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DESIGN DEFINITION STUDY OF A LIFT/CRUISE FAN/ TECHNOLOGY V/STOL AIRPLANE–SUMMARY

J. M. Zabinsky
H. C. Higgins

Final Report
August 15, 1975

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for
Ames Research Center
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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NASA-Ames Research Center
Moffett Field, California

Final Report

Technical Monitor–B. A. Lampkin

A two-engine three-fan V/STOL airplane was designed to fulfill naval operational requirements. A multimission airplane was developed from study of specific point designs. Based on the multimission concept, airplanes were designed to demonstrate and develop the technology and operational procedures for this class of aircraft. Use of interconnected variable pitch fans led to a good balance between high thrust with responsive control and efficient thrust at cruise speeds. The airplanes and their characteristics are presented.

Propulsion
V/STOL
Technology aircraft

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H. C. Higgins

1.0 SUMMARY

Hub driven, variable pitch fans connected to turboshaft engines through a mechanical transmission offer the airplane designer a flexible means for selecting a good compromise between the requirements for high thrust at low speed and efficient thrust at cruise speed. This compromise is extremely important in selecting the propulsion arrangement for high-speed, vertical takeoff (VTO) airplanes. The present study was performed to examine the applicability of such a propulsion system to vertical short takeoff and landing (V/STOL) aircraft intended for naval sea control operations.

The study was accomplished in two parts. Part I consisted of a series of naval operational aircraft designs leading to a multipurpose airplane capable of performing a variety of missions with minimum modification.

In Part II a family of technology demonstrator aircraft were designed, each of which could represent to various degrees the technical features of the multimission airplane.

The relationships of the 13 resulting configurations and their identifying model numbers are shown in figure 1.

1.1 OPERATIONAL AIRPLANES

As a result of the point design configurations studied in Part I, the ASW airplane became the basis for the multimission design. An isometric view, emphasizing the V/STOL features, is shown in figure 2. The two engines are mounted behind the variable pitch lift/cruise fans, and the engine/fan units rotate to provide thrust vectoring for V/STOL operation. A shaft-driven variable pitch lift fan is mounted ahead of the crew stations.

In cruise and high-speed flight the airplane is conventional in appearance and operation. The nose fan is disengaged for cruise flight.

A summary of the point designs developed in the Part I study is shown in figure 3. The vertical onboard delivery (VOD) aircraft is an exception to this family in that it requires three engines rather than two and its fuselage is substantially different because of the transport mission requirement. Otherwise, the ASW design is critical; that is, the ASW airplane must be somewhat larger than the other point designs, and it can be readily modified to perform the other missions in its multimission role.

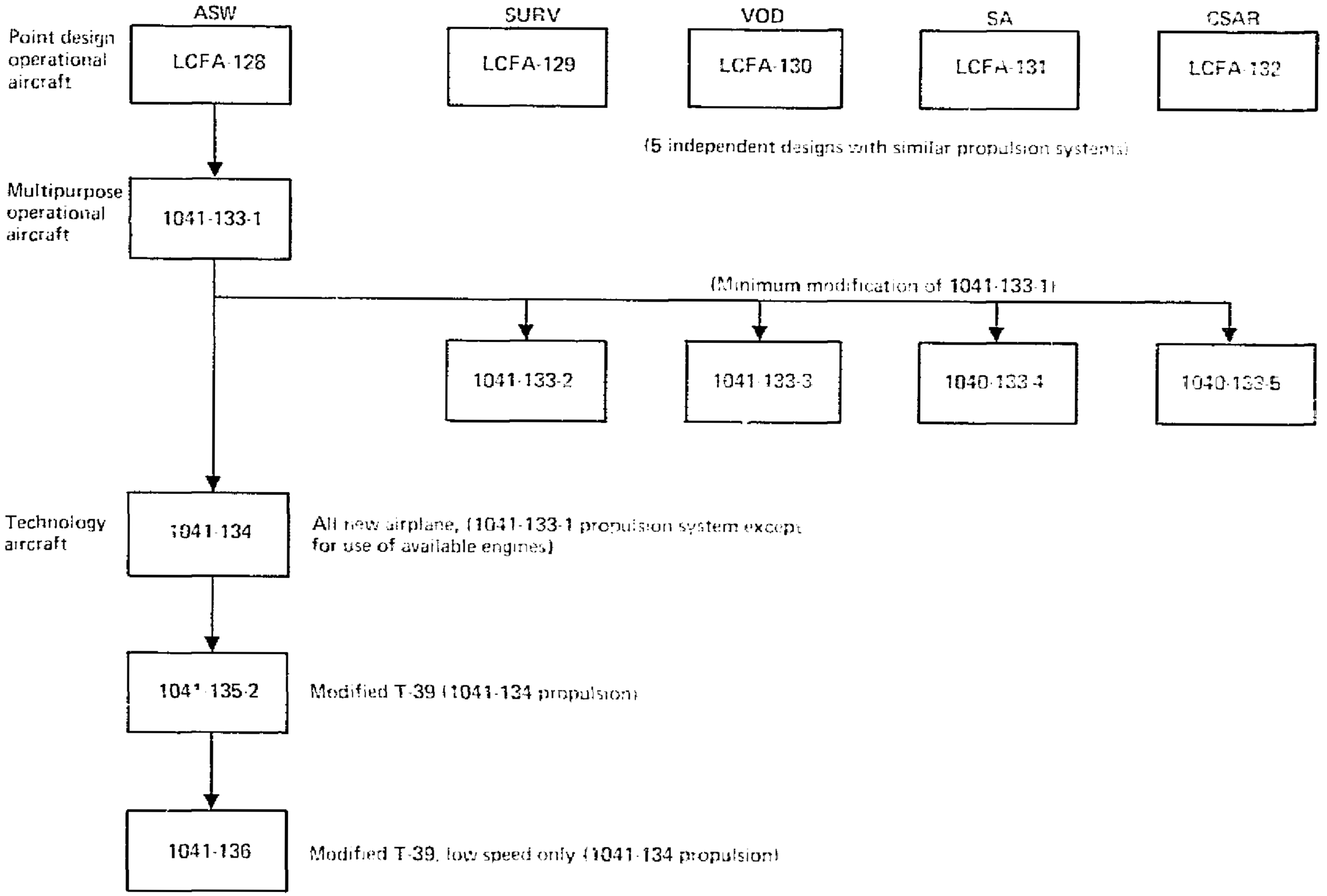


Figure 1. – Hierarchy of Design

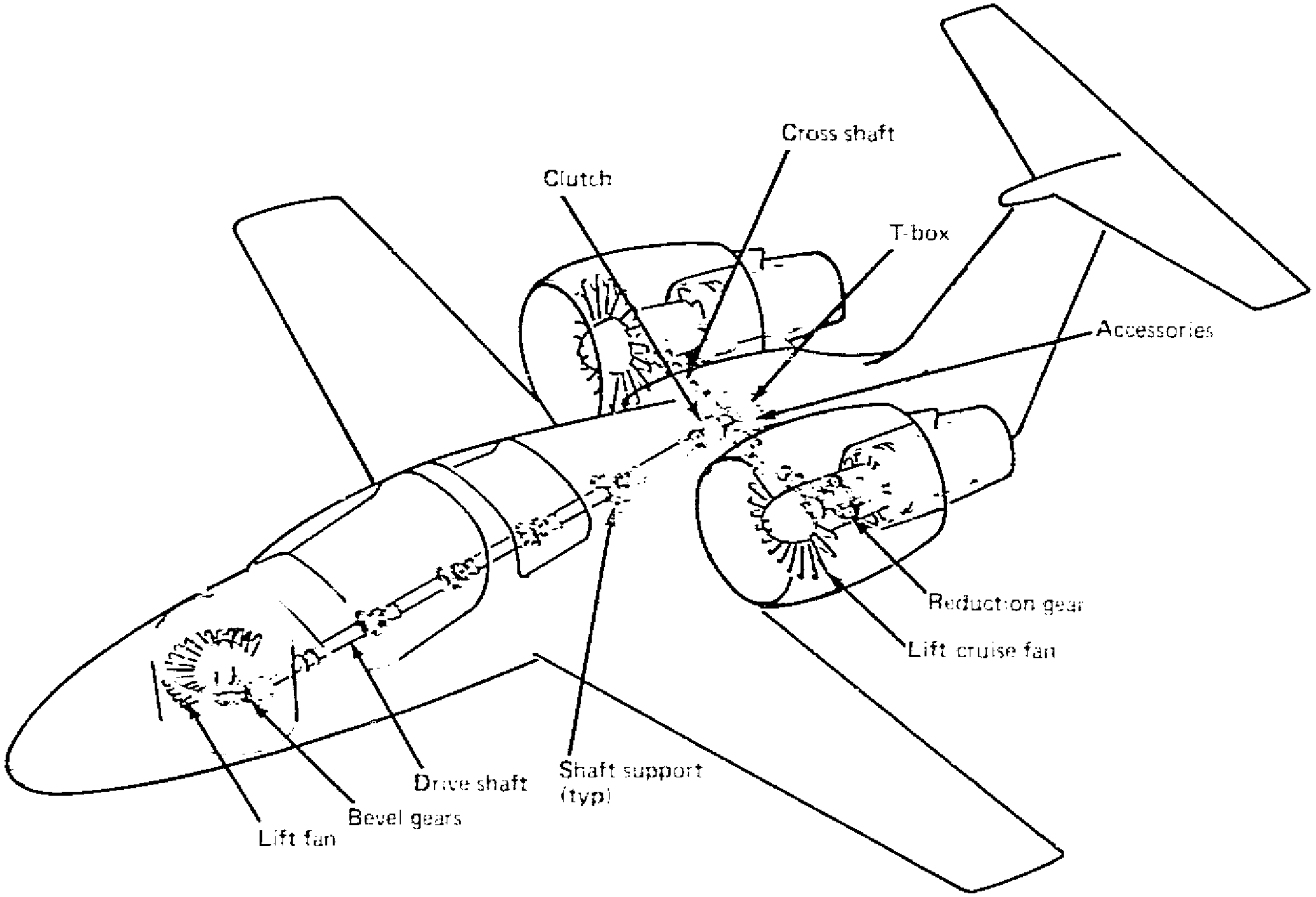
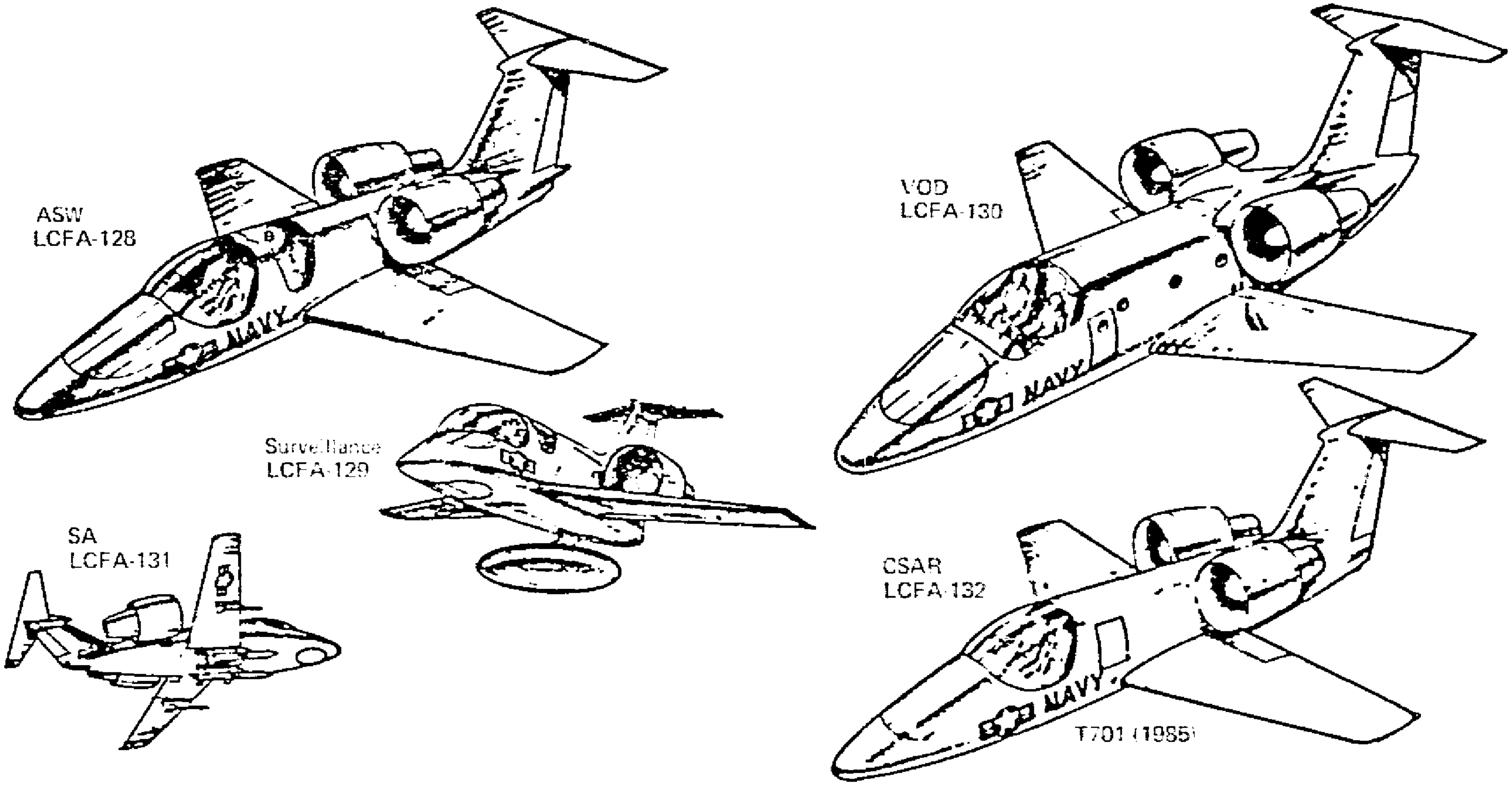


Figure 2. - 1041-133 V/STOL Aircraft



	ASW -128	Surv -129	VOD 130	SA -131	CSAR -132
Number of engines	2	2	3*	2	2
Wing area, ft^2	310	265	350	250	270
Emergency landing weight required	24 500	24 420	30 300	20 190	23 090
Emergency landing weight capability	24 500	24 500	30 300	24 500	24 500
Mission GW	37 750	32 220	42 300	30 350	31 730

*T701 (current).

Figure 3. -Point Designs

Therefore, model 1041-133-1 is presented as the typical operational airplane. The arrangement is the natural result of the basic assumptions on propulsion failure: (1) safe flight is possible after engine failure, including safe failure transients during specific flight conditions; and (2) no provision is made for fan failure during V/STOL maneuvers. The second assumption is similar to helicopter design philosophy with regard to rotor failure and is a ground rule for the study.

Model 1041-133-1 is designed to fly a 150-nmi ASW mission from a short takeoff carrying a 5500-lb payload, of which 2820 lb are disposable. It will then loiter 4 hr, return with reserves, and land vertically. With the addition of water alcohol, the airplane can fly the same mission from vertical takeoff and loiter 3.16 hr at 150-nmi radius.

The basic configuration for all the missions is similar (with the exception of VOD, which requires an extra engine). The resulting configurations have three fans, two for lift cruise and one for lift only. The three fans are identical. The two engines are developments of the Detroit Diesel Allison T701 or equivalent, and the three fans are developments of the Hamilton Standard "Q-Fan," which is a variable pitch fan. The multimission airplane weights for the various missions are listed in table 1.

Table 1. Multimission Aircraft

	ASW 1041-133-1	SURV 1041-133-2	VOD 1041-133-3	SA 1041-133-4	CSAR 1041-133-5
Number of engines	2	2	3	2	2
Mission GW, lb	37 750	32 650	42 530	30 810	30 850
Emergency landing weight, lb	24 500	25 000	30 440	21 280	23 000
Emergency landing weight capability, lb	25 000	25 000	38 000	25 000	25 000

The static performance of the propulsion combination used for both the operational and technology airplanes at sea level and 90° F is shown in table 2. Each engine drives a reduction gear set through an overrunning clutch. A right angle bevel set distributes power to the front fan through a T-box and clutch. Airplane accessory power is taken from the rear of the T-box. The clutch adjacent to the T-box disconnects the front fan during conventional flight.

Thrust vector control during V/STOL operation is achieved by rotating the lift cruise fan nacelles. The nose fan thrust vector is fixed 15° forward of vertical. During V/STOL transition, as the nacelles rotate and their moment arm about the c.g. changes, the nose fan thrust level is changed to balance the moments.

Table 2. T701 Engine[*]

	Intermediate power, two engines, three fans		Contingency power, one engine, three fans	
	Fan pressure ratio	Total fan thrust, lb	Fan pressure ratio	Total fan thrust, lb
Current (1975)	1.14	27 680	1.12[†]	21 000[†]
1985	1.17	34 000	1.13	25 330

[*] Sea level, 90° F, day

[†] Water/alcohol augmentation

A very important design constraint is the requirement for one engine-out operation during low-speed flight and hover. The operational airplane was designed to have hover engine-out capability at emergency weight (weapons, stores, and all but 1000 lb of fuel jettisoned) with the remaining engine at contingency power.

1.2 TECHNOLOGY AIRPLANES

The technology airplanes of the Part II study were based on the ASW version of the multipurpose design. The propulsion arrangement and size is the same as the ASW, except for the engines, which are current models of the operational engine. The static thrust available is shown in table 2. Water/alcohol injection is used to provide contingency power in the event of single-engine operation.

A three-view of the all new technology airplane, model 1041-134, is shown in figure 4. Compared to the multimission airplane, it has a more slender fuselage, a two-place instead of a four-place cab, and a smaller wing. The wing size was reduced to maintain the operational wing loading for similarity in flight characteristics. These differences result in an operating weight of 16 400 lb compared to 23 500 lb for the operational ASW. A comparison of pertinent weight is shown in table 3.

With full payload and two crew members at emergency landing gross weight (GW) of 20 400 lb, it carries 1490 lb of fuel. This will provide a hover endurance of 18 min. The all-engine operating thrust/weight ratio is 1.36 at this weight. Vertical flight at higher weight is safe within a limited hovering envelope.

A technology airplane based on modifying a T-39 Sabreliner was studied as a means of reducing cost (Model 1041-135-2). A general arrangement is shown in figure 5. Modification consists primarily of removing unnecessary weight, changing the nose and aft body to accept the V/STOL propulsion system, and replacing the canopy to permit ejections. Its operating weight is 700 lb heavier than the all new 1041-134. At the single-engine emergency weight, it can carry 790 lb of fuel with two crew members and full payload. A hovering endurance of 9 min can be extended by removing part of the payload or limiting the hovering envelope. This configuration retains the basic T-39 wing. The cost of reducing the wing size to match the operational wing loading would cancel the cost saving due to modification.

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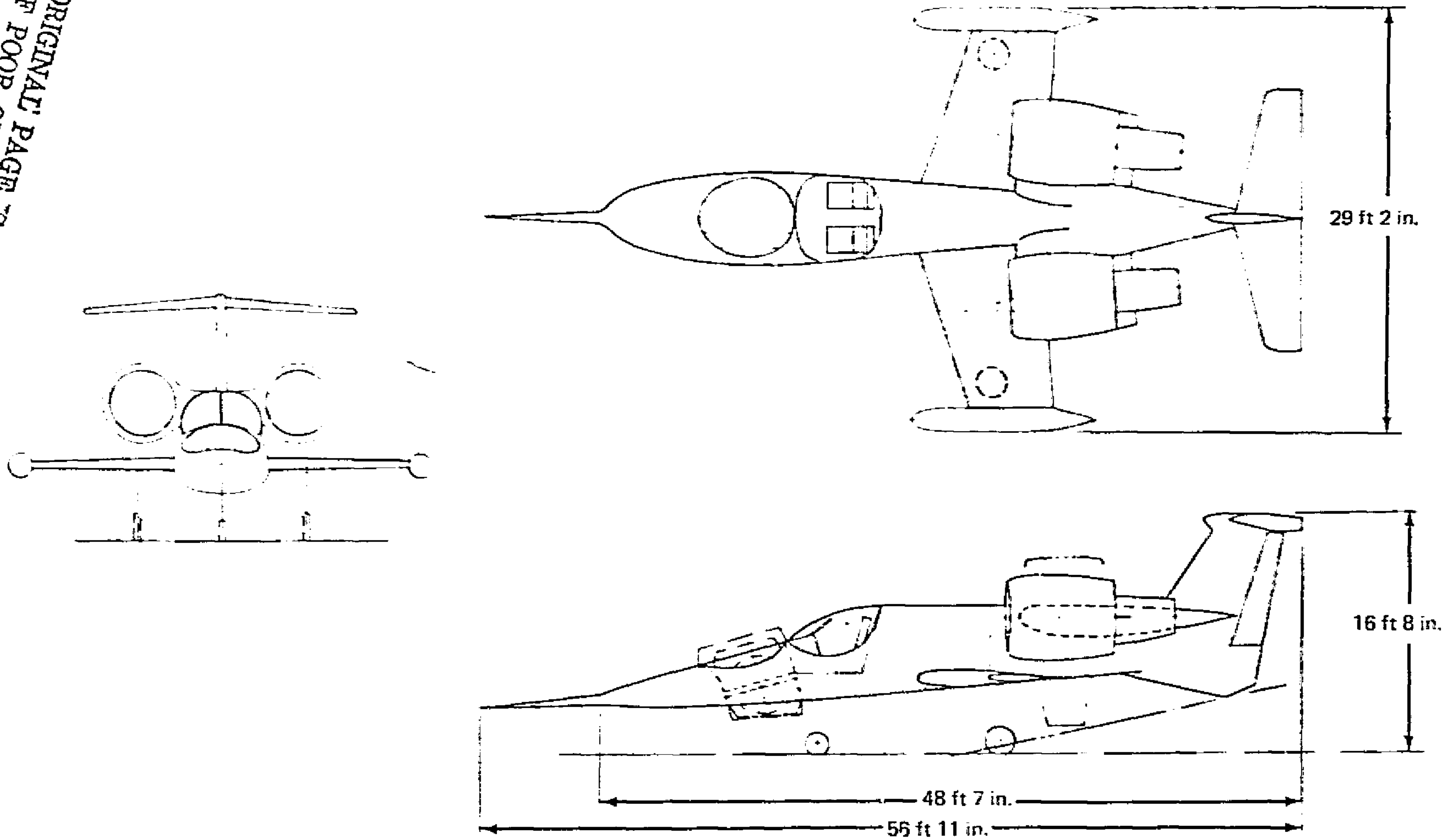

Figure 4.—All New Technology Airplane, Model 1041-134

Table 3. Operational and Technology Airplane Weight Comparison

	Operational airplane 1041 133, lb	Technology airplane 1041 134, lb	ΔWeight, lb
Structure	7 920	6 290	1 630
Propulsion	7 480	6 910	-570
Equipment	6 500	2 600	-3 900
Empty weight	21 900	15 800	-6 100
Nonexpendable useful load	1 600	600	-1 000
Operating weight	23 500	16 400	7 100
Payload	2 820	2 500	-320
Fuel	12 070*	1 540†	
Gross weight (ASW mission)	37 750		
Emergency landing weight	24 500	20 400	-4 100

*Includes external tanks.

†Includes H_2O/alcohol.

A further small cost reduction was achieved by limiting the operation of a modified airplane to the low speeds associated with takeoff, landing, and transition. This configuration is also a modification of the T-39 Model 1041-136. Additional changes consist mainly of removing the canopy, fixing the landing gear, and removing unnecessary doors and actuators. This airplane is 600 lb lighter than the Model 1041-135-2 and only 100 lb heavier than the all new Model 1041-134.

These three technology airplanes offer a classic cost/weight performance trade·

- The all new Model 1041-134 costs the most, has low risk on weight, and performs well.
- The modified T-39 is less expensive, has less weight margin, and performs well.
- The low-speed modified T-39 is the least expensive, it has low risk on weight, but its performance capability is limited to low speed.

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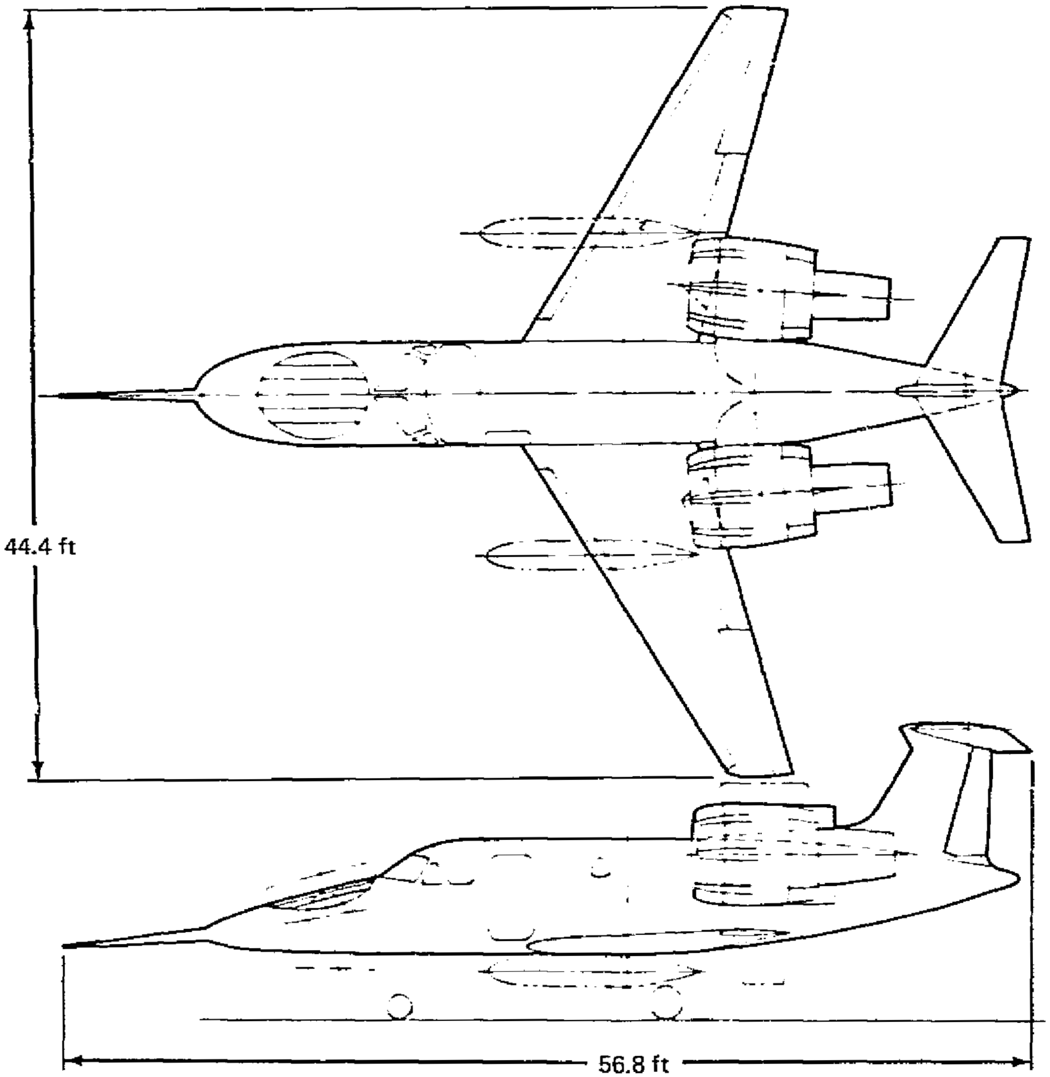


Figure 5.—Modified T-39 Technology Airplane, Model 1041-135-2

2.0 INTRODUCTION

Many successful V/STOL experimental aircraft have flown in the last two decades. Few, except for helicopters, have resulted in useful operational systems. Recent trends in the strategy of naval warfare have revealed a potential requirement for high-speed V/STOL airplanes that may well supply the mission requirement for vertical takeoff that has been missing in previous studies and experiments. This turn of events could result in the introduction of high-speed V/STOL airplanes as a major element in the composition of modern naval forces.

Successful development of vertical and short takeoff and landing aircraft with good payload range and high-speed capability will allow effective air power to be dispersed throughout the fleet instead of being concentrated on conventional aircraft carriers.

Other military applications are evident. Troop deployment, rescue, surveillance, and attack missions of both the Army and Marines could profit from the development of high-speed VTO aircraft.

In the civil applications, development and resupply at remote locations in difficult environment can also be improved by high productivity VTO aircraft.

This study has addressed the problem of designing a vertical takeoff airplane to perform the naval mission. It is shown that proper selection of modern propulsion components combined with a traditional aerodynamic configuration can yield a twin-engine airplane having very respectable, conventional performance together with excellent vertical takeoff capability and engine-out safety. Performance and control after engine failure is superior to that of conventional twins during normal flight. Conventional safety margins are retained during very low-speed flight and hover.

The selection of a lift/cruise fan system at a disk loading balanced between the requirements for low-speed thrust and high-speed fuel economy has resulted in an airplane that minimizes the inherent penalty of vertical takeoff. Figure 6 shows the application of these principles to a V/STOL ASW airplane and compares it to the performance of the conventional, carrier-based S-3A when both are flying the ASW mission.

Although the resulting design is unique, principally in its combination of previously successful components, the combination does require validation. Technical risks can be resolved by demonstrating the aerodynamic, propulsion, and flight control characteristics of the airplane in a technology demonstrator. Several possibilities of technology demonstrator airplanes are presented. They all share in common the advantages of being sized to an existing engine. The fan and transmission are practically identical to their full-scale operational counterparts, thereby demonstrating the new features at full scale but avoiding the requirement for engine development at the demonstrator stage.

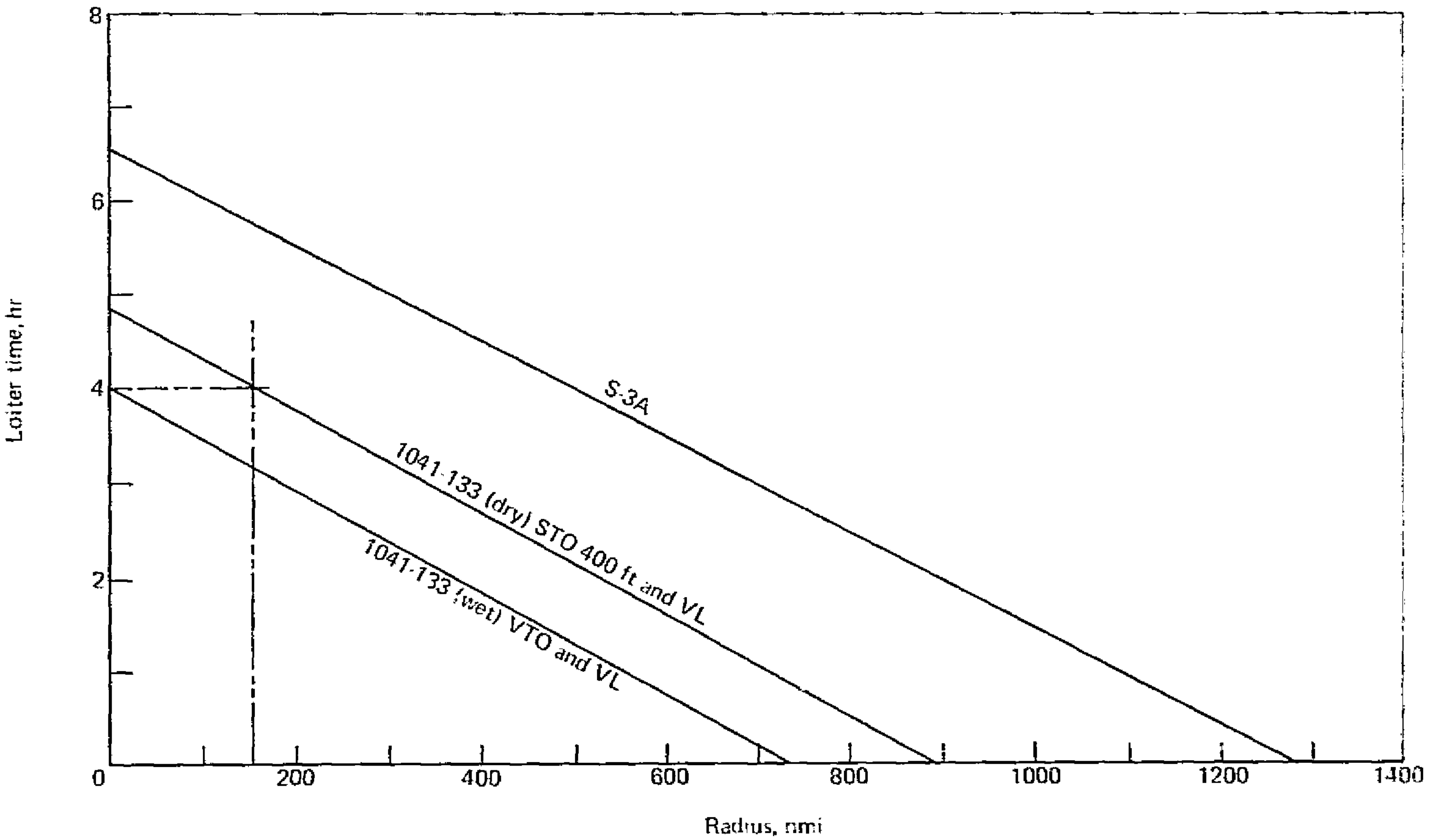


Figure 6.—ASW Mission Performance

3.0 SYMBOLS AND ABBREVIATIONS

A	aspect ratio-b^2/S; nozzle area-ft^2 (m^2)
A/P	airplane
ASW	antisubmarine
b	wing span-ft^2 (m^2)
BCAV	best cruise altitude and velocity
BPR	bypass ratio-fan airflow to primary airflow
BS	body station
$\bar{c}$	mean aerodynamic chord
c.g.	center of gravity
C_D	drag coefficient, D/qs
C_L	lift coefficient, L/qs
$C_{L\ max}$	maximum lift coefficient
C_{L_α}	lift curve slope
CSAR	combat search and rescue
D	drag, lb (N)
DDA	Detroit Diesel Allison
e	Oswald efficiency factor on drag due to lift ($C_D = C_{D_0} + CL^2/\pi Ae$)
F	thrust, lb (N)
F_G	gross thurst, lb (N)
$F_{g\ max}$	maximum gross thrust, lb (N)
$F_{L/C}$	lift cruise fan thrust, lb (N)

F_N	net thrust, lb (N)
F/W	thrust-weight ratio, lb/lb (N/N)
G.E.	General Electric Company
gpm	gallons per minute
GW	gross weight
HLH	heavy lift helicopter
HP	horsepower (W)
IOC	initial operating capability
Ix Iy Iz	moments of inertia, slug ft^2 (kgm^2)
kn	knot
KEAS	knots equivalent airspeed
KTAS	knots true airspeed
L	lift, lb (N)–characteristic length
LE	leading edge
M	Mach number; pitching moment ft lb (N m)
MAC	mean aerodynamic chord
MH	maximum horizontal flight Mach number
N	number of engines; yawing moment ft lb (N m)
OEW	operating empty weight, lb (kg)
P	pressure lb/ft^2 (N/m^2)
$P_{T_{max}}$	maximum total pressure, lb/ft^2 (N/m^2)
$P_{T_{min}}$	minimum total pressure, lb/ft^2 (N/m^2)

q	dynamic pressure, lb/ft^2 (N/m^2)
R_C	compressor pressure ratio
R_F	fan pressure ratio
S	wing or reference area, ft^2 (m^2)
SA	surface attack
SAS	stability augmentation system
SFC	specific fuel consumption, lb/hr/lb (kg/s/N)
STOL	short takeoff and landing
T	temperature, deg
TAS	true airspeed
t/c	thickness/chord ratio
TIT	turbine inlet temperature, deg
T.O.	takeoff
TOGW	takeoff gross weight, lb (kg)
V	velocity, kn (m/s)
V_H	level flight maximum speed
VL	vertical landing
V_0	freestream velocity
VOD	vertical onboard delivery
V/STOL	vertical/short takeoff and landing
VTO	vertical takeoff
VTOGW	vertical takeoff gross weight, lb (kg)
VTOL	vertical takeoff and landing
W	weight, lb (kg); airflow, lb/s (kg/s); watts

WBL	wing body line
W_F	fuel flow, lb/hr (kg/hr)
Greek:	
α	angle of attack, deg (rad)
γ	flightpath angle, deg (rad)
δ	pressure ratio $P/P_{SL,\ std}$; flap deflection, deg (rad)
θ	pitch angle, deg (rad); temperature ratio, $\frac{T}{T_{SL,\ std}}$
λ	gross thrust vector angle relative to the horizontal body reference line; when thrust is horizontal and forward, $\lambda = 0°$; when thrust is vertical and up, $\lambda = 90$ deg (rad)
$\Lambda_{c/4}$	sweep of the quarter chord line, deg (rad)
ϕ	roll angle, deg (rad)
ψ	yaw angle, deg (rad)

4.0 PART I–NAVY OPERATIONAL AIRCRAFT

As part of the Navy's control of the sea, five V/STOL aircraft missions were formulated, ranging from aerial surveillance to transport operation. Specifically, the missions were:

1. Surface attack (SA)—sea control mission. Patrol for 2 hr at 20 000 ft at a radius of 300 nmi armed with two harpoons and two AIM-9 missiles.

2. Antisubmarine (ASW)—patrol at 10 000 ft for 4 hr at a radius of 150 nmi armed with two MK-46 torpedoes and 50 sonobuoys.

3. Vertical onboard delivery (VOD)—deliver 5000 lb of payload 2000 nmi.

4. Surveillance—patrol at 25 000 ft for 4 hr at a radius of 75 nmi carrying surveillance avionics.

5. Combat (strike) search and rescue (CSAR)—accompany strike aircraft and perform the search and rescue as required.

Complete mission groundrules are given in the appendix.

V/STOL aircraft were designed for each mission. The point designs were then compared to find the best multimission airplane and to determine the mission compromises such a concept would entail.

4.1 POINT DESIGN AIRCRAFT

The point design aircraft were configured to perform the five missions. A development of an existing engine (Detroit Diesel Allison T701) and 62-in.-dia variable pitch fans were used on all airplanes. They all had three fans (one lift fan and two lift/cruise fans), and all but the VOD used two engines. The VOD needed three.

The total installed power required is dominated by the short takeoff and vertical landing requirements. There are three low-speed conditions that can define the total thrust required: (1) short takeoff, thrust/weight ratio (F/W) less than one; (2) mission end vertical landing, F/W = 1.05; and (3) emergency weight, (engine out) vertical landing, F/W = 1.0. In all cases, the engine-out vertical landing is critical. The emergency weight is the weight that can be attained after jettison of releasable payload. This condition can be satisfied with one of two engines for all the missions except VOD. The VOD emergency weight is high because of the large fuselage and nonreleasable character of the payload.

The variation in mission gross weight and emergency weight of the two engine designs is small because of the use of the same engines and fans on all the airplanes. Airplanes designed with "rubber" engines sized to the point design would have had a greater weight spread. As it is, a total mission weight variation of 7400 lb is found. For these airplanes the maximum emergency gross weight is 24 500 lb. This is the available thrust from one engine and three fans at zero speed at sea level on a 90° F day. The maximum vertical takeoff or vertical landing weight (F/W = 1.05) is 32 380 lb under the same conditions.

The SA airplane is shown in figure 7. It has a wing area of 250 ft^2. Its emergency weight is 20 180 lb, and it performs the mission from a gross weight of 30 350 lb. The mission is made from a vertical takeoff in which F/W = 1.12.

The antisubmarine design, conceptually similar to the SA, is shown in figure 8. It has 310 ft^2 of wing and performs the mission from a gross weight of 37 750 lb with a short takeoff ground roll less than 400 ft in a 10 kn wind. The emergency weight is equal to the emergency thrust. This condition was the criterion for the selection of the fan diameter.

The three-engine VOD is an anomaly in that the emergency gross weight must be achieved with full payload. The third engine for use only during takeoff and landing is beneath the floor of the cockpit (fig. 9). The shaft routing is also different from the other aircraft. A schematic is shown in figure 10. The T-box is located asymmetrically; from the T-box the shaft descends along the cabin wall below the floor. An extra gearbox is used to turn the shaft forward, under the floor, to the front fan. The effect on the cabin arrangement is shown in figure 11.

The surveillance airplane features a retractable radar under the fuselage (fig. 12). A 12-ft-dia system was used. The airplane has 265 ft^2 of wing and performs the mission from takeoff gross weight of 32 220 lb, in which F/W = 1.05. This is sufficient for a vertical takeoff.

The CSAR version is shown in figure 13. The cabin, for rescue operations, is encumbered with a shaft bulge similar to current automobiles. It performs the mission from a vertical takeoff with F/W = 1.07. It has a wing area of 270 ft^2.

The five point designs are compared in table 4. It is apparent that the ASW mission is the most stringent for the two-engine airplanes. All the other missions are performed from a vertical takeoff; only the ASW needs a short ground run. On this basis, the ASW configuration was used as the basis for the multimission airplane.

Table 4.--Point Design Weight Summary, Mission-Sized Airplanes

Configuration	LCFA-128	LCFA-131	LCFA-129	LCFA-132	LCFA-130
Mission	ASW	SA	SURV	CSAR	VOD
Operating weight, lb	23 500	19 180	23 420	22 090	24 300
Payload, lb	2 820	2 540	0	810	5 000
Fuel, lb	11 430	8 630	8 800	8 830	13 000
Mission gross weight, lb	37 750	30 350	32 220	31 730	42 300
Mission T.O., F/W	0.9	1.12	1.05	1.07	---
Emergency landing weight, lb	24 500	20 180	24 420	23 090	30 300
Wing area, ft^2	310	250	265	265	350
Lift/Cruise fan diameter, in.	62	62	62	62	62

Wing area	250 ft^2
Emergency weight	20 180 lb
Mission GW	30 350 lb
Mission T.O.—F/W = 1.12	

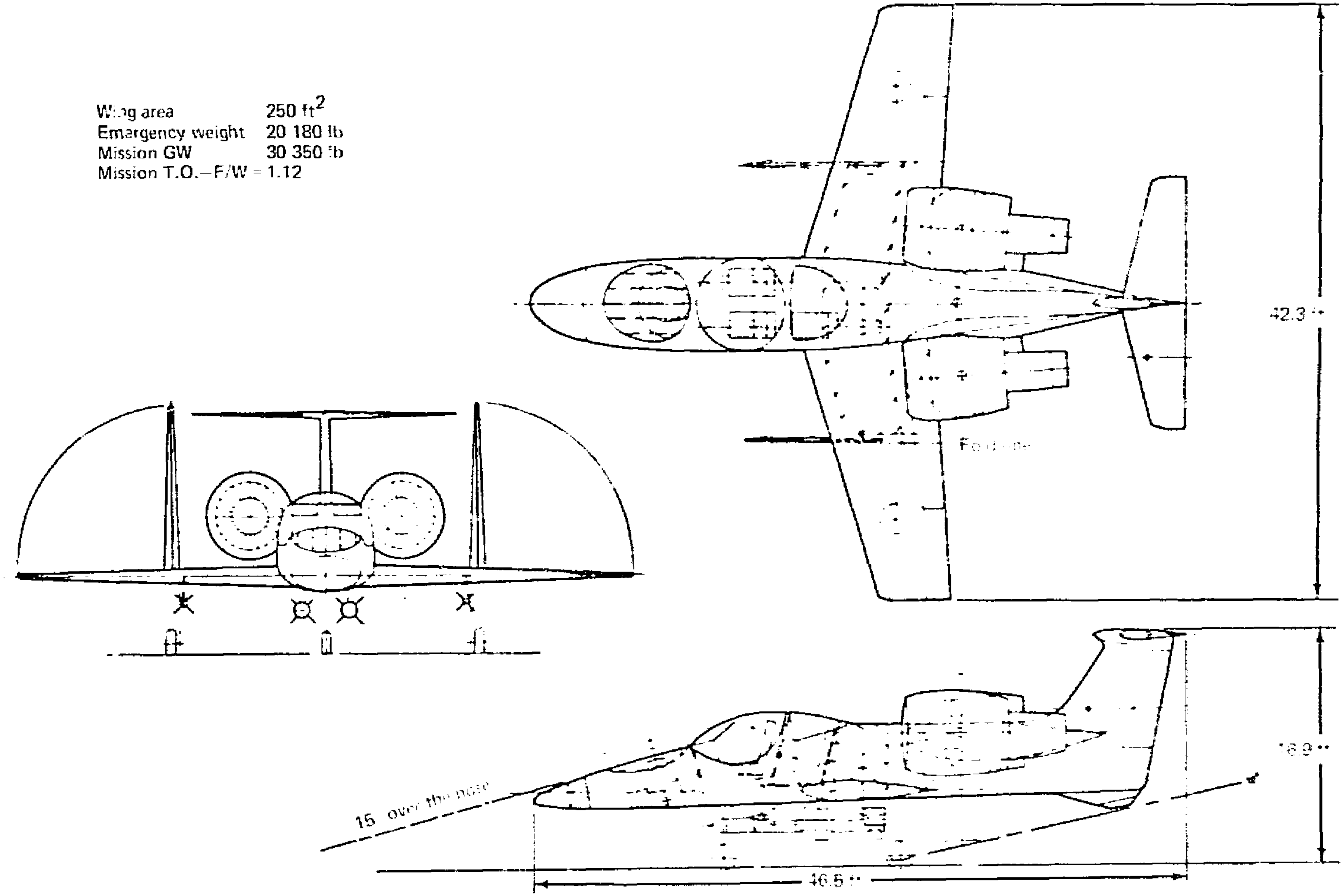


Figure 7. Surface Attack Airplane, LCFA-137

Wing area	310 ft^2
Emergency weight	24 500 lb
Mission GW	37 750 lb

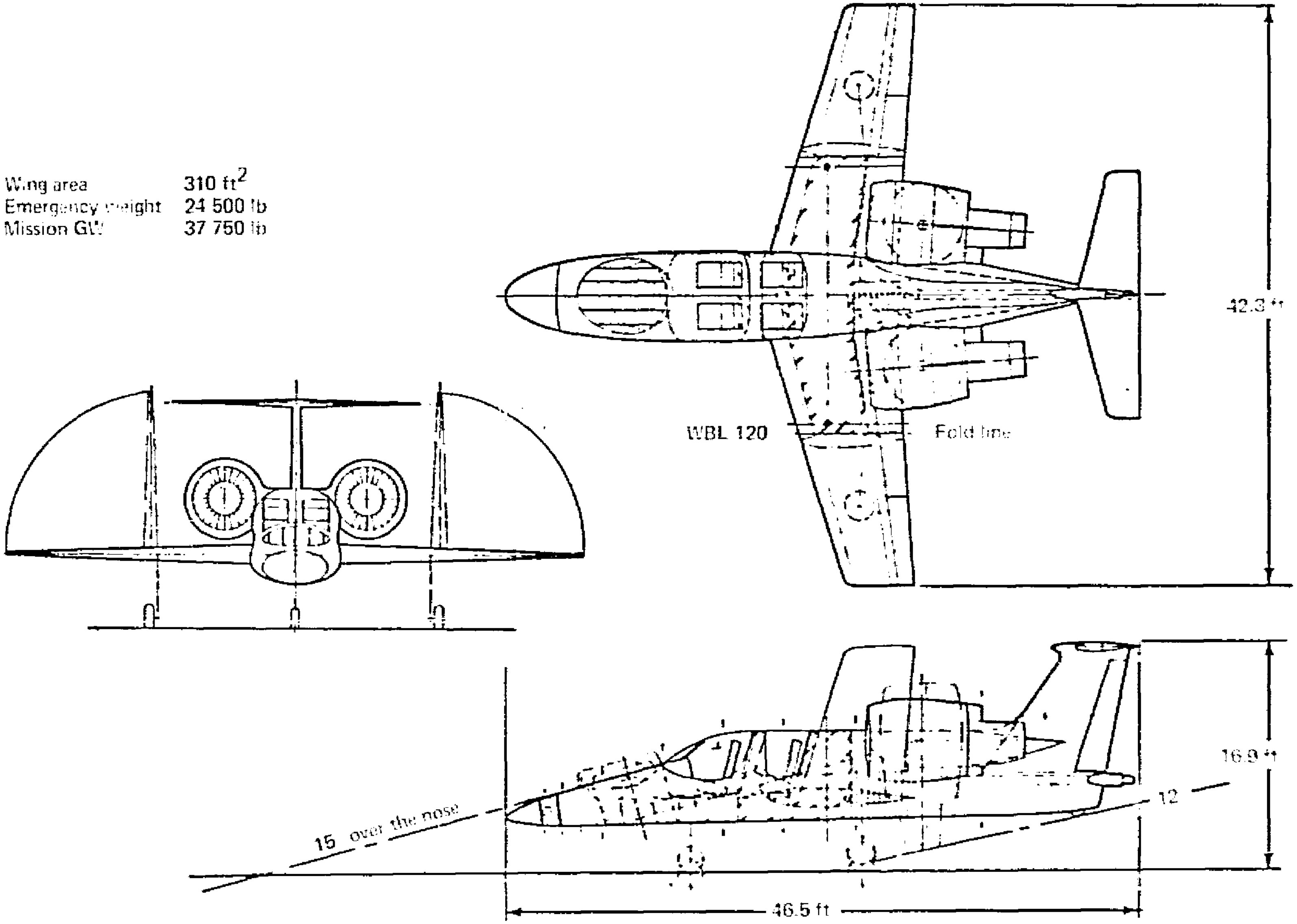
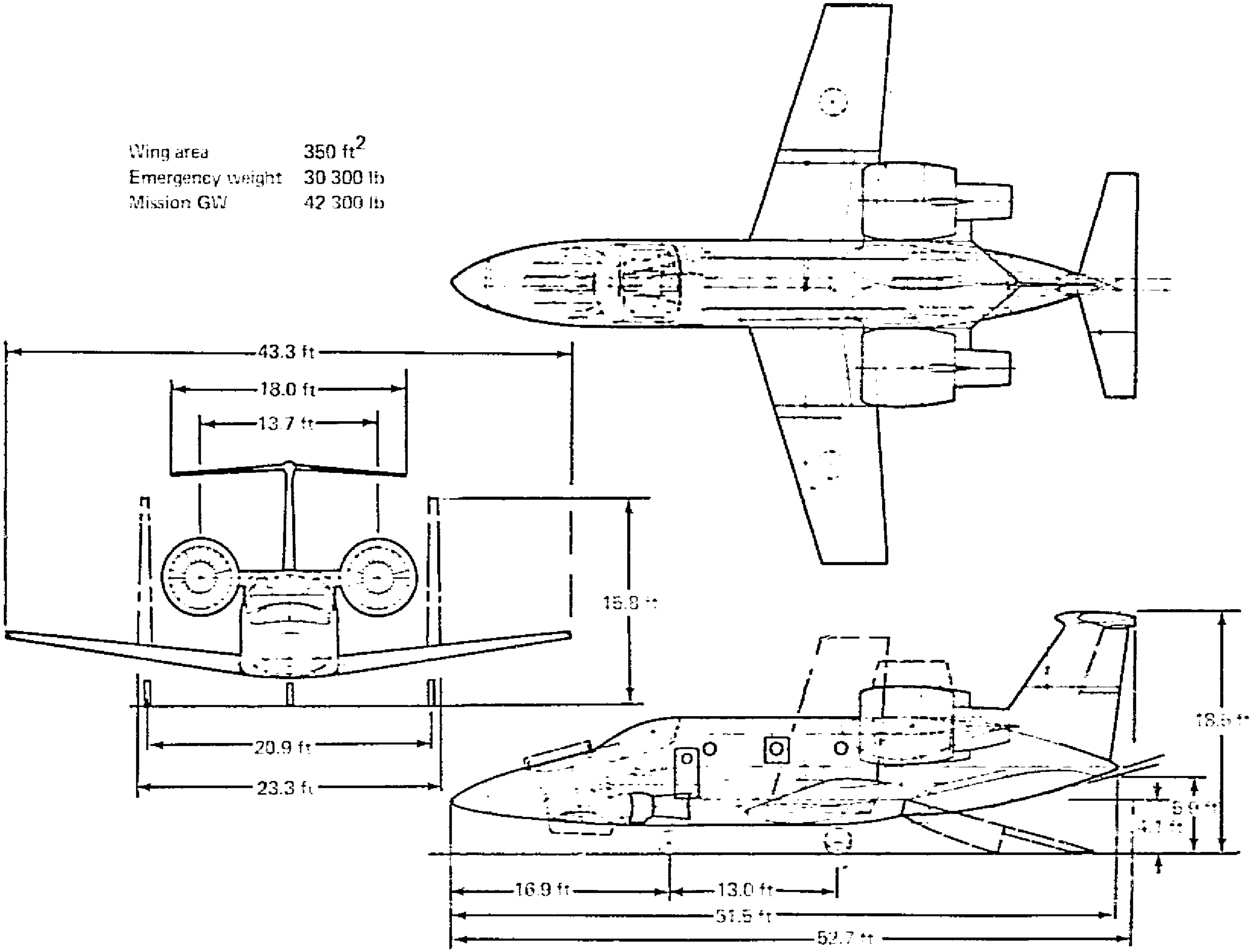


Figure 8.–Point Design ASW Airplane, LCFA-128



Wing area	350 ft^2
Emergency weight	30 300 lb
Mission GW	42 300 lb

Figure 9. – VOD Airplane, Three Engines, LCFA-130

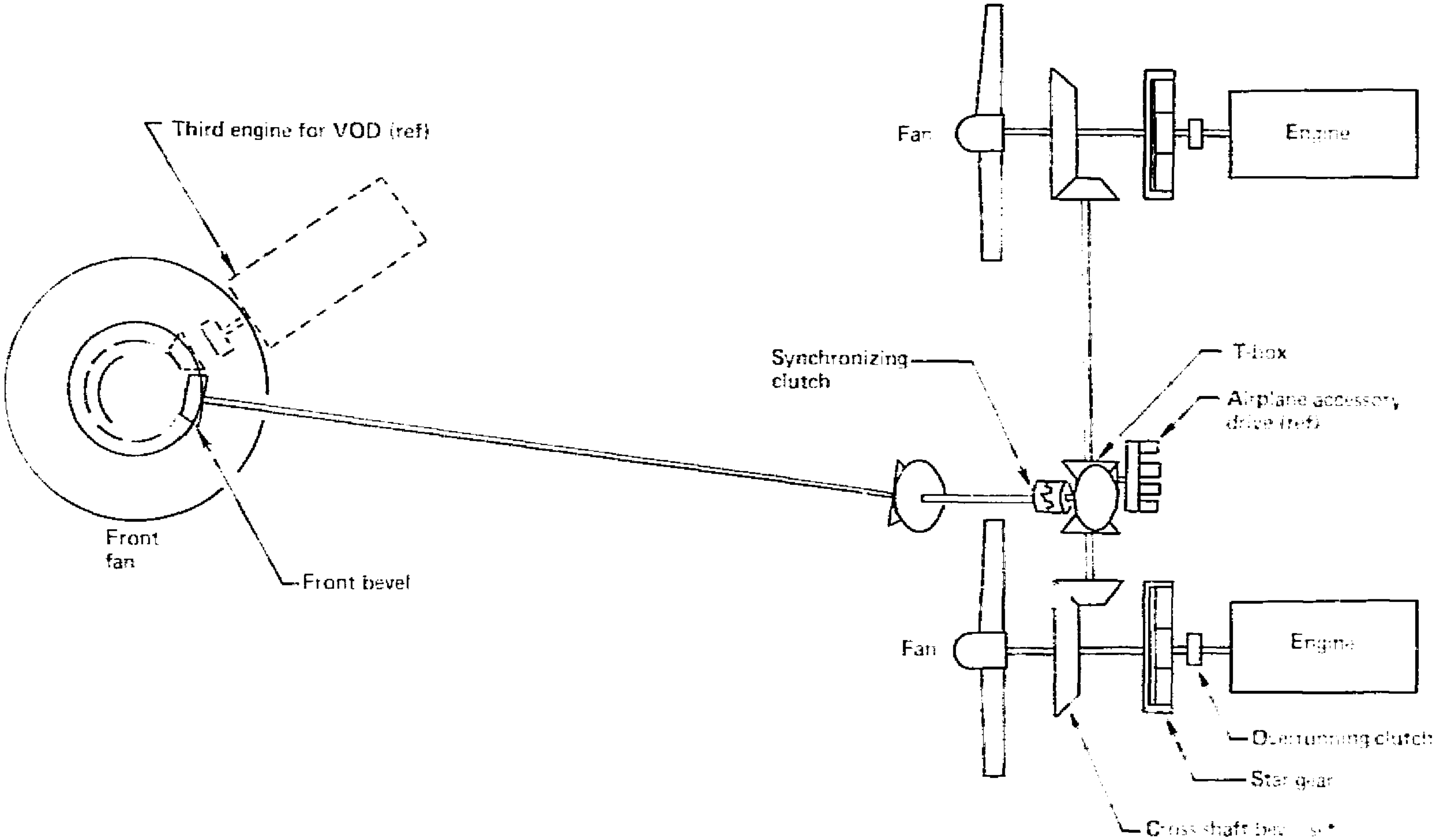


Figure 10. – VOD Three-Engine Transmission

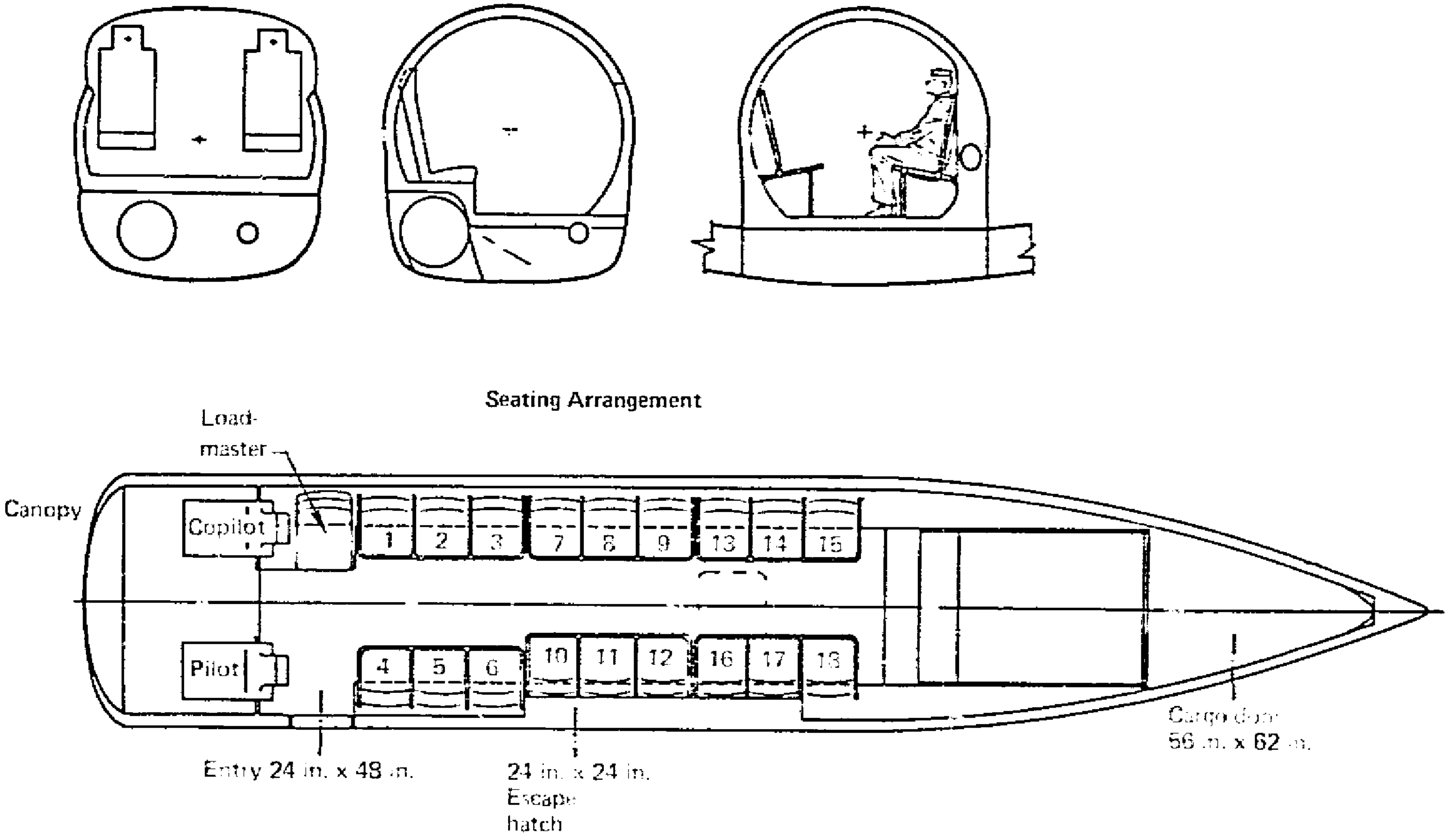


Figure 11. -VOD Airplane, Cabin Arrangement

Wing area	265 ft^2
Emergency weight	24 420 lb
Mission GW	32 220 lb

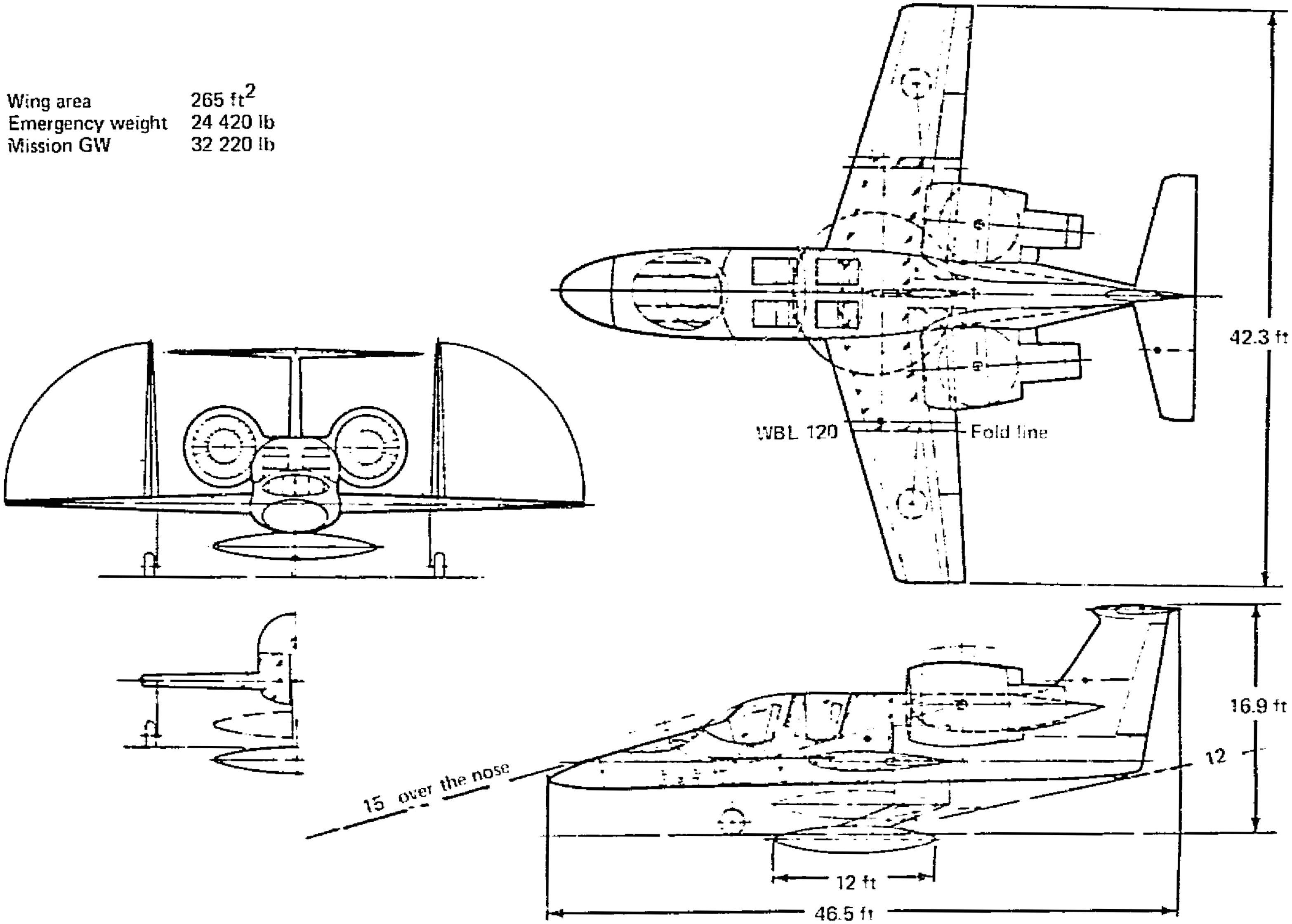


Figure 12.—Surveillance Airplane, LCFA-129

Wing area	270 ft
Emergency weight	23 090 lb
Mission GW	31 730 lb

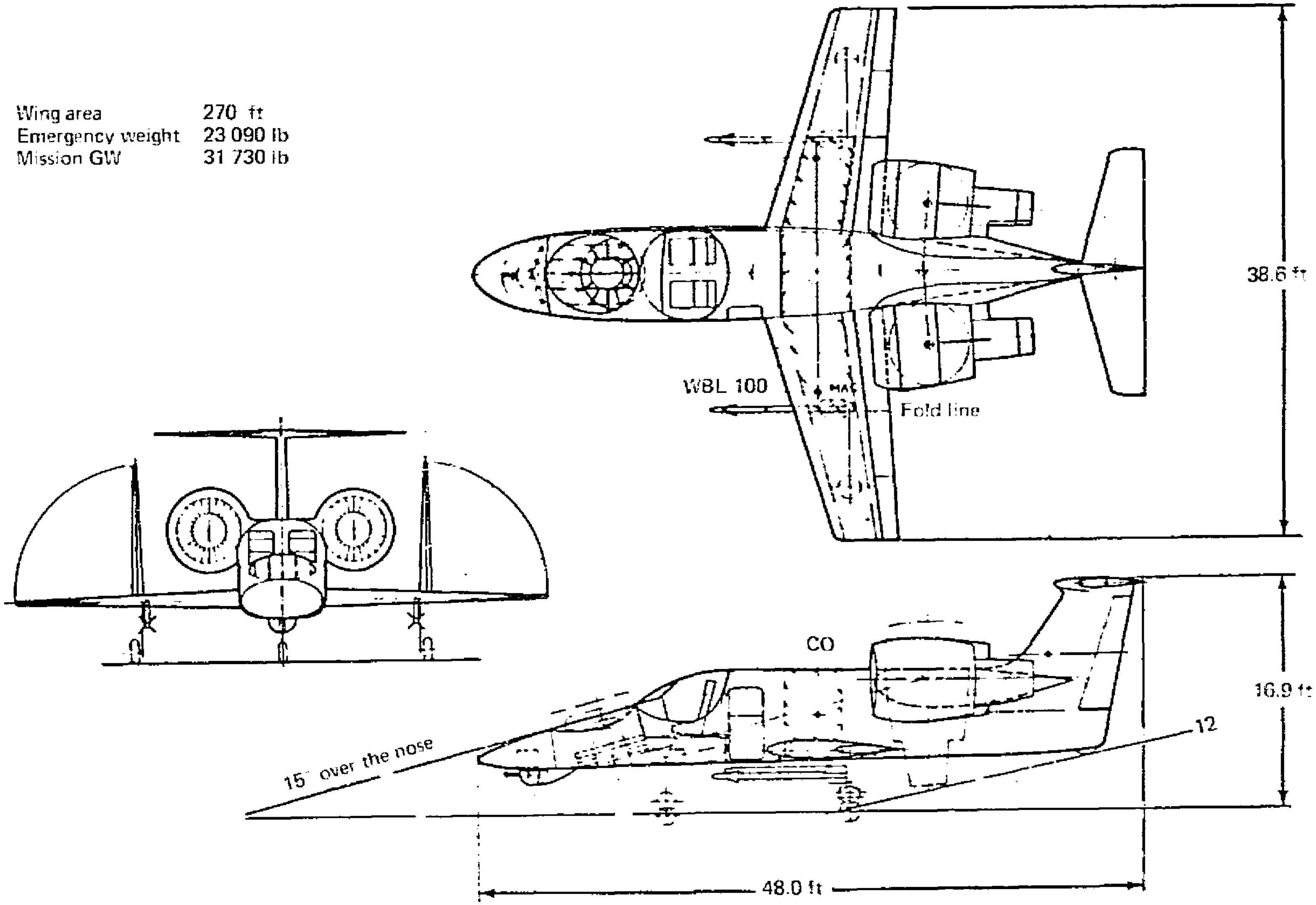


Figure 13.–CSAR, LCFA-132

4.2 MULTIMISSION AIRCRAFT

Comparison of the point designs from the standpoint of emergency weight, mission weight, and payload led to selection of the ASW as the basis for the multimission airplane. Model 1041-128 was renamed 1041-133-1 and became the ASW version of the multimission airplane. For convenience, the other versions of the multipurpose airplane were given dash numbers on the 1041-133 designation:

Antisubmarine (ASW)	1041-133-1
Surveillance	1041-133-2
Vertical onboard delivery (VOD)	1041-133-3
Surface attack (SA)	1041-133-4
Combat (strike) search and rescue (CSAR)	1041-133-5

The multimission airplane concept is conceived as being a single airplane design with only minor changes as required by the different mission roles. Except for the VOD airplane, the same wing, flight deck, propulsion, and control system will be used for all the models.

As a result of continuing design and analysis, the weights and thrusts used for the multimission airplanes are slightly different from the point designs. For example, the point design ASW (-128) airplane has a mission GW of 37 750 lb; the multimission ASW (-133-1) has a mission GW of 38 390 lb. The maximum emergency thrust for the two-engine airplane, is 25 300 lb; that is, after an engine failure with one engine driving three fans. For the VOD, the emergency thrust is 39 400 lb after an engine out with two engines driving three fans.

A summary of the five multimission airplanes is presented to show the overall capability of the system. A more detailed description of the ASW version is presented in section 3.3 and represents the entire family.

A comparison of the airplanes in the different roles is shown in table 5.

Table 5.—Multimission Aircraft Comparison

Fan Diameter = 62 in. *Wing Area = 310 ft²*

Airplane	1041-133-1	1041-133-2	1041-133-3	1041-133-4	1041-133-5
Mission	ASW	SURV	VOD	SA	SAR
No. of engines	2	2	3	2	2
Wetted area, ft^2	1674	1947	1937	1674	1674
Body: Volume, ft^3	934	934	1890	934	934
Density, lb/ft^3	22.8	16.9	12.5	14.1	13.4
Mission T.O. weight	38 890	33 360	42 520	31 250	30 180
Mission T.O. F/W [1]	0.89	1.02	1.01	1.09	1.10

[1] Sea level 90° F day.

The ability to perform the specified mission from a vertical takeoff is approached by all the aircraft except the ASW which has an F/W of 0.89. In table 6 the weight for the five versions is summarized. The empty weight cost of using a single wing area and fuselage causes the surveillance airplane to become the most critical from an emergency weight standpoint; it is still within the available thrust.

Table 6.- Multimission Weight Summary

Configuration	133-1	133-4	133-2	133-5	133-3
Mission	ASW	SA	SURV	CSAR	VOD
Operating weight, lb	23 500	20 280	23 970	21 600	24 400
Payload, lb	2 820	2 540	0	810	5 000
Fuel, lb	12 070*	7 990	9 390	8 370	13 080
Mission gross weight, lb	38 390	31 250	33 360	30 780	42 520
Emergency landing weight, lb	24 500	21 280	24 970	22 600	30 440
Emergency thrust, lb	25 300	25 300	25 300	25 300	39 400

*Includes weight of external leaks.

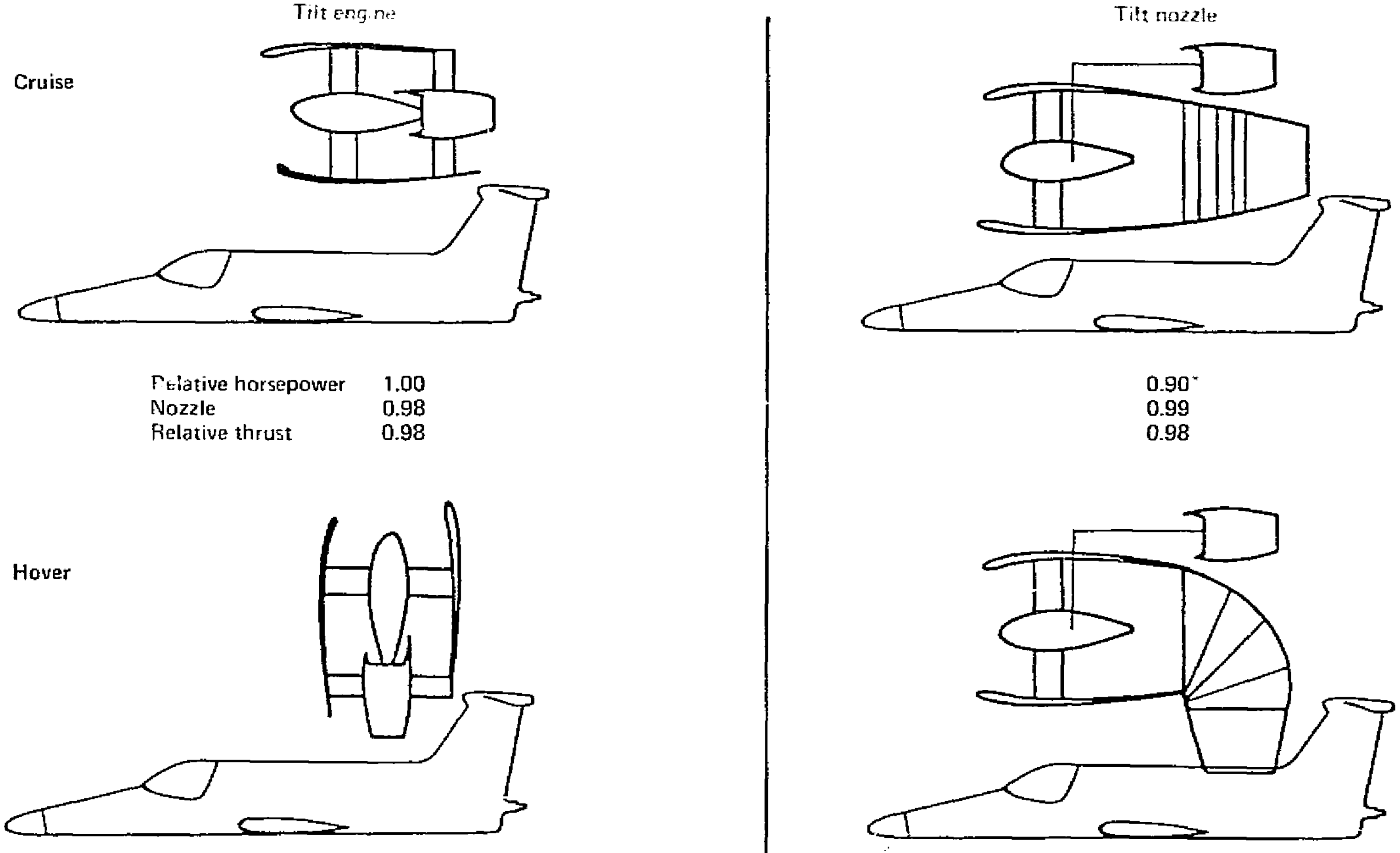
4.3 ASW AIRPLANE DESIGN, MODEL 1041-133-1

The ASW airplane has three fans and two engines; two fans are for lift/cruise and one fan is for lift only. An isometric of this basic two-engine arrangement is shown in figure 2. Each engine drives through an overrunning clutch into the lift/cruise gearbox. This gearbox contains a reduction gear that reduces engine rpm to fan rpm (11 500 rpm to 3 500 rpm) and a right angle bevel set that distributes power to the combiner gear box or T-box. Interconnecting shaft speed is equal to engine speed. At the T-box, power is distributed as required to the front fan where a bevel set reduces the speed back to fan rpm. A clutch adjacent to the T-box disconnects the front fan during conventional flight. Airplane accessory power is taken from the rear of the T-box.

Thrust vector control during V/STOL operation is achieved by rotating the lift/cruise fan nacelles. The thrust vector angle of the nose fan is fixed 15° forward of vertical ($\lambda = 75^{0}$); its magnitude is controlled with fan pitch. During V/STOL transitions, as the lift/cruise vector is rotated and its moment arm about the c.g. changes, the nose fan thrust is changed to balance the system.

Three large benefits led to selection of thrust vectoring by nacelle rotation. In addition to minimizing the number of gearboxes and permitting an aerodynamically clean engine/wing integration, rotating the nacelles provides about 15% more vertical thrust at the lift/cruise fan than would otherwise be possible with the same engines.

Use of other propulsive arrangements was considered but the performance advantage of the selected arrangement overrides other considerations. A comparison of a rotating nacelle and thrust-deflecting nozzle is shown in figure 14.



		Tilt engine	Tilt nozzle
Cruise	Relative horsepower	1.00	0.90*
	Nozzle	0.98	0.99
	Relative thrust	0.98	0.98
Hover	Relative horsepower	1.00	0.90*
	Nozzle	0.98	0.95
	Relative thrust	0.98	0.85

*No fan supercharging.

Figure 14.—Propulsion Arrangements for Thrust Vectoring

The rotating nacelle has the engine placed behind the fan. The engine is supercharged by the fan, and a single gearbox connects the engine and fan and provides the output for the interconnect system. For single-engine operation, the fan pressure ratio of 1.13 supercharges the engine for about 10% more power. When both engines are operating, the augmentation caused by supercharging is as much as 20%. The nozzle efficiency is about 98% of the ideal.

For the tilt nozzle thrust deflection system, the engine is separate from the fan. This is necessary to keep the point of action of the vertical thrust vector near the wing trailing edge without causing unfavorable interference. This separation requires the added weight and complexity of two extra gearboxes. The supercharging action of the fan is lost, resulting in about 10% less power than would have been available with supercharging. In addition, a nozzle efficiency, including duct bend losses, approaching 95% may be possible. Thus, the thrust available is 85% of the ideal with supercharging.

4.3.1 ARRANGEMENT AND CHARACTERISTICS

Figure 15 shows the general arrangement of Boeing Model 1041-133-1, multimission V/STOL airplane in its ASW role. It has a low wing, T-tail and engine pods mounted on the aft body in an arrangement similar to the majority of today's small jet transports.

The design incorporates a number of special features to suit its role as a ship-based V/STOL aircraft. The most important unique feature is the propulsion system. Two Allison advanced T701 turboshaft engines drive three Hamilton-Standard variable pitch fans by means of a mechanical drive system.

The wings fold just outboard of the engine pods. The planform of the airplane with wings folded is slightly smaller than that of the A-7. It is therefore assumed that the spotting factor relative to the A-7 is 1.0 or slightly less. Figure 16 shows the planforms of the two airplanes superimposed.

The landing gear is a conventional tricycle arrangement. The main gear attaches to the wing fold rib and retracts outboard. The nose gear retracts aft under the cockpit floor.

4.3.2 INTERNAL ARRANGEMENT

The interior arrangement of the airplane is shown in figure 17.

A four-man crew cab is provided. Each crew station is equipped with a zero-zero ejection seat. A high visibility, full bubble canopy is provided for the pilot and copilot with nearly straight down visibility over the side. Large transparent areas in the hatches for the two aft stations provide maximum use of visual observation.

Avionics is located in the noze forward of the nose fan. Access is from the bottom through a large hatch. The volume of this compartment not including the radome is 48 ft^3. Fuel is located in the wing inboard of the fold and in four body tanks. The main body tank is located above the wing box and occupies the entire bay between the front and rear spar bulkheads. A forward body tank is located just forward of the front spar and below the aft crew stations. Two aft body tanks are located aft of the rear spar on either side of the sonobuoy bay. The total internal fuel capacity is 11 400 lb.

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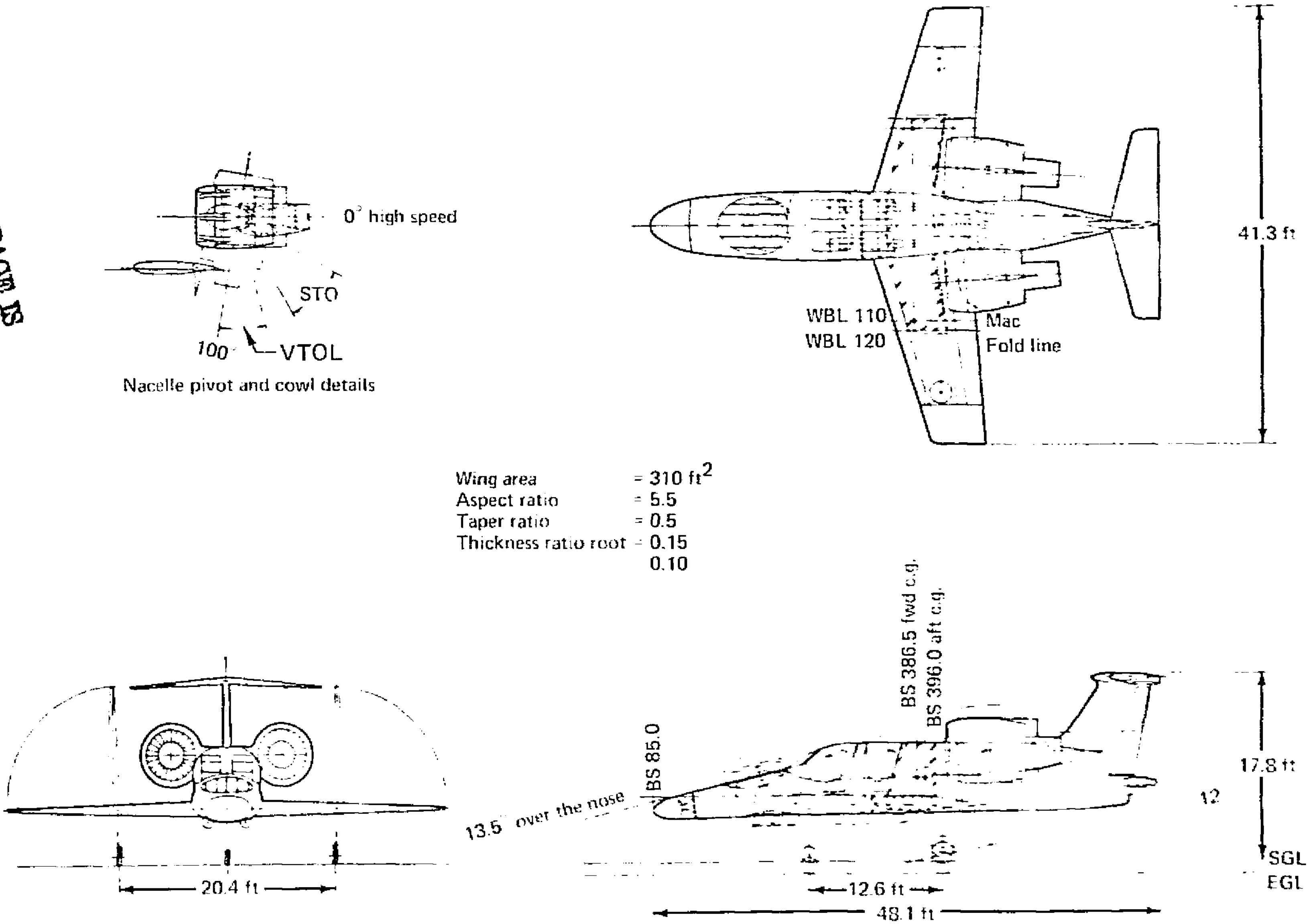

Nacelle pivot and cowl details

Wing area = 310 ft^2
Aspect ratio = 5.5
Taper ratio = 0.5
Thickness ratio root = 0.15
0.10

Figure 15.—General Arrangement, Model 1041-133

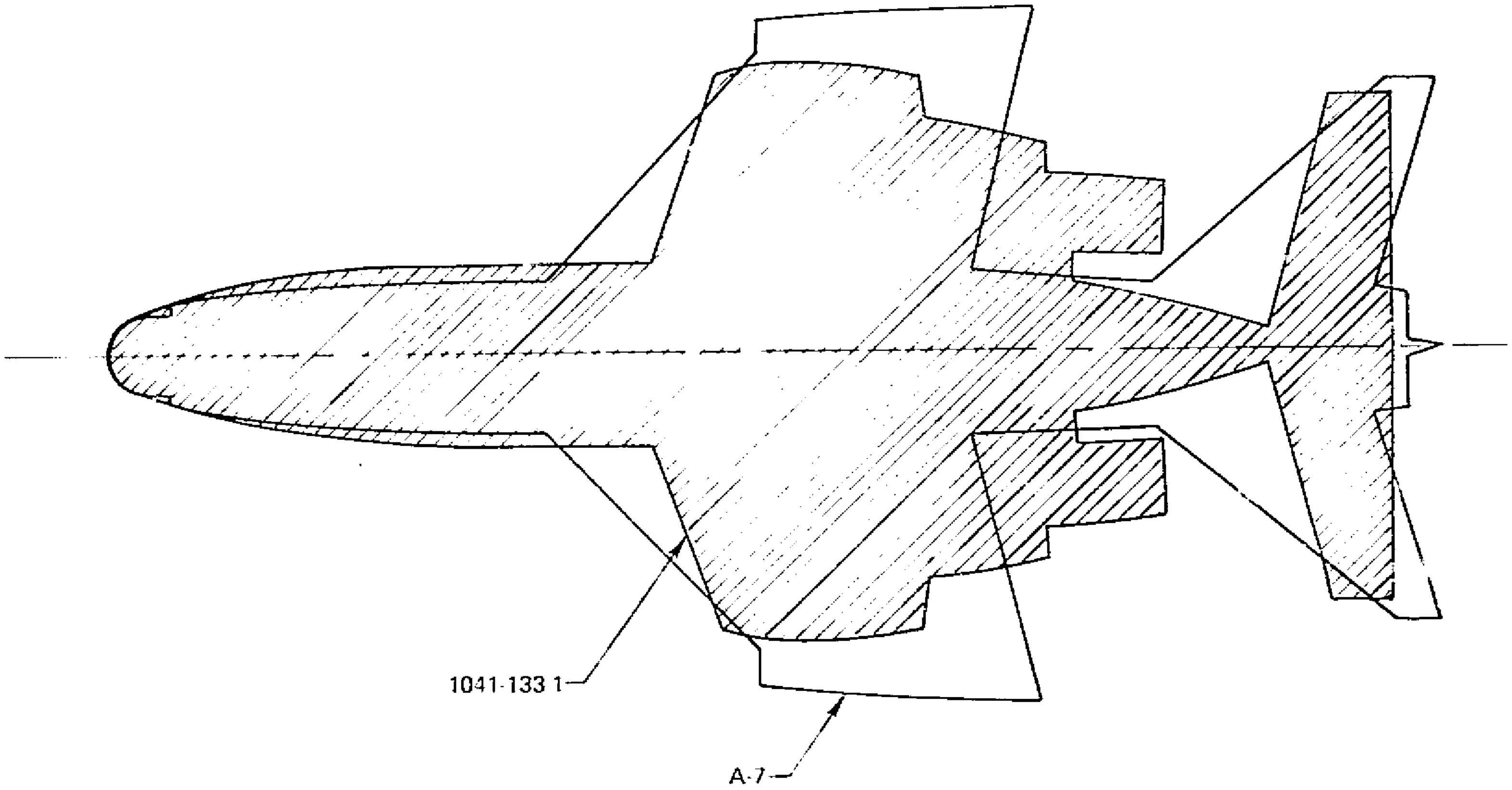

Figure 16.—Spotting Comparison

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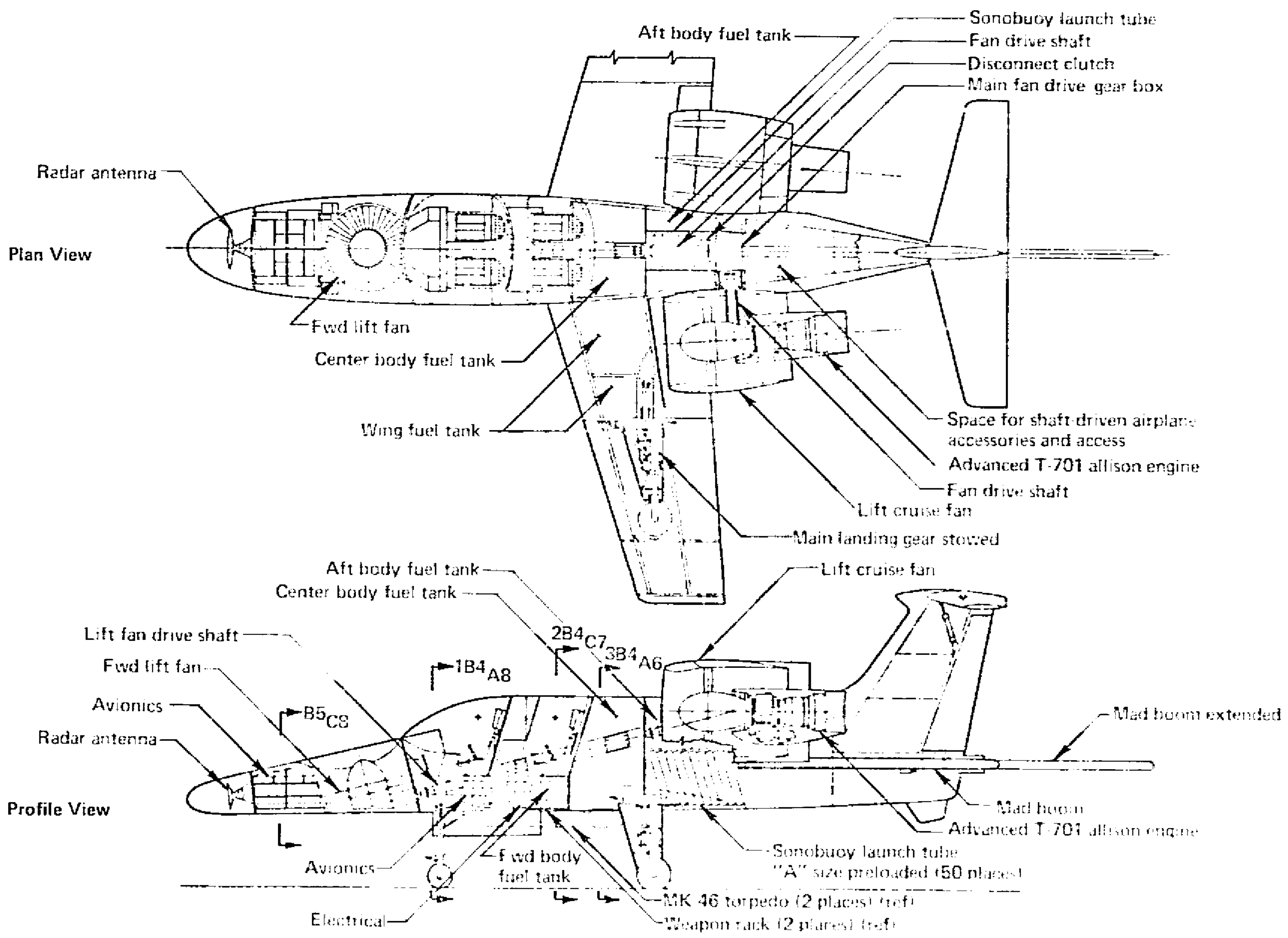
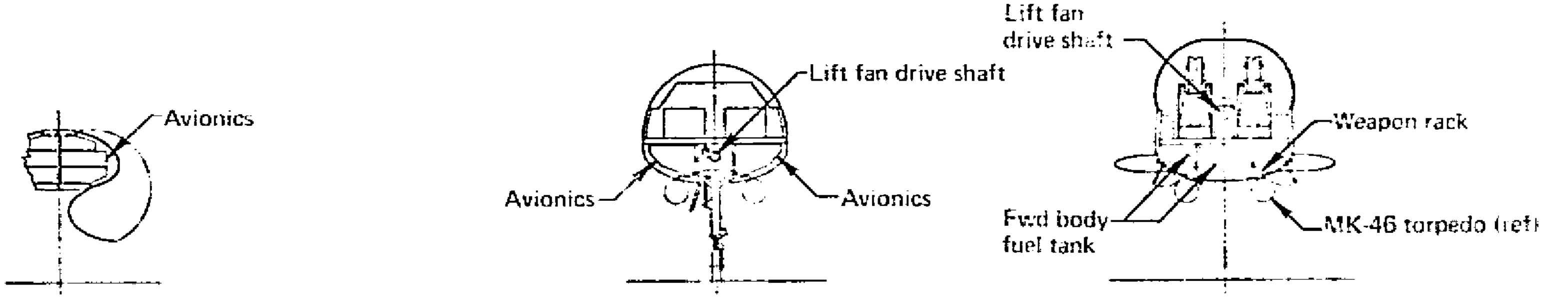


Figure 17.—Inboard Profile of Model 1041-133-1 ASW Airplane



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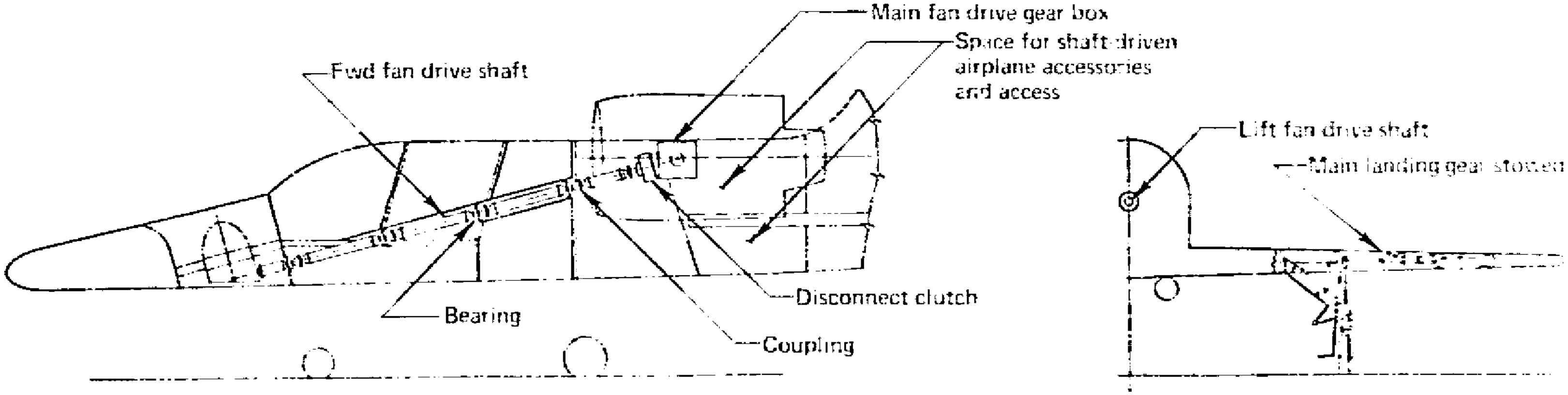


Profile—Fwd Fan Drive System Section 3B4

Figure 17.—(Concluded)

The 50-sonobuoy capacity bay is located on the body centerline aft of the wing carry-through box. A retractable mad boom is located in the body tail cone just aft of the sonobuoys.

The airplane accessory power components, two AC generators, twin hydraulic pumps, and cabin pressurization and cooling compressor, occupy the volume aft of the sonobuoy bay and below the fan drive T-box.

Figure 18 shows the distribution of body volume. The gross volume includes the nacelle/body fairings. The principal contents of the body and the volume for each (installed) are indicated. Avionics volume does not include controls and displays in the cockpits; that volume is included in the cockpit volume. The avionics volume ($46\ ft^3$) is obtained by applying a density of $35\ lb/ft^3$ to a weight of 1600 lb. Drive system volume includes all shafts and gear boxes in the body and airplane accessories; i.e., generators and hydraulic pumps. The remaining electrical and hydraulic/pneumatic systems are assumed to have densities of 50 and $25\ lb/ft^3$, respectively. The other volumes were obtained by measurement.

The total required volume is about two-thirds of the total body volume available. Growth or reduction in body volume are possible. The overall density of the body and contents is $23\ lb/ft^3$.

4.3.3 STRUCTURAL CRITERIA AND DESIGN

The flight speed/altitude envelope is shown in figure 19. The level flight maximum speed (V_H) is selected to meet the operational requirements for the ASW, surveillance, and surface attack missions. It is below the maximum speed attainable in level flight. Appropriate restrictions to the maximum usable power in conventional flight will be imposed. At a flight design weight of 33 180 lb, a limit-positive maneuvering load factor of 3 g is required. V-n diagrams for sea level and 20 000 ft are shown in figure 20.

The load stroke requirements for the main landing gear, 40 300 lb and 20 in., are based on a sink rate of 15 fps at the design landing weight of 32 700 lb. The maximum design weight is the STO gross weight of 38 390 lb.

Advanced structural materials were selected based on the results of the Advanced Transport Technology Study, NASA Report CR-112092. Full depth graphite epoxy honeycomb was selected for the empennage surfaces and engine fan cowls. Stiffened graphite epoxy and graphite epoxy honeycomb were selected for the wing surfaces and body shell, respectively. The all-flying stabilizer attachment to the fin and the wing hinge are of metal construction. Compared to conventional metal structure, this structural concept is conservatively estimated to result in a weight reduction of 10%. An important structural design detail for this airplane is the nacelle pivot support. Several concepts have been considered. The selected one is shown in figure 21.

Fly-by-wire fan pitch and throttle controls and fuel supply are introduced to the pivot structure as shown schematically in figure 22. It is of interest that once attachment is

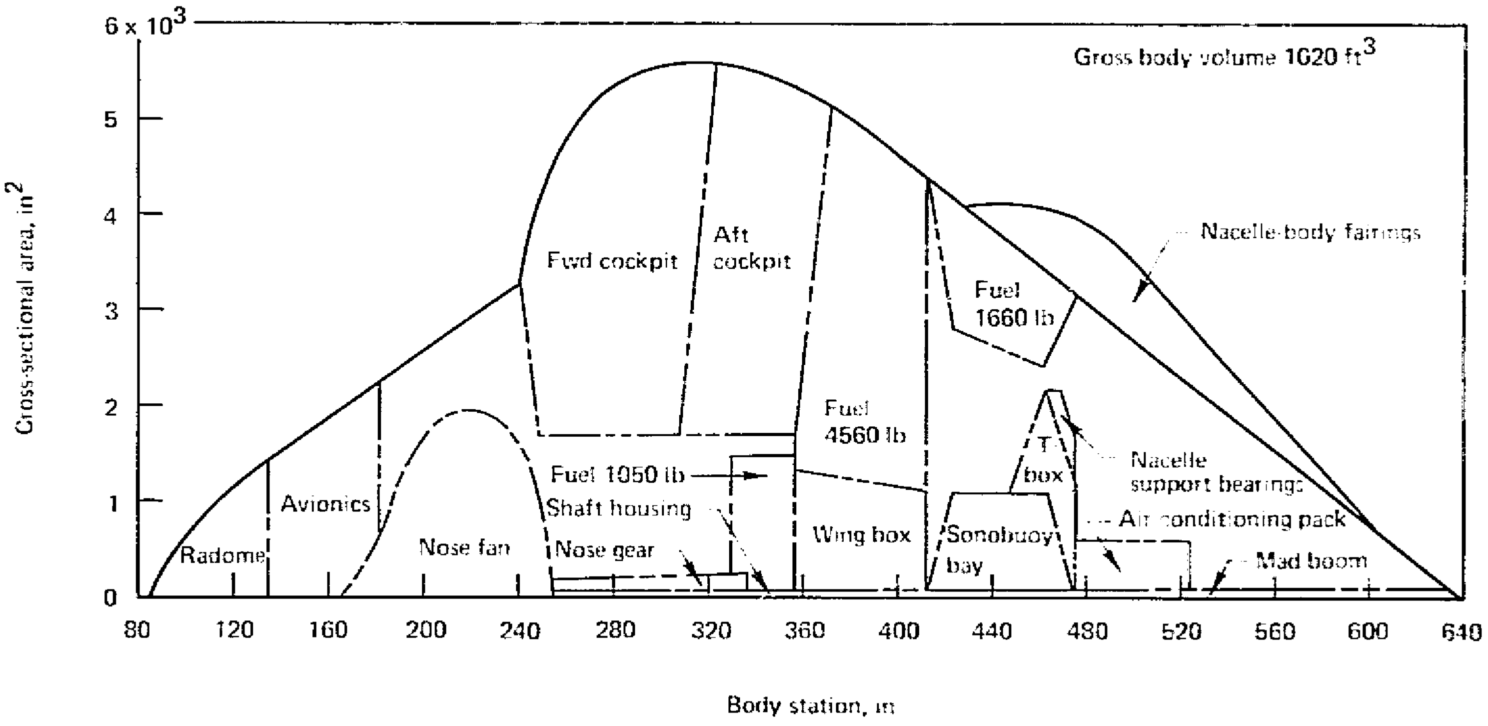


Figure 18.—Area Distribution, Model 1041-133-1

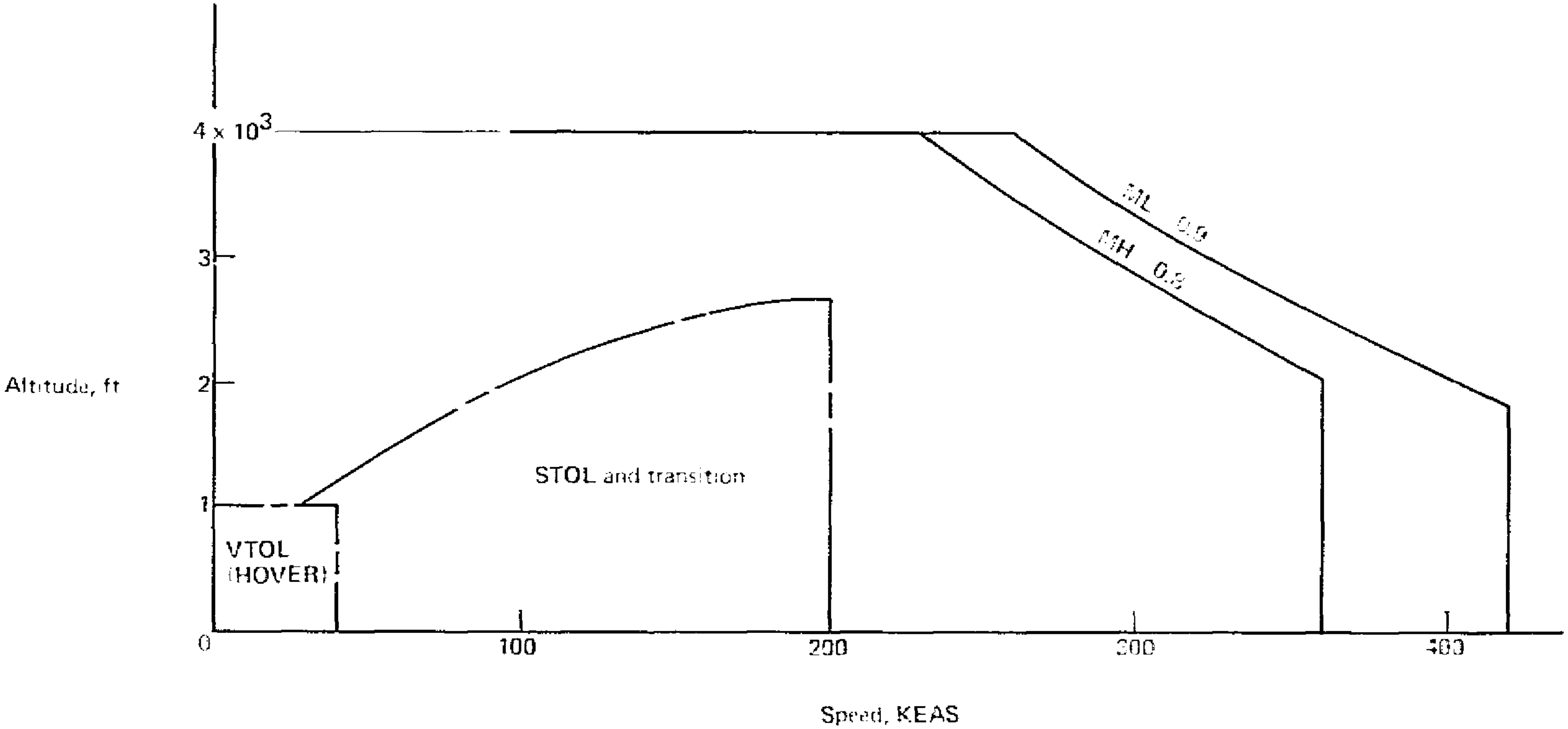
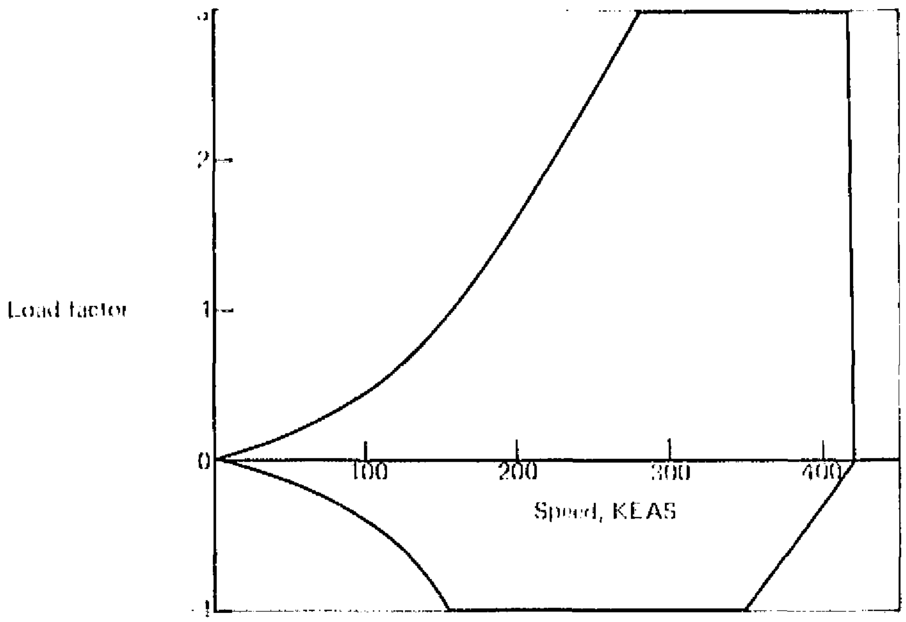


Figure 19. - Structural Speed - Altitude Envelope

Sea Level, 33 180 lb



20 000 ft Altitude, 33 180 lb

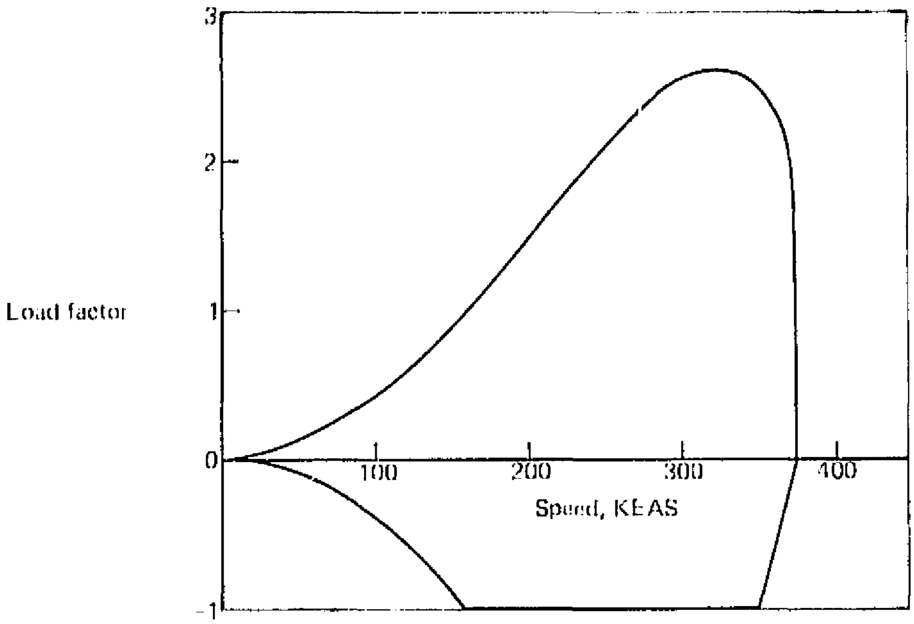


Figure 20.—V-n Diagrams

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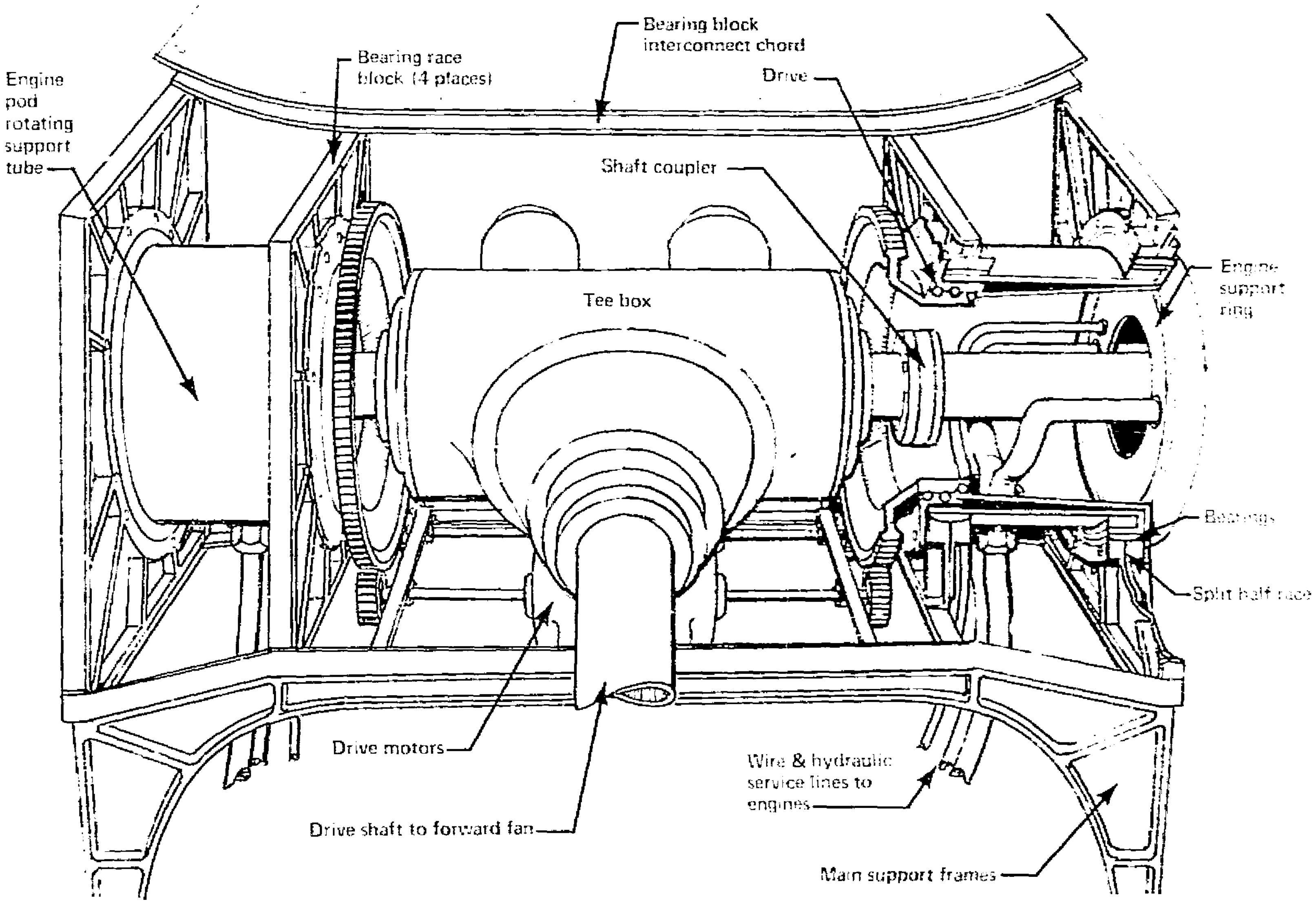

Figure 21.—General Structural Arrangement, Engine Support and Rotation Mechanism

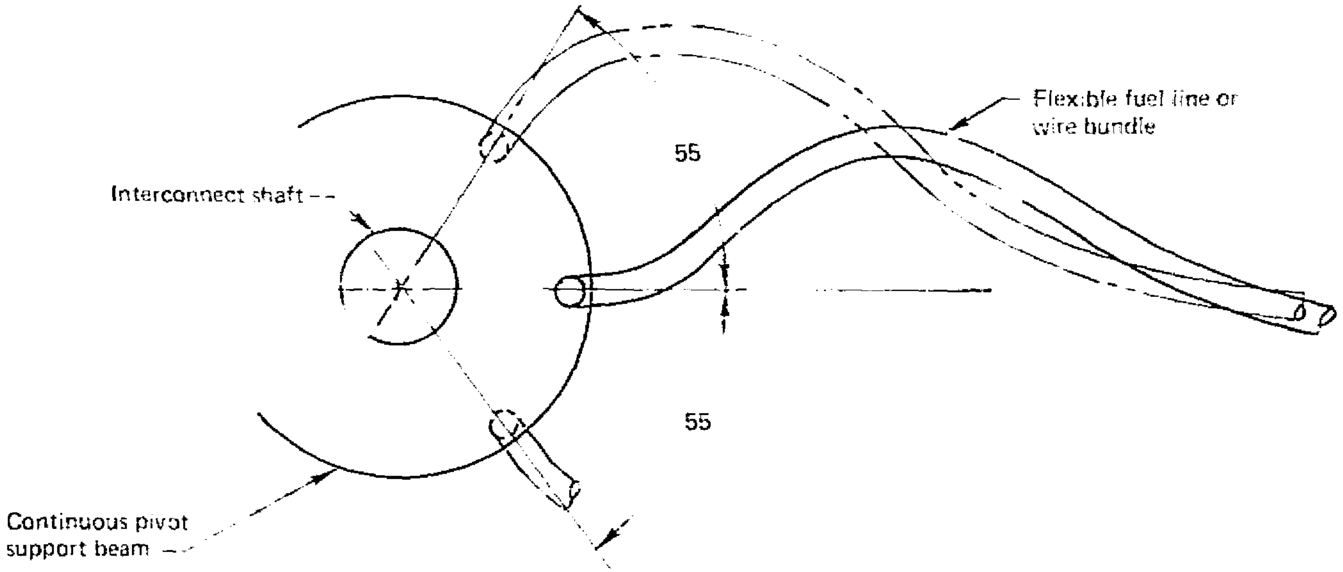

Figure 22. –Schematic of Services (Fuel, Electric, Bleed) To Pivot Beam

made to the pivot beam, the routing from that point to the engine or fan involves no relative motion between the nacelle, the pivot beam, and the services involved. By selecting the midpoint of the 110-deg throw for attachment, the extra loop material and length change accommodation is minimized. Fuel line diameter is 1½ in. Clearance is quite adequate between the drive shaft and the beam for service routing.

This short tubular beam, dual-bearing arrangement offers advantages in weight and redundancy. The short load paths and low required installation volume result in structural efficiency and low installed weight. The dual bearings assure the nacelle will be retained even if one of the bearings should fail. A section through the outer bearing is shown in figure 23. The split outer race construction provides a dual structure capability.

4.3.4 AIRCRAFT SYSTEMS

Accessory Power

The prime power source for the airplane accessories is the accessory drive gearbox located aft of and driven by the transmission T-box. The accessory drive gearbox will drive two 75 kVA integrated drive generators, two 25 gpm hydraulic pumps, one air compressor, one tachometer, and a lube pump. Engine/airplane performance is based on the following extraction:

Condition	Shaft/horsepower extraction
Normal	200
Emergency	23
Cruise and loiter	143
Design	450

Provisions included to reduce the total power extraction during emergency operation include electrical power reduction to essential power (4200 W for electronics and control) and disconnect of the air compressor.

The electrical power supply consists of two 75 kVA integrated drive generators. This provides two separate power systems. A third backup power system is provided through the use of hydraulic/electric power conversion units. A battery is installed to provide essential power for an emergency bus for ground checkout and initiation of engine start.

Hydraulic power is provided by two 4000 psi hydraulic pumps of approximately 20 to 25 gpm each supplying an independent circuit for operation of the flight control and airplane utility systems. All fan blade angles and the exhaust deflection vanes of the cruise/lift fans are powered by the airplane hydraulic system.

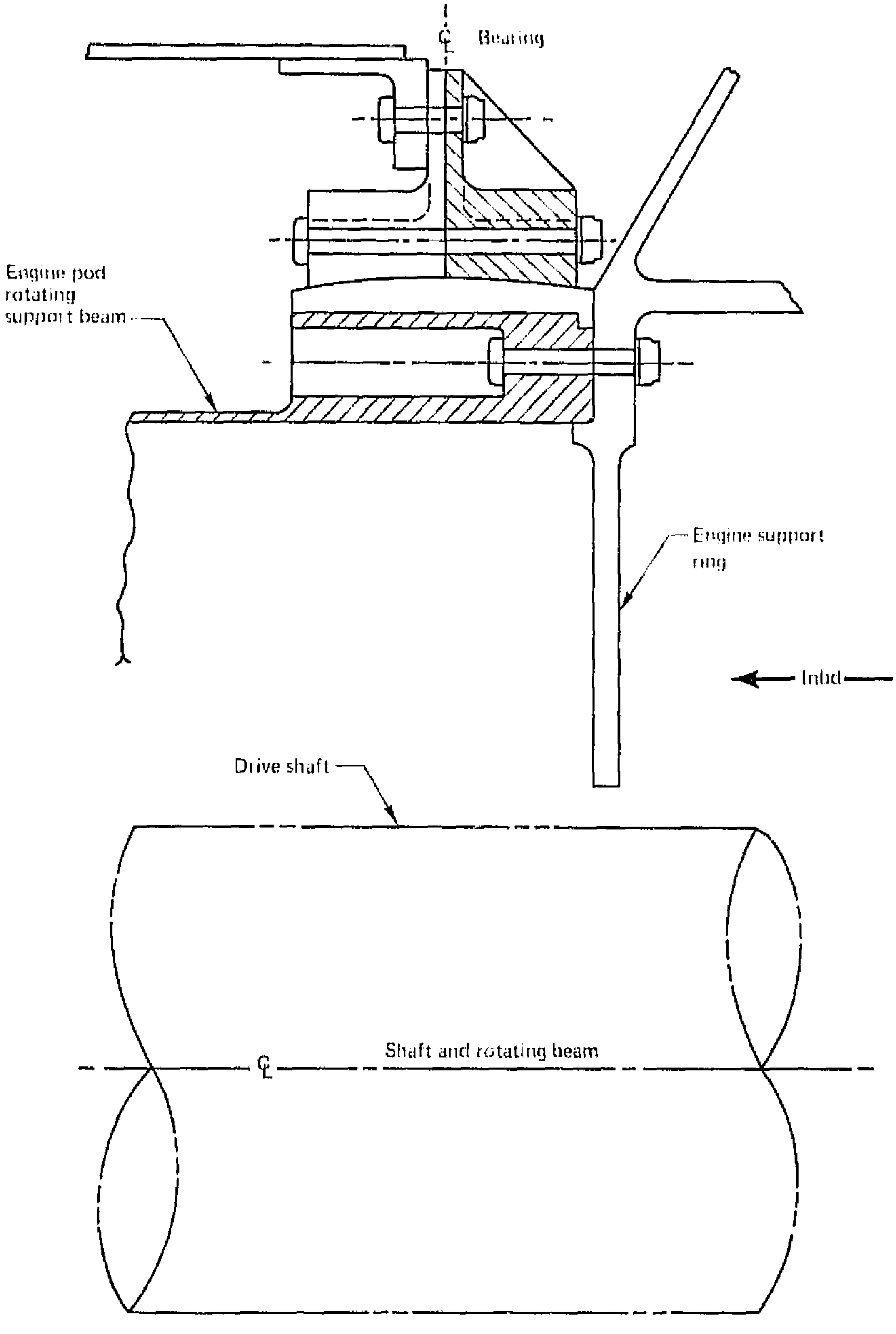

Figure 23.—Section Through Outer Bearing

Starting System

The starting system will provide for independent engine starting. In addition, the airplane weight allowances are sufficient to support the installation of a reliable inflight start system.

Environmental Control

Aircraft pressurization will be provided by an air compressor driven by the accessory drive. Cooling is provided by a conventional air turbine unit. Adequate airflow will be provided to meet cabin and electronic conditioning requirements and windshield defogging. Provisions are included to use ram air ventilation.

Protective Systems

The detailed requirements for protective systems have not been established, but allowances are carried in the weight statements. These include typically oxygen, rain removal, anti-icing, smoke clearance, and escape systems.

Mission System Provisions

The mission equipment provisions are as follows: Avionics are located in the nose forward of the nose fan and below the pilot's floor aft of the nose fan on either side of the nose wheel well; the retractable MAD boom is located aft of the sonobuoy compartment, a 50-sonobouy capacity bay is located aft of the wing carry-through box; the bay is tilted to ease loading and provide space for the flap drive; external body mounts include provisions for two MK-46 torpedos flush mounted just forward of the wing box on the lower body shoulders; and two wing attachment points are included for external fuel tanks.

Fuel System

Fuel is located in the wing box inboard of the fold and in four body tanks. The main body tank is located above the wing box and occupies the entire bay between the front and rear spar bulkheads. A forward body tank is located just forward of the front spar and below the aft crew stations. Two body tanks are located aft of the rear spar on either side of the sonobuoy bay. The weight includes allowance for inflight refueling.

Engine Bleed Air

Engine bleed air is not used on this airplane.

4.3.5 PROPULSION

The engine operational requirements are defined by the airplane operational modes. The critical engine-sizing condition is that vertical thrust equals the weight during hover with one engine inoperable. The emergency weight has been defined as operating weight plus 1000 lb fuel.

The requirements placed on availability of the propulsion system were:

- The engine had to be in service, in development, or a derivative of one in service or development.
- The fan design was to have a firm technology base consistent with Initial Operating Capability (IOC) 1985.

During initial propulsion system studies, a review of available candidate turboshaft engines was conducted. Initial engine selection studies and airplane preliminary design studies involved several iterations in matching engine power output with thrust required to achieve the V/STOL mission requirements.

Of the engines studied, a growth version of the Allison T701 and a turboshaft engine based on the GEF101 core were considered.

The Allison T701 was developed in the heavy lift helicopter (HLH) program. The T701 has successfully completed a PPFRT program and will be available for use in the technology demonstrator. The GEF101 core with modification to the low spool and turbine offers another source for the 1985 operational airplane. The current applications of the F101 core are for the B-1 bomber and with the CFM56 commercial turbofan engine. Either of these engines in conjunction with a variable pitch fan satisfies the operational airplane requirements.

The propulsion system used consists of two Allison engines and three Hamilton-Standard 62-in.-dia variable pitch fans, with the associated gearing, shafting, and clutches.

Schematically, the propulsion system is shown in figure 2 with the major components identified. The two engines are mounted behind the two lift/cruise fans. A star gear train reduces the engine speed to the fan speed, and a bevel set connects the engine/fan to a cross shaft that enters the combiner gear box. An overrunning clutch will automatically disconnect the engine from the system if it fails, and the remaining engine can run all three fans. The airplane accessories are geared into the forward output shaft from the combiner gearbox. A disconnected clutch ahead of the accessories on the forward shaft allows the nose fan with its bevel reduction gear to be disconnected during the conventional flight conditions. Inlet doors open during operation of the nose fan and close during conventional flight. The undersurface doors of the nose fan become yaw control vanes during takeoff and landing.

A sketch of the tilting lift/cruise propulsion pod is shown in figure 24. The engine receives airflow from the fan, and the fan and engine exhaust from separate nozzles. The fan nozzle area varies from wide open in vertical flight to about 70% of this area in cruise and loiter. The high performance inlet is contoured to have low cruise drag with blow-in doors to achieve good low-speed performance and acceptable distortions at incidence angles up to 115°. Fins at the fan exit provide yawing moments for the airplane control system. Airplane rolling moments and pitching moments are provided by varying the thrust of the variable pitch fans with redundant blade pitch control systems.

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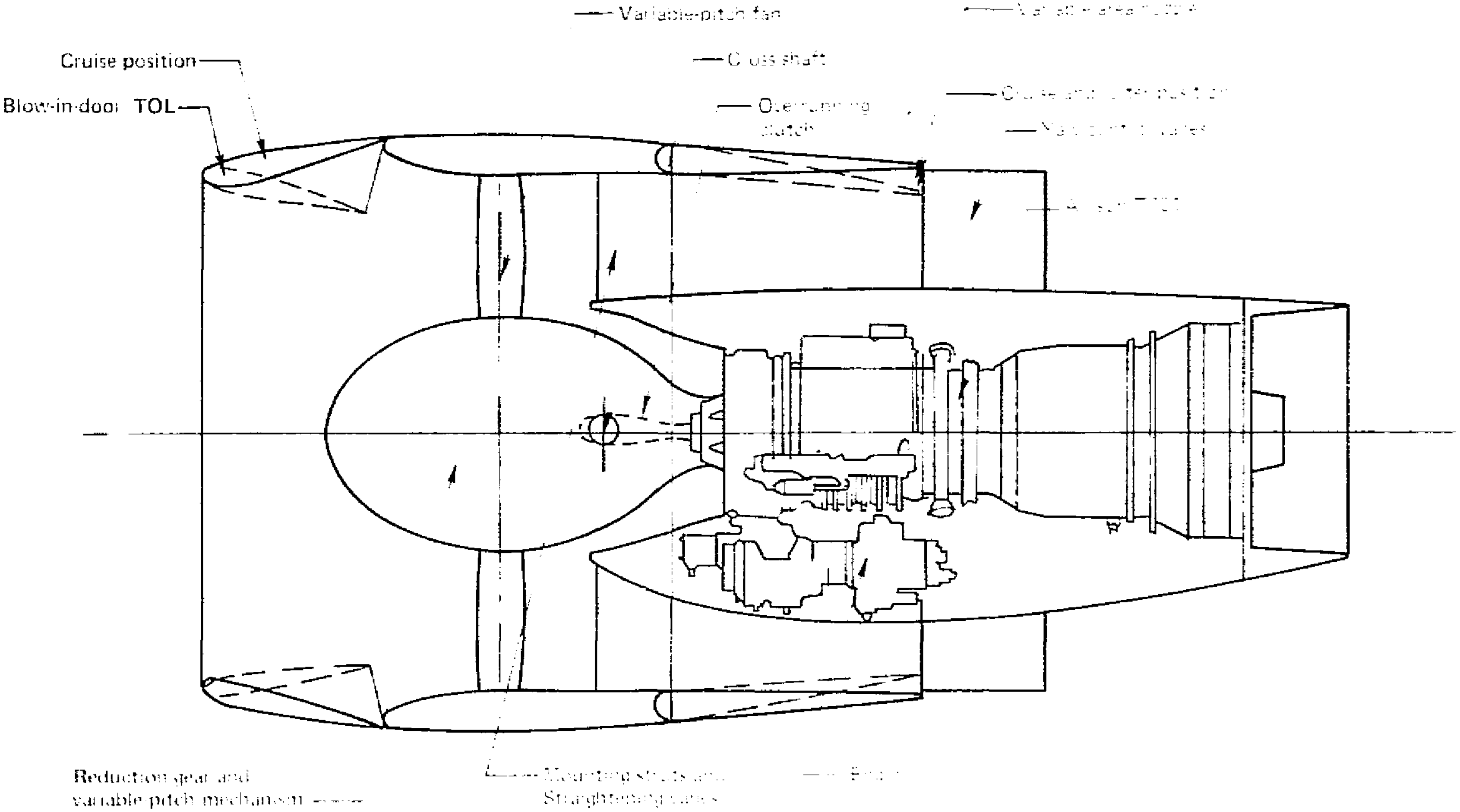

Figure 24. Cruise Lift Fan Engine Propulsion Pod

The propulsion system will provide adequate vertical thrust in normal and engine out conditions. Individual fan thrust can be rapidly increased or decreased to provide adequate pitch and roll control by varying fan blade pitch angle. The fans and engines are located the proper distances from the airplane c.g. to provide balanced lift with each fan in its design condition. Any minor thrust trimming required will be accomplished with the variable fan pitch on each fan. Installed engine performance data used for the 1041-133-1 configuration STOL conditions are listed in table 7 for sea level, 90° F, day operating conditions.

*Table 7. Installed Static Performance**

Condition	FPR	Thrust, lb	SFC, lb/lb-hr
STOL, 2 engines/2 fans	1.28	28 000	0.309
VTOL, 2 engines/3 fans	1.185	34 000	0.271
Contingency, 1 engine/3 fans	1.14	25 300	0.226

*Sea level, 90° F day

Turboshaft Engine and Fan

The engine used in the 1985 operational airplane is a growth version of the Allison T701 turboshaft engine. The engine is an outgrowth of Allison's advanced technology program.

The fans will be Hamilton-Standard 62-in.-dia variable pitch fans. The technology is to be based on Hamilton-Standard's experience with its Q-fan demonstrator and NASA variable pitch fan wind tunnel models.

The fan characteristics include:

Tip diameter	62 in.
Hub-to-tip ratio	0.425
Design tip speed	955 fps
Number of blades	26
Nominal pressure ratio	1.2

The cross section view of the advanced T701 lift cruise variable pitch turbofan engine is shown in figure 25.

Inlet

A V/STOL airplane with tilting lift-cruise nacelles puts the inlets into very high angle-of-attack conditions during transition, particularly during the landing maneuver. The inlet is required to operate at angles near 90° combined with speeds up to 100 kn.

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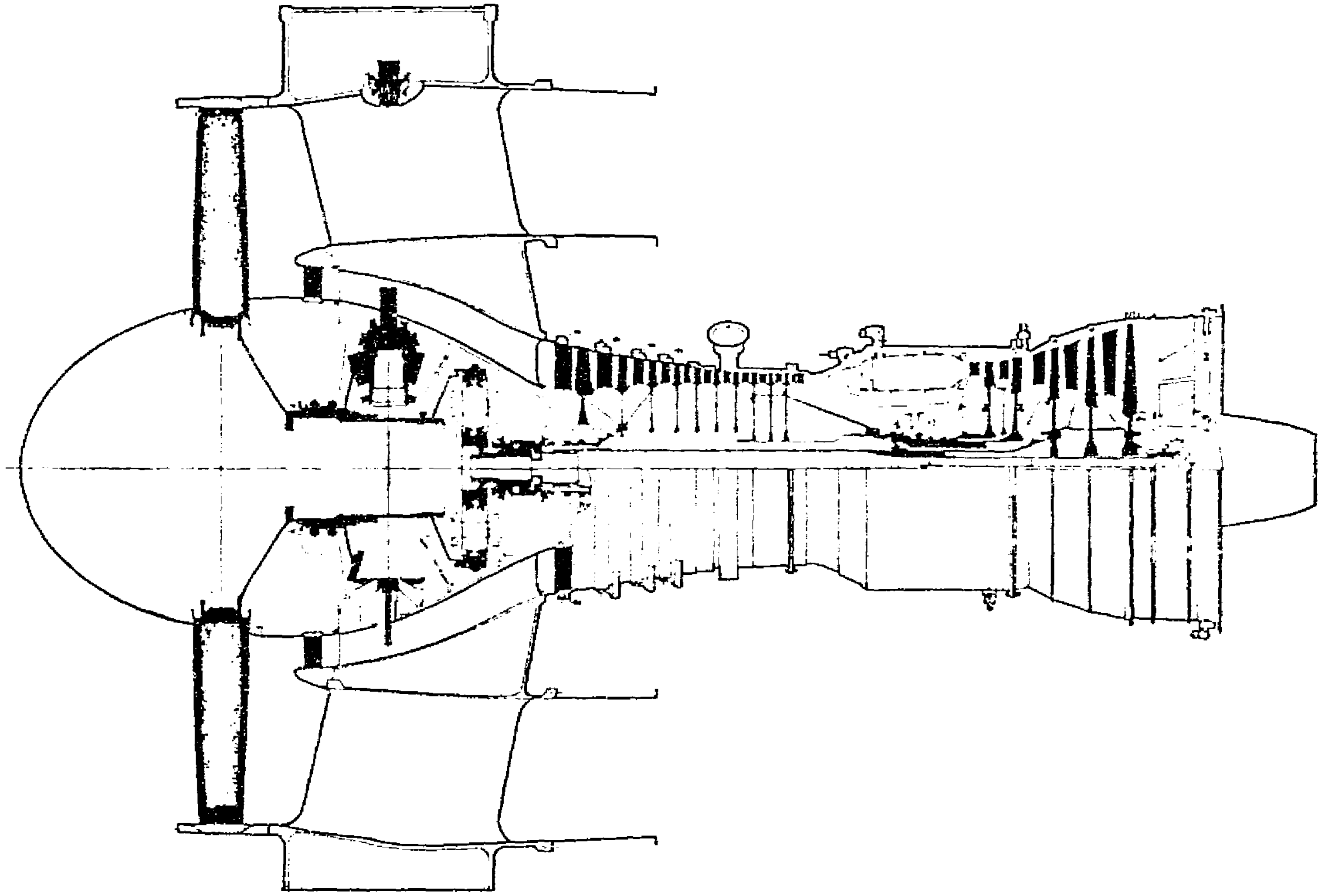


Figure 25.—Advanced T701 Compound Lift Cruise Turbofan Turboshaft Engine

Experience with blow-in door inlets in the 707, 737, and 747 airplanes has demonstrated high inlet recovery with acceptable engine-compressor face distortion. In addition, a test model is shown in figure 26. This inlet was tested at speeds up to 150 kn, crossflow angles of 0, 40°, 60°, and 90°, and correctd airflows from 34 to 42.5 lb sec ft^2 at the fan face.

Inlet pressure recovery from these tests is reflected in the installed propulsion system performance used in the V/STOL mission studies.

The fan inlet total pressure distortion obtained was within the tolerance of the variable pitch fan and the T701 engine. The total flow distortion and that within the inner core which enters the engine is shown in figure 27 at 100 kn at an angle of 90°.

Drive System

The power train, which is shown schematically in figure 28, consists of the overrunning clutches that allow an inoperative engine to drop off the line, engine start reduction gearing, fan bevel gear sets, cross shafts, lift fan drive shaft, and clutch, combining T-box and accessory drive takeoff.

An overrunning clutch is installed on each engine power shaft output drive. The technology is similar to that currently used with helicopter drives.

The cross-shaft bevel gear set is straddle mounted between the fan shaft bearings. It provides the gear ratio match required by the cross shaft and the initial power exchange link between the fans.

The forward fan bevel gear drive installation is similar to the cross-shaft bevel set and reduces the rpm at the front fan.

The lateral shaft design between the engine mount and the combiner gearbox is relatively short and well supported. A 1½-in.-dia steel shaft is used to minimize flow interference. The lift fan drive shaft consists of three elements of shafting with four flexible connectors. The shafts are similar to those used on all Boeing helicopters.

The T-box provides the element that allows both lift/cruise fan engines to exchange power and to provide power to the forward lift fan.

The clutch is mounted on the front of the T-box. The engaging mechanism consists of friction discs to synchronize speed and a positive engagement jaw clutch. The friction clutch utilizes carbon graphite disc faces developed from the HLH rotor brake technology.

4.3.6 FLIGHT CONTROLS

The flight controls system consists of conventional aerodynamic control and reaction control for V/STOL operation. The reaction control is achieved by modulation and deflection of the thrust vectors. The blending of the two systems is straightforward with the aerodynamic system increasing in authority with increasing flight speed. A fly-by-wire system with a digital flight control computer is used.

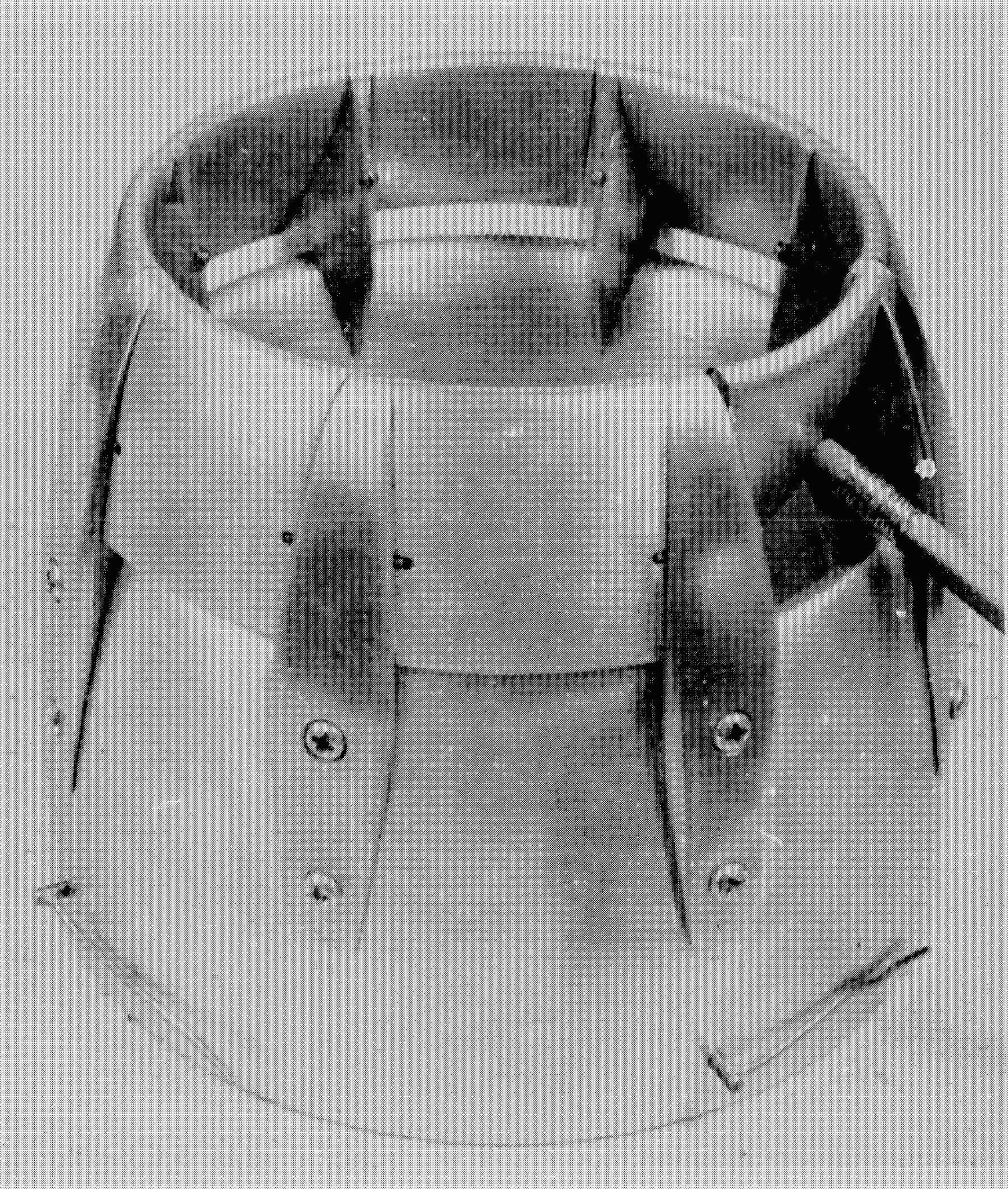
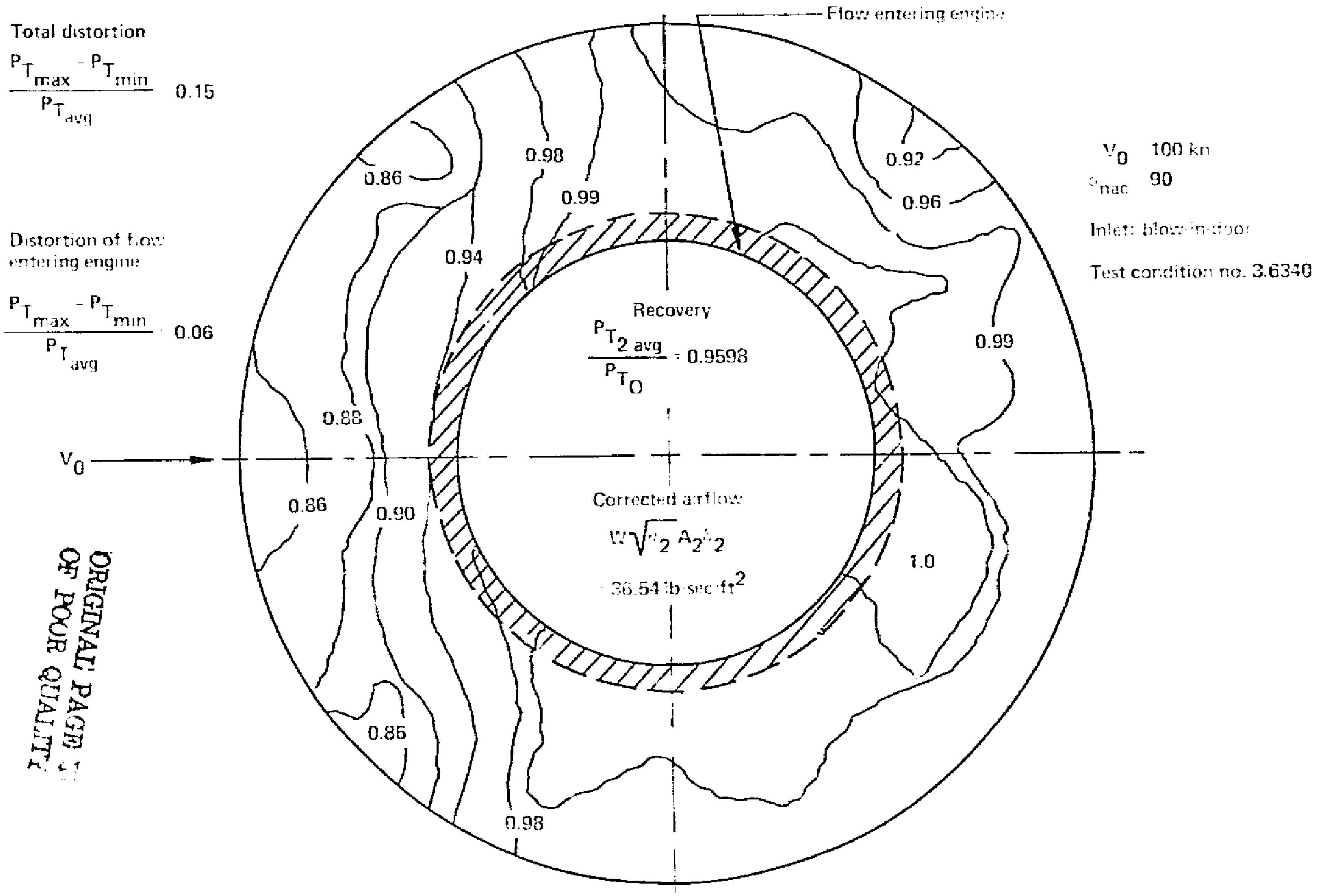


Figure 26.—Variable Geometry Inlet



Total distortion

$$\frac{P_{T_{max}} - P_{T_{min}}}{P_{T_{avg}}} \quad 0.15$$

Distortion of flow entering engine

$$\frac{P_{T_{max}} - P_{T_{min}}}{P_{T_{avg}}} \quad 0.06$$

V_0 100 kn

θ_{nac} 90

Inlet: blow-in-door

Test condition no. 3.6340

Recovery

$$\frac{P_{T_{2\,avg}}}{P_{T_0}} = 0.9598$$

Corrected airflow

$$W\sqrt{\theta_2}\,A_2\delta_2 = 36.54\ \text{lb/sec/ft}^2$$

Figure 27.--Development Test Data

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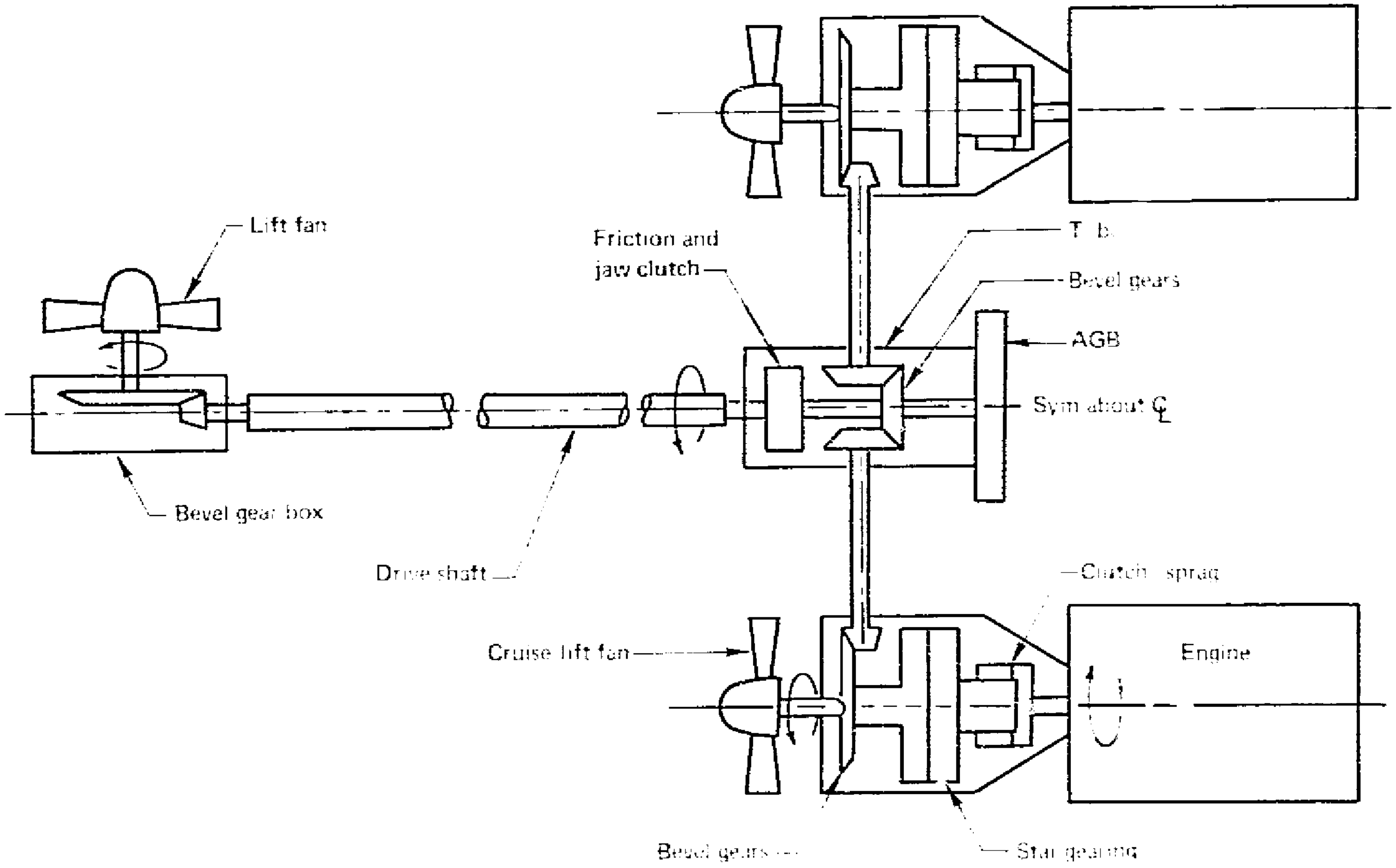


Figure 28.—Power Train Schematic

The V/STOL flight control system is based on the use of shaft-driven interconnected variable pitch fans. The fans operate at constant rotational speed. Variations in fan blade angle (pitch) controls the thrust and the demand for engine power by each fan. These thrust variations are used for trim and control. Control capability for normal and emergency operation meets or exceeds the design guidelines. Since a single engine can drive all three fans through the transmission system, the airplane will tolerate an engine failure without a delay in attitude control power. Engine-out emergency conditions result in a negligible trim change. Control system mechanization is fly by wire with control augmentation capability. A digital computer will manage the various elements of the flight control system. Computation signal transmission, actuation, hydraulic power, and electrical power will have fail-operational capability through monitored redundancy.

Control System Description

Aerodynamic control and trim is accomplished by conventional aileron, rudder, and horizontal stabilizer surfaces. Stabilizer trim setting during transition will be scheduled as a function of flight condition and airplane configuration to minimize pitching moment variation. The aerodynamic control surfaces will operate throughout the hover and transition flight mode.

Hover and low-speed control is accomplished by modulation and deflection of the thrust. Pitch and roll control results from differential thrust. Thrust modulation is achieved by varying the fan blade pitch angle, which gives excellent dynamic response. Yaw control is by thrust deflection at the exit of the nose and lift cruise fans. Fan thrust deflection and differential fan blade pitch commands will be scheduled as a function of nacelle incidence to decouple roll and yaw control inputs for nacelle incidences between zero and 90° (fig. 29). The system's capability exceeds all the requirements listed in the appendix.

A triplex digital primary system is used on the airplane. This system is considered representative of the technology that will be available and would be required for the complex operational tasks of a 1985 operational airplane. It offers the possibility for the most complete integration of the guidance and navigation functions with the primary flight control system.

The control system functions are based on piloted simulation results. The mechanization of these functions is based on YC-14 and HLH development.

The interaction between the flight control system and the propulsion system is apparent in the block diagram, figure 30. The blending of aerodynamic and reaction controls is also indicated.

Control System Performance

Maneuver control was evaluated for both normal and engine-out operation. Two constraints define the control capability of the system. One is the maximum single-fan thrust, a structural and aerodynamic limit, and the other is the maximum power that the engines can deliver. The fan thrust limit is well outside the normal demands for VTOL control but can be reached on the lift/cruise fan by a simultaneous maximum roll and pitch command. Maximum engine power is a limit that can be encountered under

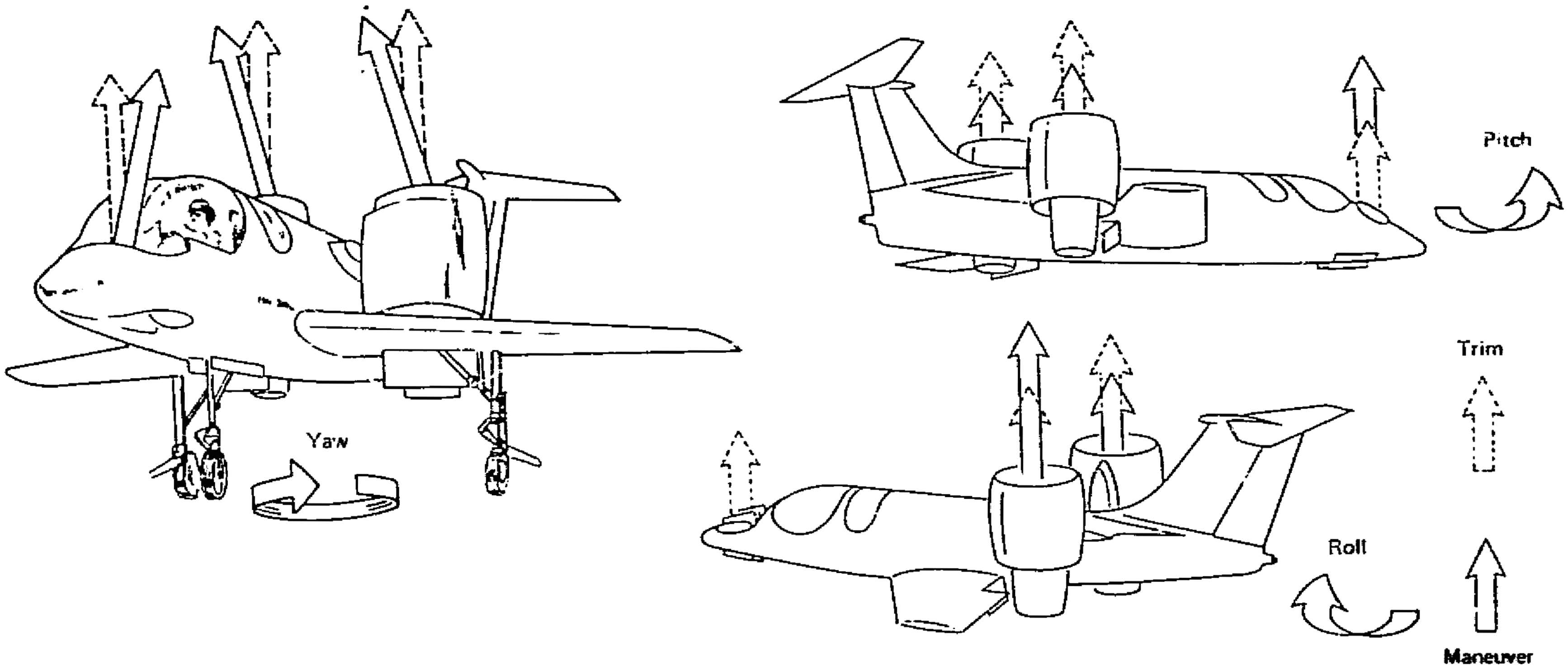


Figure 29.—Pitch/Roll/Yaw Control

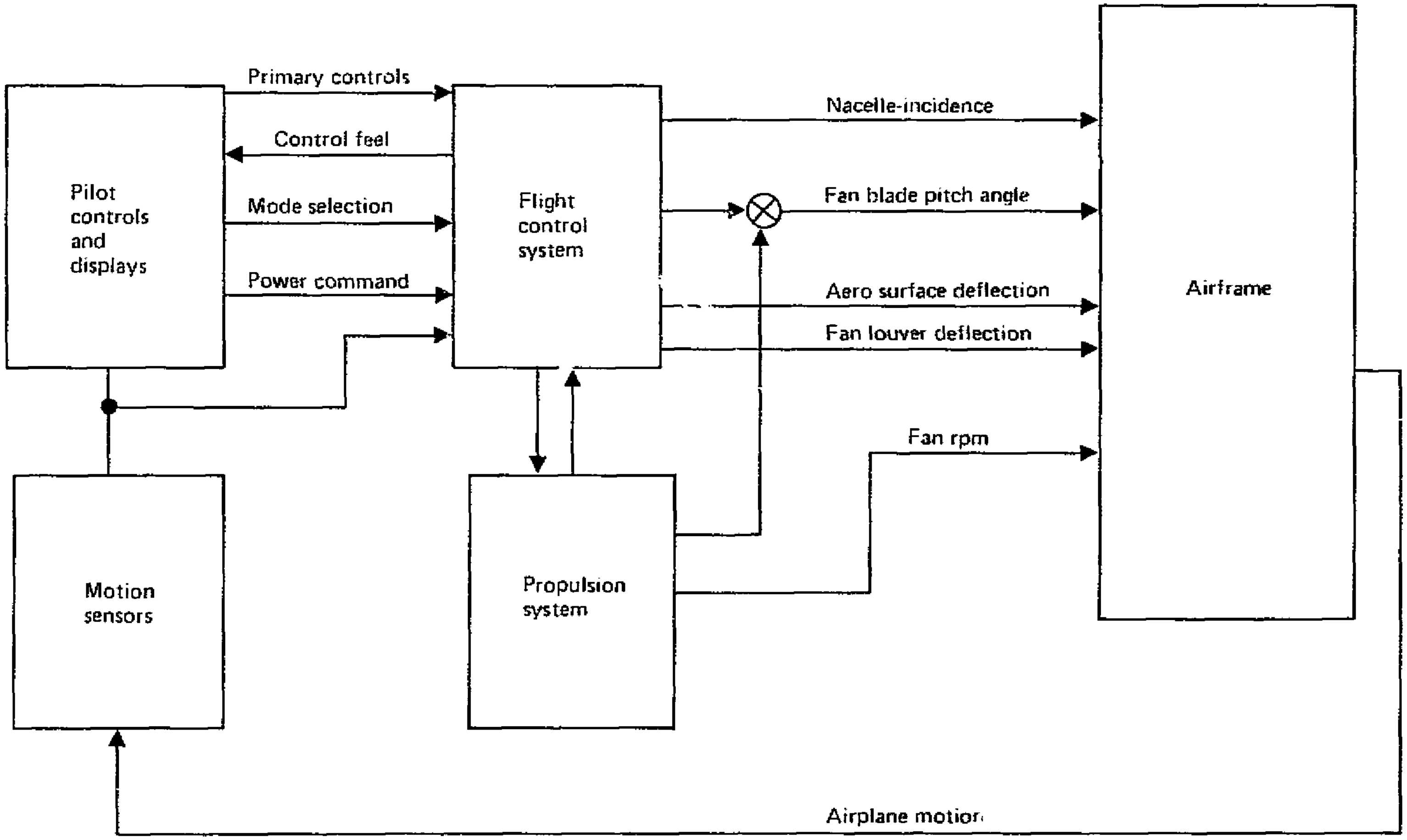


Figure 30.—Flight Control Schematic

normal operational circumstances. For example, the engine power will increase to satisfy the constant speed feature of the system. If the power required by the thrust distribution exceeds power available, the fan speed will bleed off until the torque required reaches a balance with the engine power. The speed of all operating fans is the same; consequently, the fan speed bleed down will affect all three fans simultaneously. Control system logic will provide a signal when engine power limits are encountered to wash out the blade angle of all three fans until a torque balance at essentially constant speed is achieved. This design feature allocates priority to attitude command.

Figure 31 shows the system capability in terms of lift combined with roll. A command of 100% of design roll has a 2% effect on lift. The figure also illustrates engine-out control capability. Engine-out control is well above design guideline levels. There is some effect on lift if control commands are sustained for periods that are longer than normally required for maneuvering.

The time response of the control system is excellent and exceeds the design guidelines.

The responses to attitude and flightpath commands are shown in figure 32. A rolling moment based on a thrust change of ±30% has a time constant of 0.1 sec. This is near maximum control. For smaller moments, the time constant is as low as 0.05 sec. Flightpath control is exemplified by a fly-down command. The thrust is reduced 5% with a time constant of 0.15 sec. This includes the response of the engine to the required change in power level.

Gyroscopic coupling in the hover mode occurs whenever the nacelle incidence is varied or when the airplane pitch or roll attitude is varied. Figure 33 shows an evaluation of the gyroscopic rolling moments produced by pitching of the engines and fans. When the entire airplane pitches, all three fans contribute to the gyroscopic effect. If the lift cruise nacelles are rotated, as for transition, only two fans are involved. The fans and engines rotate in opposite directions, which reduces the total angular momentum.

A gyroscopic moment less than 10% of the available control is considered acceptable. From the figure, it is apparent that the airplane can be operated with a nacelle incidence rate of about 22 deg/sec or an attitude rate of 11 deg/sec and require only 10% of the roll control to compensate for the induced roll moment. The evaluation was made for a nominal hovering condition with the fans and engines at maximum angular momentum. The fan and engine polar moments of inertia are based on Hamilton-Standard estimates for a 62-in. fan with borsic aluminum blades. The rpm, the polar moments of inertia, and the angular moments are:

		Polar moment of inertia	Angular momentum*
	rpm	Slug-ft^2	Slug-ft^2 x rad/sec
Engine compressor	+15 000	1.19	+ 1 870
Engine power turbine	+11 800	0.81	+ 1 000
Fan**	- 3 500	14.3	- 5 390
Airplane pitch attitude rate			-10 430
Nacelle tilt rate			- 5 038

*Positive angular momentum is clockwise when reviewed from rear.

**Includes gear transmission and interconnect shafts.

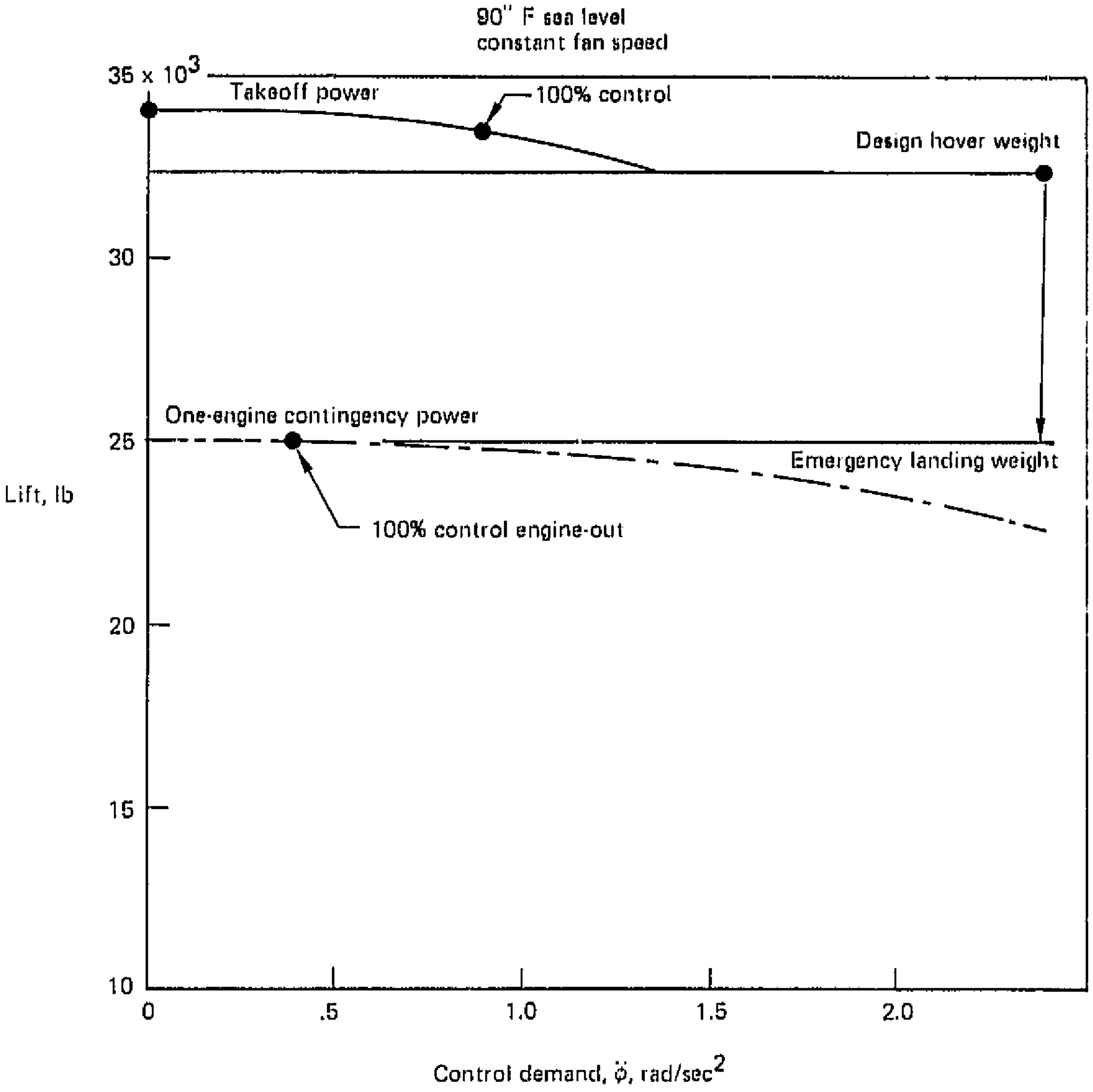


Figure 31.—Roll Control Power Capability, Model 1041-133

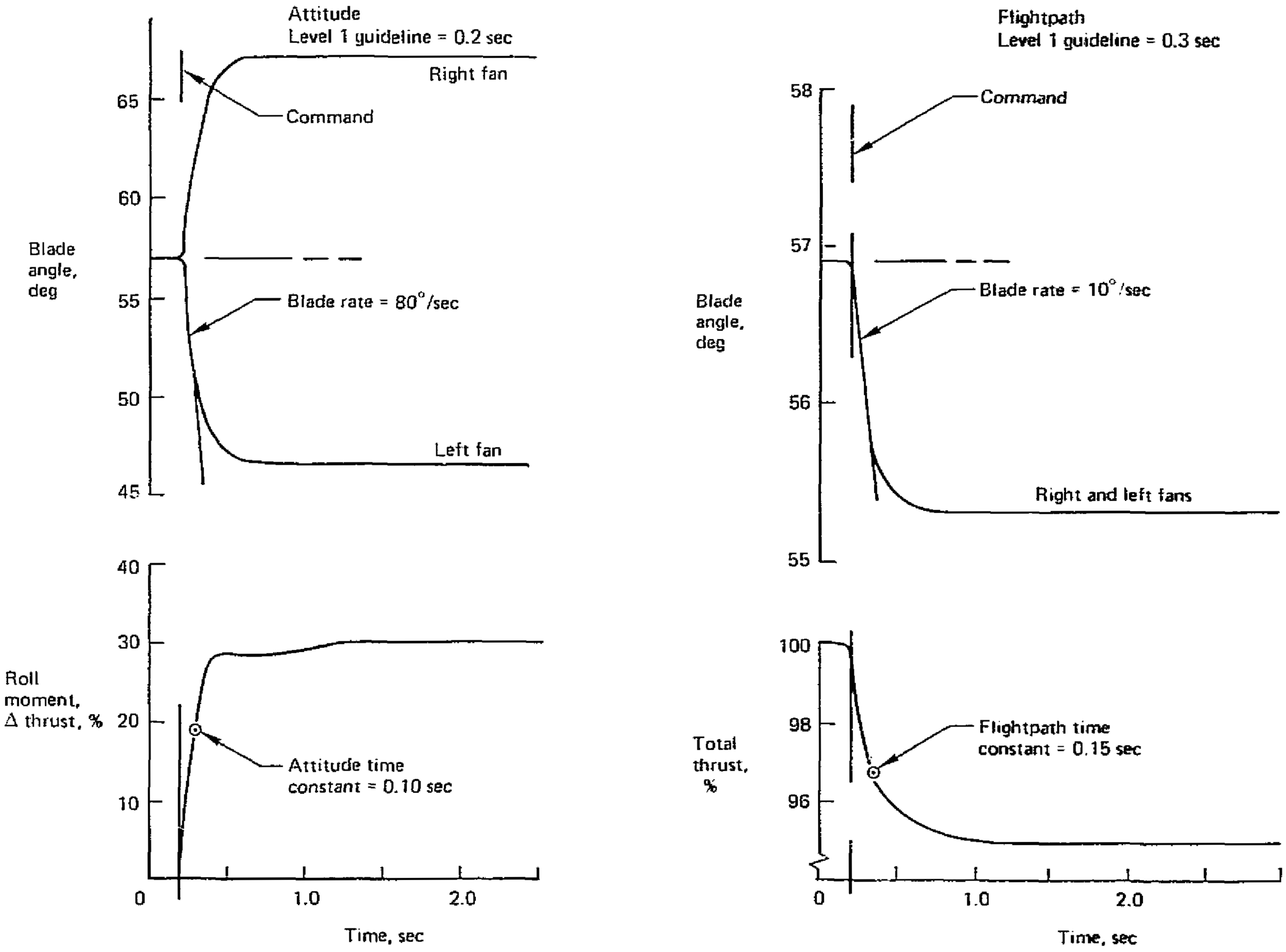


Figure 32.—V/STOL Control System Response

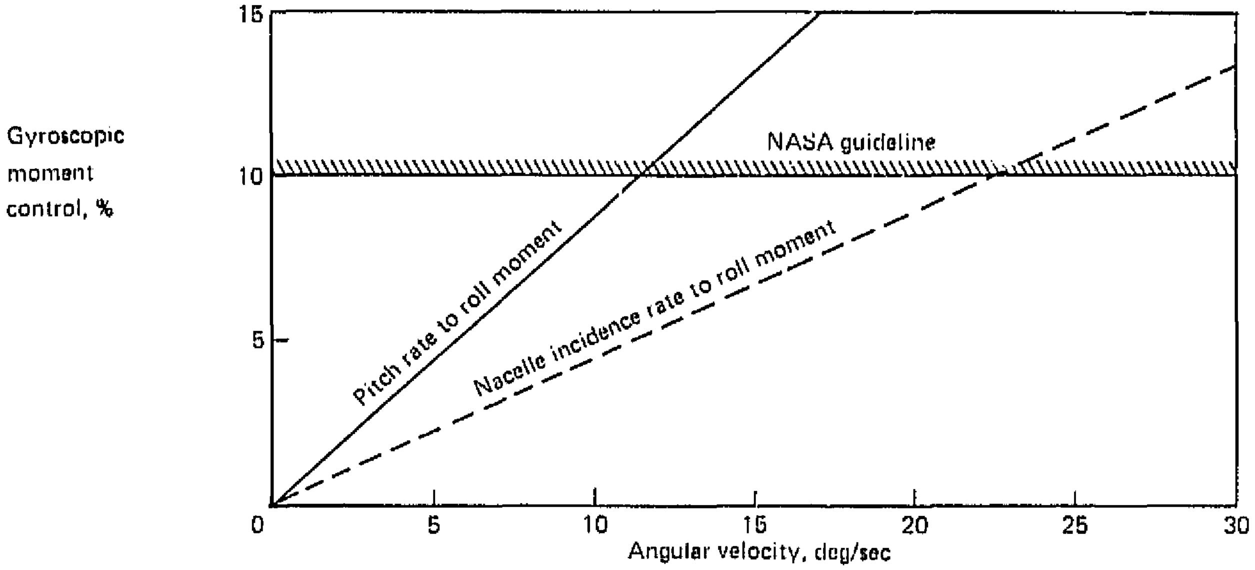


Figure 33.—Hover Gyroscopic Moments, Model 1041-133

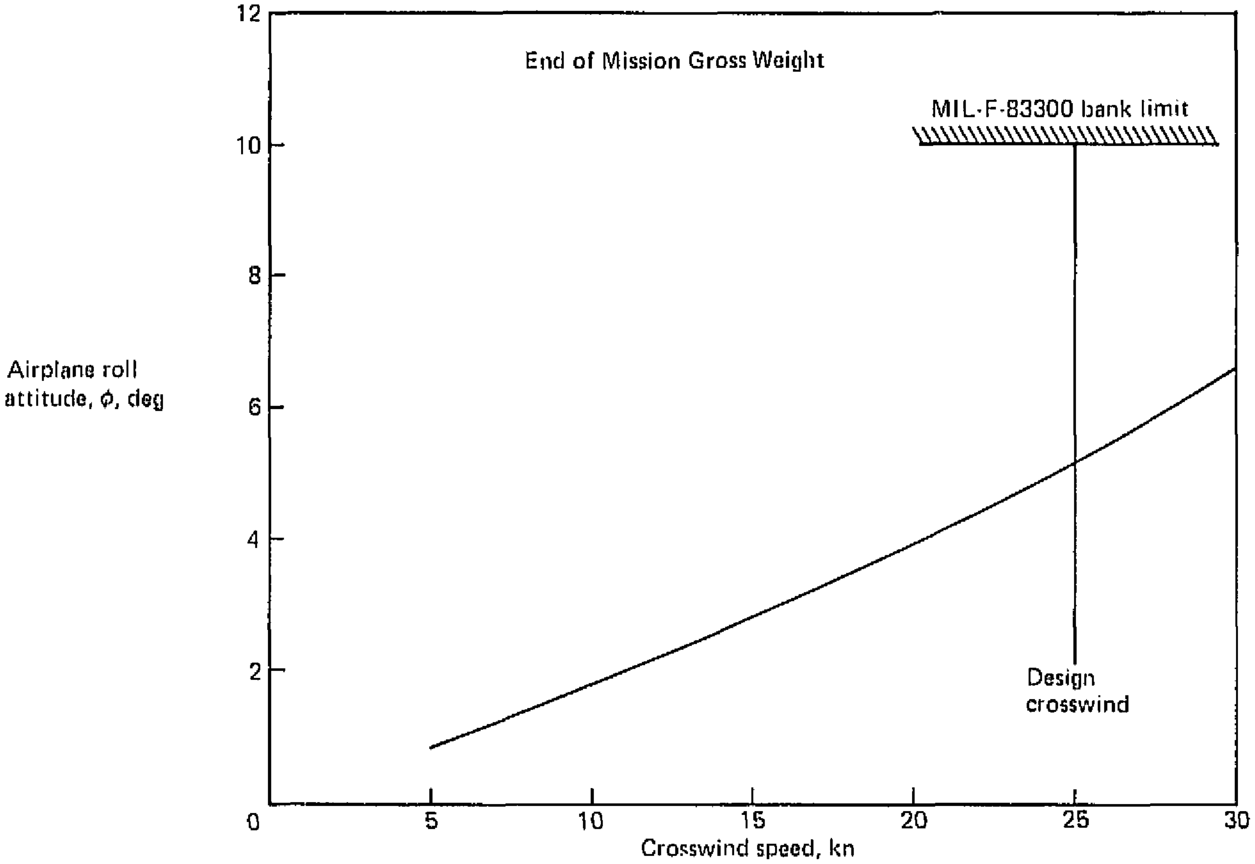


Figure 34.—Hover in a Crosswind (Light Gross Weight)

The fan angular momentum dominates.

The capability to hover in a crosswind is shown in figure 34. The guideline for a hover in a 25-kn wind is matched by banking the airplane about 5 deg.

The transition to and from vertical flight is controlled by thrust vector management. The total airplane thrust vector angle is fixed. Its fan thrust angle is 75° from the horizontal. This angle was chosen so that at the lift-off angle-of-attack for STO, the nose fan thrust would have a positive component along the flightpath. Moment balance is maintained by varying the thrust magnitude of the nose fan. This is accomplished by changing blade pitch, and power is transferred between the nose fan and the lift cruise fans. During takeoff, a constant power setting can be maintained and the thrust will gradually transfer to the cruise system. At the end of transition, the nose fan is very lightly loaded. Because most of the power is going to the cruise fans, the system is conveniently controlled for conversion to conventional flight.

The schedule of nose fan and lift/cruise fan thrust for trim as a function of nacelle angle is shown in figure 35. During hover, the nacelle tilt angle is 97° and all three fans are equally loaded. At zero degrees tilt, nacelles horizontal, the nose fan is near zero thrust and the cruise fans are at high thrust. The resultant thrust vector angle for the trimmed system as a function of nacelle tilt angle is shown in figure 36. These schedules apply at all power levels. The power distribution for balance is a function only of nacelle angle.

The moment producing elements of the V/STOL control system can undergo changes in function during transition. For example, the roll control is achieved, with the nacelles vertical, by modulating the thrust of the lift/cruise fans. With the nacelles horizontal, this same action produces a pure yaw moment. The control system mixes blade pitch angle, vane deflection, and aerodynamic control deflections as a function of speed and nacelle angle to reduce pure moments from the control input.

The vertical tail was sized by a statistical relationship between forward fuselage moment of area and vertical fin moment of area. The data basis is shown in figure 37. The tail fin area is 63 ft^2, and the volume coefficient is 0.08.

The stabilizer was sized to meet:

- Static longitudinal stability margin of 0.05 at the aft center of gravity
- Flap pitching moment trim at maximum lift coefficient
- A center of gravity of travel of $\pm 0.05\ \bar{c}$ wing

These conditions are met by a tail volume coefficient of 0.54 and a nominal center of gravity location at $0.30\ \bar{c}$ (shown in fig. 38). The stabilizer panel size is 64 ft^2. A stabilizer aspect ratio of 5.0 was chosen to achieve a favorable tail span to nacelle span for effectiveness at high airplane angle of attack.

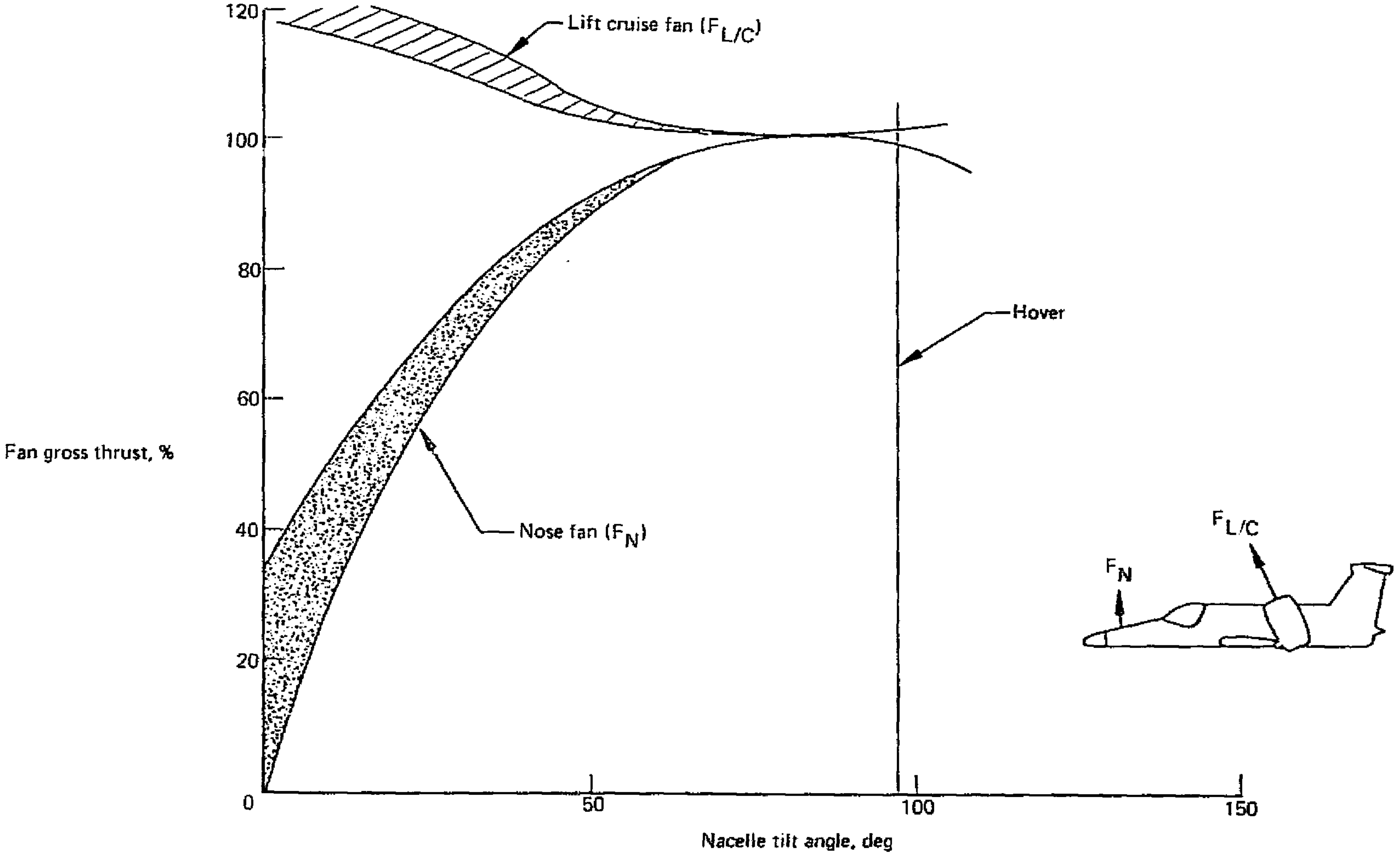


Figure 35.—Thrust Vectoring Trim Schedule, Model 1041-133

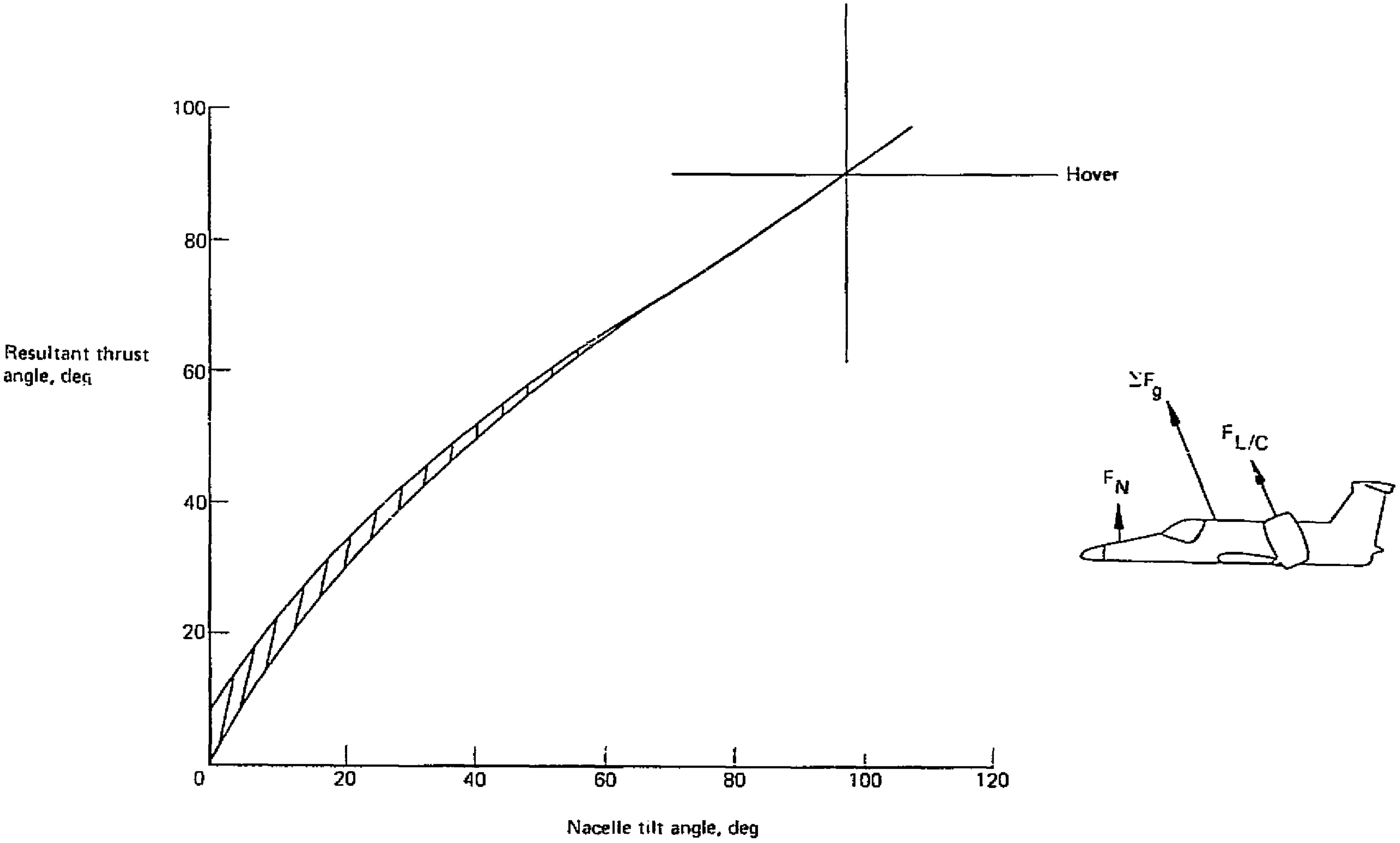


Figure 36.—Thrust Vectoring Trim Schedule, Model 1041-133

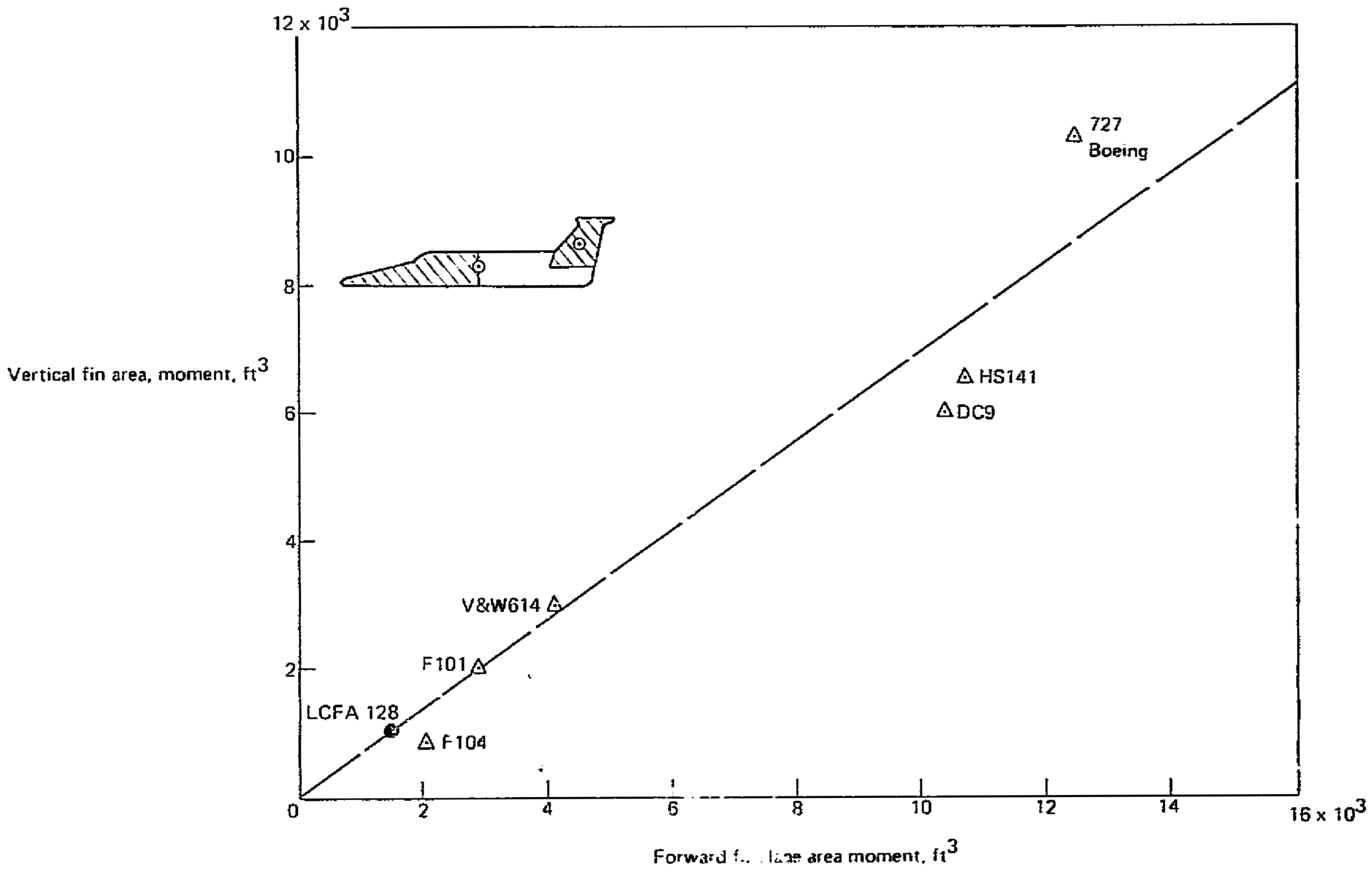


Figure 37.—Static Directional Stability Cruise

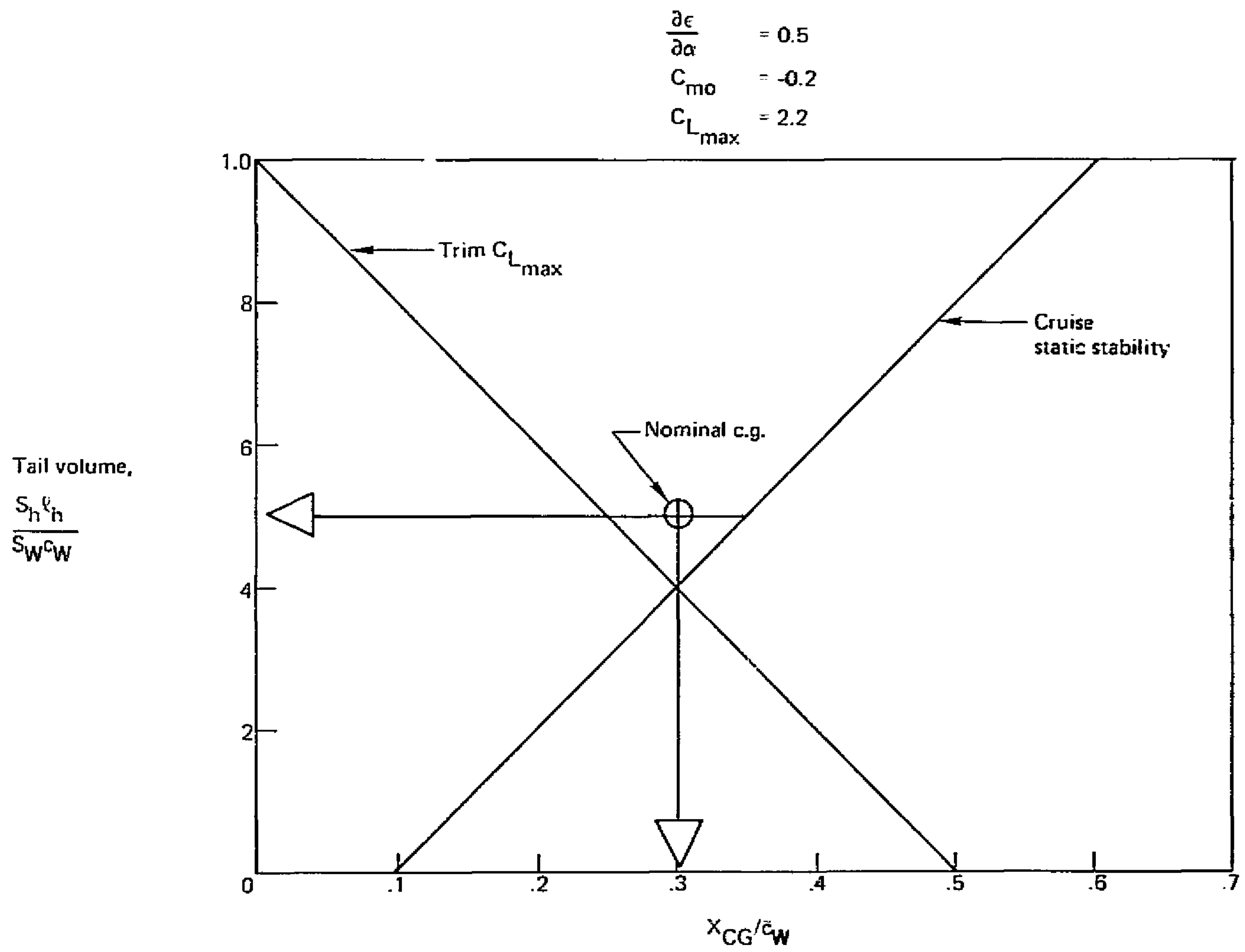


Figure 38.—Horizontal Tail Size

4.3.7 WEIGHT AND BALANCE

The weights were determined parametrically in conjunction with the NASA-Navy V/STOL design criteria.

The weight statement and dimension and structural data for the ASW configuration are presented in table 8. The individual structural group wweights have been determined for a current technology (aluminum) aircraft. A 10% weight improvement has been included to account for advanced technology improvements commensurate with initial operations in 1985.

Table 8. ASW Weight

	Weight, lb	C.G. body station, in.
Structure	7 920	408.1
Propulsion	7 480	437.5
Fixed equipment	6 500	318.2
Weight empty	21 900	391.5
Nonexpendable useful load	1 760	356.7
Operating weight	23 660	389.1
Mission weight	38 390	388.7

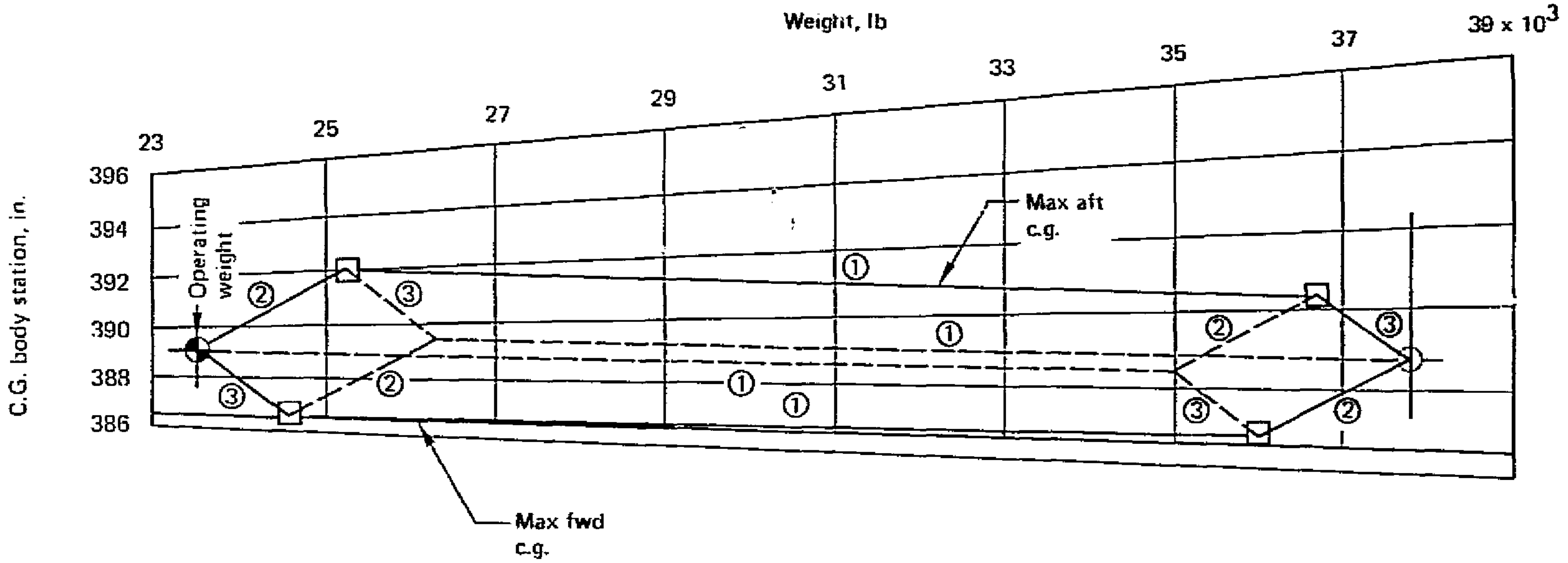
Note: (1) MAC LE is at body station 363.
(2) MAC length is 94 in.

The operating weight center of gravity and location of ASW expendable load produce the envelope of most forward and aft center of gravity and weight conditions shown in figure 39.

The list of special features related to V/STOL capability are listed in table 9.

Table 9.—Weight Increments for Special Features

Item	Weight, lb/airplane
Lift/cruise engine pod rotation	+450
T-tail	+30
Transmission system	+2650
Forward lift fan installation	+350



① Fuel

② Sonobuoys

③ Torpedoes

LE MAC at body station 363
Mac length = 94 in.

Figure 39.—Center of Gravity Loading Diagram, Model LCFA-133-1 (ASW)

4.3.8 PERFORMANCE, MODEL 1041-133-1 ASW

The ASW airplane mission requirement calls for a 400-ft takeoff in a 10-kn wind; cruise 150 nmi, then 4 hr loiter at 10 000 ft and return to base.

The shortest takeoff can be achieved by rotating the nacelles toward vertical just at lift-off; however, this airplane can meet the required goals without nacelle rotation, thus providing operational simplicity. The time history of a takeoff in which the engine tilt angle is held fixed at $\lambda = 50^\circ$ is shown in figure 40. During acceleration, the nose fan is engaged, but it is set at flat pitch in order to get maximum thrust from the lift/cruise fans. Rotation is initiated 5.5 sec after brake release at a speed of 92 fps. At 7.75 sec the airplane has rotated to $\alpha = 8^\circ$ and lift-off occurs at an airspeed of 115 fps. The lift-off lift coefficient of 1.6 used in this calculation is conservative in that no credit has been taken for induced aerodynamic effects. The takeoff run is 400 ft and the longitudinal acceleration at lift-off is 0.103 g; this exceeds the requirement of 0.065 g. The capability of making an emergency vertical landing with one engine out at a maximum sink speed of 15 fps is assumed to be met if the thrust and weight are equal. This requirement is exceeded by the Model 1041-133 which has an emergency landing weight of 24 500 lb and engine-out contingency thrust of 25 300 lb.

STO Mission

The ASW mission requirement calls for a 150-mile radius with 4 hr of loiter on station at 10 000 ft. Figure 41 presents the breakdown of the calculation of this mission in terms of speed, time, distance, and fuel burned for each mission segment. The airplane, sized to meet this mission, has a takeoff weight of 38 394 lb. Initial cruise altitude is 33 000 ft at M = 0.75. The 4-hr loiter at 10 000 ft is performed at M = 0.42. The total fuel required for the mission is 11 914 lb including landing allowance, reserves, and a 5% service tolerance on SFC throughout the mission.

VTO Mission

The addition of alcohol/water injection can substantially increase the vertical takeoff capability of the airplane. The potential that will result from developing such a system can be seen by examining the VTO mission. Figure 42 presents a breakdown for this mission. As indicated, the loiter time is 3.16 hr. The F/W at takeoff is 1.05. The resultant thrust is 38 700 lb. and mission weight is thus restricted to 36 857 lb. The configuration requires 390 lb of alcohol/water and 110 lb of tank and plumbing.

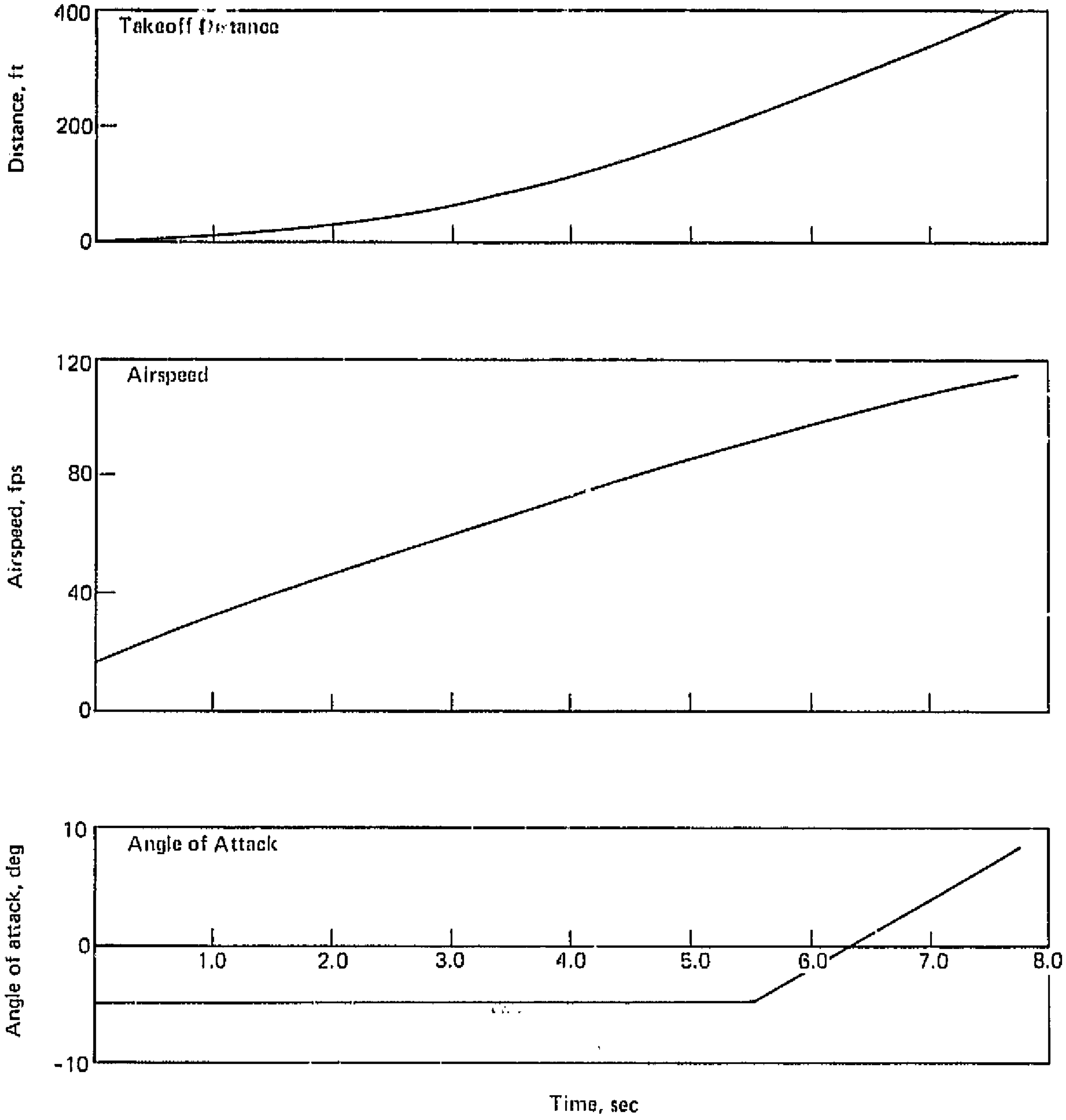
The relationship between radius and time on station is linear. The maximum mission radius with no loiter time is about 900 nmi from a short takeoff. For a vertical takeoff the mission radius with no loiter is 720 miles.

Performance Flight Envelope

Figure 43 presents the cruise configuration level flight performance envelope for standard day conditions at an airplane weight of 36 000 lb. At this weight the airplane is capable of operation up to 40 000 ft altitude where it is buffet limited. The maximum

Mach number, which is also buffet limited, exceeds 0.8 all-altitude below 35 000 ft to the altitude where the maximum dynamic pressure (q) limit occurs.

On the same figure the V/STOL flight mode envelope at about 26 000 lb is shown. The overlap between the two modes assures a good transition corridor.



Sea level, 90° F std day

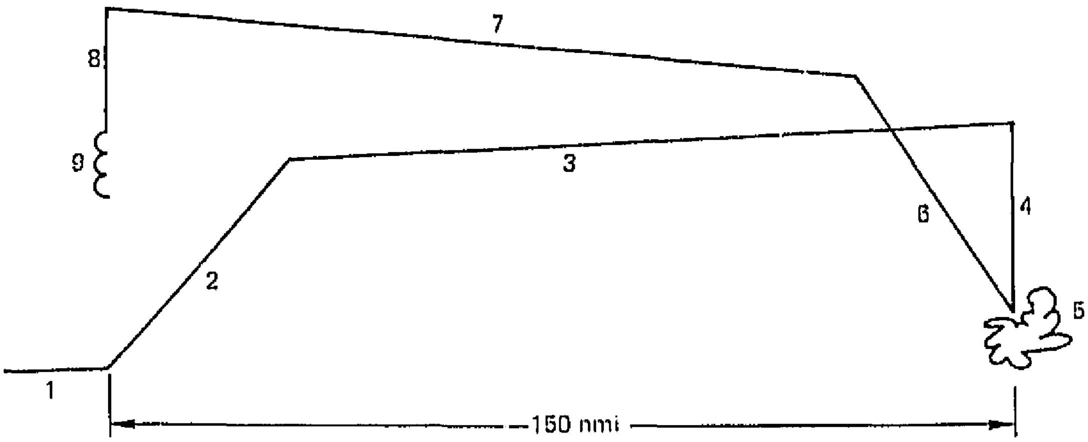
λ = constant = 60°

$C_{L_{LO}}$ = 1.6 (flap plus drooped ailerons)

$(F/W)_{static}$ = 0.7 $(F/W)_{lift\text{-}off}$ = 0.9

a_{LO} = 3.33 fps^2 (longitudinal)

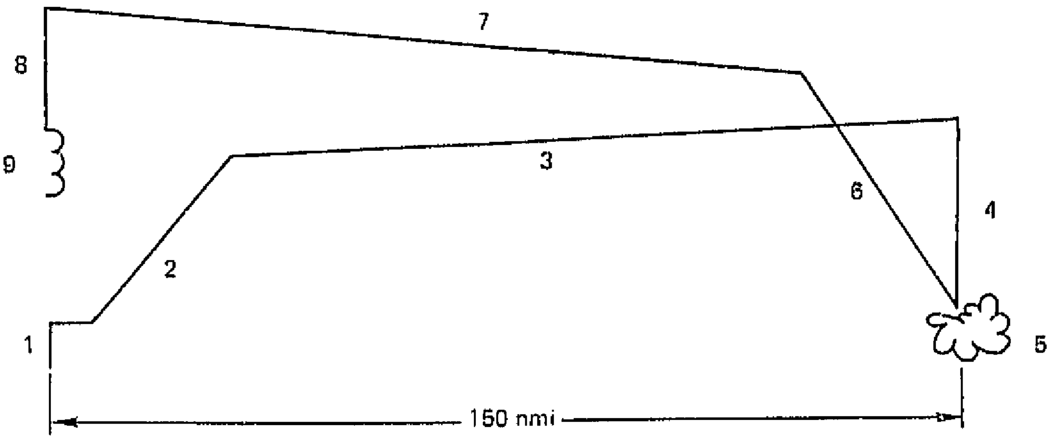
Figure 40.—STO Time History, 1041-133-1(ASW)



Segment	Speed	Time, hr	Distance nmi	Fuel* lb	A/P weight, lb start of segment
1. Warmup, takeoff, accel to climb speed	–	0.042	–	331	38 394
2. Climb to BCAV	320 CAS kn	0.083	33	624	38 063
3. Cruise at BCAV (initial altitude = 33 000 ft)	M = 0.75	0.268	117	646	37 439
4. Descend to 10 000 ft	–	–	–	–	36 793
5. Loiter at 10 000 ft	M = 0.42	4.000	–	8530	36 793
6. Climb to BCAV	M = 0.75	0.054	24	337	28 263
7. Cruise at BCAV (initial altitude = 39 000 ft)	M = 0.75	0.293	126	529	27 926
8. Descend to sea level	–	–	–	–	27 397
9. Landing allowance and reserve					
● Loiter at sea level 10 min	M = 0.31	0.167	–	350	27 397
● Total initial fuel 5%	–	–	–	567	27 047
OEW + payload					26 480†

*5% service tolerance added throughout.
†Includes 100 lb external tanks.

Figure 41.—STO Mission Breakdown, LCFA-1041-133-(ASW)



Segment	Speed	Time, hr	Distance, nmi	Fuel,* lb	A/P weight, lb start of segment
1. Warmup, VTO, conversion, accel to climb speed	–	0.042	–	826	36 857
2. Climb to BCAV	320 CAS kn	0.080	32	602	36 031
3. Cruise at BCAV (initial altitude = 33 000 ft)	M = 0.75	0.271	118	660	35 429
4. Descend to 10 000 ft	–	–	–	–	34 769
5. Loiter at 10 000 ft	M = 0.42	3.16	–	6578	34 769
6. Climb to BCAV	M = 0.75	0.054	24	337	28 191
7. Cruise at BCAV (initial altitude = 38 000 ft)	M = 0.75	0.293	126	561	27 854
8. Descend to sea level	–	–	–	–	27 293
9. Landing allowance and reserve					
● Loiter at sea level 10 min	M = 0.31	0.167	–	381	27 293
● Total initial fuel 5%	–	–	–	482	26 912
OEW + payload					26 430†

*5% service tolerance added throughout.
†Includes 440 lb of Alcohol/H_2O.

Figure 42.—VTO Mission Breakdown, LCFA 1041-133-1 (ASW)

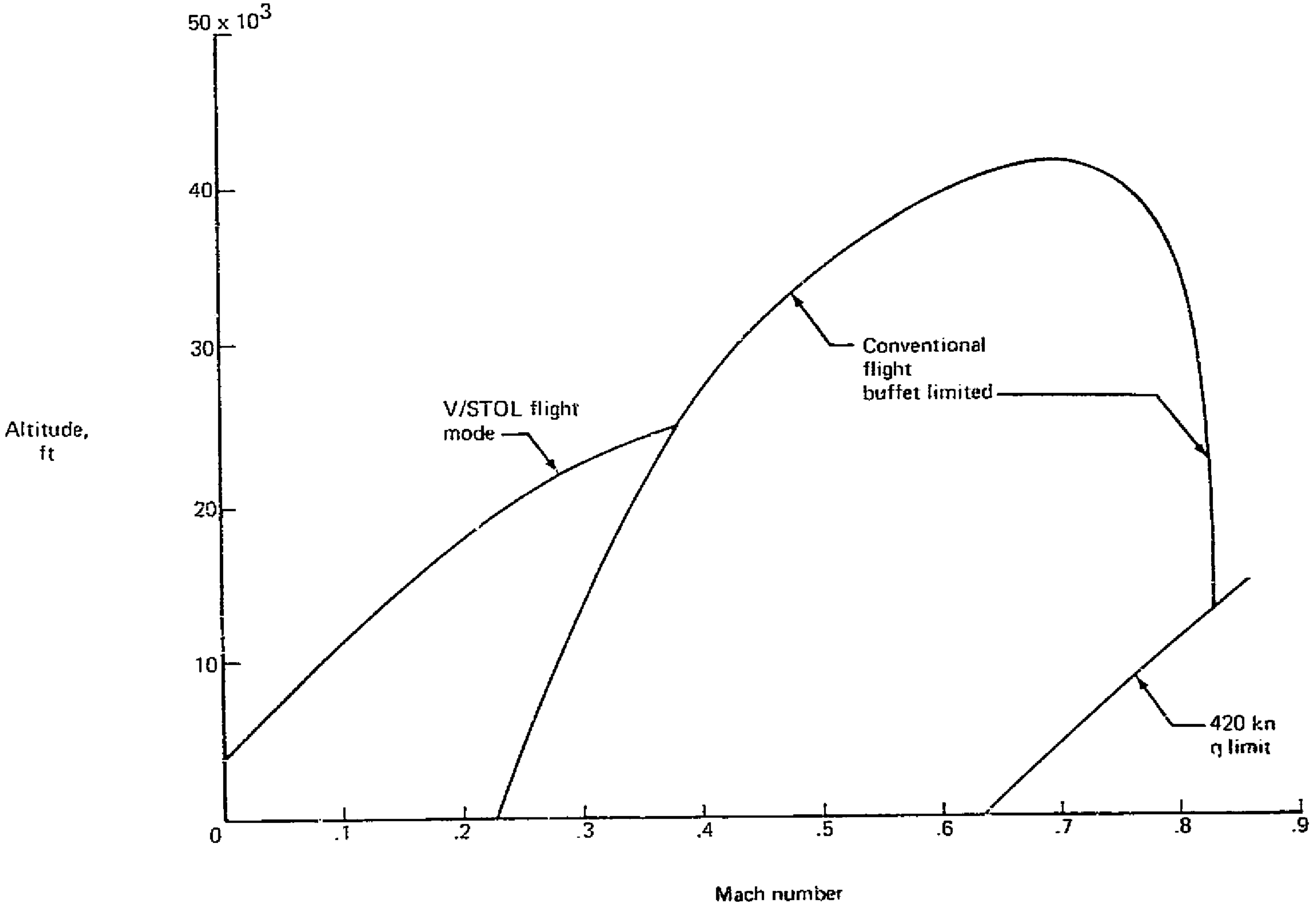


Figure 43.—Flight Envelope, Model 1041-133

5.0 PART II-LIFT/CRUISE FAN TECHNOLOGY AIRCRAFT

Three separate approaches to the design of an airplane representing the technology of the multimission aircraft developed under Part I were taken:

1. An all new airplane

2. Modification of an existing airplane (T-39)capable of operation over the same flight envelope as the all new airplane

3. Modification of an existing airplane (T-39) for low-speed operation, approximately 160 KEAS maximum speed capability

All the designs use the same cruise and lift fan hardware as the operational multimission airplane. The turboshaft engine is the XT701, essentially the same as that intended for the Army HLH program. The drive system interconnect and the T-gearbox are all designed for a later improved engine having 50% more power. The technology airplane drive system will have the advantage of operating in a derated mode.

Emphasis on minimum weight is paramount, and for a two-engine airplane, the critical design case is performed with one engine out. The research payload is 2500 lb, and the crew consists of pilot and copilot.

The T-39 (Sabreliner) is a fortunate match for an aircraft that can be modified for lift/cruise fan technology development. It is in the Department of Defense inventory and is a current production airplane.

5.1 ALL NEW AIRCRAFT, MODEL 1041-134

Major design guidelines for this airplane are that it must approximate the operational aircraft handling properties, fundamental aerodynamics, and cockpit work station. It must feature high research utility in its performance and exploration margins as well as safety. The proposed design satisfies all of these requirements.

5.1.1 CONFIGURATION

Figure 44 shows the general arrangement of the Model 1041-134. The arrangement has the appearance of a slimmed-down operational airplane with a reduced wing size. An overlay comparison of the technology and operational airplane is shown in figure 45.

For simplicity and low cost, there are no wing folds or wing fuel. Avoiding the use of wing fuel eliminates the need for many access holes, thereby saving the weight and cost that structural discontinuity and hole-framing introduce.

The airplane is designed for a limit load factor of 2.5 g and a maximum dynamic pressure (q) of 212 lb/ft^2. This is the equivalent of 250 KEAS and permits Mach 0.8 flight at about a 36 000-ft altitude.

Wing area = 200 ft^2
Aspect ratio = 3.64
Taper ratio = 0.5
Thickness ratio = 0.15

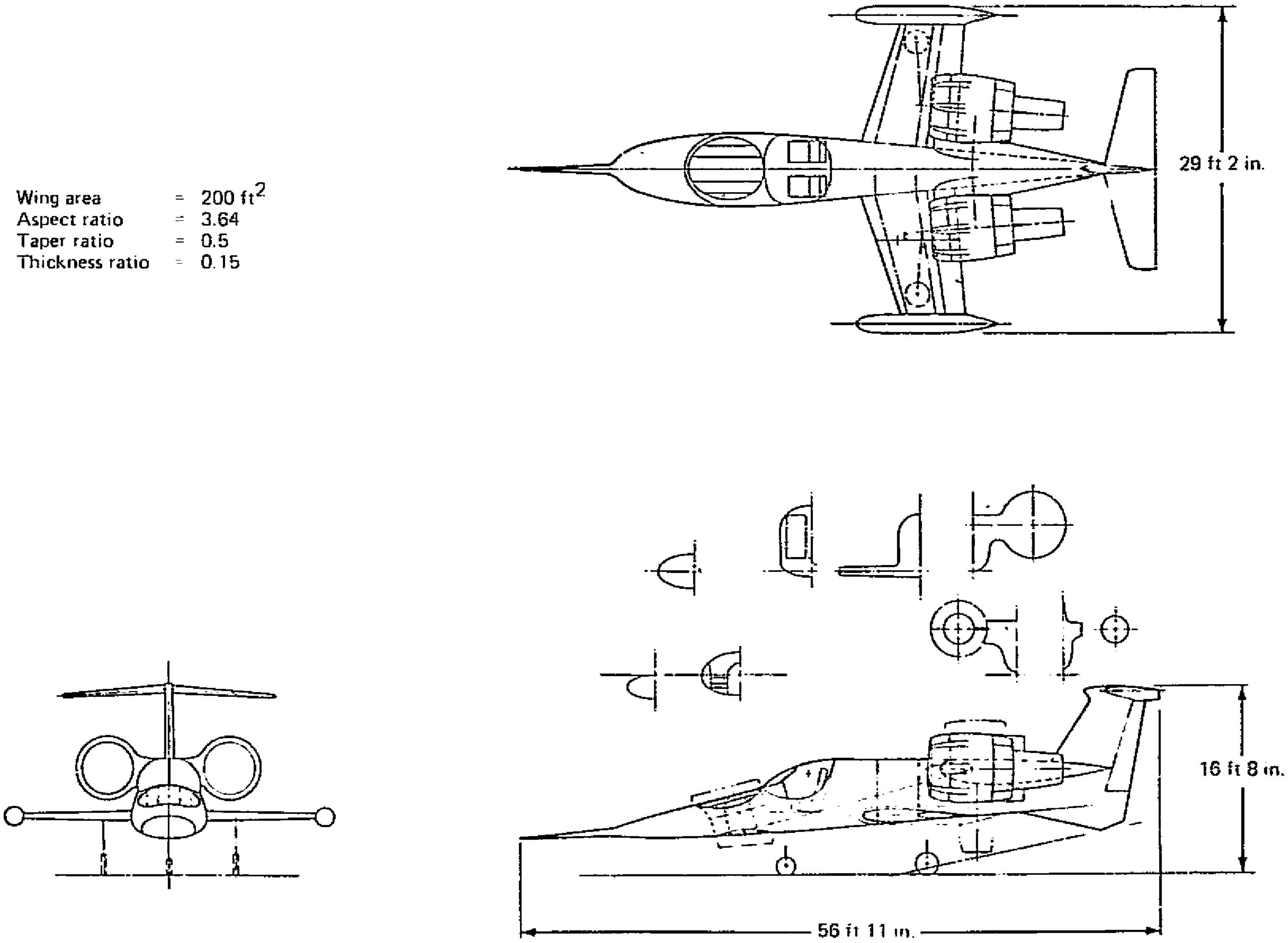


Figure 44.—General Arrangement, Model 1041-134

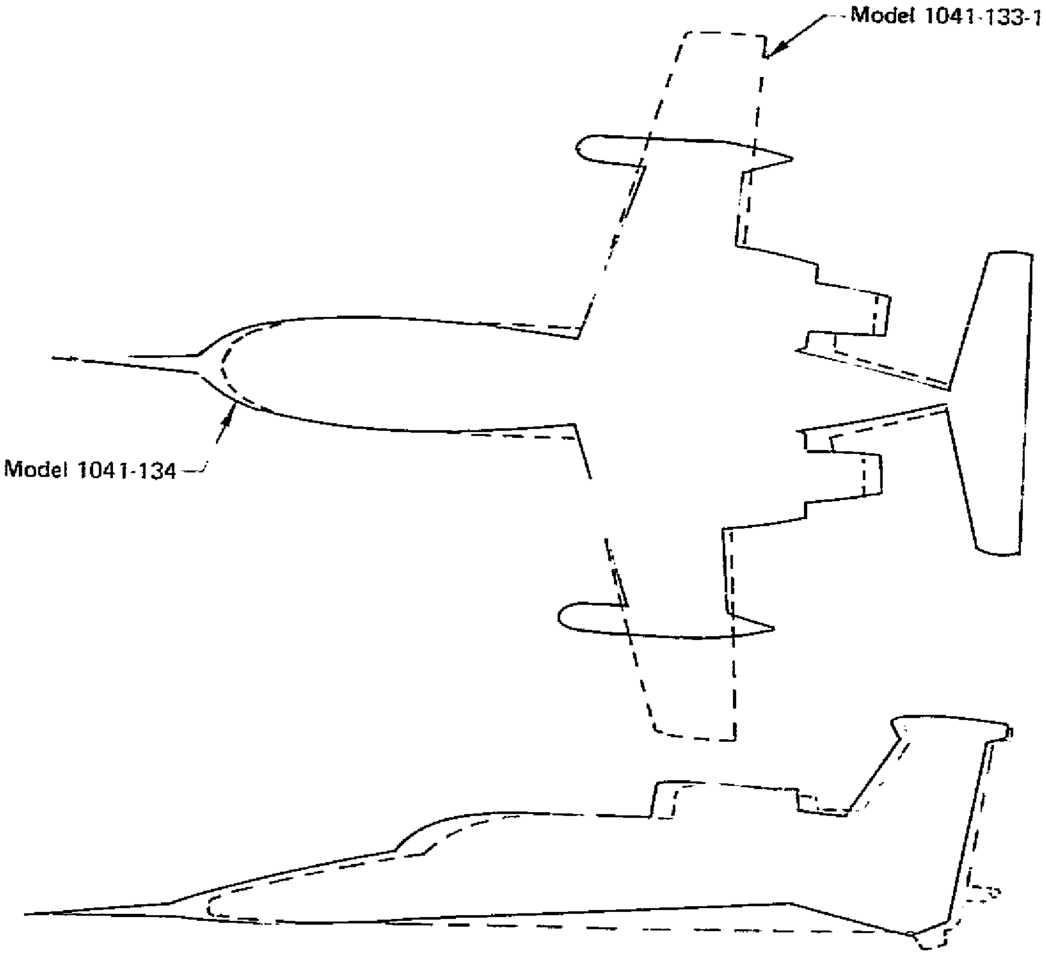


Figure 45.--Overlay Comparison

Lift/cruise propulsion pod structural support and arrangement are the same as that for the operational airplane.

The principal features of the Model 1041-134 are:

- Design weight of 20 000 lb
- Aluminum airframe
- Wing, 200 ft^2
- No cabin pressurization
- Variable pitch fans, 62-in. dia
- Allison XT701 engines
- Flying tail
- Body fuel in foamed bladder
- Dual hydraulic system, 300 psi
- Fly-by-wire flight controls using dual, redundant command augmentation system
- Variable geometry inlet
- Variable area nozzle
- Water injection for emergency single-engine flight
- Ejection through the canopy. (No pressurization and low q flight permit lightweight canopy enclosure that permits this emergency ejection approach)
- No air-conditioning or anti-icing

5.1.2 PROPULSION

The propulsion system for the technology airplane is identical to the operational airplane with the exception of the gas generator. The engine used in the technology airplane is a modified version of the current T701. Modifications will be made to the LP turbine and a water/alcohol injection system will be employed to achieve performance given in table 10. The water/alcohol injection system will be a modification of the fully developed system used on the Allison T56 turboprop engine. To ensure operational capability, the system will run continuously during the hover mode by recirculating the mixture back to the tank. During engine-out operation, a valve will open, delivering the water/alcohol mixture to the operating engine.

*Table 10.—Installed Static Performance on Technology Airplane**

Condition	FPR	Thrust, lb	SFC, lb/lb-hr
STOL, 2 engines/2 fans	1.19	21 380	0.271
VTOL, 2 engines/3 fans	1.14	27 680	0.243
Contingency, 1 engine/3 fans (water/alcohol)	1.12	21 000	0.228

*Sea level, 90° F, day

5.1.3 FLIGHT CONTROLS

The flight control system for the technology airplane is the prototype for the operational airplane. The fly-by-wire system will be developed and refined in this airplane. The control system description of the operational airplane (sec. 4.3.6) applies to the technology airplane.

The airplane moment of inertias in roll and yaw are greater than in the operational airplane because of the wing tip tanks. The thrust modulation needed to meet roll control levels for hover are larger because attitude control scales with moment of inertia. The increase in thrust modulation is available at no penalty because the fans of the technology airplane are operated well below design thrust levels. The control available is tabulated in table 11. This VTOL control capability, combined with the variable stability features achievable with a fly-by-wire system, gives the technology airplane excellent potential for handling quality research. The flight control characteristics of the technology airplane will have the flexibility to simulate a range of operational properties. The desirable operational characteristics can be established.

Table 11.—Technology Demonstration Hover Control Power, Model 1041-134

Control function	Design guideline requirement	System capability
Roll	0.90 rad/sec^2	1.80 rad/sec^2
Pitch	0.50 rad/sec^2	1.40 rad/sec^2
Yaw	0.30 rad/sec^2	0.50 rad/sec^2
Height	0.05 g	0.22 g

The control response of the system is significantly better than the guideline minimums. The response to maximum control commands, far outside of design requirements, is less than 0.2 sec. The response for the pitch, roll, and height commands is based on blade angle changes at essentially constant fan speed. Figure 46 shows the response time variations with control input size. The time response for 100% of design level roll control is 0.10 sec using a system mechanized with a blade rate of 100 deg/sec. The yaw control response is based on the deflection rate of vanes in the slipstream of the fans with similar response characteristics. Height control exercises the system more than attitude control. A "fly up" command requires a change in power to achieve an increase in fan thrust. The response of the system is a function of both blade angle changes and engine power changes. An overall response time of 0.10 sec is available.

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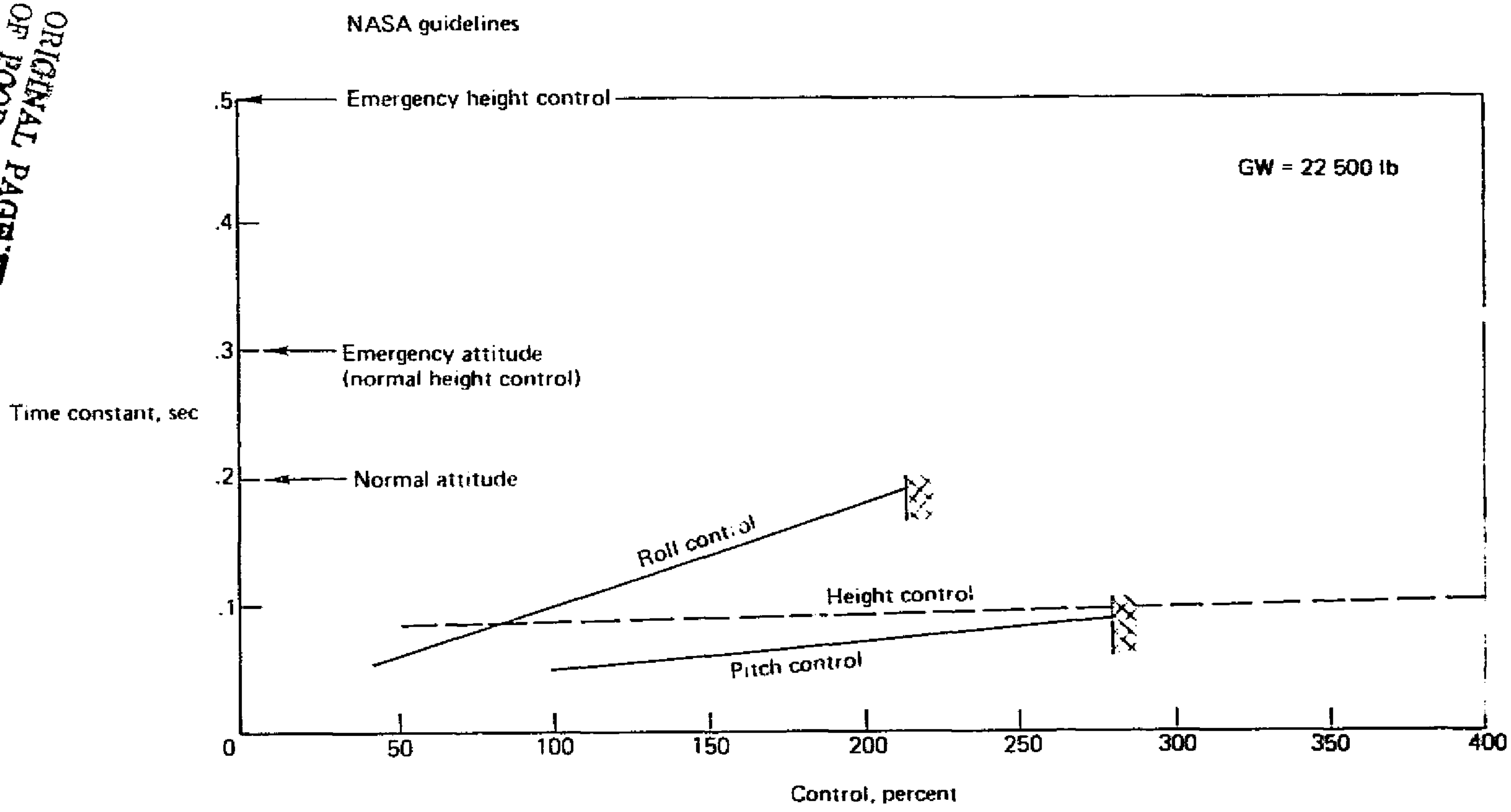


Figure 46.—Control Response Time, Model 1041-134

5.1.4 AIRCRAFT SYSTEMS

The aircraft systems in the technology airplane will be designed primarily to prototype the Model 1041-133 propulsion and flight control systems. Other systems will be capable of meeting the demonstrator operational requirements with the necessary levels of performance and safety.

The accessory power package will be similar to the 1041-133 with the exception that the two 75-kVA generators will be replaced by two 30-kVA generators and the air compressor will be deleted. Performance will be based on the following power extraction:

Condition	Shaft/horsepower extraction
Normal	100
Emergency	23
Design	450

5.1.5 WEIGHTS AND BALANCE

An abbreviated weight statement of the new technology airplane is presented in table 12. The propulsion weight is the significant contributor to an operating weight of 16 400 lb. The research payload is 2500 lb with 240 lb of water/alcohol mixture for water injection during hot-day emergency conditions; the mission weight less fuel is 19 100 lb.

Table 12.—Technology Airplane Weight Statement

	Weight, lb	C.G. Body station, in.
Structure	5 650	417.7
Propulsion	7 550	442.3
Fixed equipment	2 600	347.7
Weight empty	15 800	417.9
Nonexpendable useful load	600	328.8
Operating weight	16 400	414.7
Payload	2 500	300
H_2O plus alcohol	240	395
Mission weight less fuel	19 100	398.9

Note: (1) MAC LE is at body station 364.4.
(2) MAC length is 90 in.

5.1.6 PERFORMANCE-ALL NEW AIRCRAFT, 1041-134

The missions used to estimate fuel requirements are shown in figure 47. Eleven circuits from an initial STO and five from a VTO were used as the fuel measure.

The takeoff performance, ground roll as a function of lift-off speed, is presented in figure 48. The lift-off speed is 1.2X stall speed and no credit is taken for induced aerodynamic lift or ground effects. The airplane is assumed to accelerate with the nose fan in flat pitch. At lift-off the nose fan pitch is set to the value required for propulsive moment balance for the amount of engine tilt being used. The lift-cruise fans are held at constant angle during acceleration and lift-off.

The landing performance approach speed versus ground roll is shown in figure 49. The approach speed is 1.2X stall speed and no credit is taken for induced aerodynamic effects. Thrust reversal is not used.

Emergency vertical landing can be accomplished at a gross weight of 20 400 lb and a thrust weight ratio of 1.03. At higher gross weights, a short landing can be accomplished within the limit sink speeds.

Five VTO mission circuits can be accomplished with 1300 lb of fuel. The mission takeoff weight is 20 400 lb, which is equal to the single-engine emergency landing weight at F/W = 1 03. By trading payload for fuel or accepting a limited hovering envelope at higher gross weight, a longer VTO mission can be had. The 11 STO circuits can be made from a gross weight of 21 200 lb. The available thrust, both engines operating, is 27 680 lb. The STO missions are not limiting.

A ferry range of 820 nmi is possible at a gross weight of 25 000 lb. The thrust weight ratio is still greater than one.

The level flight performance envelope is presented in figure 50 for the cruise and V/STOL configurations. The cruise configuration altitude capability is about 37 000 ft and the maximum Mach number is about 0.76. The V/STOL configuration envelope is based on an optimum value of engine tilt angle, λ, at each point on the envelope. Hovering is possible at altitudes up to 10 000 ft and the maximum flaps-down altitude is about 29 000 ft. No credit has been taken for induced aerodynamic lift in these calculations. The crosshatched area represents conditions where the envelopes overlap, allowing the conversion maneuver to be performed.

5.2 MODIFIED AIRCRAFT (FULL FLIGHT ENVELOPE)

Several candidate aircraft were reviewed for potential use as a modification base for the lift-cruise fan technology airplane, and the T-39 (Sabreliner) was selected because: (1) it is available from government inventory, (2) it is a low wing configuration, and (3) its size is correct for the available propulsion system. The modified airplane differs from the all new aircraft in two ways; the wing loading is considerably lighter, and it is about 700 lb heavier.

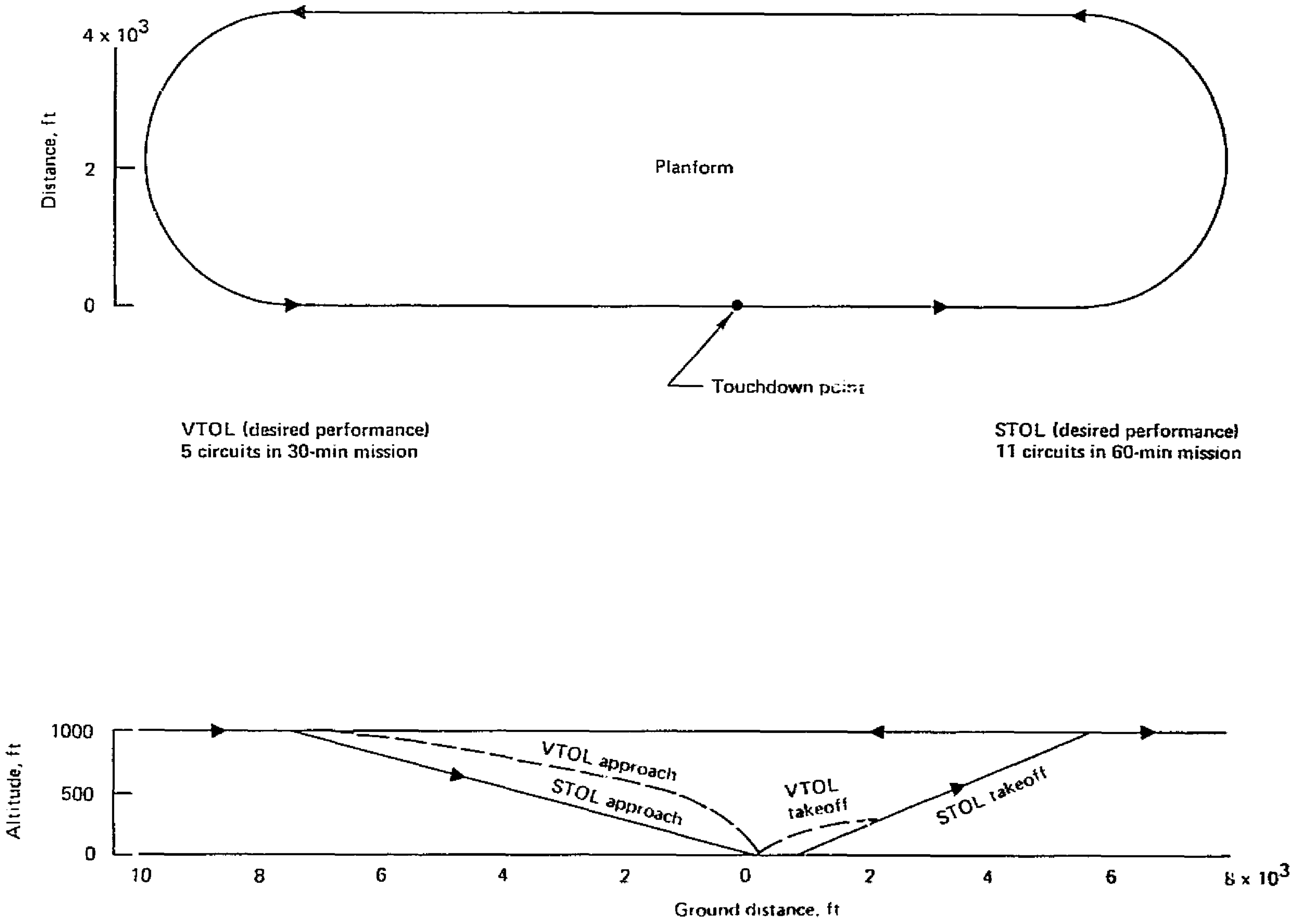


Figure 47.--LCFA Technology Airplanes
Typical Terminal Area Test Missions

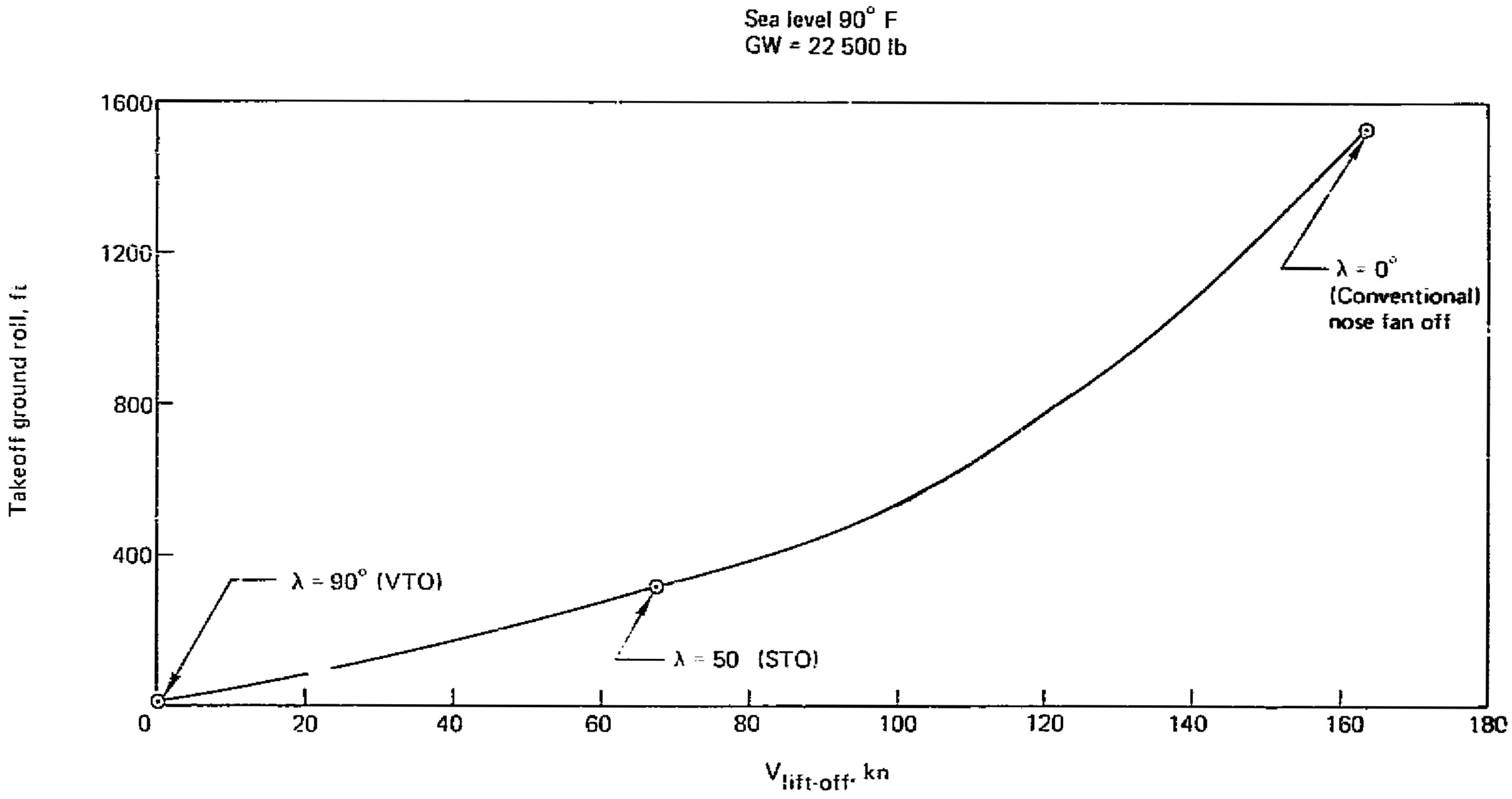


Figure 48. - Takeoff Performance, LCFA 1041-134 (All New Airplane)

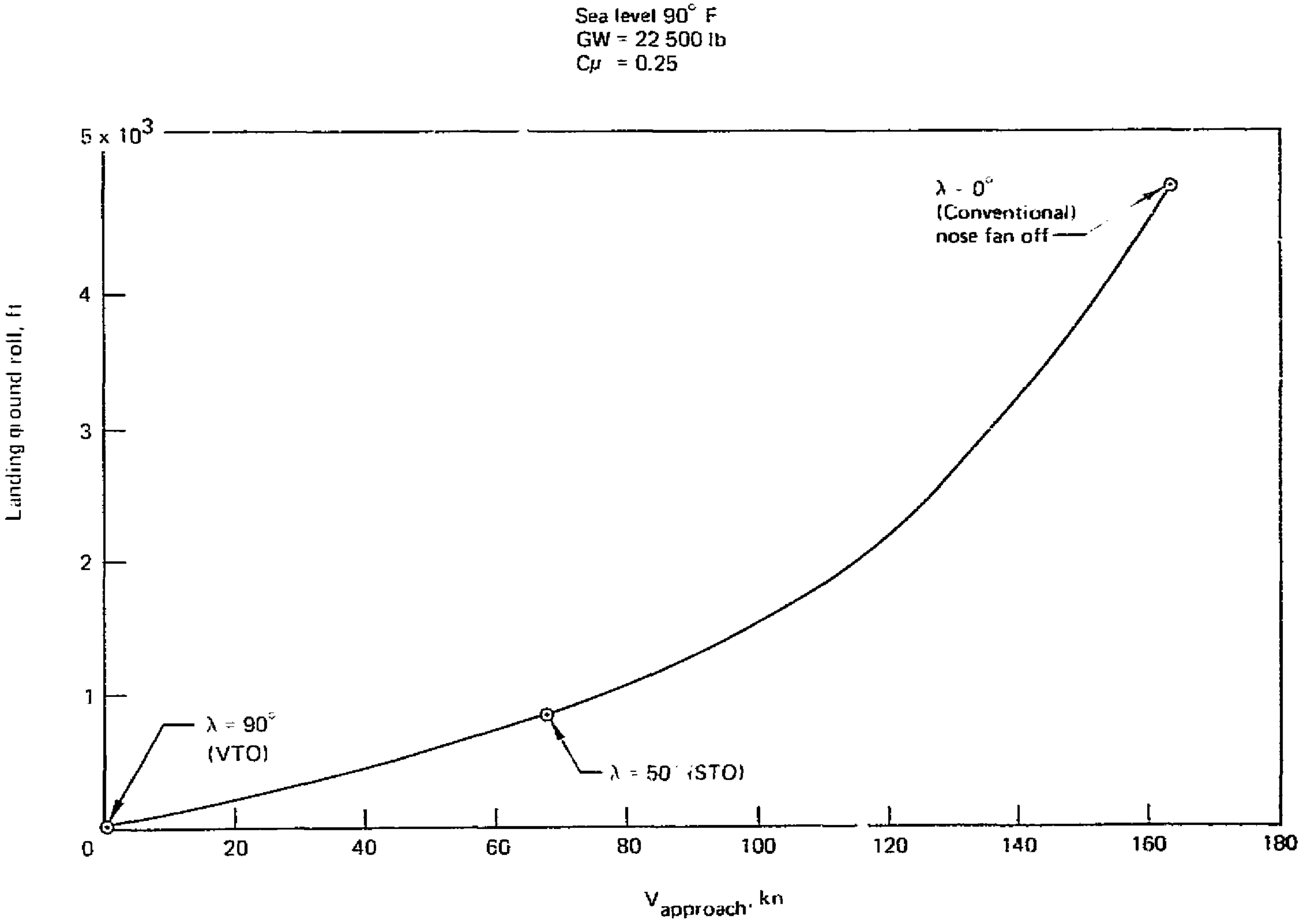


Figure 49.—Landing Performance, LCFA 1041-134 (All New Airplane)

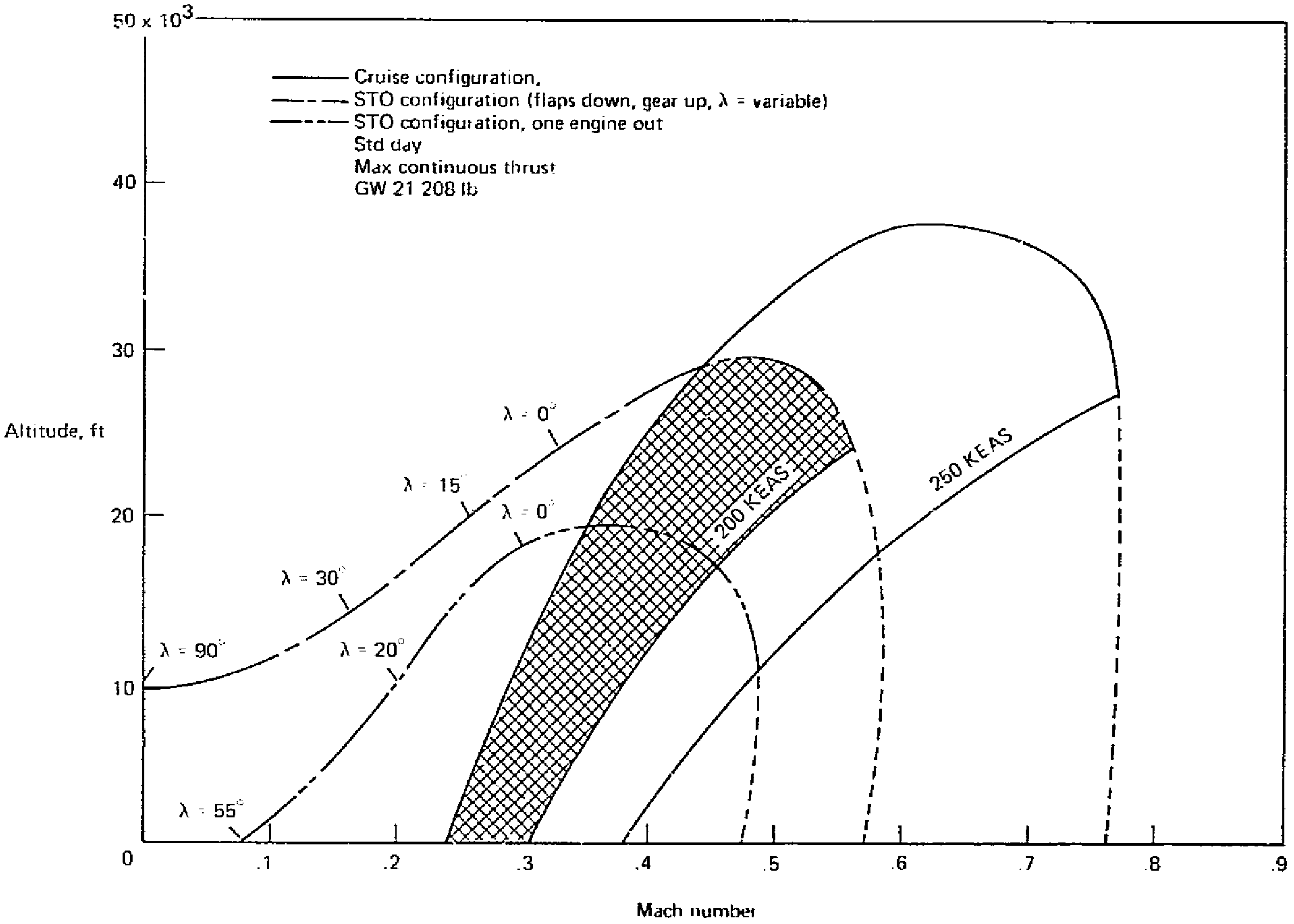


Figure 50.—Level Flight Capability, LCFA 1041-134 (All New Airplane)

5.2.1 CONFIGURATION

Figure 51 shows the general arrangement of the modified Sabreliner (1041-135-2). An overlay comparison with the operational airplane is shown in figure 52.

The necessary modifications include: a new nose to accommodate the fan installation; new vertical and horizontal tails; canopy replaced with lightweight enclosure fixed in place; mechanical flight control system adapted (use of control actuation and retention of the existing mechanical system to be investigated); flap deflection will be increased to clear the tilting pod; new hydraulic system due to increased power requirements; reworked landing gear metering needed to accommodate the higher sink speed requirements of vertical landing; new nose gear installation needed to accommodate an aft swinging strut due to fan installation; body strengthening required for the lift cruise propulsion pod installation and the new T-tail loads. The propulsion system will be the same as one in the all new technology airplane.

5.2.2 FLIGHT CONTROLS

The modified T-39 (Model 1041-135-2) requires the same flight control systems as the all new airplane. The hover inertia and gross weight characteristics are within the capability of the reaction control system for airplane trim and control during VTOL.

5.2.3 WEIGHT AND BALANCE

The operating weight of the modified T-39A is 17 100 lb. The modifications result in a net empty weight increase to the T-39A of 7240 lb and the resulting technology airplane is 700 lb heavier than the all new airplane.

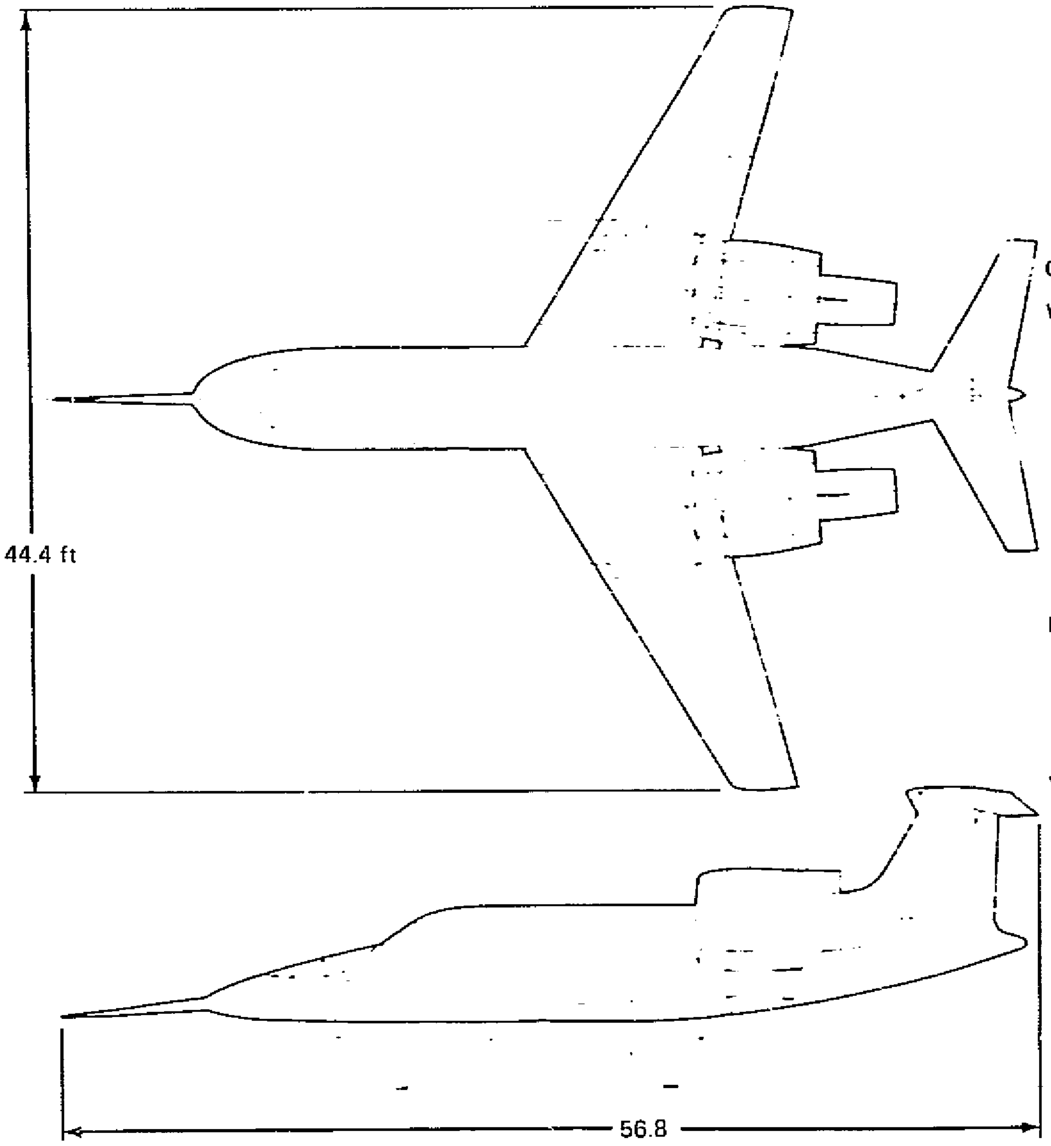
5.2.4 PERFORMANCE

The takeoff and landing performance is improved over the all new airplane because of the difference in wing loading: from 120 lb/ft^2 to 70 lb/ft^2. This increased capability is unimportant.

The number of VTO circuits available from the emergency landing weight is reduced as a result of the weight increase. Three instead of five are available.

5.3 MODIFIED AIRCRAFT (LIMITED FLIGHT ENVELOPE)

This version of the modified Sabreliner airplane was examined to determine whether significant cost savings were possible. The savings are nominal since much of the program cost is associated with the propulsion system, which is essentially identical to that of the full envelope airplane. Flight is limited to takeoff and landing traffic speeds–about 160 KEAS.



GEOMETRY

Wing (T-39 unchanged)	
Area	342 ft^2
Aspect ratio	5.8
Taper ratio	0.33
Sweepback	28.6 deg C/4
Airfoil	64, A212 (mod) root 64, A012 (mod) tip
MAC	100.6 in.
Span	44.5 ft
Incidence	0° root, 2.9° tip
Dihedral	3.1 deg
Horizontal tail (new)	
Area	64 ft^2
Aspect ratio	5.0
Taper ratio	0.35
Sweepback	26 deg C/4
Vertical tail (new)	
Area	59 ft^2
Aspect ratio	1.175
Taper ratio	0.393
Sweepback	25 deg C/4

Figure 51.—Technology Airplane, Modified T-39 (Sabreliner), Model 1041-135-2

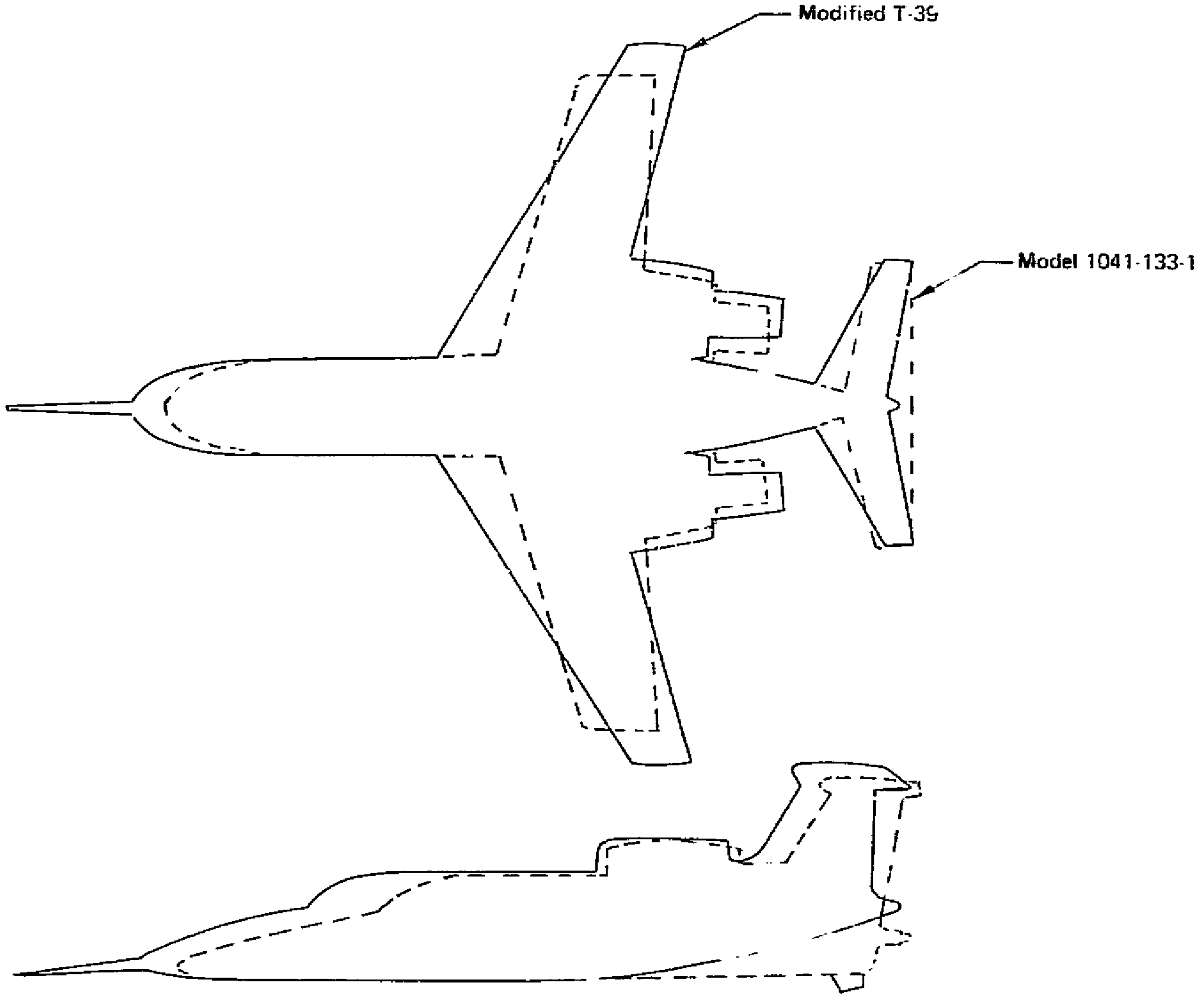


Figure 52.—Overlay Comparison

Major development savings consist of:

- A reduced flight test program
- No requirement for analysis and simulation of high Mach number characteristics
- Drag refinements unnecessary in analysis and fabrication
- High-speed tunnel testing not required
- Ejection through canopy verification not required

Figure 53 shows the general arrangement of Model 1041-136, the limited flight envelope modified existing airplane. The modifications are the same as for the previously described airplane except:

- An open cockpit is used
- Landing gear is fixed
- Fan nozzles are fixed on the aft pods
- No nose fan inlet doors are used

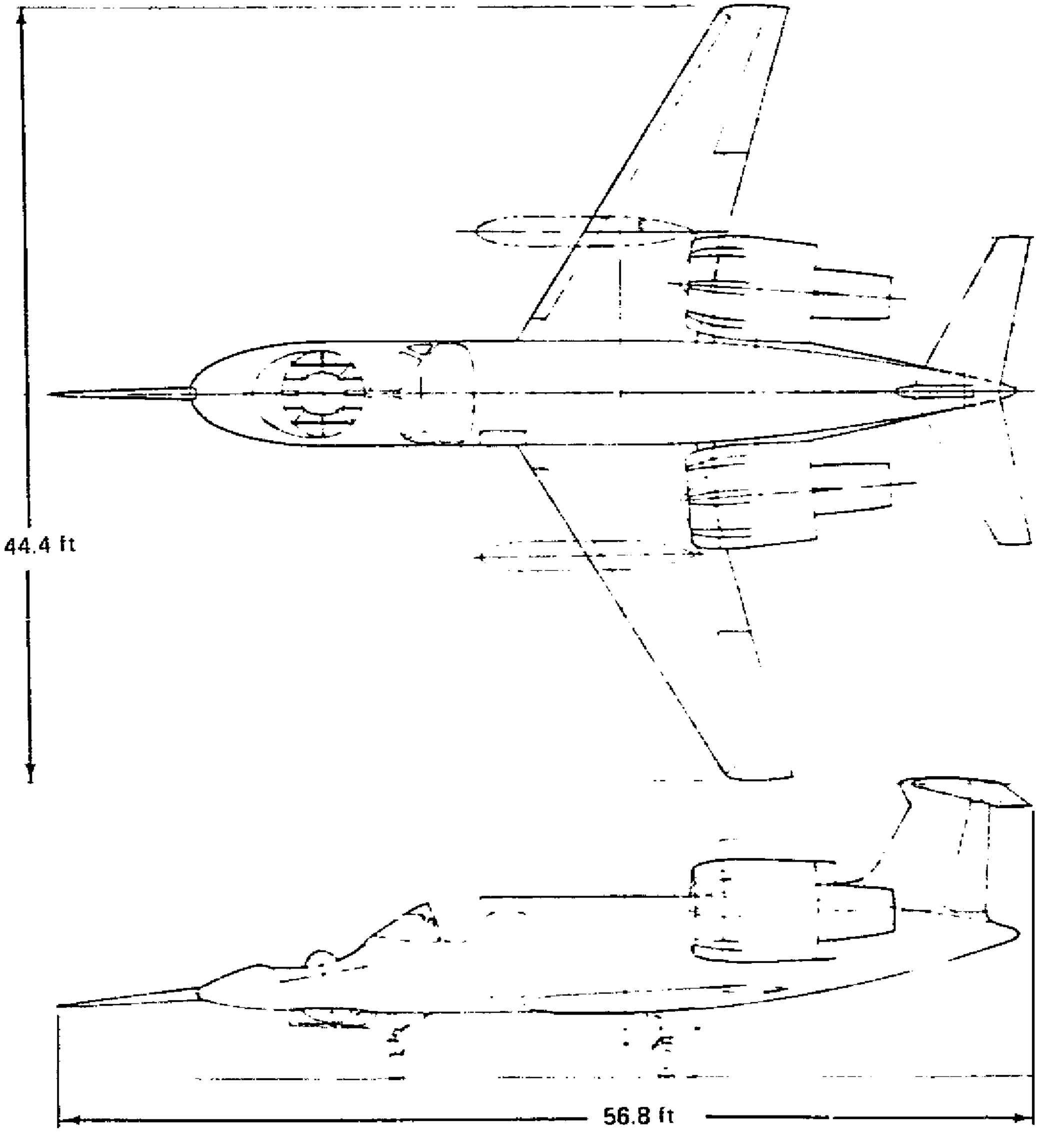
The weight savings resulting from these changes make this version of the modified airplane about 100 lb heavier than the all new airplane. It will have about the same VTO mission capability as the all new airplane.

The propulsion system will be the same as that for the all new technology, except that the inlet vanes for the nose fan will be fixed.

This airplane will have the same flight controls system and empennage features as the unlimited modified airplane (Model 1041-135-2).

5.4 TECHNOLOGY AIRCRAFT COMPARISON

The comparison of the three technology airplanes offers classic cost/weight/performance tradeoffs. Table 13 presents a weight comparison of the three airplanes. The modified Sabreliner with normal flight envelope is approximately 700 lb heavier than the new airplane. The Sabreliner with limited flight envelope is 100 lb heavier.



Geometry

Wing (T-39 unchanged)	
Area	342 ft^2
Aspect ratio	5.8
Taper ratio	0.33
Sweepback	28.6 deg C/4
Airfoil	64, A212 (mod) root 64, A012 (mod) tip
MAC	100.6 in.
Span	44.5 ft
Incidence	0° root, 2.9° tip
Dihedral	3.1 deg
Horizontal tail (new)	
Area	64 ft^2
Aspect ratio	5.0
Taper ratio	0.35
Sweepback	26 deg C/4
Vertical tail (new)	
Area	59 ft^2
Aspect ratio	1.175
Taper ratio	0.393
Sweepback	25 deg C/4

Figure 53.—Limited Flight Envelope Technology Airplane, Modified T-39 (Sabreliner), Model 1041-136

In Summary:

- The all new Model 1041-134 costs the most, has low risk on weight, and performs well.
- The modified T-39 is less expensive, has less weight margin, and performs well.
- The low speed modified T-39 is the least expensive; it has low risk on weight, but its performance capability is limited to low speed.

Table 13.—Weight Summary Technology Airplane

Configuration	New airplane	Modified Sabreliner	Low-speed Sabreliner
Model 1041	-134	-135-2	-136
Structure, lb	5 650	6 320	6 020
Propulsion, lb	7 550	7 580	7 530
Equipment, lb	2 600	2 600	2 350
Weight empty, lb	15 800	16 500	15 900
Nonexpendable useful load, lb	600	600	600
Operating weight, lb	16 400	17 100	16 500

The Boeing Company
P.O. Box 3707
Seattle, Washington 98118
August 15, 1975

THE APPENDIX
EXCERPTS FROM WORK STATEMENT AND DESIGN GUIDELINES

STATEMENT OF WORK

DESIGN DEFINITION STUDY OF A LIFT CRUISE FAN TECHNOLOGY V/STOL AIRCRAFT

INTRODUCTION

1.0 Recent studies by the Navy and by NASA during contractor studies have confirmed the future need for a high performance V/STOL aircraft for both military and civil applications. The Navy requires a multimission V/STOL aircraft in the 1980's that is capable of sea control operations from many platforms as well as ship-to-shore and shore-to-ship functions.

1.1 The turbotip or mechanically driven lift/cruise fan V/STOL aircraft exhibits an excellent potential because of its high speed, high altitude and range capability, coupled with its overall operational suitability. The expected benefits of this concept for multirole applications makes it advisable to conduct a lift/cruise fan technology aircraft flight program. Successful completion of the flight program and related technology support programs in propulsion, aerodynamics, and simulation will result in a firm basis from which multimission aircraft for the U.S. Navy can be designed with confidence. The technology developed would also be useful in consideration of future civil utility aircraft for purposes such as offshore oil rig operations and other construction, lumbering, or development sites that are located in areas difficult to reach rapidly by other modes of transportation.

1.2 As an initial step in developing a realistic technology aircraft, a study phase shall be performed to quantify Navy operational aircraft requirements, develop conceptual designs of research aircraft, and assess their applicability to operational requirements. This design definition study shall be directed toward a minimum cost research program consistent with providing maximum research productivity, Navy operational demonstration capabilities, and proper attention to safety.

2.0 Basic design guidelines for the technology aircraft are given in attachment I.

2.1 Part I—Navy operational aircraft requirements

The contractor shall evaluate Navy requirements for V/STOL aircraft to perform the missions outlined in attachment II. Considering mission deficiencies, cost, and the potential for design commonality, the contractor shall postulate a compromise design

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mission and design approach to commonality for approval of Navy and NASA. Based upon this compromise mission, a multipurpose aircraft (or aircraft system) shall be synthesized and evaluated for adequacy against the original design missions.

2.2 Part II - Design definition of lift-cruise fan technology aircraft

To allow a true comparison of program cost and value, the contractor shall prepare and evaluate at least three separate design approaches for the technology aircraft. One approach will be based upon a new airframe using the compromise aircraft design of Part I; the second will be based upon modifying an existing airframe to accept the propulsion system and demonstrate an ability to operate in a full envelope (i.e., hover, transition, and high-speed cruise); and the third approach would be based upon modifying an existing airframe to accept the propulsion system but to be flight limited to a maximum velocity of approximately 160 kn.

ATTACHMENT 1

DESIGN GUIDELINES AND CRITERIA FOR DESIGN DEFINITION STUDY OF A LIFT CRUISE FAN TECHNOLOGY V/STOL AIRCRAFT

The purpose of these guidelines is to provide a basis for comparing the conceptual designs of V/STOL technology aircraft using the remote lift-cruise fan propulsion system. These guidelines will provide direction for only those items required for *conceptual design considerations.* This is not an attempt to provide criteria for either the *preliminary* or *detail design of military aircraft.*

Except where specific criteria are given, handling qualities shall be consistent with the intent of AGARD-R-577-70 and MIL-F-83300. Under MIL-F-83300, the aircraft will be considered in the Class II category. Two levels of operation will be considered. Level 1 is normal operation with no failures. Level 2 is operation with a single reasonable failure of the propulsion or control system.

Upon any reasonable failure of a power plant or control system component, the aircraft shall be capable of completing a STOL flight mode takeoff and continuing sustained flight. For the vertical landing flight mode, upon failure, sustained hovering flight is required at some useful aircraft gross weight to be determined by the contractor. At higher gross weights for which hovering flight cannot be sustained after a failure, sinking vertical flight is permitted provided aircraft attitude remains controllable and the landing gear design sink is not exceeded. Fan failure during low-speed flight is not a design requirement (as similarly the case for rotor type or propeller-driven concepts), although consideration of gas generator failure is a design requirement.

1.0 Flight safety and operating criteria

1.1 Handling qualities criteria (low-speed powered-lift mode)

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 military pilot.

Level 2: Flying qualities are adequate to continue flight and land. The pilot workload is increased but is still within the capabilities of the average military pilot.

1.1.1 Attitude control power (S.L., 90° F)

Applicable for all aircraft weights and at any speed up to V_{con}. For purposes of this study, the VTOL values will apply near hover (0 to 40 kn); where the STOL values will apply when operating above 40 kn. The tables list minimum values; higher levels are desirable for research purposes.

Level 1. The low-speed control power shall be sufficient to satisfy the most critical of the three following sets of conditions:

(a) Following to be satisfied simultaneously:

(1) Trim with the most critical c.g. position

(2) Provide control power in each control channel for maneuver only, equal to the most critical of the requirements given in the following table:

Axis	Maximum control moment inertia		Attitude angle in 1 sec after a step input	
	VTOL	STOL	VTOL	STOL
Roll Pitch Yaw	±0.9 rad/sec^2 ±0.5 rad/sec^2 ±0.3 rad/sec^2	±0.6 rad/sec^2 ±0.4 rad/sec^2 0.2 rad/sec^2	±15 deg ±8 deg ±5 deg	±10 deg ±6 deg ±3 deg

These maneuver control powers are applied so that 100% of the most critical and 30% of each of the remaining two need occur simultaneously.

(b) At least 50% of the above control power shall be available for maneuvering, after the aircraft is trimmed in a 25-kn crosswind.
(c) At least 90% of the control power specified in condition (a) shall be available after compensation of the gyroscopic moments due to the maneuvers specified in condition (a). This condition includes trim with the most critical c.g. position.

Level 2: The low-speed control power shall be sufficient to satisfy, simultaneously, the following:
(a) With the most critical c.g. position trim after any reasonable single failure of power plant or control system.
(b) In each control channel, provide control power, for maneuver only, equal to at least the following:

Axis	Control moment Inertia		Attitude angle in 1 sec after a step input	
	VTOL	STOL	VTOL	STOL
Roll	±0.4 rad/sec^2	±0.3 rad/sec^2	±7 deg	±5 deg
Pitch	±0.3 rad/sec^2	±0.3 rad/sec^2	±5 deg	±5 deg
Yaw	±0.2 rad/sec^2	±0.15 rad/sec^2	±3 deg	±2 deg

Simultaneous maneuver control power need not be greater than 100%—30%—30%.

1.1.2 Flightpath control power (sea level to 1000 ft, 90° F)

1.1.2.1 VTOL (0 to 40 KTAS and zero rate of descent)

At applicable aircraft weights and at the conditions for 50% of the maximum attitude control power of critical axis specified in para. 1.1.1, it shall be possible to produce the following incremental accelerations for height control:

Level 1:
(a) In free air ± 0.1 g
(b) With wheels just clear of the ground -0.10 g, +0.05 g

Level 2:
(a) In free air -0.1 g, +0.05 g
(b) With wheels just clear of the ground -0.10 g, +0.00 g

It shall also be possible to produce the following horizontal incremental acceleration but not simultaneously with height control.

Level 1: ±0.15 g

Level 2: ±0.10 g

At applicable aircraft weights it shall be possible to produce the following stabilized thrust-weight ratios without attitude control inputs.

Level 1: F/W = 1.05 in free air (takeoff power rating)

Level 2: F/W = 1.03 in free air (emergency power rating)

1.1.2.2 VTOL and STOL approach (40 kn to V_{con})

At applicable landing weight, the aircraft shall be capable of making an approach at 1000 fpm rate of descent while simultaneously decelerating at 0.08 g along the flightpath.

It shall be possible to produce the following incremental normal accelerations by rotation alone (angle of attack change and constant thrust) in less than 1.5 sec at the STOL landing approach airspeed where reasonable rotation (angle-of-attack changes) will produce at least 0.15 g.

Level 1: ±0.1 g

Level 2: ±0.05 g

It shall be possible to produce the following normal accelerations in at least 0.5 sec for flightpath, flare, or touchdown control by either thrust changes or combined thrust changes and rotation at STOL landing approach speeds below which 0.15 g can be produced by reasonable rotation alone.

Level 1: ±0.1 g

Level 2: ±0.05 g

1.1.3 VTOL and STOL low speed control system lags (SL to 1000 ft 90° F)

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

	Level 1	Level 2
Atitude control moments	0.2 sec	0.3 sec
Flightpath control forces	0.3 sec	0.5 sec

With a step-type input at the pilot's control, the commanded control moment or force shall be applied within the following:

Level 1: 0.3 sec for 0.5 in. of pilot's control
0.5 sec for full pilot's control

Level 2: 0.5 sec for full pilot's control

1.2 STOL takeoff performance

The climbout gradient in the takeoff configuration, at takeoff gross weight with gear down and most critical power plant failed at lift-off, shall be positive, and the aircraft will continue to accelerate.

During takeoff, wing lift shall not exceed 0.8 CL_{max}. No catapults or arresting gear will be utilized. The rolling coefficient of friction will be 0.03 (for calculations).

1.3 Conversion requirements (STOL and VTOL)

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

The maximum speed in the powered-lift configuration shall be at least 20% greater than the power-off speed in the converted configuration for level 1 operation, and the speed in the powered-lift configuration shall be at least 10% greater than the power-off stall speed for the level two operation.

2.0 Mission

2.1 Mission Summary

The mission, payload, and range of the technology aircraft will be derived through consultation with the contractor, Navy, and NASA and will be based upon the findings of Part I of this study.

ATTACHMENT II

SUMMARY OF MISSIONS, DESIGN GUIDELINES, AND DESIGN TECHNICAL INFORMATION DESIRED FOR THE PRELIMINARY AIRCRAFT DESIGNS AND MULTIPURPOSE AIRCRAFT DESIGNED FOR THE COMPROMISE MISSION (PART I)

INTRODUCTION

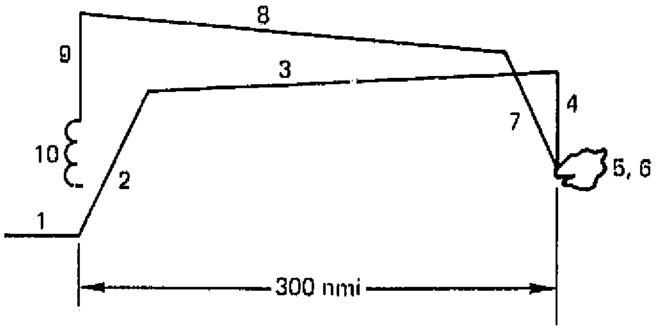
The purpose of Attachment II is to provide the basis for designing the preliminary aircraft of Part I and the multipurpose aircraft designed for the compromise as specified in Part I of the Statement of Work. Five missions are described.

C. 2

Mission summary and design requirements:

1.0 Mission summary

A. Surface Attack (SA)—Sea Control Mission



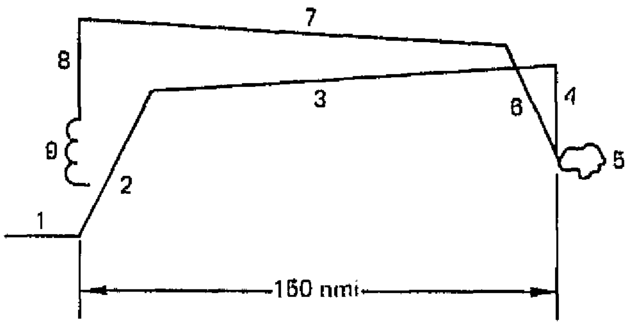
Loading: (2) Harpoon, (2) AIM-9

Conditions: STO with 400-ft deck run and vertical landing both at 89.8° F. Ten-kn WOD for takeoff. All fuel consumption to be calculated at standard day conditions.

Note: External fuel permitted if within STO capability; tanks dropped when empty or prior to combat, whichever occurs first.

1. Warmup, takeoff, acceleration to climb speed—2-1/2 min at intermediate thrust. Installed sea level static conditions
2. Climb—to best cruise altitude and velocity (BCAV) at intermediate thrust
3. Cruise—to radius to BCAV
4. Descend to 20 000 ft—no fuel used, no time or distance credit
5. Loiter—2 hr at 20 000 ft at speed for best endurance
6. Combat—5 min at intermediate thrust at 20 000 ft M = 0.8
7. Climb—from 20 000 ft to BCAV at intermediate thrust
8. Cruise—at BCAV to point of takeoff
9. Descend to sea level—no fuel used, no time or distance credit
10. Landing allowance and reserve—fuel for:
    (a) 10 min loiter at best endurance speed at sea level
    (b) 5% total initial fuel

B. Antisubmarine (ASW)

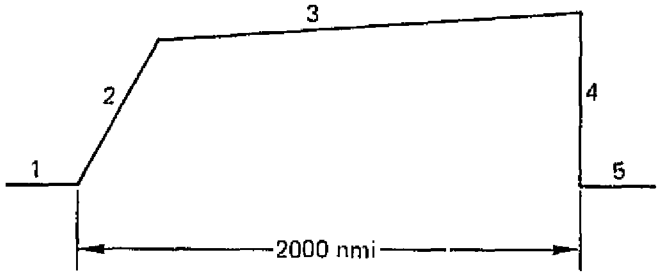


Loading: (2) MK-46 torpedoes, (50) mixed sonobuoys (sonobuoy weight 1760 lb) without containers

Conditions: STO with 400-ft deck run and vertical landing both at 89.8° F. Ten-kn WOD for takeoff. All fuel consumption to be calculated at standard day conditions.

1. Warmup, takeoff, acceleration to climb speed—2-1/2 min at intermediate thrust. Installed sea level static conditions
2. Climb—to BCAV at intermediate thrust
3. Cruise—to radius at BCAV
4. Descend—to 10 000 ft no fuel used, no time or distance credit
5. Loiter—at 10 000 ft and speed for best endurance—4 hr
6. Climb—at intermediate thrust to BCAV
7. Cruise—to starting point at BCAV
8. Descend—to sea level. No fuel used, no time or distance credit
9. Landing allowance and reserve—fuel for:
   (a) 10 min at best endurance speed at sea level
   (b) 5% total initial fuel

C. Vertical onboard delivery (VOD)



Loading: 5000 lb disposable payload, may include pallets, but not life rafts, cargo loading equipment, etc.

Conditions: STO with 450 ft deck run and vertical landing, both at 89.8° F. Twenty kn WOD for takeoff. All fuel consumption to be calculated at standard day conditions.

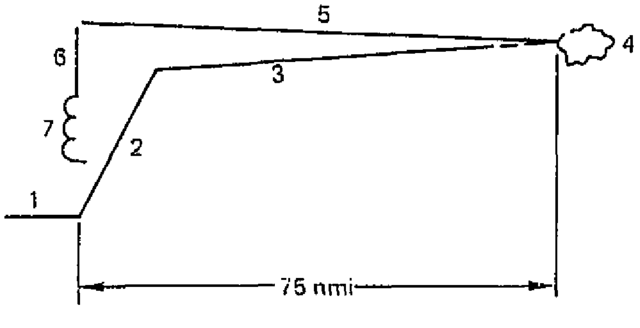
1. Warmup, takeoff, acceleration to climb speed—2-1/2 min at intermediate thrust. Installed sea level static conditions
2. Climb—to BCAV at intermediate thrust
3. Cruise—to radius at BCAV
4. Descend—to 10 000 ft, no fuel used, no time or distance credit
5. Landing allowance and reserve—fuel for:
   (a) 20 min loiter at best endurance speed at sea level
   (b) 5% total initial fuel

Note: VOD designs should be sized to carry at least the following:

(a) Passengers: 17 to 23 plus three crew
(b) 350 in rotor blade
(c) F401 engine on stand (no afterburner)
(d) 463L half pallet (88 in. by 54 in.)
(e) TF34 engines on stand

If internal carriage of the rotor blade creates an adverse impact upon the aircraft design, external carriage may be considered. External carriage of blades up to 420 in. long should be examined.

D. Surveillance

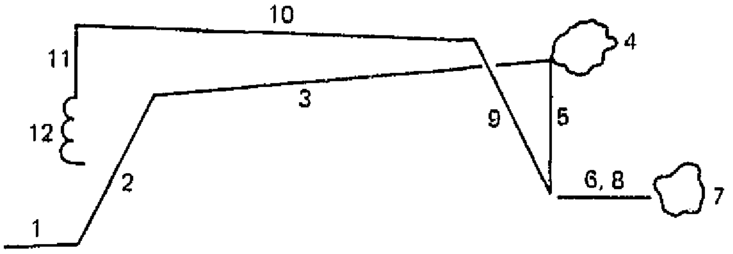


Conditions: STO with 400 ft deck run and vertical landing both at 89.8° F. Ten kn WOD for takeoff. All fuel consumption to be calculated at standard day conditions.

Loading: Mission avionics

1. Warmup, takeoff, and acceleration to climb speed—2-1/2 min at intermediate thrust. Installed sea level static conditions.
2. Climb—to BCAV at intermediate thrust
2. Cruise—to radius at BCAV
4. Loiter—on station 4 hr at best endurance speed at 25 000 ft or higher
5. Cruise—to point of takeoff at BCAV
6. Descend—to sea level. No fuel used, no time or distance credit
7. Landing allowance and reserve—Fuel for:
   (a) 10 min loiter at best endurance speed at sea level
   (b) 5% total initial fuel

E. Combat (strike) search and rescue (CSAR)



Loading: (2) AIM-9, Mini gun and 1000 rounds ammo (production gun turret system) (all retained) and 600 lb Armour.

Conditions: STO with 400 ft deck run, midpoint hover, and vertical landing at 89.8° F. All fuel consumption to be calculated at standard day conditions.

Note: External fuel permitted if within STO capability; tanks dropped when empty or prior to hover, whichever occurs first.

1. Warmup, takeoff, acceleration to climb speed—2-1/2 min at intermediate thrust. Installed sea level static conditions.
2. Climb—to BCAV at intermediate thrust
3. Cruise—to 350 nmi at BCAV less distance covered in climb
4. Loiter—20 min at optimum altitude and airspeed
5. Descent—to sea level, no fuel used, no time or distance credit
6. Dash—50 nmi at sea level, M = 0.8 to pickup area
7. Personnel pickup—fuel allowance for 10 min hover at sea level (OGE) pickup two personnel (400 lb)

8. Dash—at M = 0.8, 50 nmi at sea level
9. Climb—to BCAV at intermediate thrust
10. Cruise—at BCAV to point of takeoff, 350 nmi less distance covered in climb
11. Descend—to sea level. No fuel used, no time or distance credit.
12. Landing allowance and reserve—fuel for:
    (a) 10 min loiter at best endurance speed at sea level
    (b) 5% total initial fuel