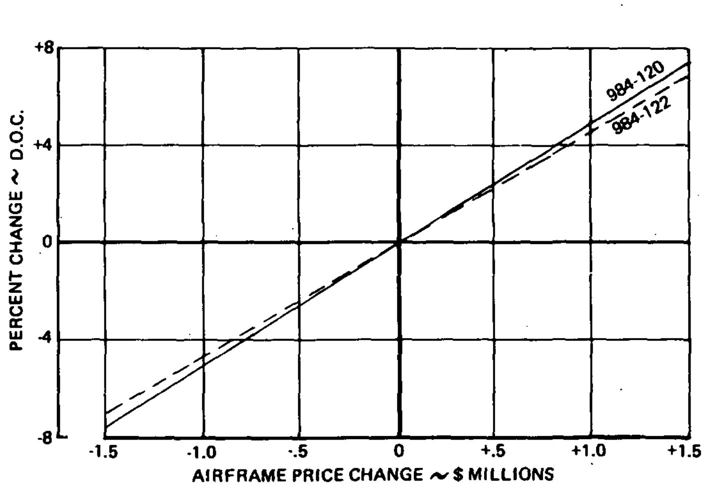

FIGURE 38 AIRFRAME PRICE CHANGE DOC SENSITIVITY TO AIRFRAME PRICE

2.3.6 Engine Maintenance

Engine maintenance costs are dominated by maintenance material requirements, which in turn are determined by engine cost. For the V/STOL transport, with a propulsion system as much as five times costlier than an equivalent CTOL aircraft, the engine maintenance component of DOC is a significant part of total trip cost. Any improvement in engine maintenance costs will, therefore, have a large impact on V/STOL DOC.

Two areas of particular importance are the effects of under utilization of available thrust, due to reserve thrust required for VTOL takeoff and landing, and the application of maintenance levels which reflect mature engine maintenance practices. The engine derating effect resulting from under utilization of onboard thrust can reduce overall engine maintenance costs by as much as 20 percent and is characteristic of V/STOL aircraft (based on informal Pratt and Whitney information). The application of mature engine maintenance characteristics affects a further reduction in maintenance costs.

The DOC's developed for the aircraft in this study reflect engine maintenance levels predicted by General Electric and Hamilton Standard. These maintenance levels which incorporate inservice characteristics of existing engines are presumed to contain the effects of both maturity and derating. They are substantially lower than those predicted by the 68 AIA formula.

Figure 39 shows the impact of engine maintenance costs on DOC's. Engine maintenance costs predicted by the engine manufacturers are approximately 55 percent under the levels predicted by 68 AIA formula. The DOC's presented for these aircraft would be 18 percent to 20 percent higher if 68 AIA values were used.

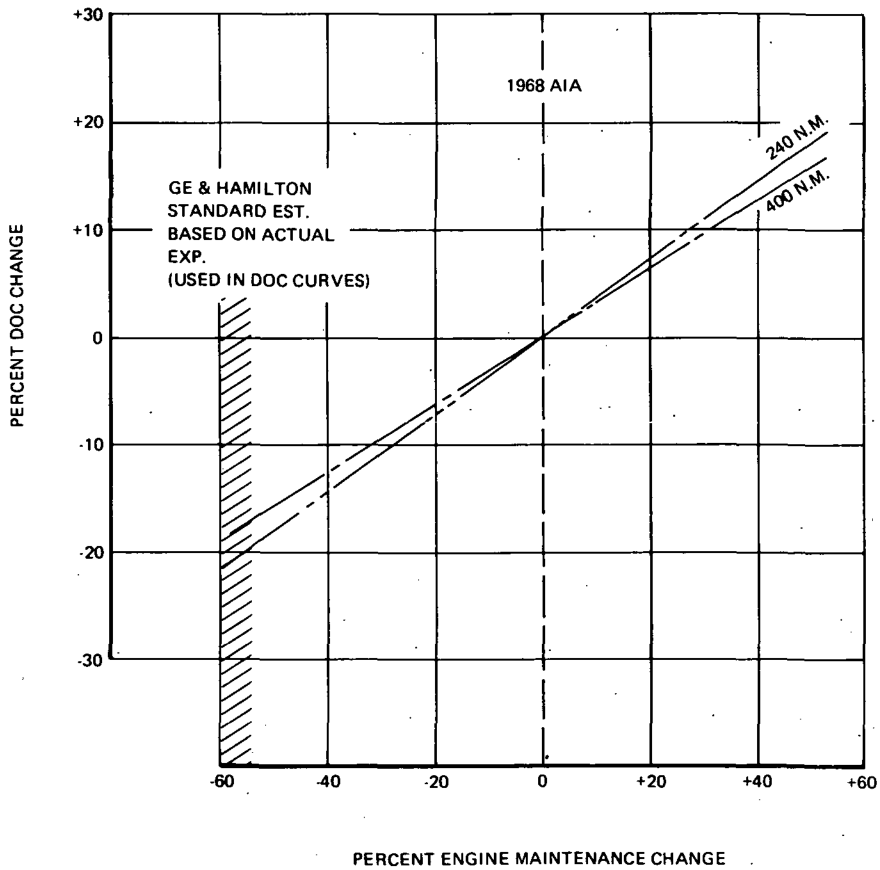

FIGURE 39 MAINTAINANCE SENSITIVITY

The 1980-1985 commercial V/STOL aircraft will serve a short range market like that radiating from New York/Newark, Washington, D. C./Baltimore and Chicago. The need for improvement in that market is not questioned, but the economic feasibility of a V/STOL system is not known. The short range market is currently dominated by 727, 737, and DC-9 aircraft. A comparison of V/STOL DOC with that of these aircraft is presented in Figure 40. The V/STOL aircraft vary from 62 percent to 125 percent higher than the average of the CTOL aircraft. A comparison with the top of the CTOL band (737-100 and DC9-10) shows the best of the V/STOL designs (-128 prop fan) to be approximately 30 percent higher in DOC at the average range of 240 n. mi.

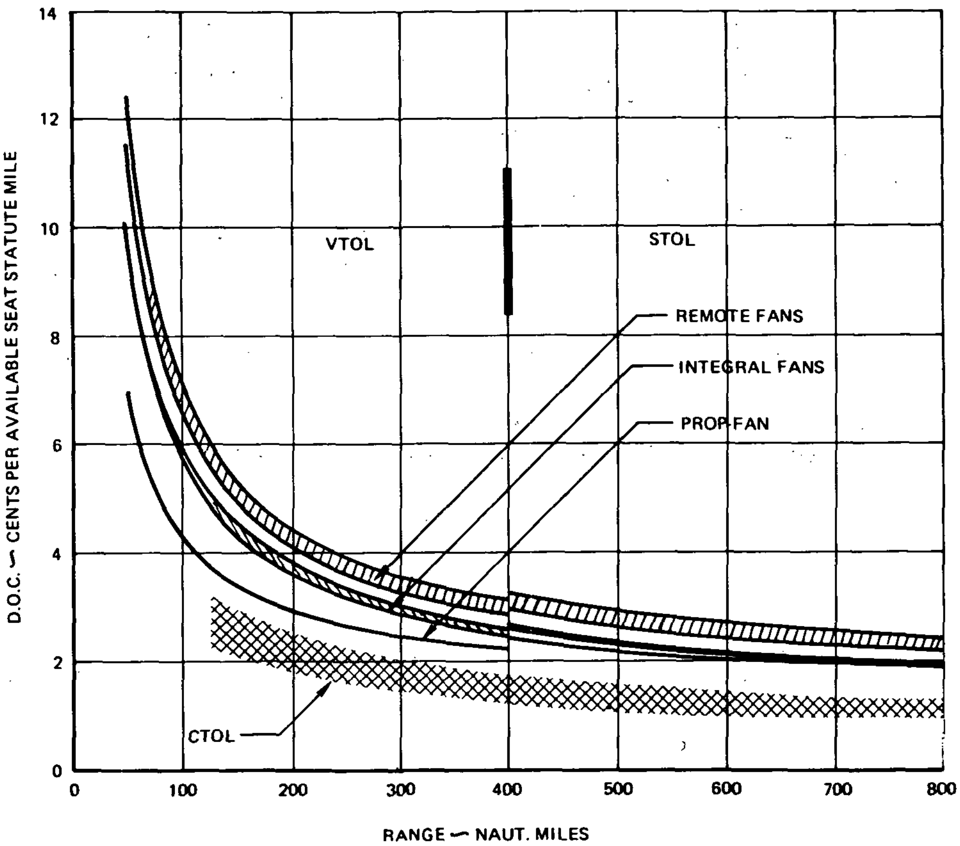

FIGURE 40 DIRECT OPERATING COST SUMMARY-COMPARISONS WITH CTOL

In the discussion of DOC sensitivity, the most sensitive areas were seen to be airplane cost, utilization, and engine maintenance while maneuver and low altitude speed were not important. Figure 41 summarizes the possible effects of these design and operational changes on the DOC of the -128 configuration. The effects of engine maintenance improvements are included in the basic DOC level.

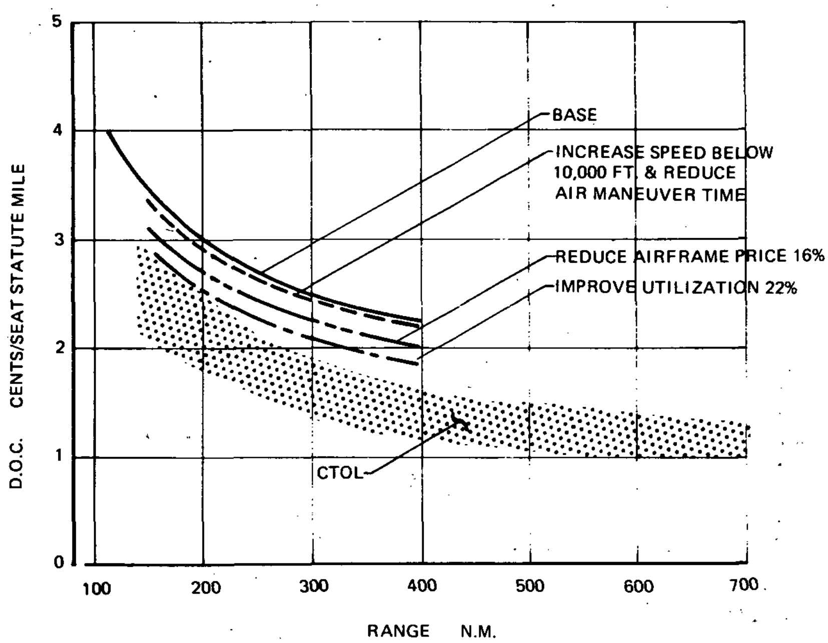

FIGURE 41 POSSIBLE DOC IMPROVEMENT, 984-128

3.0 CONCLUSIONS

These studies led to conclusions about weight, cost, noise and control. In all of these areas, the integral lift fan and the prop fan airplanes were the most attractive as summarized in the following:

- The best integral and prop fan designs each weigh 110,000 lb with a spread of less than 0.2 percent.

- The best remote fan design weighs 128,800 lb.

- The primary difference between interconnected remote fan and noninterconnected integral designs is in the installed thrust weight ratio required, compared with the weight and volume of interconnection. The remote fan designs though having the lowest installed thrust weight ratio are heavy due to the large weight and volume of the ducting, valves, etc. The duct temperature limits are an additional handicap to these aircraft.

- Adequate control systems, from the standpoint of response time and control shaping, is possible with all the propulsion types.

  - The prop fan system is very fast and straightforward. All thrust changes are made at constant rpm.

  - The remote fans use a combination of thrust spoiling and power transfer to achieve the desired combination of thrust magnitude and response.

  - The integral fans are each operated independently and will need both a rapid response system, similar to spoiling on the remote fans, and an rpm change for the long term effect.

- All the airplanes meet the noise goal of 95 PNdB at the 500-ft sideline within 1.5 dB. The maximum area enclosed by the 95 PNdB contour during takeoff and landing is less than 70 acres. This compares to more than 7000 acres for current short haul jet aircraft.

- These V/STOL aircraft will be more expensive than conventional short haul transports.

    - Initial costs will be two to three times as high. The prop fan airplanes will be least expensive; the integral fans a close second with the remote fans a poor third.

    - Direct operating costs on a 250-n. mi. mission will be between 30 percent and 40 percent higher for the prop fan. The same rating of configuration types is found; prop fans are lowest and remote fans highest.

- The development of V/STOL aircraft will not occur independent of the V/STOL system which includes such items as real estate, access, terminals, navigation aids and fare structure because of the high cost. Any development to be economically competitive must account for the entire system, not just the airplane.

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APPENDIX A

Propulsion Performance

1. Integral Lift Fans

The characteristics of the integral lift fan M are presented in Figures A1 to A7. The reference performance is based on a total flow of 100 lb second at M = 0.75 at 25,000 ft.

The cruise version has a two-area position nozzle. The cruise area is the design area; the area ratio for low speed is given on Figure A1. If only a lift application is intended, this low speed nozzle area is used.

2. Remote Lift Fan Performance

The performance of the remote lift fan shown on Figures A8 to A11 were provided by General Electric for this study.

3. Cruise Fan Performance

The cruise fan performance is presented on Figures A12 to A15. The reference level is based on a total airflow of 100 lb/sec at M = 0.75 and 25,000 ft. The engine has a two-position nozzle for takeoff and cruise operation.

4. Prop Fan Performance

The performance of the prop fan is summarized on Figure A16. The cruise data is shown on Figures A17 to A18 for a reference engine at 100 lb/sec at M = 0.75 and 25,000 ft. The engine as sized for the -128 is 5.31 times the reference size.

SEA LEVEL STATIC, STANDARD DAY	
MAXIMUM CONTROL RATING	
GROSS THRUST, LB,	4026
SPECIFIC FUEL CONSUMPTION, LB /HR /LB,	0.34
TURBINE ENTRY TEMPERATURE, DEGREES R,	3000
TOTAL AIRFLOW, LB/SEC,	185
BYPASS RATIO	12.7
OVERALL PRESSURE RATIO	10.22
FAN PRESSURE RATIO	1.31
FAN NOZZLE AREA RATIO (A_{SEC})	1.2
PRIMARY NOZZLE AREA RATIO (A_{PRI})	1.6
MACH 0.75, 25,000 FEET, STANDARD DAY	
MAXIMUM CONTINUOUS RATING (DESIGN POINT)	
NET THRUST, LB,	956
SPECIFIC FUEL CONSUMPTION, LB/HR/LB,	0.75
TURBINE ENTRY TEMPERATURE, DEGREES R,	2800
FAN NOZZLE AREA RATIO (A_{SEC})	1.0
PRIMARY NOZZLE AREA RATIO (A_{PRI})	1.0
TOTAL AIRFLOW, LB/SEC.	100

FIGURE A-1 INTEGRAL LIFT FAN “M”

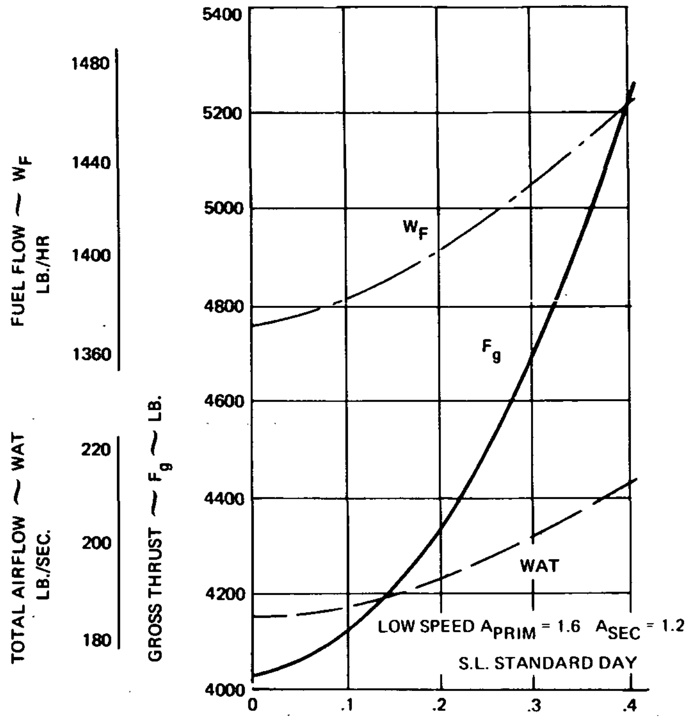


FIGURE A-2 INTEGRAL LIFT FAN "M"–LOW SPEED

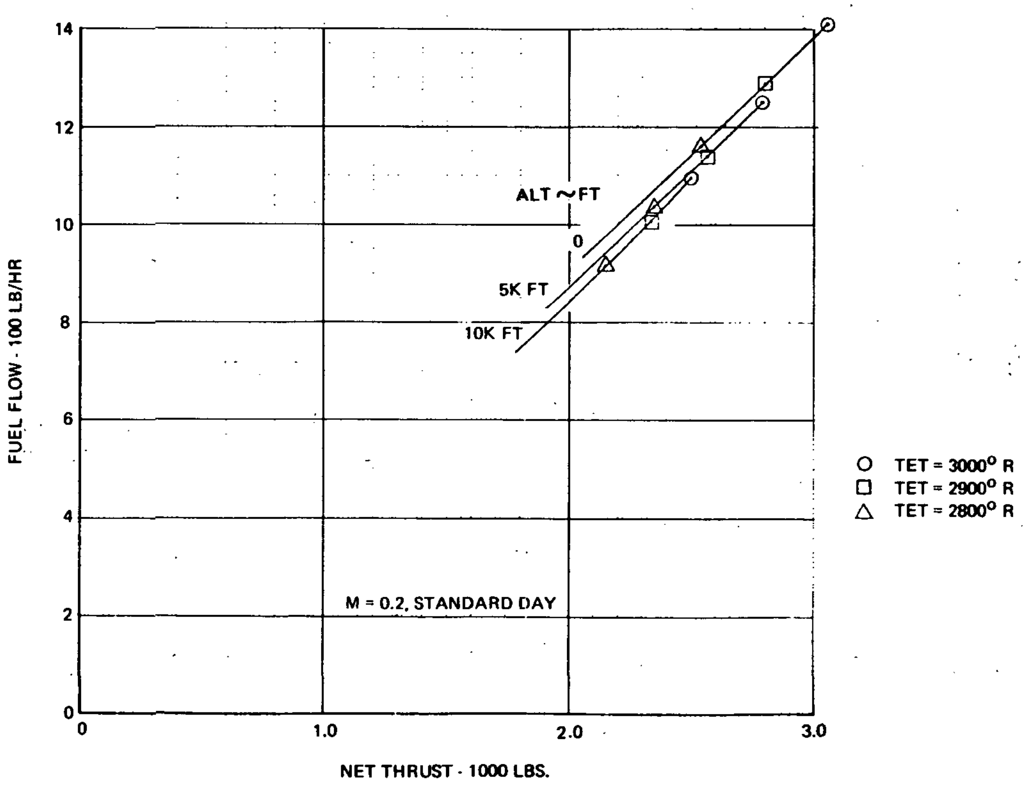


FIGURE A-3 INTEGRAL LIFT FAN "M"–M = 0.2

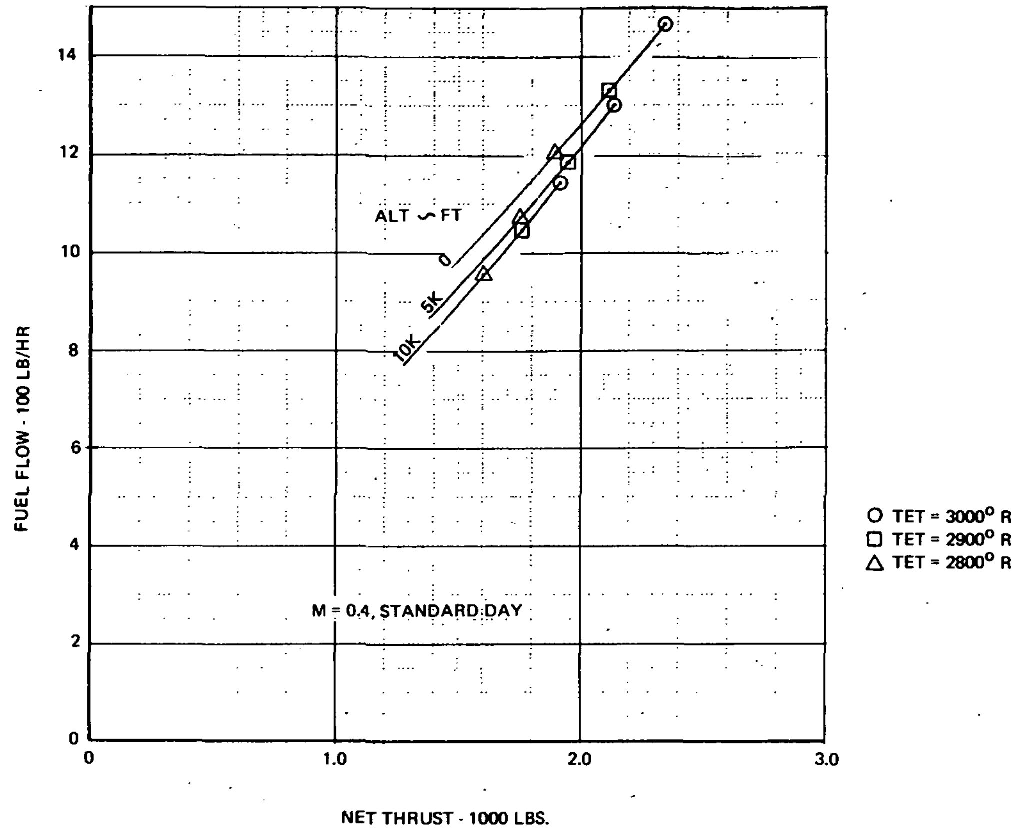


FIGURE A-4 INTEGRAL LIFT FAN "M"–M = 0.4

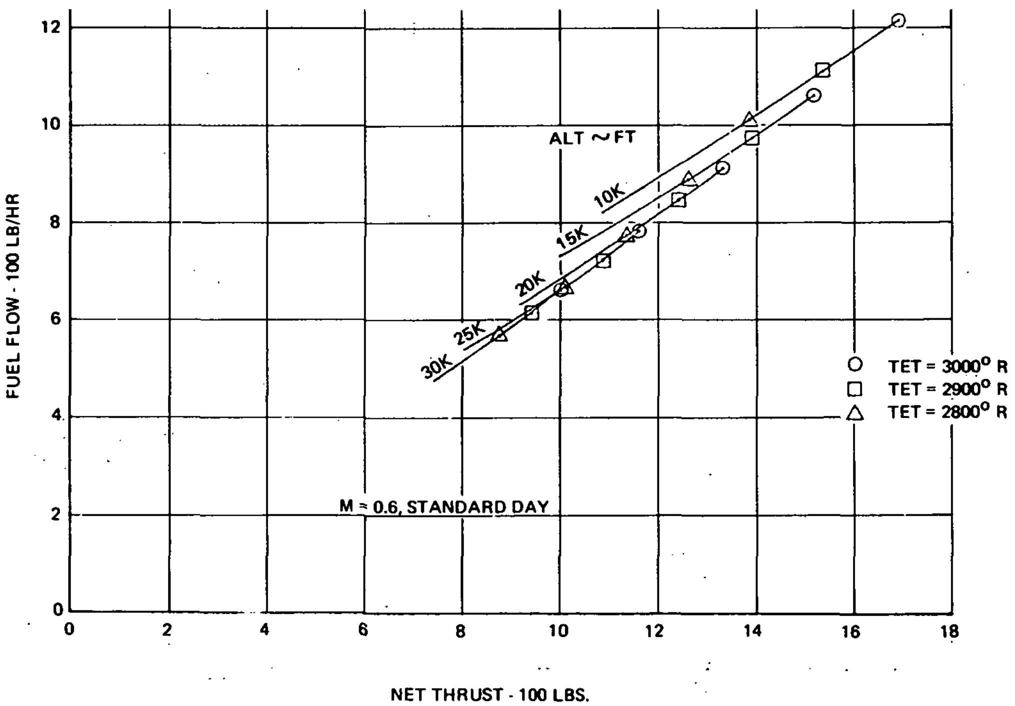


FIGURE A-5 INTEGRAL LIFT FAN "M"–M = 0.6

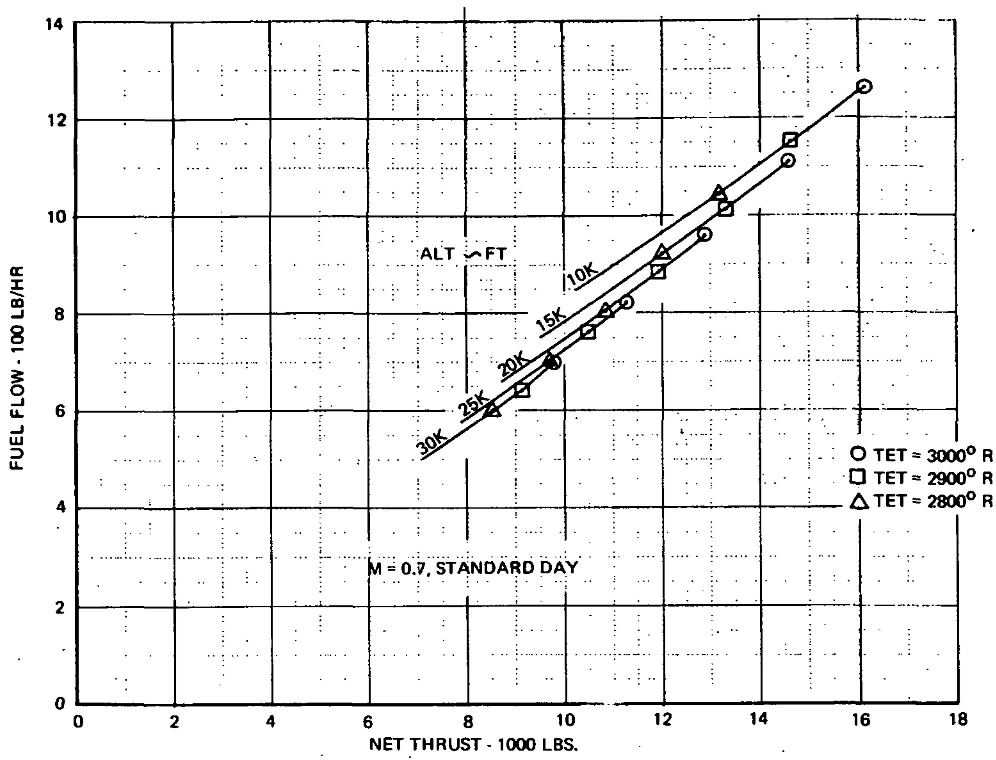


FIGURE A-6 INTEGRAL LIFT FAN "M"–M = 0.7

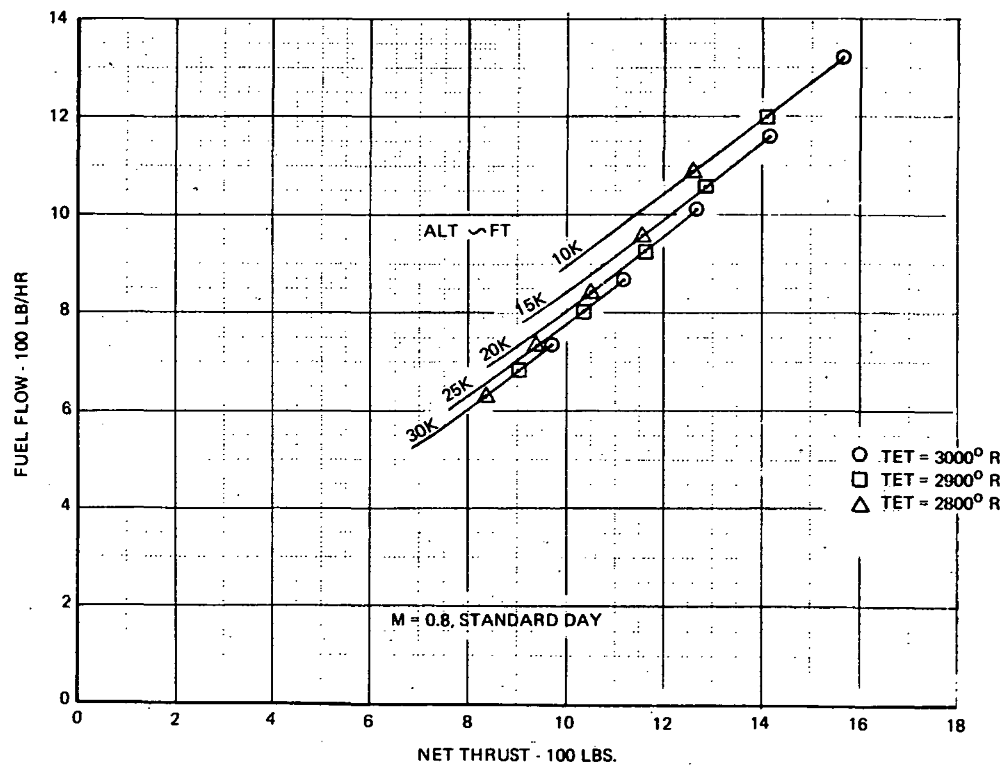


FIGURE A-7 INTEGRAL LIFT FAN "M"–M = 0.8

<u>MAXIMUM CONTINUOUS ~ NO POWER TRANSFER</u>	
FAN TURBINE ENTRY TEMPERATURE (TET)	1860°R
FAN PRESSURE RATIO (R_p)	1.25
F_{GROSS}	12330. LB.
TOTAL AIR FLOW WAT	737. LB./SEC.
B.P.R.	10
<u>MAXIMUM CONTROL ~ 8% POWER (PRIMARY FLOW) TRANSFER</u>	
OPPOSITE FAN LOSSES POWER	
FAN TET	2060°R
FAN R_p	1.31
F_{GROSS}	15200. LB.

FIGURE A-8 REMOTE LIFT SYSTEM A

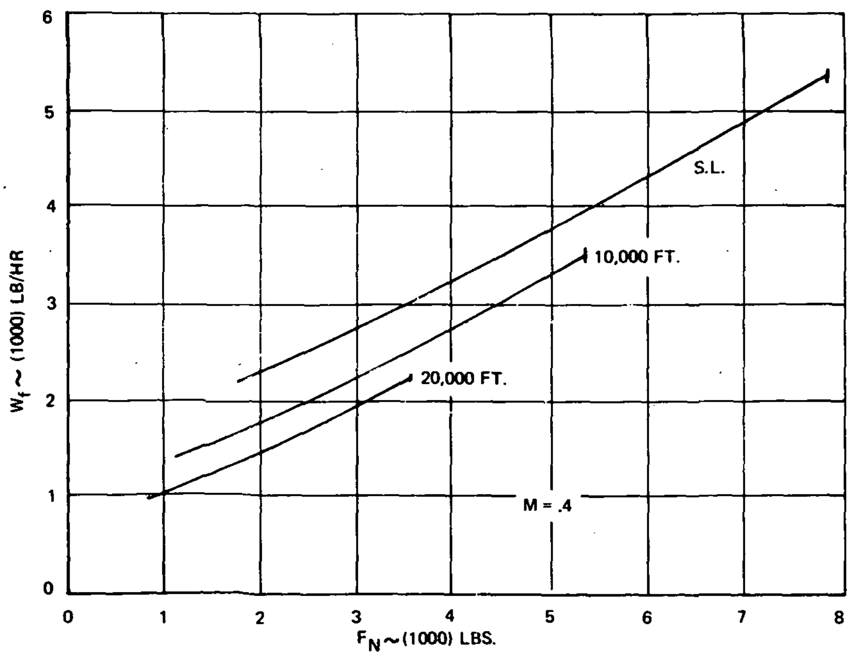


FIGURE A-9 REMOTE LIFT SYSTEM A–M = 0.4

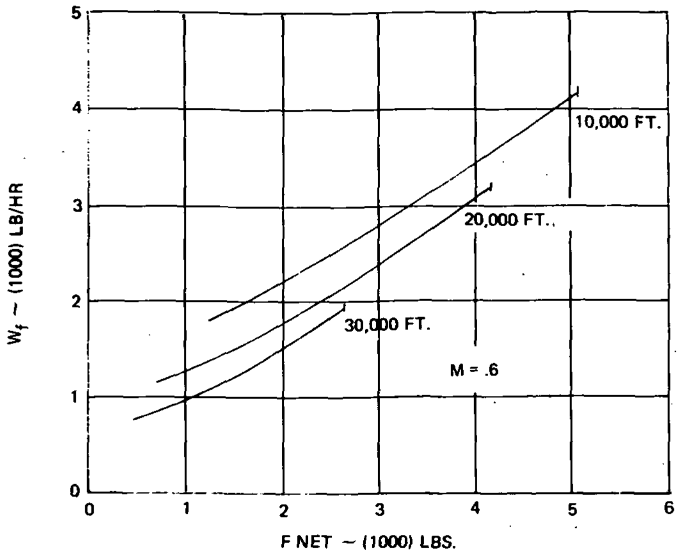


FIGURE A-10 REMOTE LIFT SYSTEM A–M = 0.6

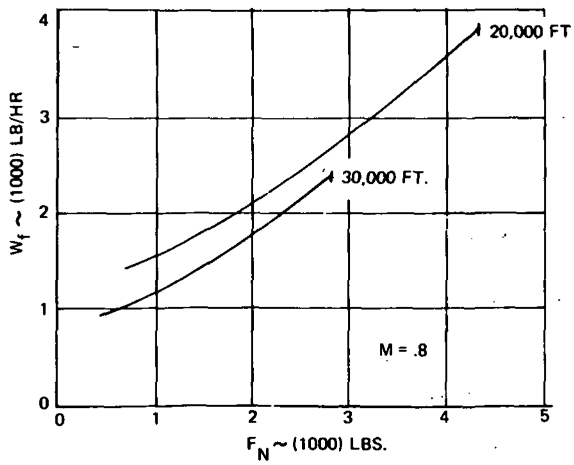


FIGURE A-11 REMOTE LIFT SYSTEM A–M = 0.8

SEA LEVEL STATIC, STANDARD DAY

MAXIMUM CONTROL RATING

GROSS THRUST, LB,	3914
SPECIFIC FUEL CONSUMPTION, LB/HR/LB,	0.310
TURBINE ENTRY TEMPERATURE, DEGREES R,	3000
TOTAL AIRFLOW, LB/SEC,	172.1
BYPASS RATIO	12.0
OVERALL PRESSURE RATIO	20.5
FAN PRESSURE RATIO	1.33
FAN NOZZLE AREA RATIO (A_{SEC})	1.1
PRIMARY NOZZLE AREA RATIO (A_{PRI})	1.5

MACH 0.75, 25,000 FEET, STANDARD DAY

MAXIMUM CONTINUOUS RATING (DESIGN POINT)

NET THRUST, LB,	971
SPECIFIC FUEL CONSUMPTION, LB/HR/LB,	0.655
TURBINE ENTRY TEMPERATURE, DEGREES R,	2800
FAN NOZZLE AREA RATIO (A_{SEC})	1.0
PRIMARY NOZZLE AREA RATIO (A_{PRI})	1.0
TOTAL AIRFLOW, LB/SEC.	100

FIGURE A-12 BOEING CRUISE FAN "P"

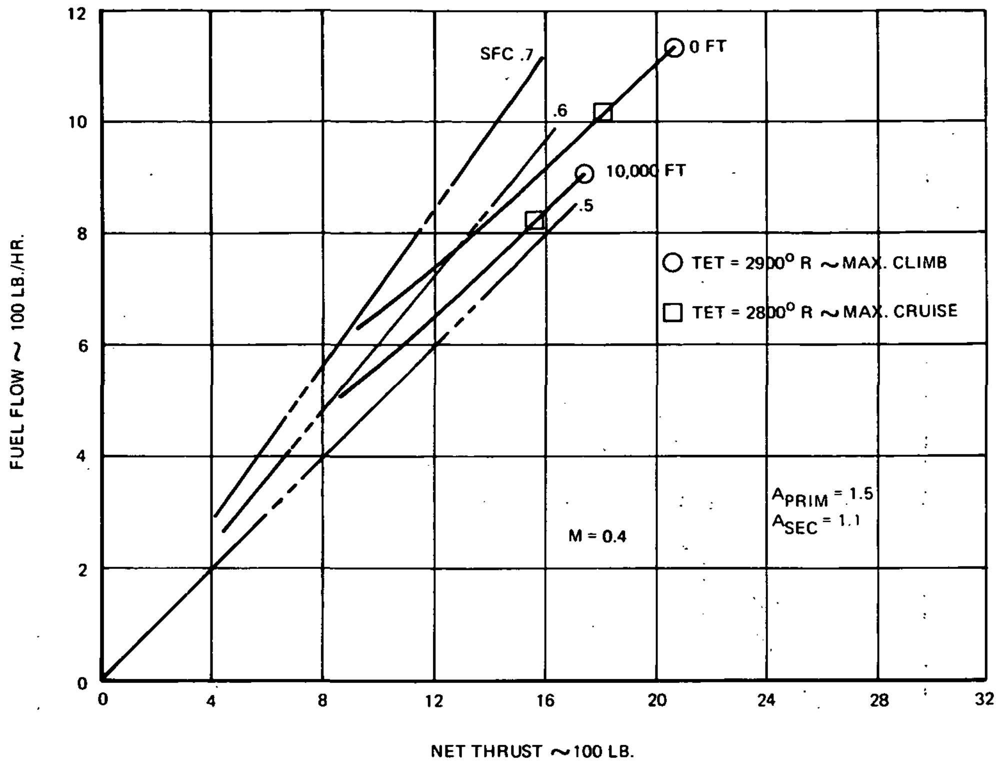


FIGURE A-13 CRUISE FAN "P"–M = 0.4

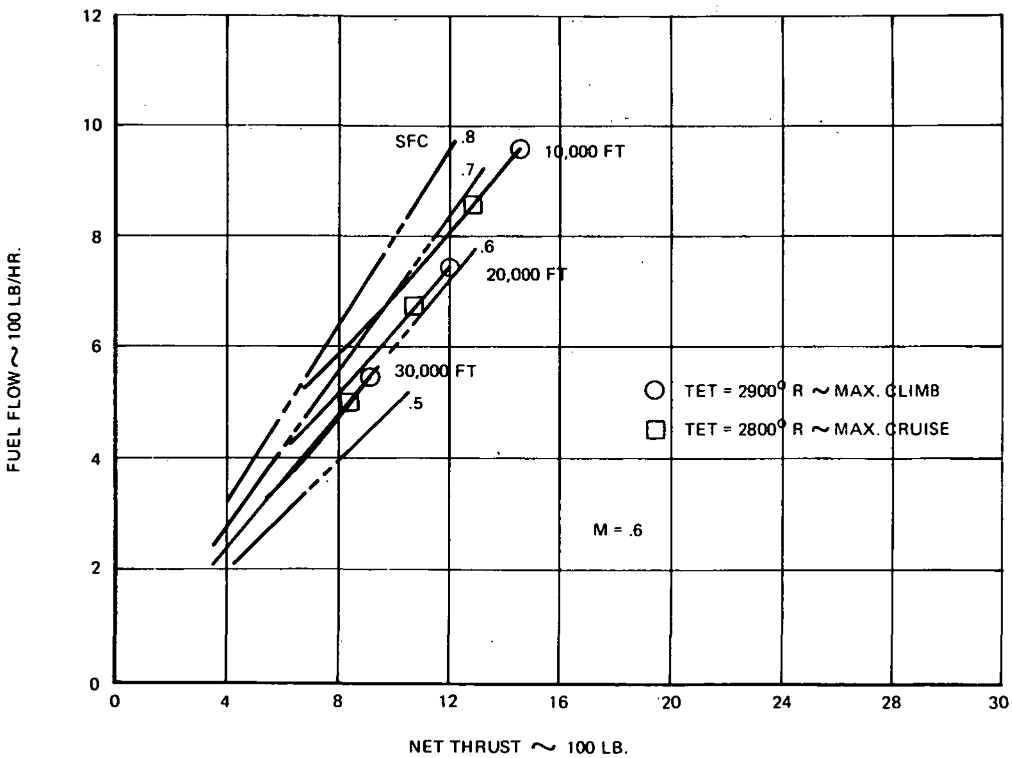


FIGURE A-14 CRUISE LIFT FAN "P"–M = 0.6

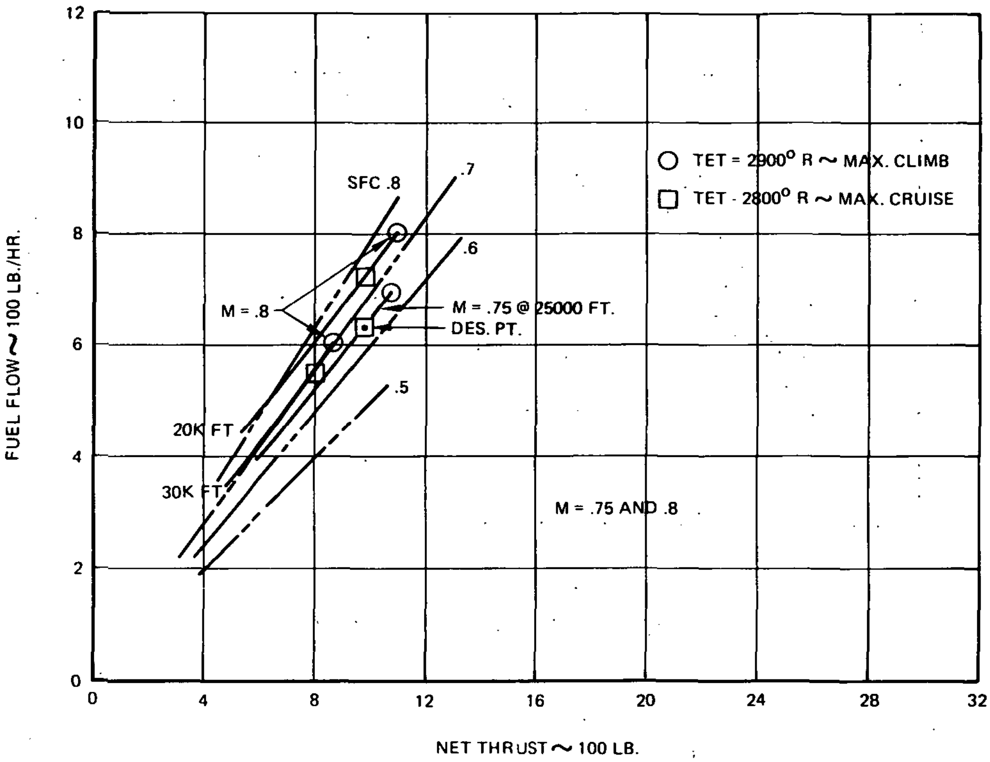


FIGURE A-15 CRUISE FAN "P"–M = 0.75 AND 0.8

THE TABULATED DATA BELOW IS FULL SIZE, FOR 948-128*

GAS GENERATOR

S.L. STATIC TAKEOFF RATING 17800 HP

LIFT/CONTROL FANS SEA LEVEL STATIC

CONTROLS NEUTRAL 6670 HP/FAN $F = 11{,}600$ LB/FAN

MAX. POWER TRANSFER (FAN DESIGN POINT)

8530 HP/FAN $F_{MC} = 14{,}500$ LB/FAN

LIFT/CRUISE FAN

M = .75, H = 25,000 FT. (DESIGN POINT)

$R_F = 1.33$ $F_N = 6700$ LB.

$W_{AT} = 531.$ LB/SEC

SEA LEVEL STATIC

A) TAKEOFF CONDITION. ONE FAN AND 5/8 OF HP GAS GENERATOR (11,130 HP)

$F = 18{,}400$ LB. $R_F = 1.23$

B) ONE FAN, ONE GAS GENERATOR.

$F = 23{,}750$ LB. $R_F = 1.4$

*REF. LIFT/CRUISE PROP/FAN "S" IS BASED ON 100 LB/SEC. MASS FLOW AT M = .75 AND 25,000 FT. THE FANS USED ON THE -128 ARE 5.31 TIMES AS LARGE.

THE PERFORMANCE ON THE ACCOMPANYING FIGURES OF PROP/FAN "S" IS FOR REFERENCE SIZE.

FIGURE A-16 PROP/FAN "S"

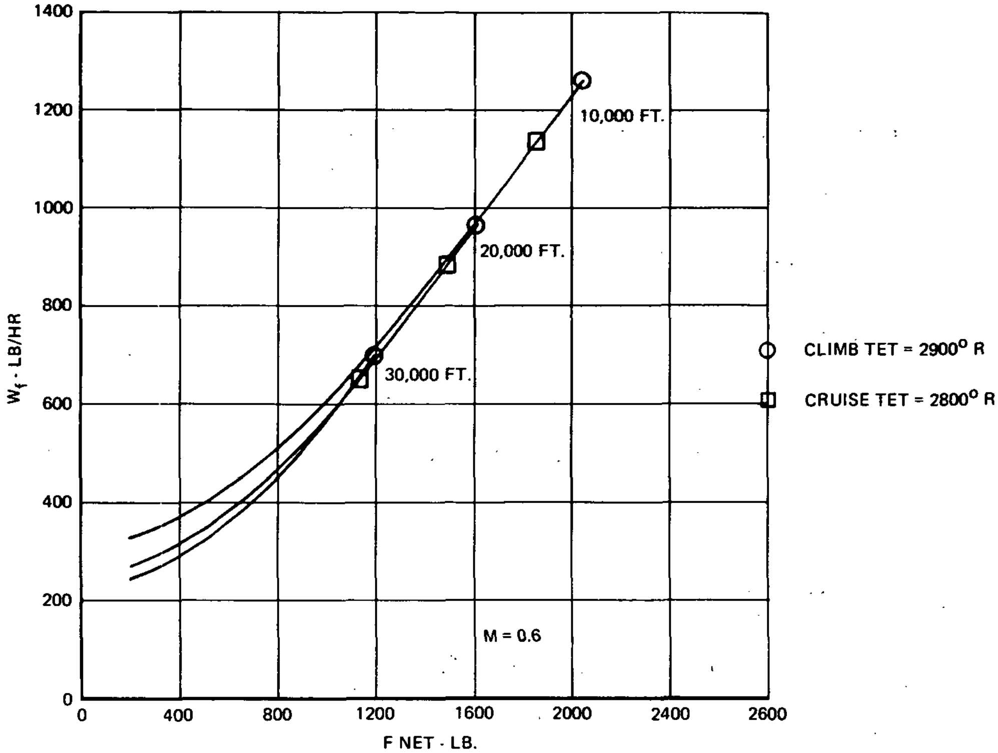


FIGURE A-17 PROP/FAN "S"–M = 0.6

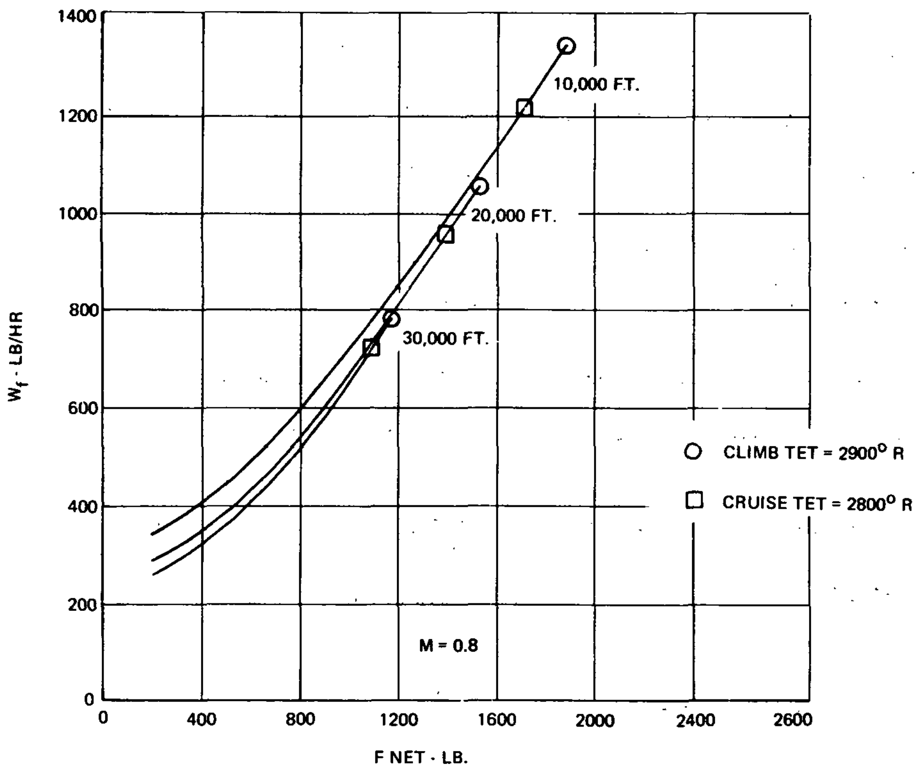


FIGURE A-18 PROP/FAN "S"–M = 0.8

APPENDIX B

Excerpts from Study Guidelines and Design Criteria for Conceptual Design of V/STOL Lift Fan Commercial Short Haul Transport

The guidelines and design criteria which primarily influenced the design of the V/STOL lift fan commercial short haul transport are reproduced so that the bounds on the design are clear.

1. Introduction

There is a considerable body of documented data and recommendations related to aircraft design criteria, particularly those criteria concerning flight safety margins and handling qualities. Of these criteria the most important, because they represent certification requirements, are contained in the Federal Airworthiness Regulations (FAR's). A criterion is incorporated in the FAR's if it affects safety. . . . The search for a suitable set of criteria must encompass not only the published data and recommendations but also the hitherto undocumented opinions of those concerned with the development of V/STOL transport aircraft. The response to the request for suggested design criteria and guidelines . . . has been an important contribution to this search . . .

The design criteria and guidelines for the 1980-85 V/STOL transport are presented under the following main headings: Flight Safety Criteria, Performance, Operating Economics, General Design Guidelines and Passenger Comfort Criteria and Guidelines. The Flight Safety Criteria section is concerned with questions of safety margins, control characteristics and handling qualities. The performance section deals with the specification of the desired performance of the baseline 1980-85 V/STOL transport aircraft and includes airfield performance, altitude and payload-range. The Operating Economics section specifies a set of rules for determining the DOC and discusses other possible economic yardsticks.

General Design Guidelines section addresses questions such as external noise, number of passengers, mandatory aircraft equipment, design life, etc. Finally the Passenger Comfort Criteria and Guidelines section gives limitations on all design parameters which have a bearing on passenger comfort. This involves specification of passenger cabin environment and ride qualities. In areas not specifically covered by criteria given in this document it should be assumed that the appropriate requirements given in FAR's 25, 36 and 121 apply.

The criteria and guidelines given here merely represent the considered opinion of NASA personnel associated with the forthcoming V/STOL study and have no official status outside the study at which they are directed. These criteria and guidelines are therefore not to be interpreted as a statement of NASA policy.

2. Flight Safety and Operating Criteria

This section is concerned with flight safety and operating criteria and includes the type of criteria usually found in the Federal Airworthiness Regulations . . .

2.1 Power Plant Failure Philosophy

The only sure approach to the power plan failure question is based on component failure statistics obtained from operational experience. This experience has shown that a gas generator failure must be allowed for, in the design of multi-engined commercial aircraft, if the catastrophic accident rate is to be tolerable. A similar positive statement cannot be made about tip turbine driven remote fans and shaft driven prop-fans simply because the required amount of operating experience has not yet been obtained. However, the directly applicable experience to date, coupled with experience on related types of machinery, indicates that both fans and prop-fans will have lower probabilities of failure than gas generators. What is not certain, at this time, is that these failure probabilities will be sufficiently low that failure of these devices need not be allowed for in the aircraft design . . . Even if the failure probabilities are not low enough to permit remote fans and prop-fans to be considered "no fail" there is no reason why the flight safety criteria for this type of failure should be as stringent as, for example, a gas generator. The flight safety criterion for remote fan and prop-fan failures may be assumed to be simply that the aircraft be controllable and capable of being landed while staying within its structural design limits.

Study participants are therefore invited to study, in depth, aircraft configurations which reflect their preferred power plant failure philosophy. However, it is requested that participants also study the alternative power plant philosophy in sufficient depth to be able to present estimates of the differences in aircraft layout, aircraft gross weight, installed thrust to weight ratios and DOC's.

2.2 Handling Qualities Criteria (speeds below the conversion speed V_{con})

Except where specific criteria are given, handling qualities shall comply with the recommendations of AGARD-R-577-70. Where possible two levels-of-criteria are stated, the first is intended for normal operation and the second for operation following any reasonable single failure of the power plant or control system. Definitions of the two levels are as follows:

Level 1: Flying qualities are as near optimal as possible and the aircraft can be flown by the average commercial pilot.

Level 2: Flying qualities are adequate to complete the mission. The pilot work load is increased but is still within the capabilities of the average commercial pilot.

2.2.1 Attitude Control Power (S.L., ISA + 31°F)

Level 1: At all aircraft weights and at all speeds up to V_{con}, the low speed control power shall be sufficient to satisfy the most critical of the two following sets of conditions.

Condition (a)—to be satisfied simultaneously

1) Trim with the most critical CG position (see Section 5.9).

2) In each control channel provide control power, for maneuver only, equal to the most critical of the requirements given in the following table.

AXIS	MAX ANGULAR ACCELERATION AFTER A STEP INPUT		ATTITUDE ANGLE IN 1 SEC AFTER A STEP INPUT	
	VTOL	STOL	VTOL	STOL
Roll	±0.6 rad/sec^2	±0.4 rad/sec^2	±10 deg	±6 deg
Pitch	±0.33 rad/sec^2	±0.3 rad/sec^2	±6 deg	±5 deg
Yaw	±0.25 rad/sec^2	±0.2 rad/sec^2	±5 deg	±3 deg

These maneuver control powers are applied so that 100% of the most critical and 50% of each of the remaining two need occur simultaneously.

Conditions (b)—to be satisfied simultaneously

1) Trim in a 25 kt TAS cross wind with the most critical CG position.

2) In each control channel provide control power, for maneuvering only, equal to the most critical of the requirements given in the following table.

AXIS	MAX ANGULAR ACCELERATION AFTER A STEP INPUT		ATTITUDE ANGLE IN 1 SEC AFTER A STEP INPUT	
	VTOL	STOL	VTOL	STOL
Roll	±0.4 rad/sec^2	±0.3 rad/sec^2	±6 deg	±4.5 deg
Pitch	±0.33 rad/sec^2	±0.3 rad/sec^2	±6 deg	±5 deg
Yaw	±0.17 rad/sec^2	±0.15 rad/sec^2	±3 deg	±3 deg

As for conditions (a) simultaneous maneuver control power need be no greater than 100% - 50% - 50%.

Level 2: At all aircraft weights and at any speed up to V_{con}, the low speed control power shall be sufficient to simultaneously satisfy the following.

1) Trim in a 25 kt TAS cross wind with the most critical CG position.

2) Trim after any reasonable single failure of power plant or control system.

3) In each control channel, provide control power, for maneuver only, equal to at least 50% of the most critical of the requirements given in the table above for Conditions (b). As for Conditions (a), simultaneous maneuver control power need be no greater than 100% - 50% - 50%.

2.2.2 Flight Path Control Power (SL to 1000 ft., ISA + 31^{o}F)

2.2.2.1 VTOL (0 to 40 kt TAS and zero rate of descent)

At all aircraft weights, at the conditions for maximum control power specified in Section 2.2.1 and with this control power applied, it shall be possible to produce the following incremental accelerations for height control.

Level 1:

a) In free air ±0.1g

b) With wheels just clear of the ground –0.10g, +0.05g

Level 2:

a) In free air –0.1g, +0.05g

b) With wheels just clear of the ground –0.10g, +0.00g

2.2.2.2 VTOL Approach (40kt TAS to V_{con})

At the maximum landing weight and in a 25 kt crosswind the aircraft shall be capable of an approach flight path angle of 20 deg, and the following incremental accelerations.

Level 1: ±0.15g tangential to the flight path and ±0.20g normal to the flight path. (but not simultaneously)

Level 2: ±0.1g tangential to the flight path and ±0.10g normal to the flight path (but not simultaneously)

2.2.2.3 STOL Approach

At the maximum landing weight and in a 25 kt cross wind the aircraft shall be capable of the following incremental accelerations.

Level 1: ±0.15g tangential to the flight path and ±0.25g normal to the flight path (but not simultaneously)

Level 2: ±0.1g tangential to the flight path and ±0.15g normal to the flight path (but not simultaneously)

2.2.3 VTOL and STOL Low Speed Control System Lags (S.L. to 1000 ft, ISA +31°F)

The effective time constant (time to 63% of the final value) for attitude control moments and for flight path control forces shall not exceed the levels given in the following table:

	Level 1	Level 2
Attitude Control Moments	0.2 sec	0.4 sec
Flight Path Control Forces	0.3 sec	0.6 sec

The step type input is assumed to be applied at the pilot control. . . .

2.3 VTOL Takeoff and Landing Safety Criteria

A no-penetration (NP) surface is defined which is 35 ft. above all surfaces defined for the VTOL port . . . except for the area of the primary surface . . .

With any assumed takeoff or landing operational procedure, any reasonable single failure of the power plant or control system, together with a simultaneous discrete gust . . . shall not result in the aircraft entering the NP surface. Compliance with FARXX.79 is required.

The airfield shall be assumed to be at sea level and the atmosphere ISA + 31°F with a 25 kt. crosswind.

2.4 STOL Takeoff and Landing Safety Criteria

A requirement similar to that given in Section 2.3 shall be satisfied . . .

The airfield shall be assumed to be at sea level and the atmosphere ISA +31°F, with a 25 kt. crosswind.

2.4.1 STOL Takeoff Safety Criteria

The following relationship between the various ground speeds shall hold

$$V_{LOF} \geqslant V_R \geqslant V_1 \geqslant 1.05\ (V_{MCG} \text{ and } V_{MCA})$$

Where V_{MCG} = minimum control speed on the ground FAR XX.149

V_{MCA} = minimum control speed in the air FAR XX.149

V_1 = critical decision speed FAR XX.53

V_R = rotation speed

V_{LOF} = lift off speed FAR XX.53

The obstacle clearance speed V_2 shall satisfy the following relationships.

$$\begin{aligned} V_2 &\geqslant V_{LOF} \\ &\geqslant 1.15\ V_{MCA} \\ &\geqslant V_{MCA} + 10 \text{ kts.} \\ &\geqslant 1.2\ V_{MIN} \end{aligned}$$

V_{MIN} = minimum flying speed with gear down FAR XX49.

The angle of attack, during climbout, shall be 10 deg. or more below the angle of attack for stall, in the takeoff configuration, with gear down and the most critical power plant failure.

The climbout gradient, in the takeoff configuration with gear down and power plant fully operative, and with gear up and the most critical power plant failure, shall be at least 6.7% (15:1).

The takeoff field length shall be the greatest of

a) 115% of all engine takeoff distance to 35 ft.

b) 100% of the critical power plant failure takeoff distance to 35 ft.

c) 100% of the acceleration stop distance.

2.4.2 STOL Landing Safety Criteria

The approach speed at the 35 ft. threshold, V_{AP} shall satisfy the following relationships

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

$$\geqslant V_{MCA} + 10\text{ kt.} \qquad \alpha_{AP} \geqslant \alpha_{STALL} - 10^{o}$$

$$\geqslant 1.2\ V_{MIN}$$

The landing climbout gradient at V_{AP} under the following conditions shall be at least 3.33% (30:1)

a) power plant at full power

b) gear down

c) landing flap angle

or

a) the most critical power plant failure with the remaining power plant at full power

b) gear up

c) landing flap angle

The landing climbout gradients under the above conditions but with a configuration change shall be at least 6.7% (15:1) . . . The landing field length is defined as the total distance from the 35 ft. threshold, divided by 0.7.

2.5 General Safety Requirements (VTOL and STOL)

2.5.1 Transition

It must be possible to stop and reverse the transition procedure quickly and safely without undue complicated operation of the powered lift controls.

2.5.2 Conversion

The conversion from powered-lift flight and vice versa shall be accomplished with minimum attitude changes.

The maximum speed in the powered-lift configuration shall be at least 30% greater than the power-off stall speed in the converted configuration.

2.6 Fuel Reserves

It is well known that fuel reserves for V/STOL aircraft has a much greater impact on design gross weight and DOC than for CTOL aircraft . . . Furthermore there appears to be sound justifications for reducing the fuel reserves below the minimum specified by the FAA. . . . hold . . . 20 minutes for VTOL and 30 minutes for STOL. The table below gives a summary of the fuel reserves to be used in this study. These reserves are to be

	FUEL - Reserves	
Holding at 5000 ft. and most economical speed	20 min.	30 min.
Flight to alternate airport at cruise altitude and speed	50 nm	100 nm
TYPE OF LANDING	VTOL	STOL

calculated on the basis that the flight to the alternate airport is a continuation of the mission cruise without change of speed or altitude and the hold at 5000 ft. is on the descent at the alternate airport.

The interesting possibility exists that a V/STOL aircraft on a STOL mission may be able to land vertically, if necessary, at the destination. The aircraft may, in this case, use the smallest of the VTOL or STOL fuel reserves given in the table.

3. Performance

This section is concerned with assumptions to be used in calculating the aircraft performance. . . .

3.1 Airfield Performance

It is usual practice when dealing with CTOL aircraft to specify an airfield performance in terms of a balanced field relative to a certain threshold height. . . . it is proposed to define standard STOL and VTOL ports and to define airfield performance in terms of these standards.

3.1.1.1 STOL Port and VTOL Port Definition

The proposed STOL port . . . has a length for normal operations of 1500 ft. with 100 ft. extensions at each end. The aircraft may start its ground roll from the appropriate runway extension. The obstruction boundary has a 15:1 slope in the flight direction and a 4:1 slope perpendicular to the flight direction. Very little information is available on VTOL port specifications. The VTOL port defined for this study has an obstruction boundary which has a 4:1 slope in any direction perpendicular to the edge of the deck. The operations deck has a 200 ft. by 100 ft. takeoff and landing area with a 100 ft. extension at each end.

3.1.2 Pilot and Aircraft Operating Capability

The following assumptions regarding the aircraft operating capability will be used in the calculation of airfield performance. These assumptions are valid, where appropriate, for both VTOL and STOL operation . . . under all weather conditions. . . .

OPERATING FUNCTION	ASSUMED CAPABILITY
Maximum deceleration on the ground	0.4g
Rolling coefficient of friction	0.03
Pilot reaction time to initiate any emergency procedure, excluding the response time of any mechanism activated	2 sec
Time lag after touchdown for activation of lift spoiling and decelerating devices, excluding the response time of any mechanism activated	0.5 sec. for automatic 1.0 sec. for non-automatic
Maximum rate of aircraft rotation	6 deg/sec
Maximum rate of descent below 35 ft. altitude	600 fpm

3.2 Payload-Range

3.2.1 Maximum Payload

. . . accommodation for 100 passengers is specified. Each passenger will be assumed to have a weight of 200 lb. (160 lb. per passenger and 40 lbs. of baggage). The maximum design payload is therefore 20,000 lbs.

3.2.2 Range with Maximum Payload

Several studies have been made into the relationship between V/STOL range and potential market. . . .

On the basis of the . . . study, . . . the VTOL range at maximum payload is 400 nm and the average range 240 nm. It is desirable that the STOL range at maximum payload be 800 nm but this should be regarded as a target rather than a requirement.

3.2.3 Altitude

The altitude shall be the smaller of

a) The altitude for minimum DOC or acceptable ride qualities.

b) The altitude such that the cruise distance is one half of the total distance.

3.2.4 Cruise Speed

. . . for this study, the minimum cruise speed is defined by a Mach number of 0.75 or an equivalent air speed of 350 kt, whichever is the least.

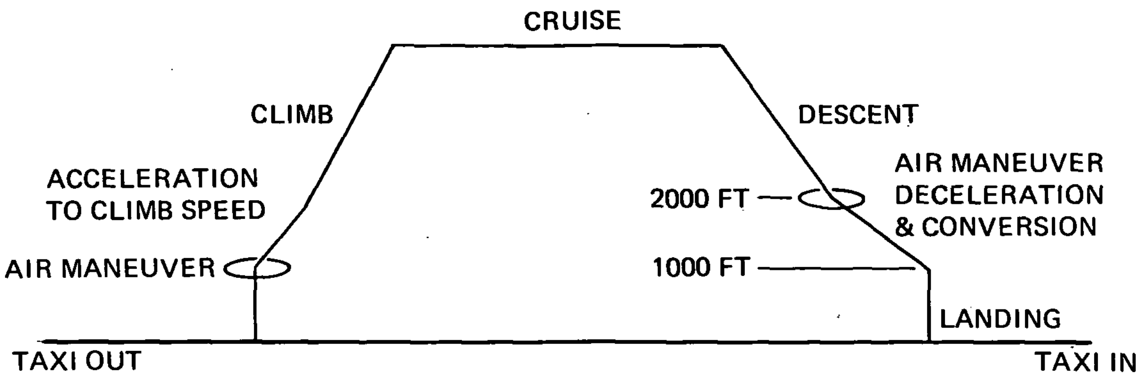
3.2.5 Mission Profile Definition

For the purpose of standardization of payload-range and DOC calculations . . . the mission profile definition to be used in this study is shown in Figure B1. The following notes are to be used in conjunction with Figure B1.

1) The performance of short-haul V/STOL transportation systems may be compromised by the speed limitations defined in FAR 91.70. These regulations state that the maximum speed of all aircraft shall not exceed 250 kt IAS below 10,000 ft. altitude and, for turbine driven aircraft, not exceed 200 kt IAS in the airport traffic area. The CAB is currently investigating the applicability of these regulations to V/STOL transport systems. For the present study the FAR 91.70 regulations will be retained but the penalties associated with these restrictions are to be assessed.

2) The rate of descent shall not exceed 5000 fpm above 2000 ft. For pressurized operation, climb and descent rates shall be such that the rate of cabin pressure altitude does not exceed 300 fpm.

3) Standard atmosphere and zero wind will be used for all payload range calculations.



SEGMENT	TIME		DISTANCE		REMARKS
	VTOL	STOL	VTOL	STOL	
TAXI OUT	1 MIN	2 MIN	0	0	
TAKEOFF, TRANSITION & CONVERSION TO CONVENTIONAL FLIGHT	0.5 MIN	0.5 MIN	0	0	
AIR MANEUVER (ORIGIN)	0.5 MIN		0	0	
ACCELERATION TO CLIMB SPEED	AS CALCULATED				
CLIMB	AS CALCULATED				AT OPTIMUM CLIMB SPEED
CRUISE	AS CALCULATED				AT CONSTANT INTEGRAL 1000-FT ALTITUDES (NO ENROUTE ALTITUDE CHANGES)
DESCENT TO 2000 FT	AS CALCULATED				5000 FPM MAXIMUM RATE OF DESCENT
AIR MANEUVER AT 2000-FT (DESTINATION)	1.5 MIN	3 MIN	0	0	
DECELERATING APPROACH APPROACH & CONVERSION TO POWERED LIFT FLIGHT, 2000 FT TO 1000 FT	AS CALCULATED		0	0	1000 FPM MAXIMUM RATE OF DESCENT
TRANSITION & LANDING FROM 1000 FT TO TOUCHDOWN	AS CALCULATED		0	0	1000 FPM MAXIMUM RATE OF DESCENT DOWN TO 35 FT; 600 FPM MAXIMUM RATE OF DESCENT BELOW 35 FT
TAXI IN	1 MIN	2 MIN	0	0	

FIGURE B-1 V/STOL MISSION PROFILE DEFINITION

6.5 Passenger Cabin Requirements

The following list of cabin requirements is intended to provide some measure of standardization in required cabin volume and weight of cabin equipment to cater to the passengers.

Aisle width	19 in.
Seat pitch	34 in.
Seat width	21 in. (overall)
Cabin baggage	
Overhead	carry-on soft-type only
Under seat	room for attache case (9" x 16" x 23")
Floor mounted coat rack (capacity for 80% of passengers)	
Beverage service	
Galley	temperature holding type only
Lavatories	two
Magazine racks	two
Folding table	one per seat
Air vent	one per pax
Ticket center	
Attendants seats	

APPENDIX C

Weight

Design Point Weight Statement

When the minimum weight design point for each configuration was determined, a weight statement for that design point was calculated. Table C1 presents weight statements for the ten configurations.

Balance and loadability.–The configurations are balanced about the 25 percent mean aerodynamic chord at maximum vertical takeoff weight. The loadability of Model 984-122, determined for this c.g. condition, is typical of the 100 passenger V/STOL configurations. A center of gravity diagram is shown as Figure C1.

The balance and loadability analysis was made to derive a wing-body-engine position relationship such that the static pitch trim requirements are minimized during hover without limiting the flexibility of passenger loading. The best engine lift center was assumed to be at 25 percent of the MAC; therefore, the design procedure is to place the engines with the lift center at 25 percent of the MAC and then to place the wing on the body in such a way as to minimize the c.g. excursion from 25 percent of the MAC. A number of assumptions were made.

- The balance and loadability are predicted upon the hover conditions (engine thrust providing trim and control) and not conventional flight.
- The forward body engines are fixed at their location on the initial layout. The aft body engines are moved as the wing is shifted so that the resulting body engine lift center is at 25% of the MAC. (The wing engines were located at 25% of the MAC and of course remained there.)
- The main landing gear is shifted with the wing and stays a constant distance behind the wing quarter chord.
- The tail volume coefficients are constant.
- Passenger loading follows the generally accepted pattern in which window seats are filled first, then the aisle seats, and finally the remaining seats. Both front-to-rear and rear-to-front loading are used to determine the c.g. range due to passenger loading.
- A tolerance of 2 percent MAC on the probable passenger plus fuel loading conditions is taken on the fore and aft center of gravity limits. Consideration of the in-flight movement of passengers, shifts in fuel due to changes in aircraft attitude, and customer variances led to this tolerance.

Analysis of the V/STOL loadability for various passenger and baggage loadings reveals that the trim requirements of c.g. diagram can be met by about 1 percent of the installed thrust. This represents an increase of approximately 1200 pounds of VTO gross weight to provide for normal passenger seating and in-flight movement variations. At high angles of attack during periods of transition, trim for fuel shift is available without additional thrust.

Inertias.—Inertias were developed for the individual configurations by analysis of the mass properties about three axes at wing loading of 125 psf and a maximum vertical takeoff gross weight of 115,000 lb. The inertias were then scaled to the matched and sized configuration weights. The airplanes with wing-loading greater than 125 psf have conservative roll, pitch and yaw mass properties. Table C2 presents the inertias for which the control thrust is determined.

The cross product of inertia (I_{XZ}) for the Model 948-120 is 81,000 slug-ft^2. This produces an angle of inclination of the neutral axis of 4.7^o nose down. The configuration characteristics that produced this condition are the T-tail and the vertical position of the lift fans on the body. This is typical of the eight-engine V/STOL configurations of this study.

TABLE C-1 V/STOL ADVANCED TECHNOLOGY WEIGHT

	INTEGRAL FANS			REMOTE FANS						PROP/FAN
MODEL	-120	-122	-134	-124	-133	-126	-127	-131	-132	-128
WEIGHT LBS / WING AREA FT^2	934	757	788	883	859	950	877	889	871	788
WING	6817	5835	5875	7080	6825	7790	7047	7594	6970	5875
HORIZ TAIL	853	500	525	730	675	890	720	680	695	525
VERT TAIL	1270	860	785	1095	1035	1245	1070	1105	1065	875
BODY	15340	14225	14880	16200	16050	16660	16520	16580	14560	13750
GEAR, NACELLE, PAINT, ETC.	13382	14290	13560	17990	16720	20320	15678	16575	17150	12120
TOTAL STRUCTURE	37662	35710	35625	43095	41305	46905	41035	42534	40440	33145
ENGINE	21760	18400	19430	20360	25025	27020	21630	25850	25305	14060
FUEL SYST, CONTROLS, ETC.	2397	2393	2388	2421	2415	2435	2210	2422	2418	2388
DUCT SYSTEM	-	-	-	4230	3580	1840	6590	5910	5325	-
INTERCONNECT & DRIVE SYST	-	-	-	-	-	-	-	-	-	8400
TOTAL PROPULSION GROUP	24157	20793	21818	27011	31020	31295	30430	34182	33048	24848
FIXED EQUIPT, STD & OPERATIONAL ITEMS	20781	20797	20657	21394	21275	21700	21035	21084	20912	20207
OPERATIONAL EMPTY WT	82600	77300	78100	91500	93600	99900	92500	97800	94400	78200
PAYLOAD	20000	20000	20000	20000	20000	20000	20000	20000	20000	20000
FUEL	14100	16200	12100	20900	15200	22500	19100	15400	16200	11900
MAXIMUM VTO GROSS WEIGHT	116700	113500	110200	132400	128800	142400	131600	133200	130600	110100

TABLE C-2 INERTIAS

	INERTIA SLUG $FT^2 \times 10^6$ AT MAXIMUM VTO WEIGHT		
MODEL	ROLL	PITCH	YAW
984-120	.49	1.41	1.67
984-122	.49	1.38	1.63
984-124	.60	1.67	1.99
984-126	.65	1.80	2.14
984-127	1.01	2.21	2.97
984-128	.55	1.10	1.48
984-131	1.02	2.23	3.01
984-132	.81	1.21	1.82
984-133	.59	1.62	1.93
984-134	.46	1.33	1.56

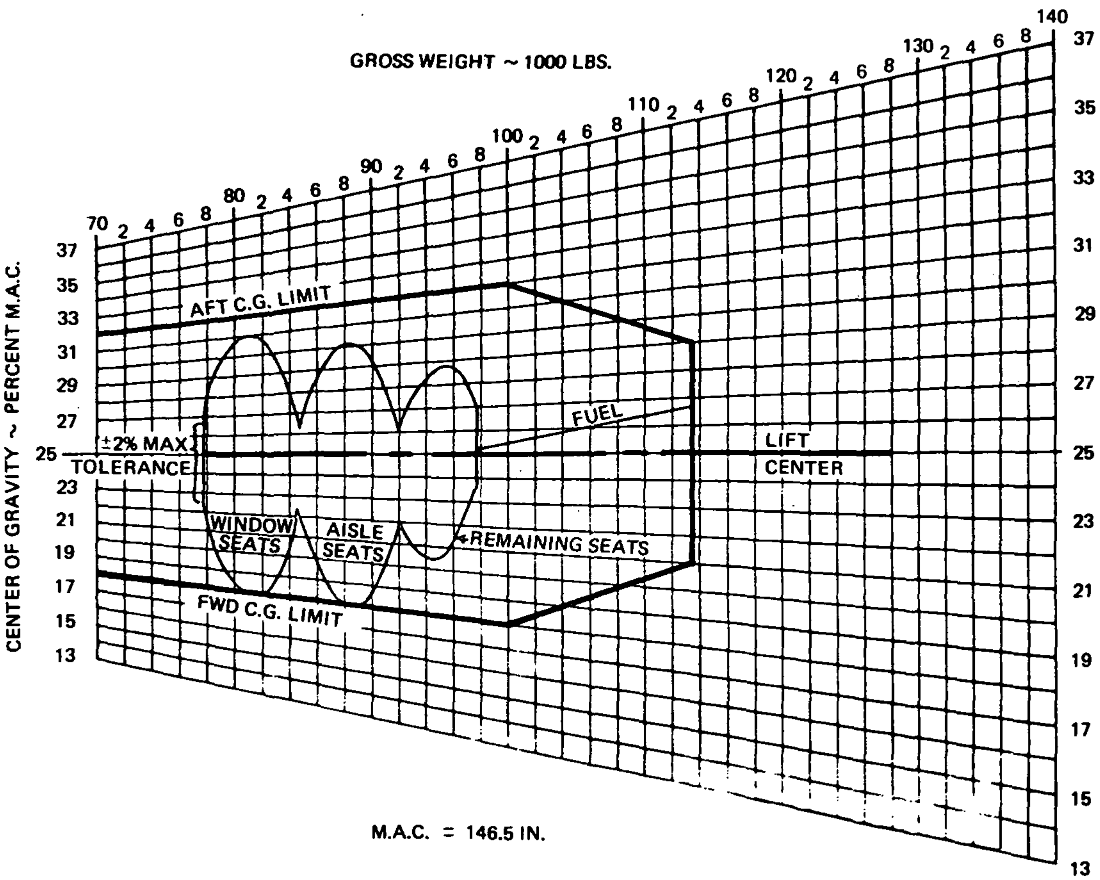


FIGURE C-1 MODEL 984-122 C.G. DIAGRAM

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APPENDIX D

Performance of Model 984-134

A detailed performance analysis of Model 984-134 exemplifies the capability of these aircraft. The layout is shown in Figure D1.

The flight envelope is shown in Figure D2. The left-hand boundary represents zero climb gradient. Vertical equilibrium includes both aerodynamic and engine lift with engine thrust vectored forward enough to overcome drag at each flight speed. All eight engines are at maximum climb power; this boundary typifies the steady state low speed capability of the aircraft.

The flaps up and flaps down boundaries are conventional; the transition line was drawn to close the flight envelope between all engine flaps down and two engine flaps up operation.

The hovering capability of the model 984-134 configuration is shown in Figure D3. The lower curve, which is based on the study guidelines, shows a maximum VTOL weight hovering capability up to 2300 feet because the cruise engines are oversized for takeoff.

The drag polars shown in Figure D4 include the low speed polars flaps up and down as well as the high speed polar buildup. The low speed configuration has the lift engines extended. Low speed C_D's are also given for gear down and forward lift engines at angles other than 60^o.

The lift curves shown in Figure D5 reveal $C_{l_{max}}$ capability flaps up of 1.62, and flaps down of 3.32 and the corresponding 1 "g" stall speeds are 157 KEAS and 111 KEAS, respectively.

The gust sensitivity parameter is shown in Figure D6. NASA-Ames guidelines for passenger ride quality indicate that the Model 984-134 will have acceptable qualities for climb and cruise above 14,000 ft. Climb schedules can be chosen for lower altitudes which give acceptable ride quality without significantly increasing mission fuel.

Figure D7 shows the speed capability of the model 984-134. Mach number of 0.75 is attainable up to an altitude of 30,000 ft following a maximum VTOL weight takeoff; the altitude is about 28,000 ft for a maximum STOL weight takeoff. The -134 configuration has V_{MO} speed capability at maximum weights up to approximately 18,000 ft.

The model 984-134 shows excellent short field takeoff and landing characteristics at maximum STOL weight (Figure D8). Since maximum STOL weight (119,100 lb) is only 8 percent higher than maximum VTOL weight (110,200 lb), F/W available is equal to 1.438, only slightly below the VTOL requirement of 1.47. However, power is set below F/W = 1.0 to provide the required control capability. Therefore, forward speed is required to achieve the combined aerodynamic and propulsive lift needed for takeoff.

Lift-off speed is defined as 1.2 x minimum flying speed and equals 44 knots for maximum STOL weight. Approach speed, which is also 1.2 x V_{MIN}, is equal to 40 knots for the -134 configuration at maximum STOL weight. The difference between takeoff and landing speed results from the thrust vector angle used. It is 70^o for acceleration on takeoff and 90^o for landing.

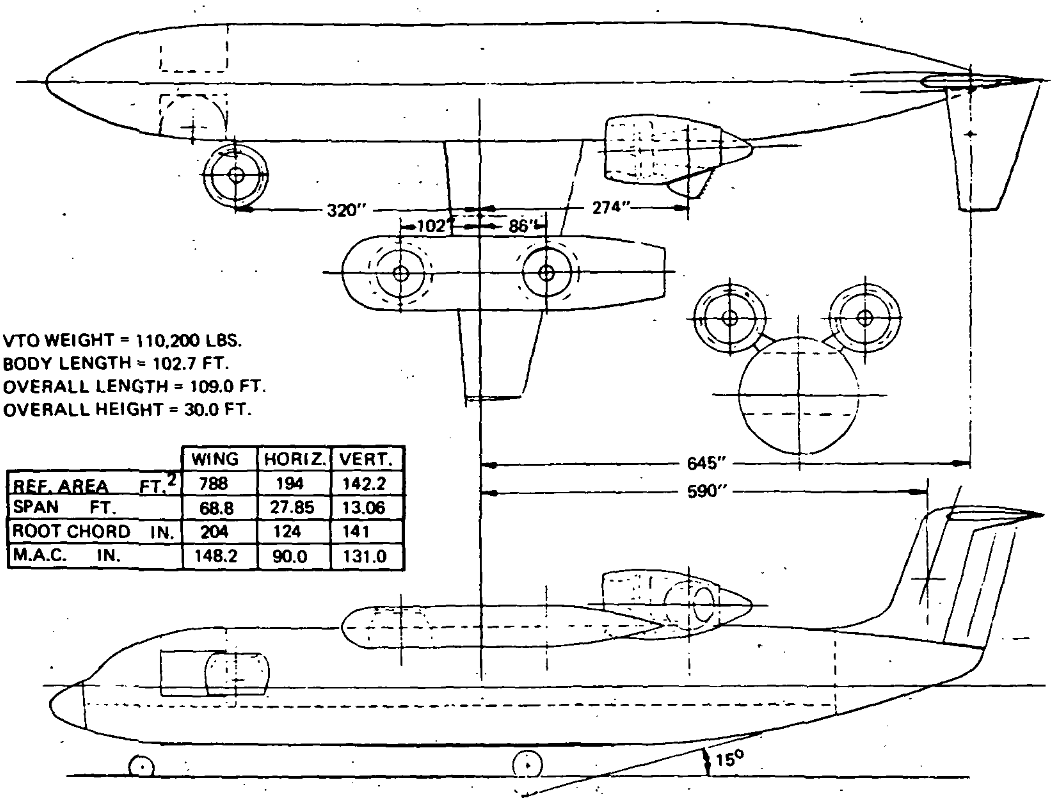
Figure D8 shows the resulting STOL takeoff and landing fields lengths for the -134 configuration for sea level, ISA + 31^o F day with a 25-knot crosswind.

The wing has 3000 lb more fuel capacity than is needed for the 800-n. mi. STOL mission. Figure D9 shows the resulting payload vs range capability using the full fuel capacity on VTOL and STOL missions.

The airplane has 1,000-n. mi. range with more than 12,000-lb payload on a VTOL flight and with more than 17,000-lb STOL. However, with payloads less than 11,000 lb, the VTOL mission has greater range than STOL because of the higher STOL reserve requirement. In fact, at payloads less than 11,000 lb, the STOL rules do not apply since the takeoff weight with full fuel is within the VTOL range.

The range with zero payload is 1420 n. mi.

Generalized performance for climb and cruise are shown in Figures D10, D11 and D12. Figure D10 shows flaps up climb time, distance and fuel used for climb at 250K equivalent airspeed accelerate to 320 KEAS and climb until M = 0.7, then climb at constant Mach number to cruise altitude. Figure D11 is a presentation of cruise fuel mileage for two altitudes and several gross weights and Figure D12 shows NAM/lb for long range and at M = 0.75.



	WING	HORIZ.	VERT.
REF. AREA FT.^{2}	788	194	142.2
SPAN FT.	68.8	27.85	13.06
ROOT CHORD IN.	204	124	141
M.A.C. IN.	148.2	90.0	131.0

FIGURE D-1 MODEL 984-134

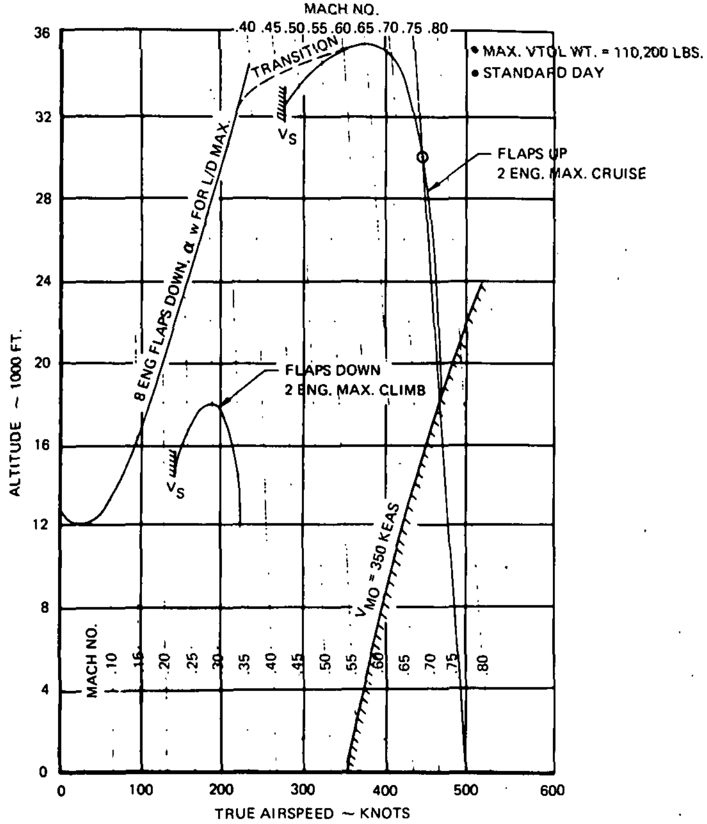


FIGURE D-2 MODEL 984-134 FLIGHT ENVELOPE

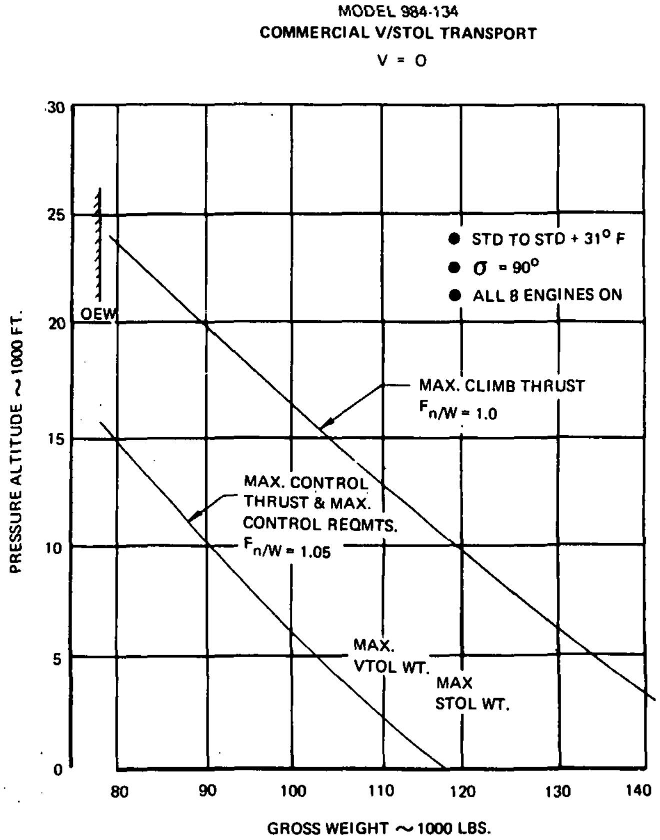


FIGURE D-3 HOVERING CAPABILITY

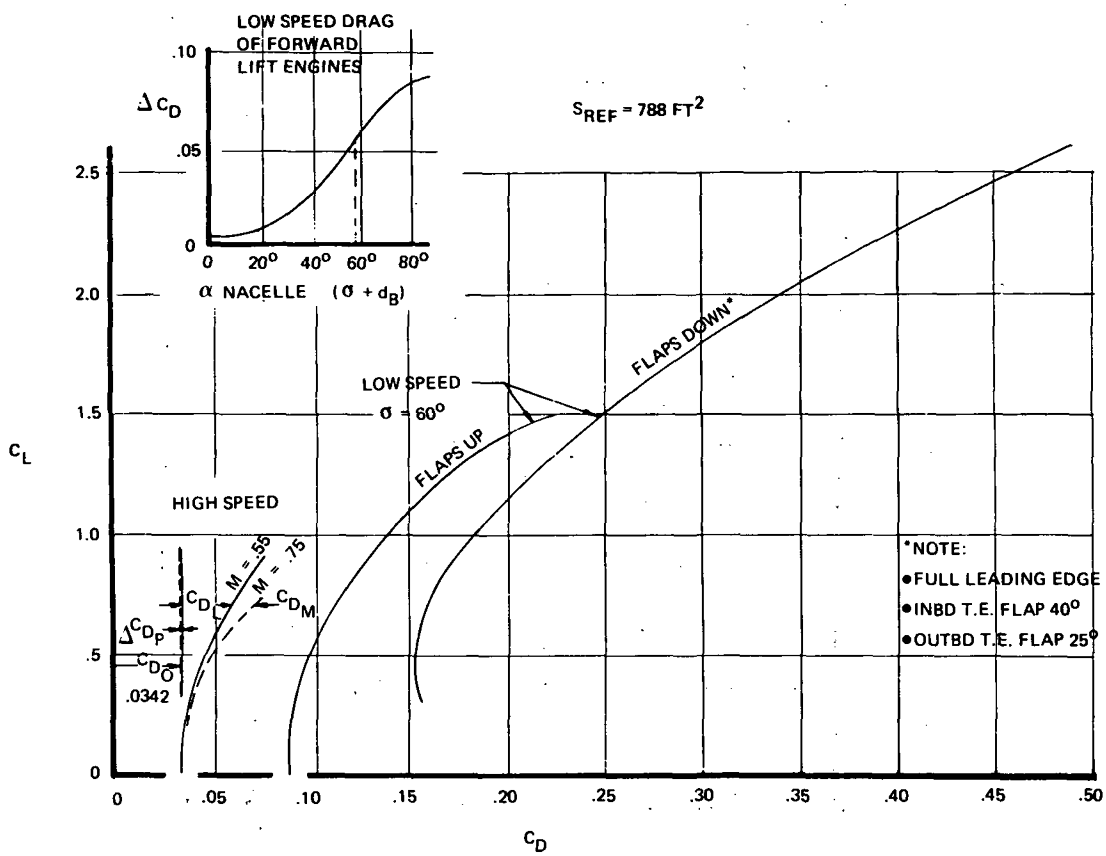


FIGURE D-4 DRAG POLAR

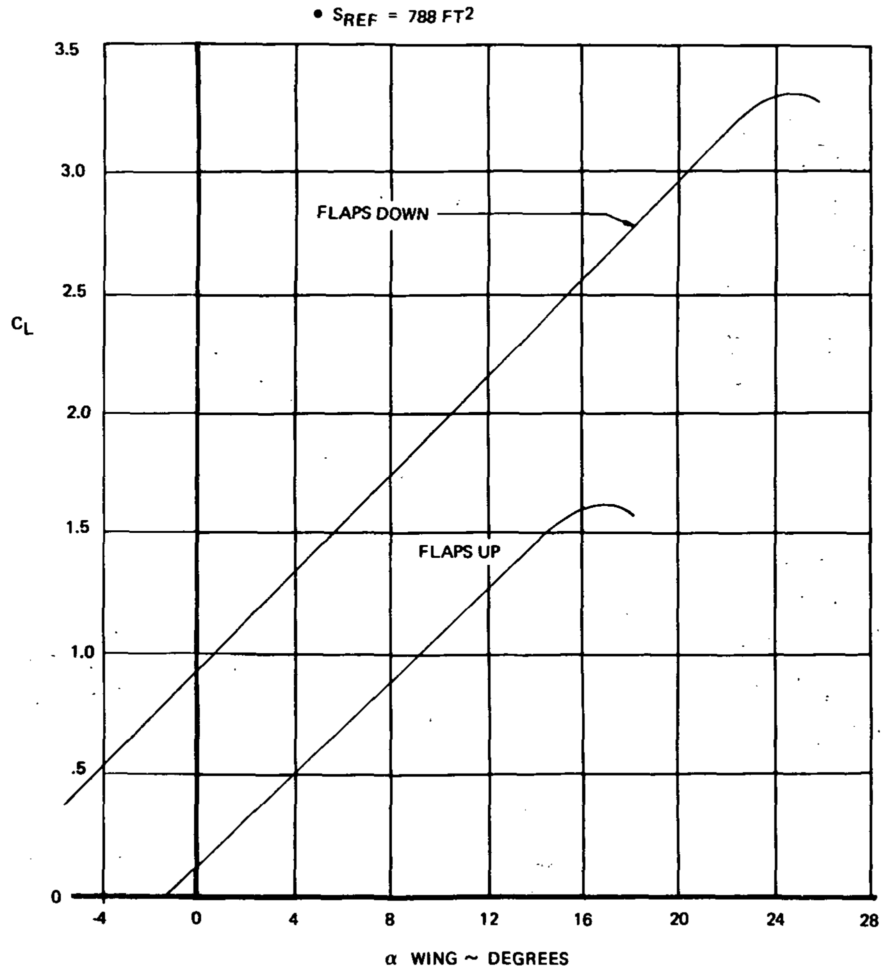


FIGURE D-5 LIFT CURVE

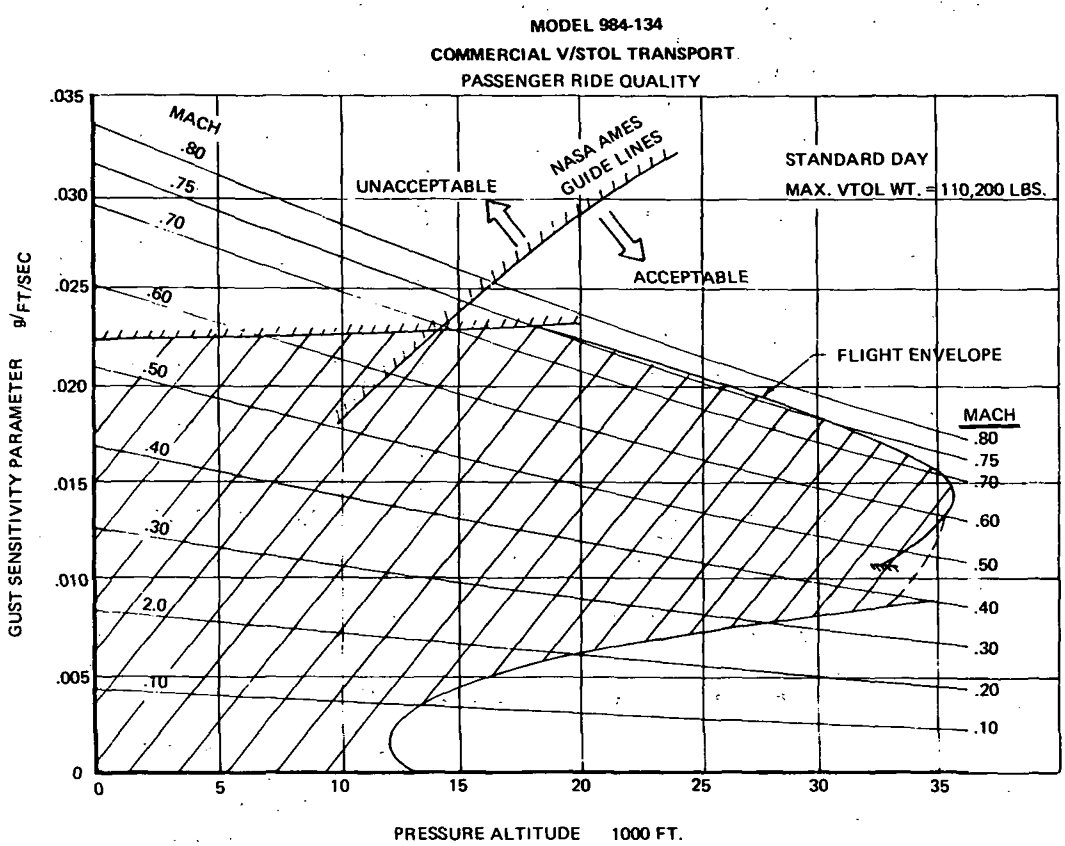


FIGURE D-6 · PASSENGER RIDE QUALITY

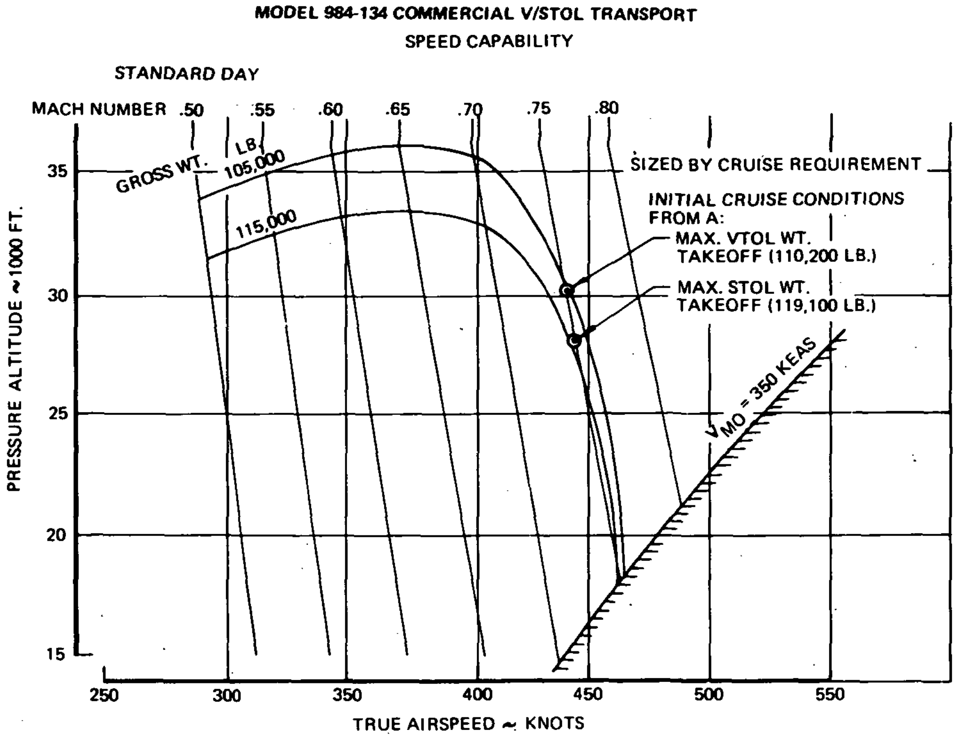


FIGURE D-7 MODEL 984-134 SPEED CAPABILITY

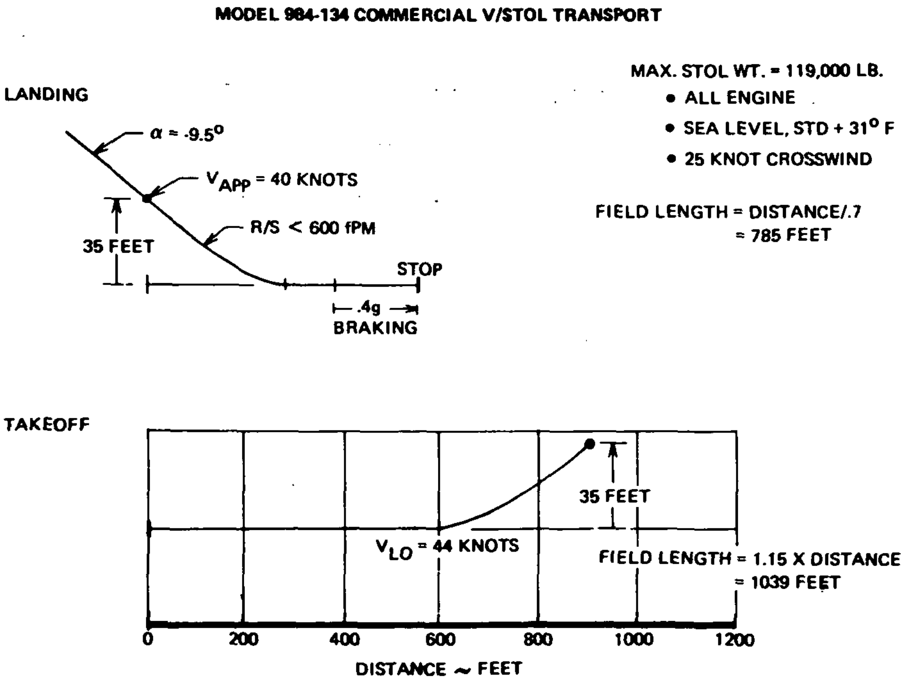


FIGURE D-8 STOL TAKEOFF AND LANDING CHARACTERISTICS

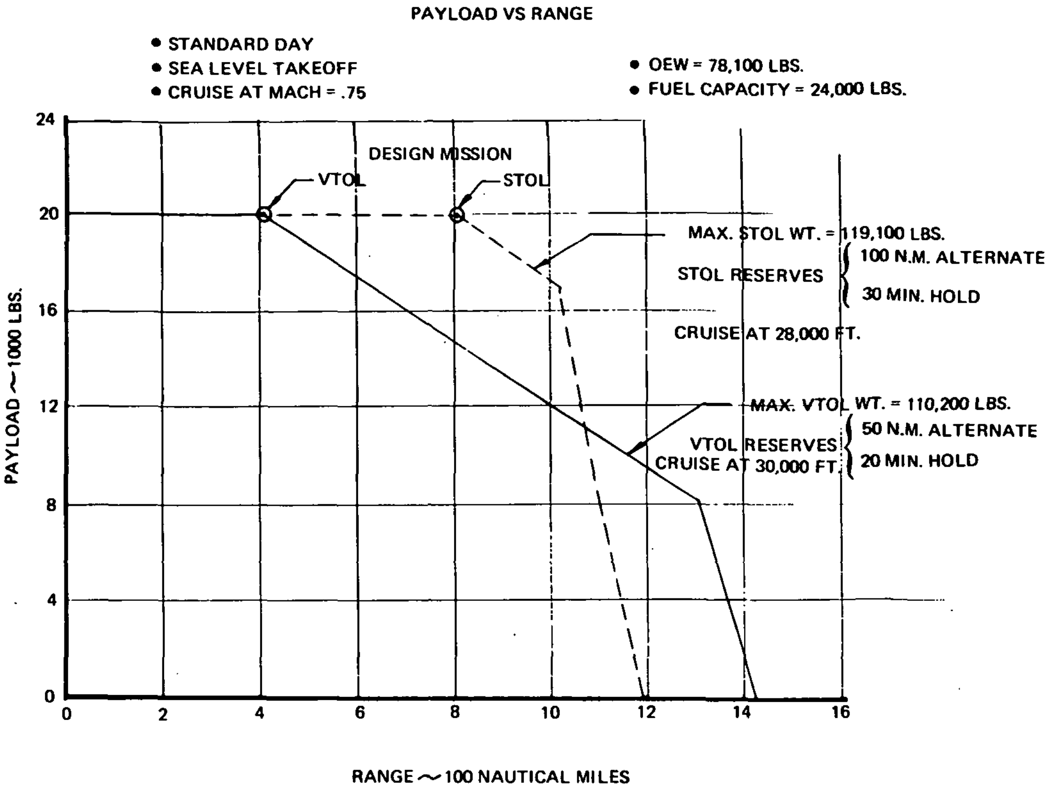


FIGURE D-9 MODEL 984-134 PAYLOAD - RANGE

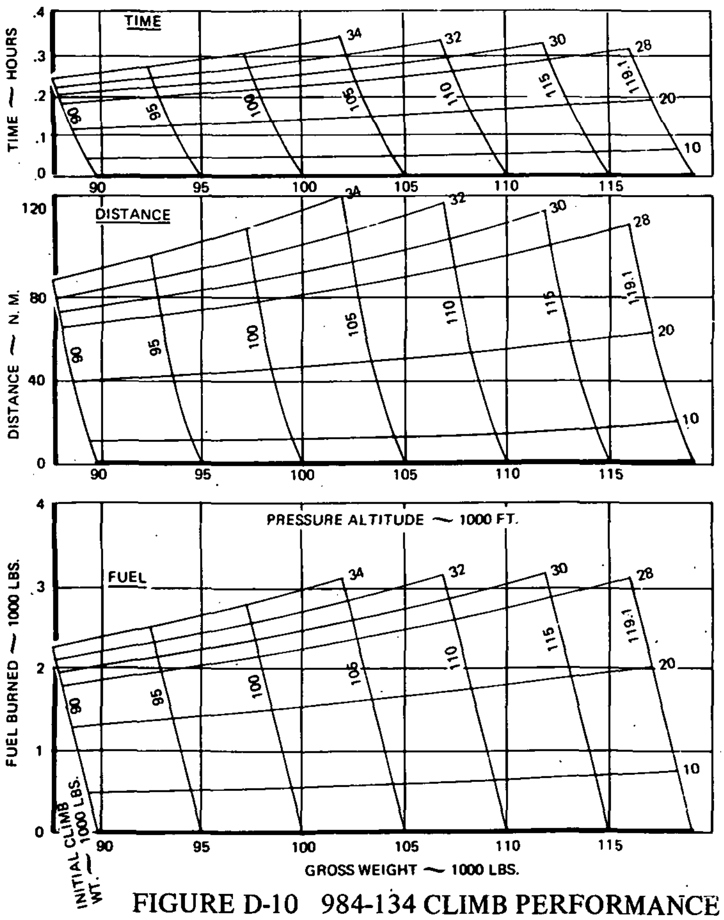


FIGURE D-10 984-134 CLIMB PERFORMANCE

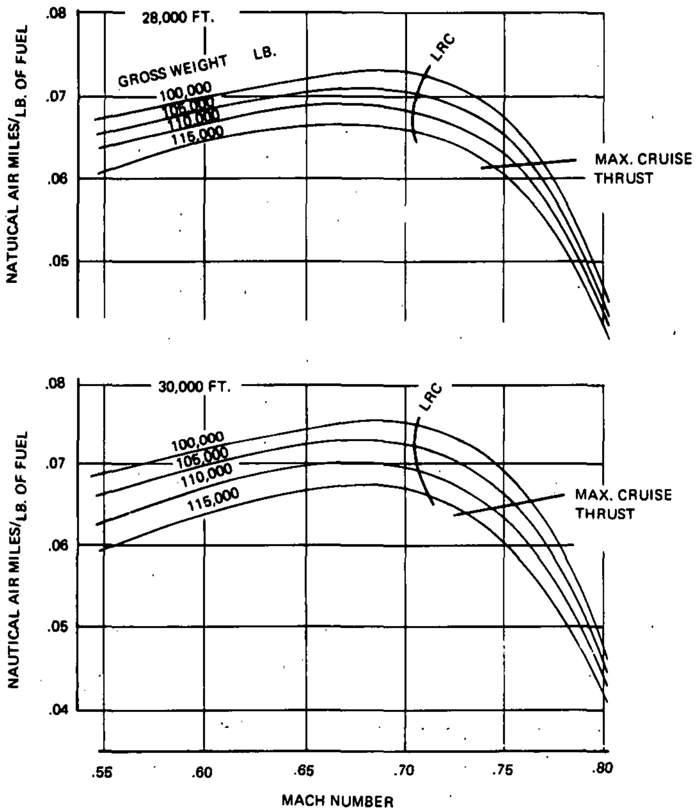


FIGURE D-11 CRUISE FUEL MILEAGE-CRUISE vs MILEAGE

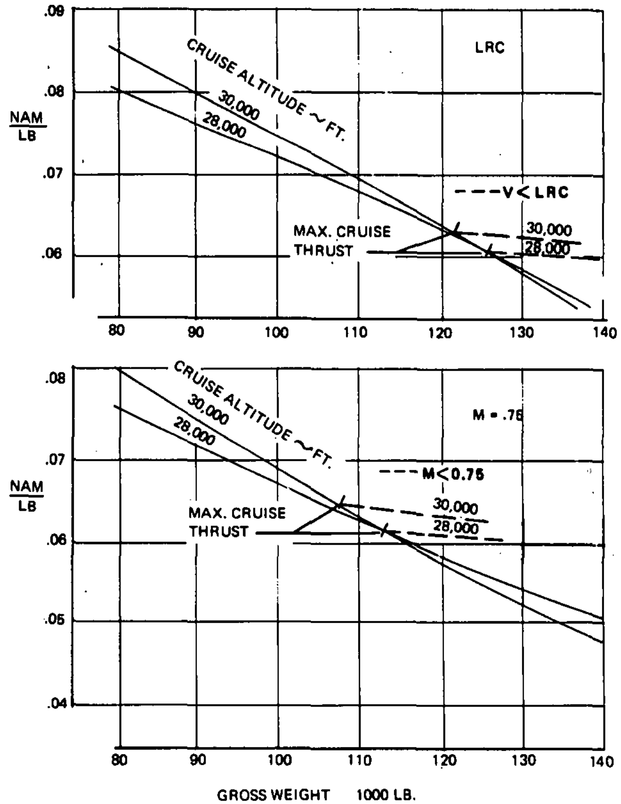


FIGURE D-12 CRUISE FUEL MILEAGE