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

VOLUME II

TECHNOLOGY AIRCRAFT

BY
V/STOL AIRCRAFT ADVANCED ENGINEERING

PREPARED UNDER CONTRACT NO. NAS 2-5499 BY

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FOR
AMES RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

SUMMARY

This report presents results of Part II of a study by McDonnell Aircraft Company for NASA Ames Research Center and the U.S. Navy to define a Lift/Cruise Fan V/STOL Technology Aircraft. The objective of Part II of the study was to define technology flight vehicles for at least three different approaches which could demonstrate the concept and characteristics of the multipurpose aircraft established for the Navy missions and described in NASA CR-137678. The three vehicle design approaches are:

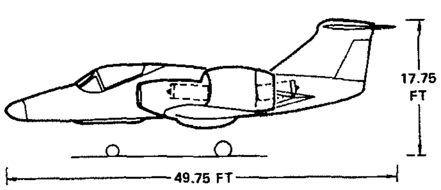
- Approach 1: New Airframe - Full flight envelope
- Approach 2: Modified Aircraft - Full flight envelope
- Approach 3: Modified Aircraft - Limited flight envelope

The propulsion system used for the various technology flight vehicles was representative of that established for the multipurpose aircraft. Existing J97-GE-100 gas generators were selected based on cost, availability and exhaust characteristics. The LF459 fans were also selected and are compatible with both technology and operational vehicles. To comply with the design guideline safety criteria, it was determined that three gas generators were required to provide engine out safety in the hover flight mode. The final propulsion system established for the technology aircraft was three existing J97 gas generators powering three LF459 fans. This system is identical to the one designed for the multipurpose vertical-on-board delivery aircraft defined in Part I of this study. The selected propulsion system can also be operated in the two gas generator/three fan mode which is representative of the multipurpose ASW aircraft.

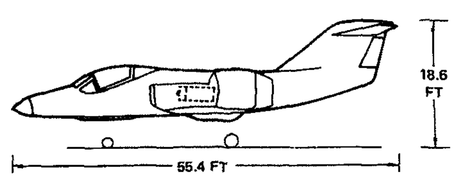
Initially eight different aircraft candidates were evaluated for application to the three designated design approaches. Each configuration was evaluated on the basis of (1) propulsion system integration, (2) modification required, (3) pilot's visibility, (4) payload volume (50 ft^3), and, (5) adaptability to compatible location of center-of-gravity/aerodynamic center and thrust center. This list of candidates was reduced to five, all of which were capable of meeting the applicable design guideline requirements.

The aircraft configured for the full flight envelope, Approaches 1 and 2, are illustrated below. The vehicle selected for Approach 1, designated "New Airframe",

APPROACH 1 AND 2 AIRCRAFT



Approach 1: New Airframe

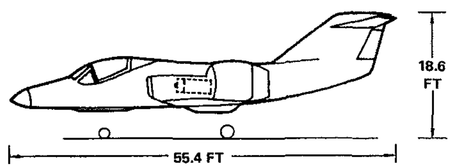


Approach 2: Composite

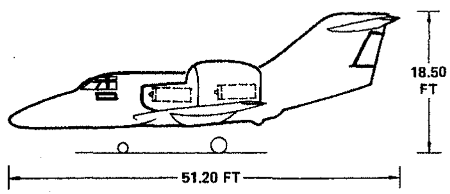
was a new airframe but still used a number of existing parts to minimize cost. These existing airframe components were A-6 cockpit and canopy, modified A-6 stabilizer and A-4 landing gear. The vehicle selected for Approach 2, designated "Composite", consisted of a more extensive usage of existing airframe components integrated by means of a new fuselage center section. The major existing airframe components were F-101 aft fuselage and empennage, A-6 wing, A-6 cockpit and canopy, and A-4 inlets and landing gear. Both aircraft were designed to meet the full flight envelope and are nearly identical to the multipurpose ASW aircraft.

Three technology aircraft were configured for the limited flight envelope, Approach 3, and are illustrated below. The Composite (low speed version) is identical to the Approach 2 version except that the landing gear is fixed in the down position and the associated systems and fairings are removed. The modification to the Sabreliner consisted of installation of the propulsion system, F-101 aft fuselage and empennage, and fixed A-4 landing gear. The modification to the Voodoo

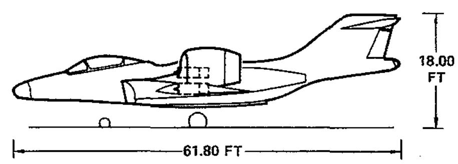
APPROACH 3 AIRCRAFT



Composite (Low Speed Version)



Sabreliner



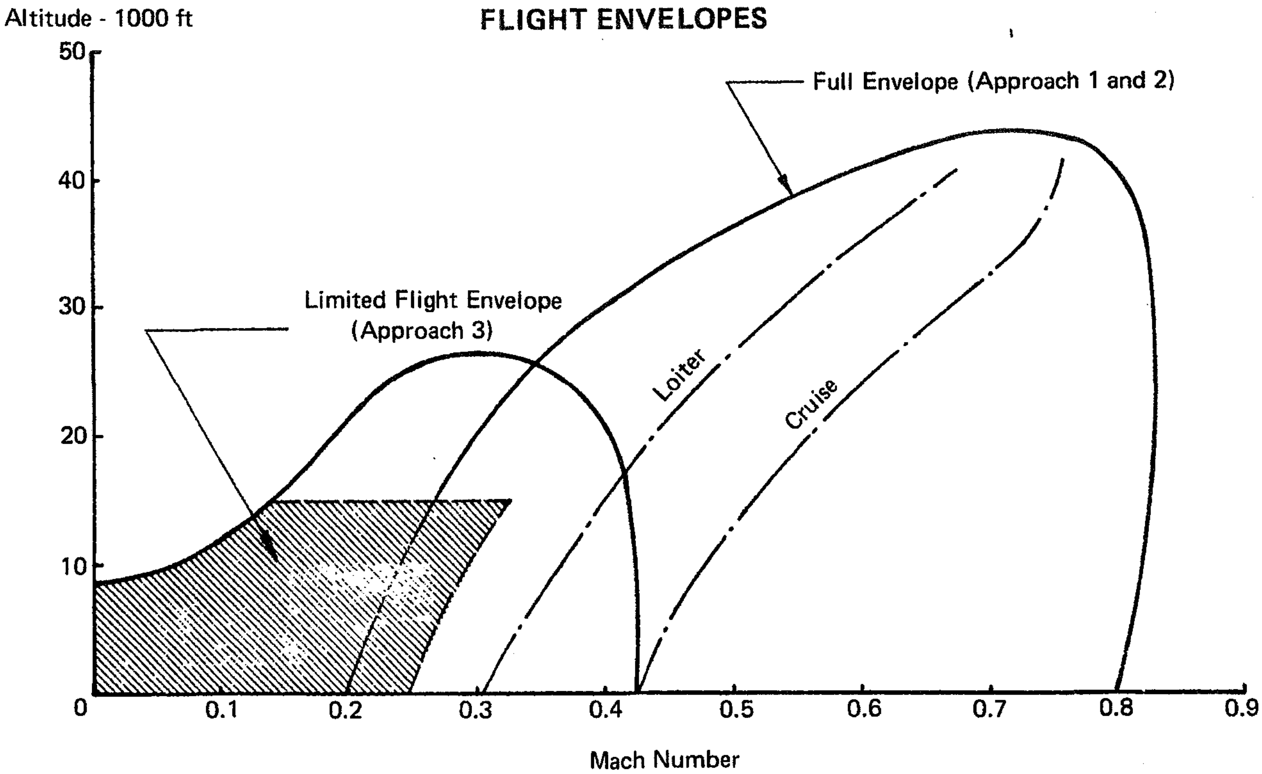
Voodoo

consisted mainly of removal of a 75 inch section of the forward fuselage to obtain proper fan spacing and installation of the propulsion system. Although the Voodoo selected is a single place aircraft, it was retained due to the minimum modifications required and the attendant low cost. All three aircraft configurations were designed to meet the specified low speed flight envelope (approx 160 KEAS and 15,000 ft altitude).

Mission performance analyses were conducted for the selected aircraft and compared to the design guideline requirements for VTOL circuits, STOL circuits and Cruise/Endurance. The New Airframe, Composite and Sabreliner exceeded or essentially met all the individual mission requirements. The Voodoo was slightly below the VTOL and STOL circuit requirements and would require refueling or increased TOGW. The flight envelope and mission performance for the selected technology aircraft are shown on page iv.

As evidenced by the performance characteristics, the New Airframe approach exhibits the best potential for a technology demonstrator aircraft based on applicability to an operational aircraft, maximum research productivity and demonstration of Navy oriented missions. The Composite aircraft is also representative of the multipurpose aircraft and can easily be configured from a low speed to a high speed version by minimum modifications. All the selected vehicles are viable candidates but only the New Airframe and Composite are capable of adequately demonstrating the high speed characteristics which are of importance in both operational relevance and propulsion system exposure. Budgetary estimates were prepared for each of the aircraft based on an austere development and flight test program and are presented in Addendum 1 to MDC Report No. A3440, Vol II.

FLIGHT ENVELOPES



CANDIDATE AIRCRAFT PERFORMANCE SUMMARY

	CAND A/C / REQMT	VOODOO	SABRELINER	COMPOSITE	NEW AIRFRAME
VTOL CIRCUIT	~30 MIN	19	37	23	39
	~5 CIRC	3	7	4	8
STOL CIRCUIT	~60 MIN	45	49	58	63
	~11 CIRC	9	10	12	13
CRUISE/ENDURANCE TOS (STO)	~ 2 HRS	2.3	2.7	3.5	4.2

GP75-0013-166

- VTOGW Limited to 28,000 lb for Hover Safety
- Payload = 2500 lb

INTRODUCTION

Recent studies by the Navy and NASA 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 capable of sea control operations from many platforms as well as ship-to-shore and shore-to-ship functions. The objectives of this study may be summarized as follows:

Part I: Define a multimission V/STOL aircraft for use by the U.S. Navy in the 1980's.

Part II: Define alternate approaches for developing a flight vehicle to demonstrate the proposed lift cruise fan concept.

The results of this study are reported in the following three volumes:

Volume I - Navy Operational Aircraft
Volume II - Technology Flight Vehicle Definition
Volume III - Technical Data Addendum.

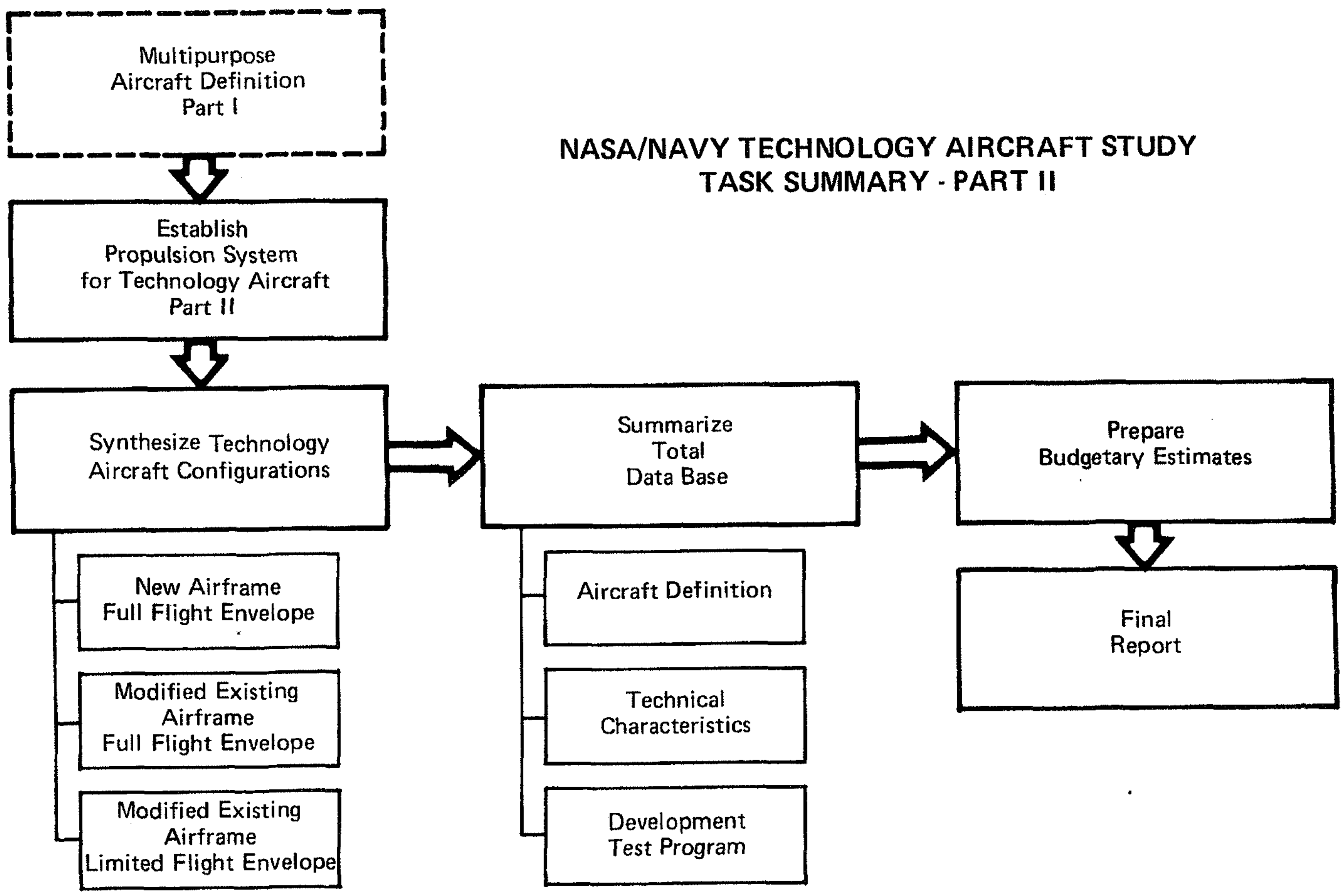
This volume defines the technology aircraft programs proposed to assess the benefits of the multipurpose aircraft designs generated in Part I of the study. The major test objectives of the technology aircraft program are to:

- o Develop integrated propulsion/control system for a V/STOL aircraft.
- o Evaluate this concept in powered lift and aerodynamic flight regimes.
- o Exploit the benefits of the lift/cruise fan system.
- o Define future V/STOL aircraft design requirements.
- o Obtain operational experience.
- o Develop operating techniques.
- o Serve as a facility for control/propulsion system tests.
- o Provide the capability to perform experiments related to terminal area operation with advanced stabilization, guidance, and navigation systems.

In accordance with the Statement of Work, the design definition study was directed toward a minimum cost research program consistent with providing maximum research productivity, Navy operational demonstration capabilities, and proper attention to safety. The specified Design Guidelines are presented in Appendix A of the report.

The propulsion system selected for all the technology vehicles was three existing gas generators powering three LF459 fans and the system description and selection rationale are presented in Section 2. Section 3 presents the description, avionic suites, weight analysis, and data base summary for the selected technology flight vehicles. The mission capabilities were determined and compared to the design guideline requirements and are presented in Section 4. A detailed analysis of aircraft control and handling qualities was performed for each aircraft and is summarized in Section 5. Excess control margins are provided in all axes for research purposes. An austere development test program was established for the aircraft and is presented in Section 6.

The tasks performed in this Part II study are shown in the following Work Flow Diagram.



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List of Illustrations

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LIST OF PAGES

Symbols and Abbreviations

ACS	-	Active Control System
AR	-	aspect Ratio
b, b_w	-	wing span, ft.
C_D	-	drag coefficient
C_{D_o}	-	zero lift drag coefficient
C_{D_f}	-	equivalent skin friction coefficient
C_L	-	lift coefficient
CFE	-	Contractor Furnished Equipment
CNI	-	Communication, Navigation, Identification
CSD	-	Constant Speed Drive
deg	-	degree
e	-	Oswald efficiency factor
EGT	-	Exhaust Gas Temperature, degrees
ETaC	-	Energy Transfer and Control
f	-	drag area, ft^2
ft	-	feet
FPR	-	Fan Pressure Ratio
g	-	gravitational constant, 32.2 ft/sec.
GW	-	gross weight, lb
GFE	-	Government Furnished Equipment
GSE	-	Ground Support Equipment
K	-	induced drag factor
KEAS	-	equivalent airspeed, kt
L/D	-	lift to drag ratio
lb	-	pounds
m	-	meters
M	-	Mach number
M/I	-	ratio of control moment to moment of inertia, radians per sec^2
MAC	-	mean aerodynamic chord
N	-	Newtons
NM, nm	-	nautical miles
OWE	-	operating weight empty, lb
S	-	area, ft^2
SCM	-	Signal Conversion Mechanism
SFC	-	specific fuel consumption, lb/hr/lb

Symbols and Abbreviations (Cont'd)

SL	-	sea level
STO	-	Short Takeoff
STOL	-	Short Takeoff and Landing
S_W	-	wing area, ft^2
t/c	-	airfoil thickness ratio
TDPR	-	Turbine Discharge Pressure Ratio
TOGW	-	Takeoff Gross Weight, lb
TRM	-	Thrust Reduction Modulation
T/W	-	thrust to weight ratio
V	-	aircraft velocity
V_j	-	effective jet velocity, ft/sec
VL	-	Vertical Landing
VTO	-	Vertical Takeoff
VTOGW	-	Vertical Takeoff Gross Weight, lb
VTOL	-	Vertical Takeoff and Landing
V/STOL	-	Vertical/Short Takeoff and Landing
λ	-	taper ratio
$\Lambda_{c/4}$	-	sweep angle of quarter chord, deg.
ρ	-	density
ρ_j	-	jet exhaust density, lb/ft^3

1. DESIGN REQUISITES

1.1 DESIGN GUIDELINES AND CRITERIA

Attachment I of the Statement of Work provides basic design guidelines and criteria for the design definition of the lift cruise fan technology V/STOL aircraft (Appendix A). These specified requisites pertain to general design and mission requirements, flight safety, and operating criteria. Handling qualities including control power, conversion, stability and engine out criteria are also prescribed. The technology aircraft handling qualities are specified to be consistent with AGARD-R-577-70 and MIL-F-83300. The aircraft are to be considered in the Class II category; and Level I handling qualities are to be provided for normal operation with no failures. The fulfillment of these detail design requirements was the ultimate goal for the lift cruise fan V/STOL aircraft design effort. Certain fundamental V/STOL aircraft design approaches and requisites must be complied with to assure achievement of this goal. These fundamentals are addressed in the following paragraphs.

1.2 CONFIGURATION INTEGRATION

The lift cruise fan aircraft configuration selected for both the multipurpose and the technology aircraft is the culmination of extensive R&D effort including wind tunnel test substantiation. Three pneumatically interconnected tip turbine driven fans are spaced longitudinally and laterally to maximize control and provide symmetrical lift following an engine failure. Fan spacing also permits compensation for suck-down while in ground effect by fountain forces. Lift cruise fans are positioned on top of a low wing at the fuselage-wing root juncture to provide power induced lift in STO and transition, to reduce power direct trim moments and to minimize the V/STOL structural penalty; i.e., the basic wing structure remains intact. A low wing position is also widely accepted as the optimum for civil transport aircraft. A T-tail empennage was selected based on wind tunnel test results which showed that this design provided optimum stability and control contributions over the operational angles of attack, retained adequate control power at post wing stall angles of attack, and minimized trim stabilator changes with thrust vectoring. The large installed thrust (T/W = 1.05); the aero-propulsion ground effects; and the minimization of trim moments by judicious location of the thrust, weight and aerodynamic centers, place added emphasis on power effects in all flight modes.

1.3 RELATIONSHIP OF THRUST, WEIGHT & AERODYNAMIC CENTERS

A major requisite for V/STOL aircraft configuration viability is compatible locations of the aircraft thrust center (TC), weight center (CG), and wing aerodynamic center (AC). The neutral point (NP) rather than the AC is the appropriate aerodynamic criterion since it defines the stability level and must be aft of the CG. However, the AC is specified since it is readily estimated early in the design layout process. Coincident TC and GG locations forward of the NP are required to minimize the weight penalties associated with control provisions for all operating flight modes. In vertical flight (VTOL), the thrust and weight centers must coincide. Large thrust vector deflections generally are required to provide efficient horizontal acceleration forces for STO and for transition. Design considerations of space and control often dictate horizontal and vertical spacings of lift units. Improper spacing or displacement of the vectored thrust can cause large trim moment variations which must be trimmed by differential thrust modulation or by thrust vector scheduling. In aerodynamic flight, the cruise stability margin (no stability augmentation) for the technology aircraft was specified to be 5 per cent Mean Aerodynamic Chord at the critical center of gravity.

The tri-center relationship is often difficult to achieve. All three centers are mutually dependent upon component locations that are specified or restricted to achieve increased aerodynamic, propulsive and structural efficiencies. Each center is established by a myriad of design considerations such as vectoring efficiencies; equipment, fuel and stores location; and, basic aircraft component integration. The complexity of this center criterion is compounded when attempting to adapt or integrate existing aircraft components into a V/STOL flight test vehicle capable of demonstrating the concept and mission capability. V/STOL aircraft performance and handling qualities are more configuration dependent than CTOL aircraft. This sensitivity requires that the technology vehicle be representative of the multi-purpose aircraft in-so-far as is practical if relevance is desired.

2. PROPULSION

2.1 SYSTEM SELECTION

The Statement of Work required the propulsion system designed for the technology flight vehicle to reflect, as near as practical, the system defined in Volume I for the multipurpose aircraft. Specific operational capabilities were also required following any reasonable failure of a power plant or control system component, excluding a fan. These engine-out requirements are as follows:

- STOL Flight Mode - Takeoff completion plus continuing sustained flight with positive acceleration/climb gradients.
- Vertical Flight Mode - Sustained hover at contractor specified gross weight; at gross weights in excess of sustained hover gross weight provide control and limit landing velocity to 12 fps; provide T/W = 1.03.
- Provide Level 2 flying qualities

The existing J97-GE-100 gas generator (GG) was selected for the technology vehicles based on its operational characteristics, availability and attendant low cost. Aircraft performance is based on dry ratings only. The estimated additional lift margin or VTO growth potential with water injection included in this section is only for information. The LF459 turbotip driven fan, defined for the multipurpose aircraft, was selected as it is adaptable to both existing J97 and growth J97 gas generators and to either 2 or 3 gas generator configurations. These major propulsion elements are representative of the multipurpose aircraft.

Both two and three gas generator configurations were evaluated in fulfilling the critical requirement for an "engine-out" emergency landing during vertical operations with 2500 lb payload plus mission fuel. Figure 2-1 shows the estimated maximum structural plus subsystem weights (excluding propulsion) allowable for engine out condition versus VTOL operating time. These curves served as a basis for determining potential aircraft candidates and indicate that for a VTOL operating time of 30 minutes (guideline) the weight should not exceed approximately 3,000 lb for a twin engine aircraft, and 13,000 lb for a three engine design. With zero VTOL operating time the maximum allowables are 6,500 and 17,500 lb respectively. Estimated structural plus subsystems weights of the candidate aircraft are superimposed on the permissible weight curves in Figure 2-1 and indicate the desirability of three gas generators in accommodating the engine out guideline and in expanding the number of airframes capable of being modified for the technology aircraft.

An assessment of critical exposure time to gas generator failure, when operating at weights above hover capability, was also investigated for the two engine aircraft at a gross weight of 24,000 lb. The study indicated an exposure time of 5.5 seconds in performing a vertical takeoff and acceleration to 80 knots (critical air speed) and an exposure time of 12.0 seconds during deceleration from 80 to 0 knots. The total exposure time of 17.5 seconds represents approximately 6.5 percent of the time required to perform a typical VTOL circuit described in the guidelines. Aerodynamic flight with engine out exhibits no critical exposure time.

Despite this low exposure time, a three gas generator system, Figure 2-2, was selected since it not only expanded the candidate aircraft selections but provided

FIGURE 2-1
PERMISSIBLE AIRCRAFT WEIGHT (STRUCTURE + SUBSYSTEMS)
Technology Aircraft Candidates - One Gas Generator Inoperative

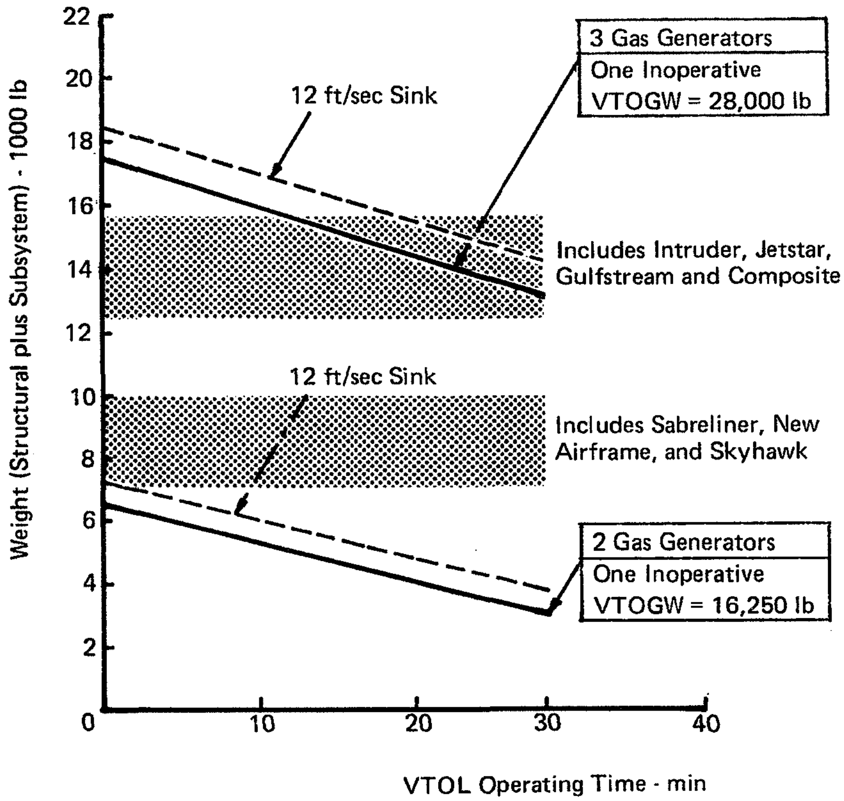
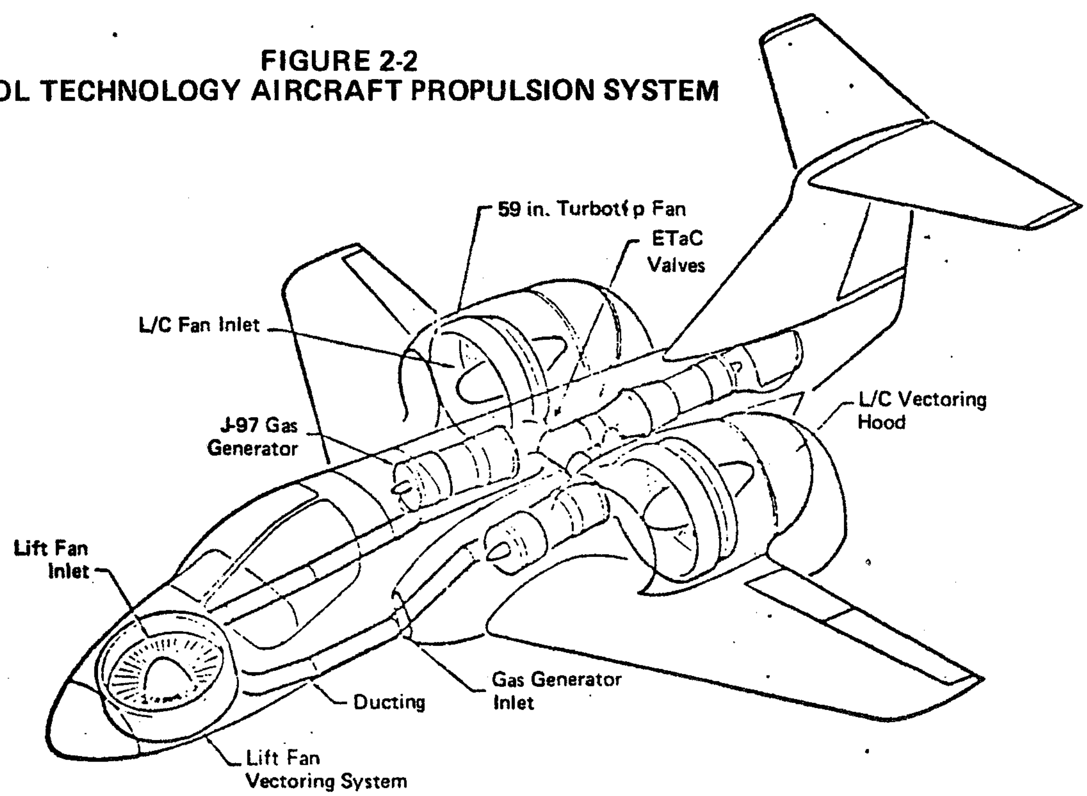


FIGURE 2-2
V/STOL TECHNOLOGY AIRCRAFT PROPULSION SYSTEM



complete engine-out safety appropriate for a research vehicle. In the event of gas generator failure during powered lift flight, the throttles of the remaining two engines are advanced to satisfy the required thrust level. The aircraft VTOL gross weight (28,000 lb) is established by the (2) G.G. emergency dry rating, S.L. 89.8°F day. Sustained three G.G. hovering at this gross weight level is permissible since the emergency rating time period is sufficient to permit acceleration to flight velocities where the available intermediate thrust exceeds the thrust required level. The two GG sustained hover gross weight is 25,516 lb, established by the intermediate rating. By limiting the VTOGW to 28,000 lb, complete engine out safety and adequate handling qualities are provided for all aircraft evaluated during this study. Additional "V" capability is available at a slightly higher risk since the installed thrust is adequate for VTOGW up to 34,300 lbs.

The selected system is representative of the multipurpose VOD and will allow demonstration of multipurpose aircraft characteristics and facilitate significant V/STOL research. Some of the desirable characteristics of a multipurpose aircraft which may be evaluated are:

- Fan jet efflux velocity and temperature compatible with unimproved landing sites, and rescue operation
- Attitude control and hover maneuvering capability
- Single engine loiter capability
- Engine out safety
- VTOL, transition and STOL performance

Research areas include:

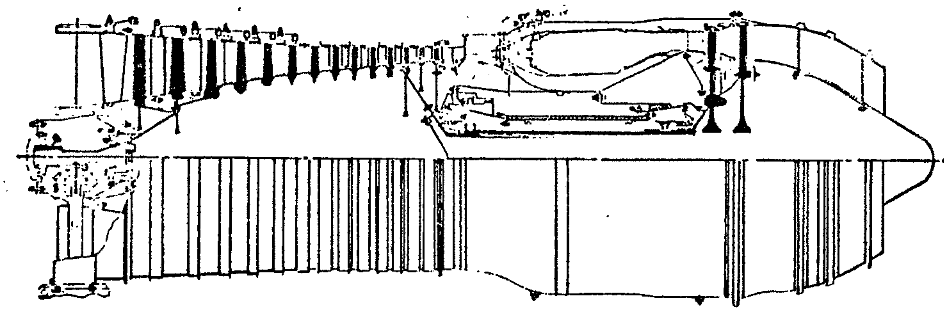
- Both two and three gas generator operation including engine out
- Investigate operation of future uprated gas generators, i.e. water injection
- V/STOL noise research including suppression treatment effects
- Terminal area navigation
- Control authority necessary for operations from air capable ships

2.2 GAS GENERATOR/FAN DESCRIPTION

The J97-GE-100, Figure 2-3, is a single-spool turbojet with a 14-stage compressor, an annular combustor, and a two-stage turbine. This engine has been tested in a full scale ETaC program at MCAIR which demonstrated VTOL control performance and compatibility of the J97, including the fuel control system, with ETaC. The third (centerline) gas generator is normally used for VTOL only and is shut down during aerodynamic flight.

Identical LF459 fans are used at each of the locations, one lift fan in the forward fuselage and two over-the-wing lift/cruise fans. The forward fan is used for VTOL flight only and is shut down during cruise. The LF459 is a single-stage 1.32 pressure ratio fan with a single-stage turbine mounted directly to the fan tip which extracts power from the gas generator exhaust gases to drive the fan.

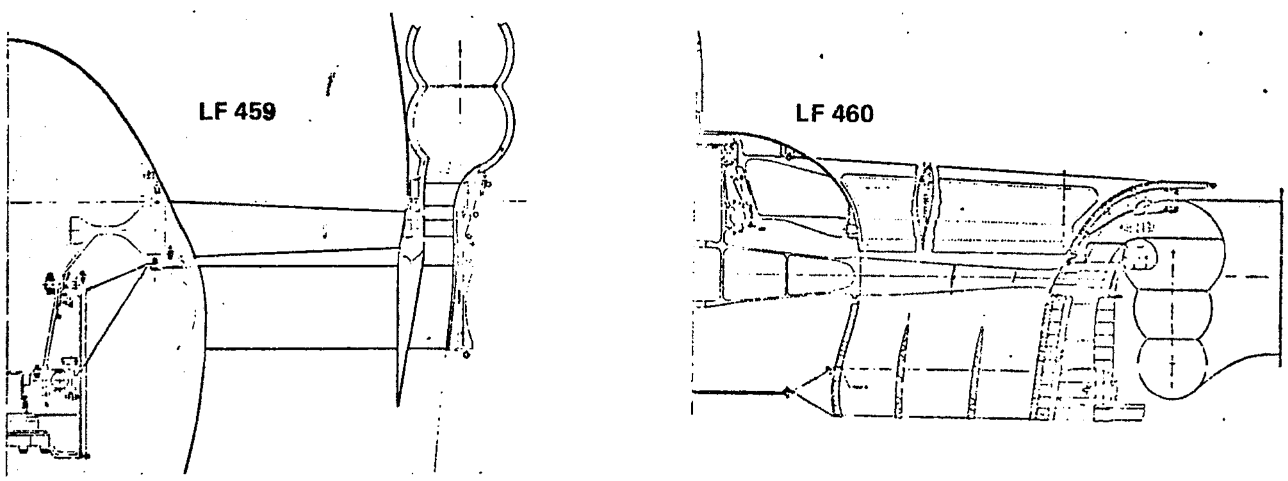
FIGURE 2-3
J-97 GAS GENERATOR



Inlet Airflow	70.0 lb/sec
Exhaust Temperature	1374°F
Exhaust Pressure	51.6 lb/in.^{2}
Ideal Gas HP	13,450
Ideal Gas HP/lb of Airflow	192 HP/lb/sec
Ideal Gas HP/lb of Weight	18.6 HP/lb

This fan concept has been flight demonstrated in the XV-5 aircraft. An 80-inch diameter, 1.3 FPR model has been tested, producing a thrust of 28,000 lb. The LF459 fan, Figure 2-4, is derived from the LF460 technology with design changes to reduce risk and suit the multipurpose aircraft requirements. Design improvements include substitution of a downstream combination stator/strut/frame for the forward strut/frame of the LF460, thereby deleting the need for anti-icing provisions. Other changes include a reduction in number of blades, reduced blade aspect ratio, air inlet angle and scroll shape for cruise fan applications, and deletion of the noise attenuation material.

FIGURE 2-4
LF 459 FAN - DERIVED FROM LF 460 TECHNOLOGY



Fan Characteristics S.L. 59°F - Uninstalled	LF 459	LF 460
Fan Pressure Ratio/TDPR	1.32/1.30	1.35/1.13
Airflow (lb/sec)	624	617
*Thrust (lb)	16,310	15,050
*SFC	0.350	0.321
Weight	700	789
Thrust/Weight (Fan Only)	23.3	19.1
Thrust/Weight (Fan + GJ97)	10.9	9.85

*Includes 3% Derate

2.3 THRUST VECTORING AND THRUST MODULATION SYSTEMS

The lift and lift/cruise fans are each equipped with thrust vectoring and Thrust Reduction Modulation (TRM) systems. Thrust direction in the aircraft vertical (X-Z) plane is mechanically controlled such that during vertical takeoff through transition to wingborne flight thrust moments are cancelled leaving full pitch control available at any powered flight condition. Thrust is also vectored transversely (side force) for yaw control during powered lift mode. Thrust modulation devices reduce the thrust as required at any one or two of the three fans during pitch or roll control demands only.

The lift fan thrust vectoring system is shown in Figure 2-5. Lateral louvers vector exhaust flow in the X-Z plane from 15° forward of vertical to 60° aft, and longitudinal vanes vector exhaust flow transversely ±8° for yaw control. The longitudinal vanes function as closure doors after transition to aerodynamic flight. The fan is tilted forward 15° to improve air inlet performance and to reduce the peak thrust deflection required in the vertical plane.

Figure 2-6 shows the lift/cruise fan thrust vectoring nozzle concept. Rotating hood segments vector thrust from 105° to 0° (cruise) in the X-Z plane and longitudinal vanes vector thrust ±4° in the transverse direction for yaw control. The yaw vanes close during aerodynamic flight. A thrust modulation port in each nozzle reduces thrust as required during roll/pitch control applications only.

FIGURE 2-5
FORWARD FAN VECTORING SYSTEM

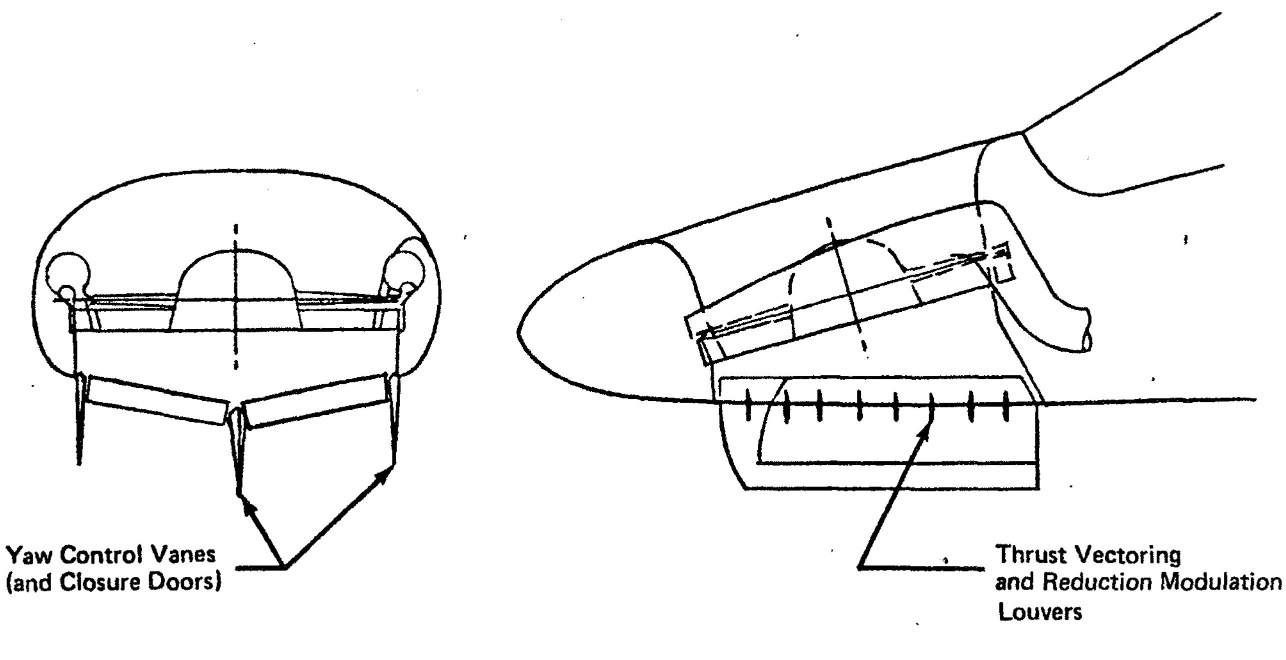
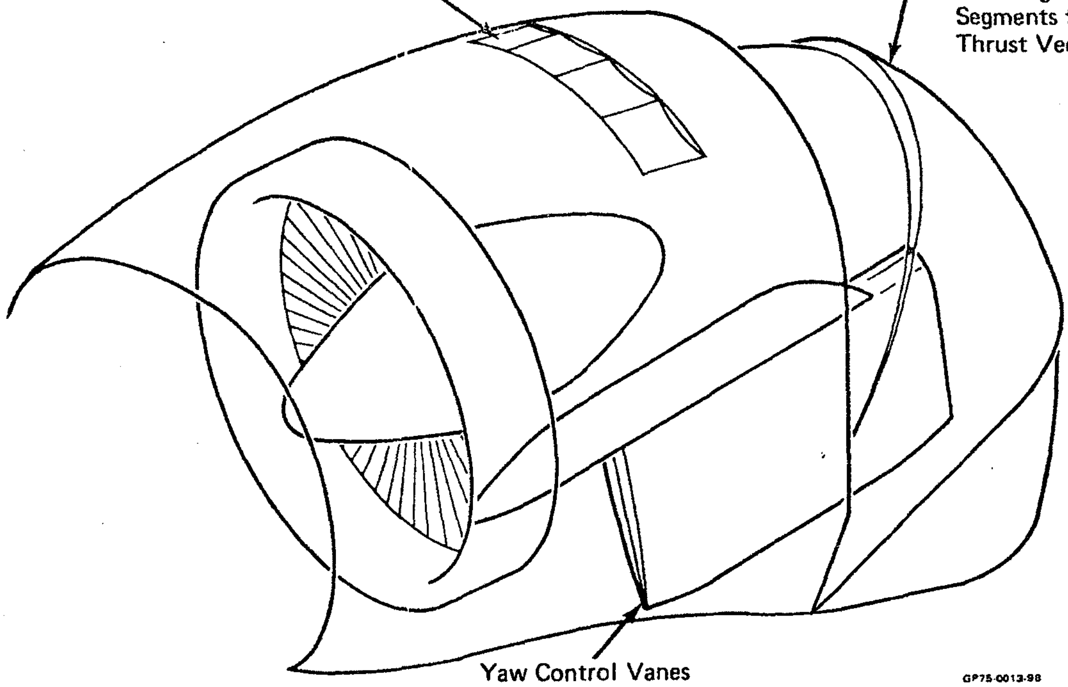


FIGURE 2-6
LIFT/CRUISE THRUST VECTORING SYSTEM



2.4 ENERGY TRANSFER AND CONTROL (ETaC) SYSTEM

Energy transfer and control of the power generated by the three gas generators is accomplished with the gas interconnect ETaC system shown schematically in Figure 2-7. The system is designed to distribute the total power available, whether it be from two or all three of the gas generators to the lift and lift/cruise fans as necessary during all modes of operation. During STOL and VTOL operation, ETaC delivers gas power to each of the three fans as necessary to produce balanced thrust (lift) and roll and pitch attitude control. Yaw control is achieved with lateral thrust deflection vanes in the thrust vectoring systems downstream of each fan. During wingborne or conventional flight, gas power is delivered only to the two lift/cruise fans and attitude control is accomplished with conventional aerodynamic aircraft control surfaces. In the event of engine failure or shutdown of any one of the gas generators, the ETaC system isolates the failed engine from the distribution system and continues to distribute the total remaining gas power available to the fans.

Energy transfer to accomplish pitch or roll control in the VTOL mode is shown in Figure 2-8. With a control application for pitch-nose up, the ETaC valves for the aft (lift/cruise) fan modulate, reducing flow to these fans, causing a transfer of gas and increase in power to the forward fan. The resulting increase in back-pressure to the gas generators is compensated by a momentary increase in engine fuel flow, commanded by the engine fuel control, to maintain constant engine speed. The attendant increase in gas pressure, temperature, and flow produce a momentary

FIGURE 2-7
GAS GENERATOR/FAN ETaC INTERCONNECT SYSTEM

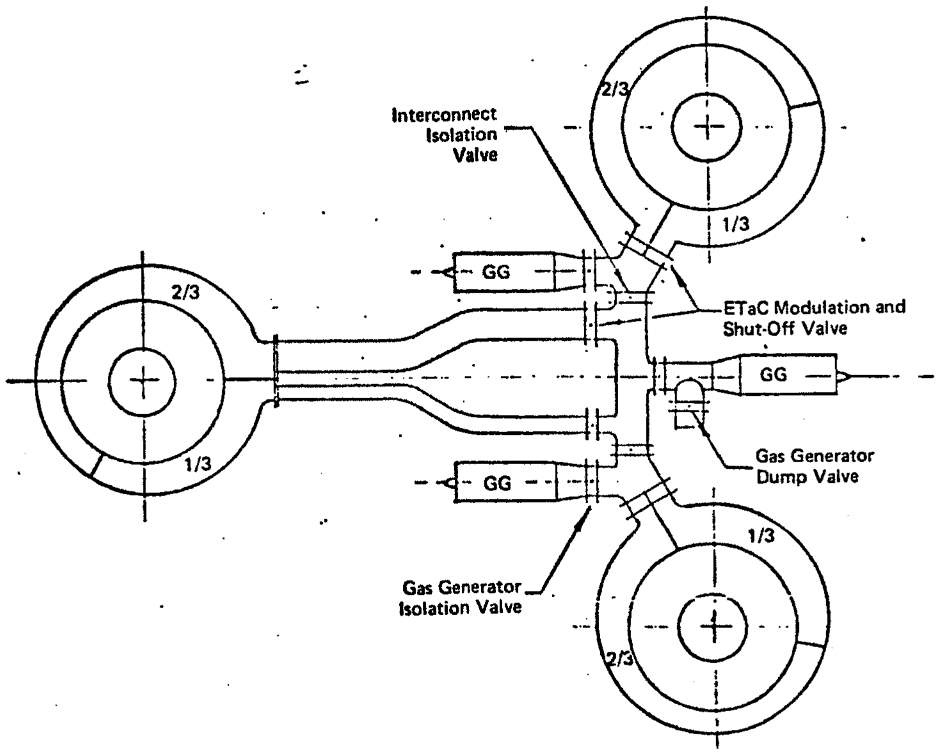
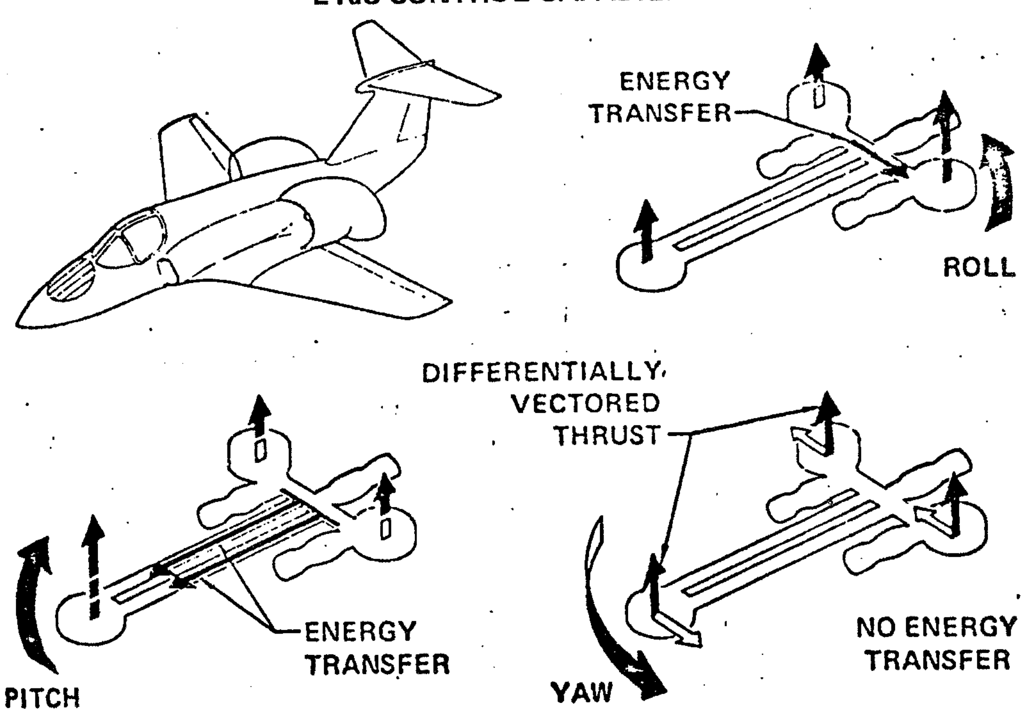


FIGURE 2-8
ETaC CONTROL CAPABILITY



increase in the total power and lift available as shown in Figure 2-9(a). Thrust reduction modulation is employed at the aft fans to cancel the temporary increase in lift, Figure 2-9(b). Roll control is effected by the ETaC system in a manner similar to pitch control with the exception that power transfer and thrust modulation takes place only at the aft lift/cruise fans. Yaw control is accomplished with thrust vector vanes and requires no energy transfer.

Use of only a Thrust Reduction Modulation (TRM) system for control results in a lift penalty since a portion of the available power must be reserved for control. ETaC uses the inherent capability of the gas generator to produce short term energy increases for control power transients. This feature allows use of maximum available lift since the attitude control is accomplished by extracting transient power (at constant RPM) from the gas generator. The characteristics of these two control approaches is illustrated in Figure 2-10. The principles and characteristics of ETaC were conclusively demonstrated with actual YJ97 gas generators in a full scale test at MCAIR.

FIGURE 2-9
ETaC PERFORMANCE CHARACTERISTICS

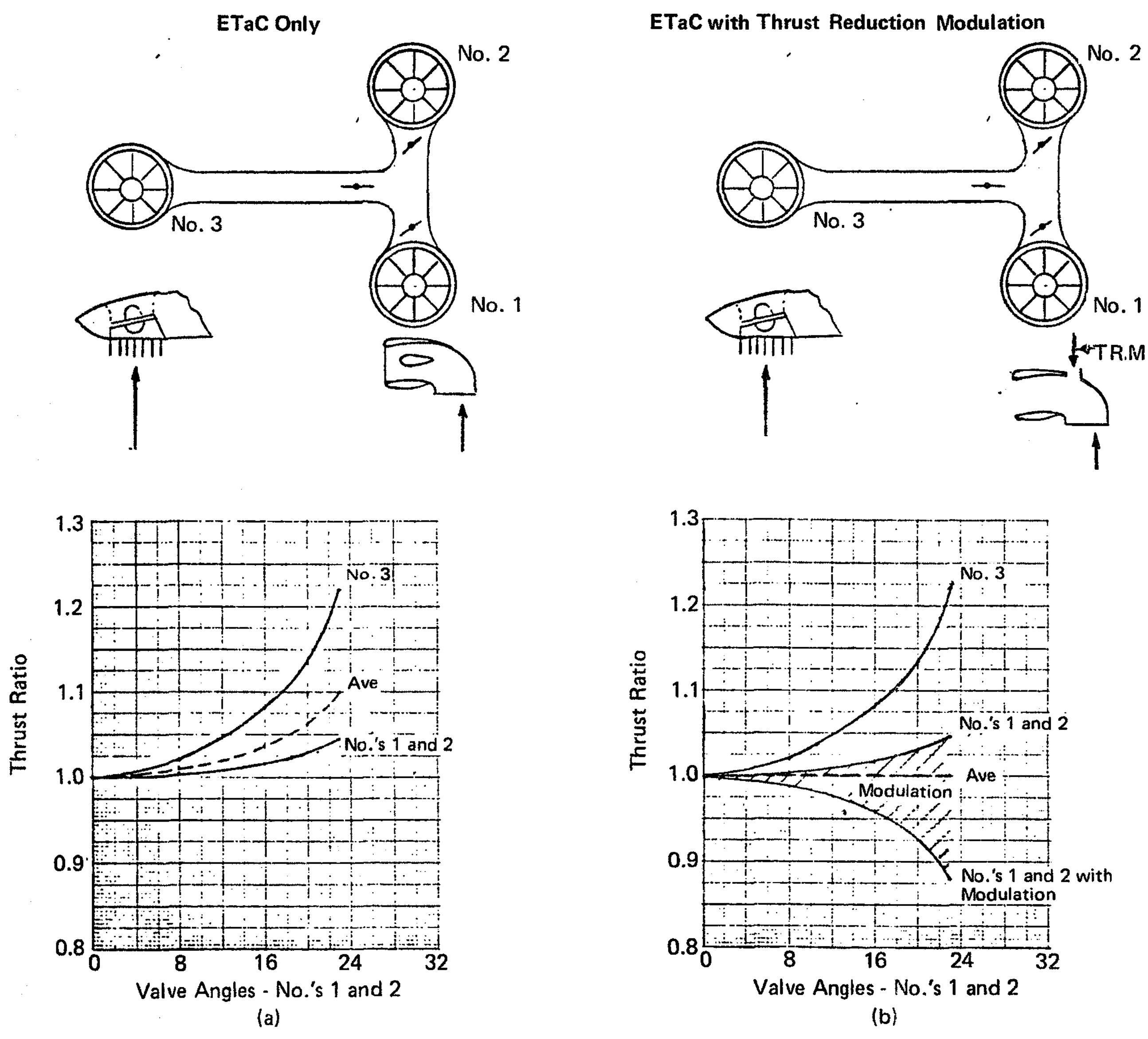
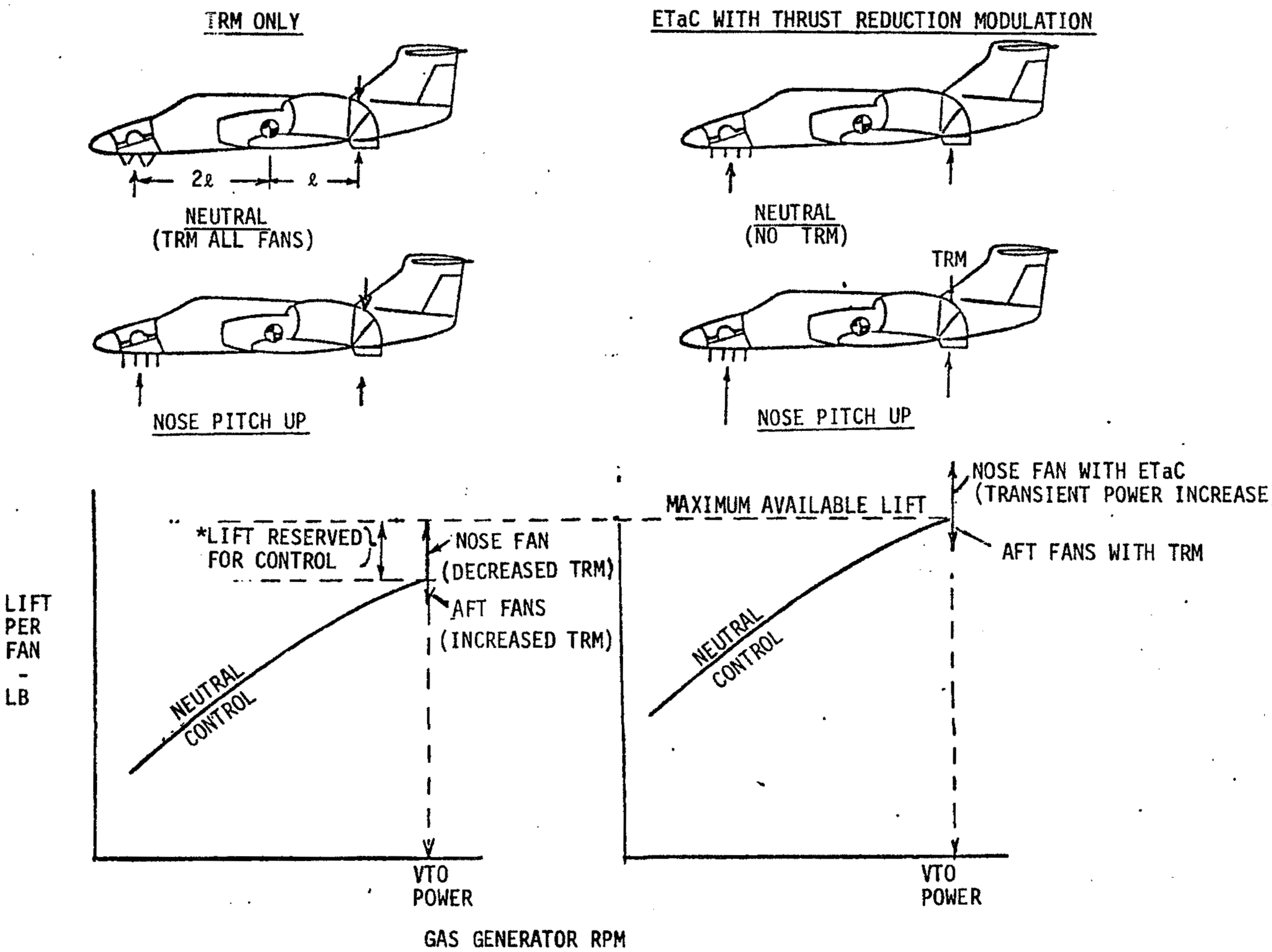


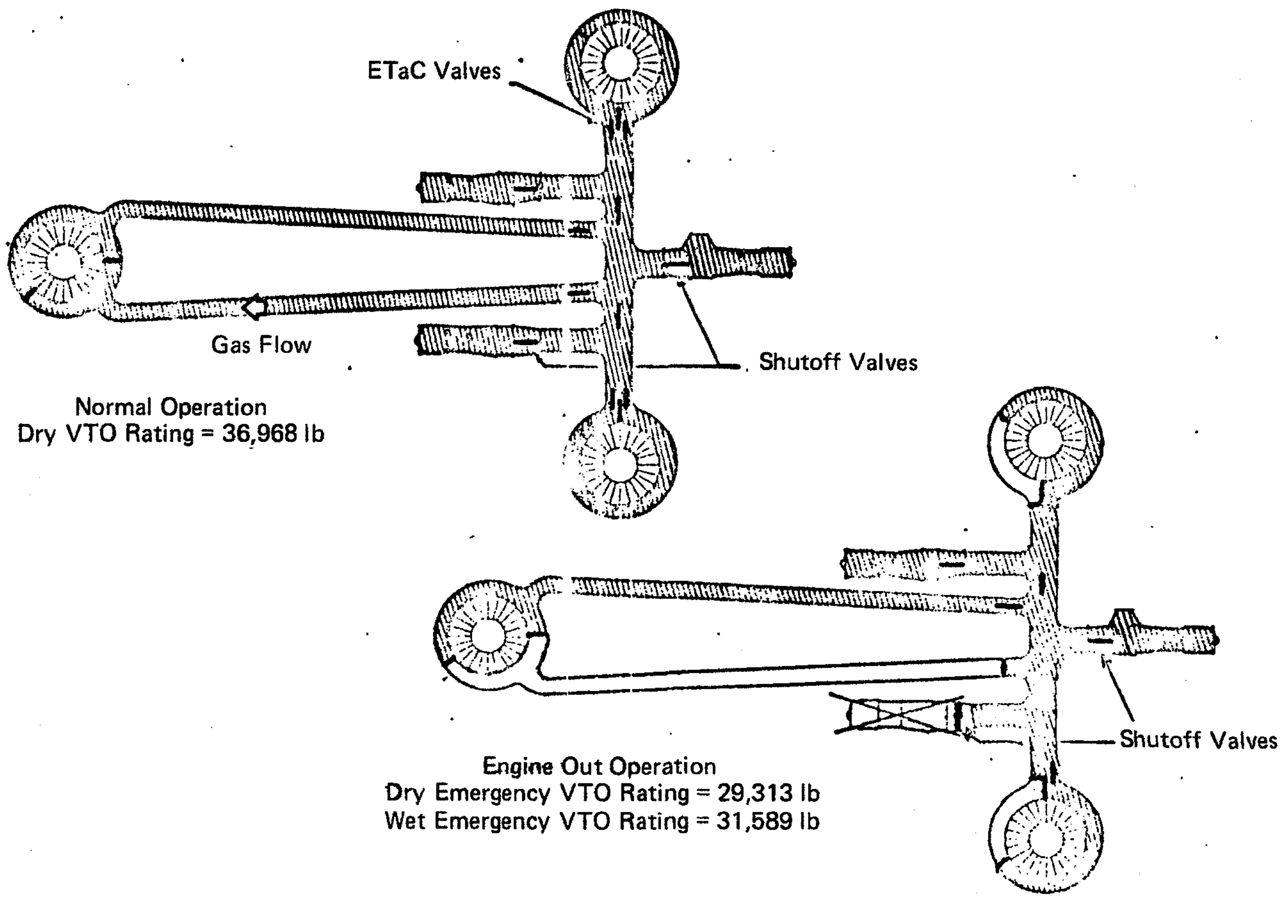
FIGURE 2-10
ETaC UTILIZES MAXIMUM AVAILABLE LIFT
(PITCH - NOSE UP EXAMPLE)



*SAME PENALTY APPLIES TO ALL NON ENERGY TRANSFER SYSTEMS

Safe operation is provided in the event of a gas generator failure since the ETaC duct and valve system allows redistribution of the gas flow uniformly to all fans. Figure 2-11 illustrates the valve positions following failure of a gas generator in the 3 GG/3 fan technology propulsion system. In this condition, the failed gas generator isolation valve is closed and 1/3 of each fan scroll is isolated. All of the remaining available gas flow is equally distributed to each fan to maintain balanced lift. The gas generator speed is allowed to increase to

FIGURE 2-11
SYMMETRICAL LIFT
Normal and Engine Out 89.6°F Day



emergency power level to increase engine out lift and adequate attitude control power is available. Besides the engine out safety aspects of the ETaC system, the thrust reduction modulation devices on the lift and lift/cruise vectoring systems provide a redundant control system in the event of loss of an ETaC function. This feature is discussed in Section 5.

ETaC also allows operation of one gas generator in the aerodynamic flight mode to accommodate an engine failure or for single engine loiter. In case of a fan failure, the failed fan can be isolated and the aircraft can be flown with one gas generator and one fan.

2.5 PROPULSION SYSTEM PERFORMANCE

The most critical performance requirement for the technology aircraft occurs during VTO "engine-out" and therefore determines maximum VTO gross weight. Figure 2-12 shows the normal and "engine-out" lift available with the 3 existing gas generator/3 LF459 fan system. Individual fan thrust for the same condition is presented in Figure 2-13 along with the most critical control requirements of the technology aircraft configurations. A large margin over the requirements is available during normal operation, Figure 2-13(a). Dry emergency rating provides adequate control margin for the "engine-out" condition as shown in Figure 2-13(b). The use of water injection offers the potential of increasing the "engine-out" control margin approximately 300% or increasing the VTOGW.

FIGURE 2-12
TECHNOLOGY AIRCRAFT
INSTALLED LIFT PERFORMANCE
SEA LEVEL, STATIC, 89.8°F

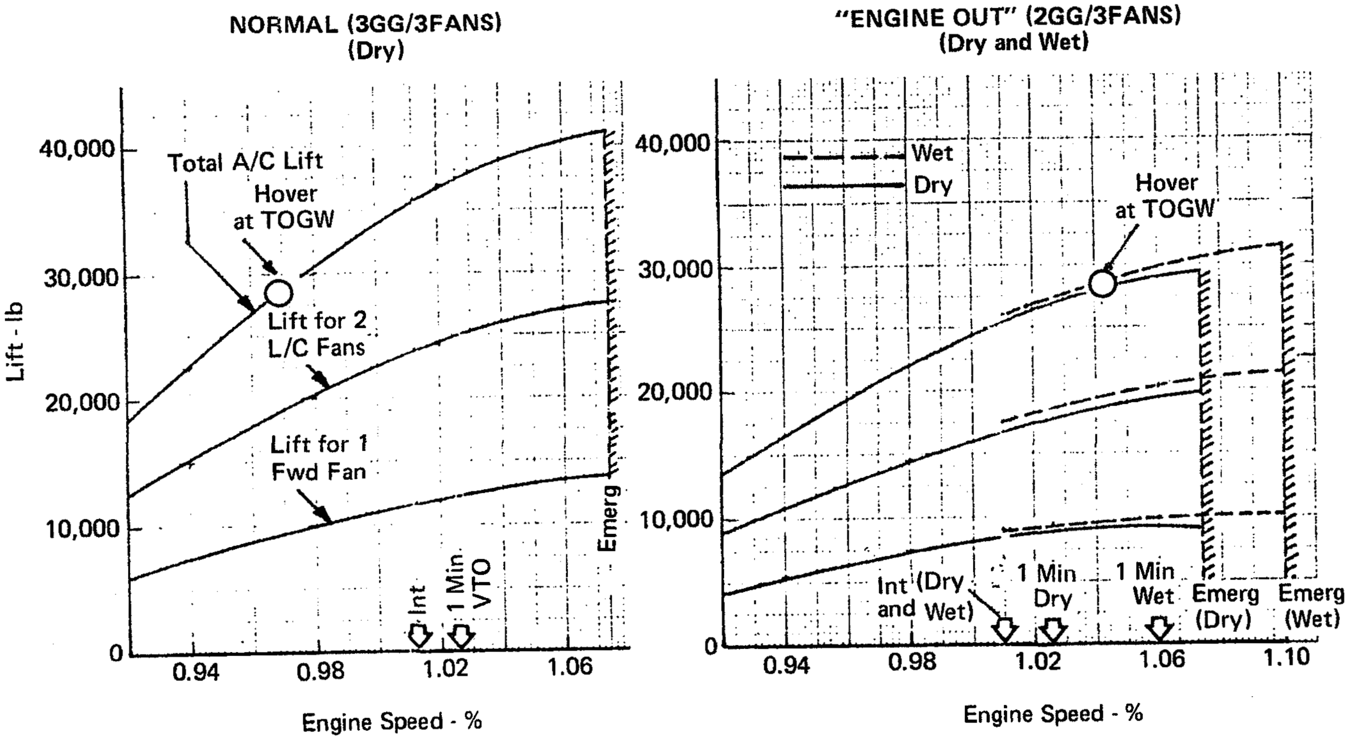
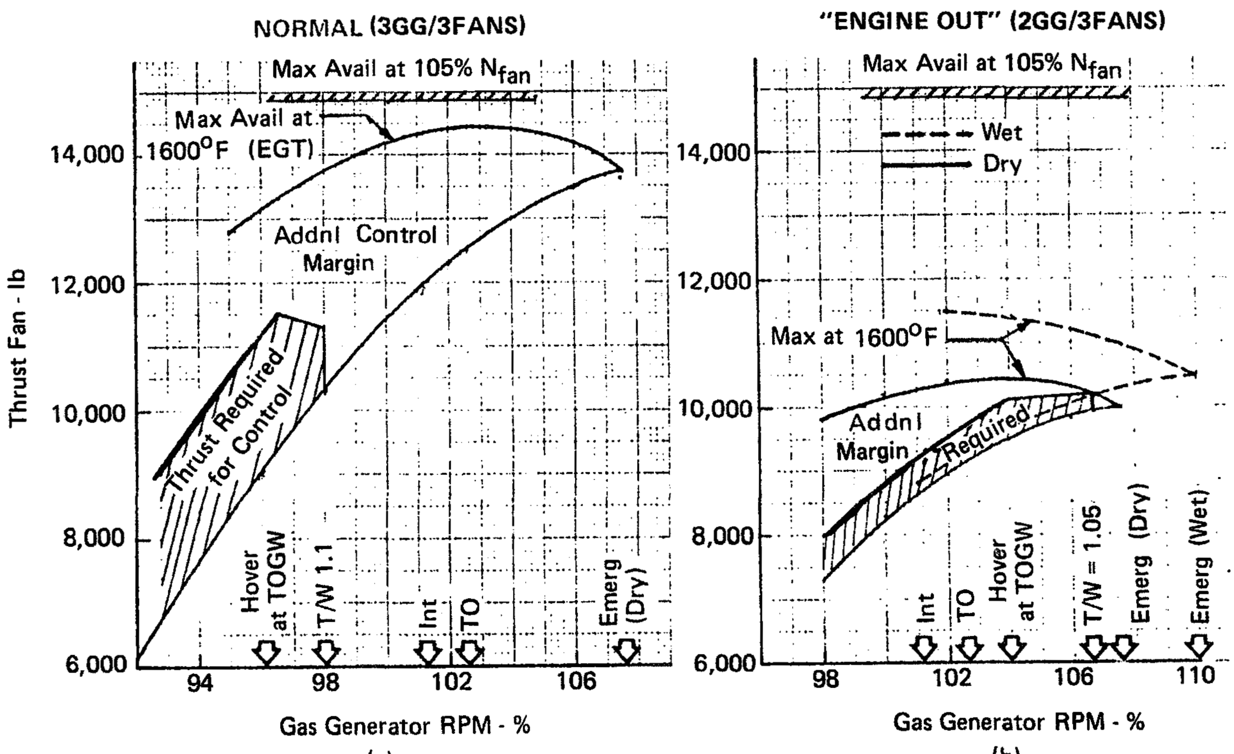


FIGURE 2-13
TECHNOLOGY AIRCRAFT CONTROL
Installed Sea Level 89.8°F Day



3. FLIGHT VEHICLE DESIGN

3.1 DESIGN GUIDELINES

The technology aircraft were designed to the Statement of Work requirements, Appendix A, and the V/STOL design requisites presented in Section 1. The guideline requirements which have a major impact on the aircraft designs are summarized in Figure 3-1. Other major considerations include the following:

- Configuration and propulsion system similarity with multipurpose aircraft
- Low program cost
- High research capability and productivity per dollar
- Low program risk, including basic design and modification complexity, reliability of new and existing components, and state of the art

FIGURE 3-1
MAJOR DESIGN REQUIREMENTS

Flight Safety Criteria	
T/W for Normal VTOL Operation	1.05 Note (1)
T/W for Engine Out, VTOL Operation	1.03 Note (2)
Control Powers in Emergency (% of Level 1)	45 to 70
Notes: (1) Intermediate gas generator rating (2) Emergency dry rating	
Propulsion System	
System Type	Remote Lift Fan
Gas Generator	J97-GE-100
Fan (Single Stage)	LF459 Type Note (1)
Design Fan Pressure Ratio	1.32 Note (1)
Note: (1) Per multipurpose design of Part I	
Payload/Mission	
Payload (lb)/ft^3	2500/50
VTOL Missions, Total (hr)	1/2
STOL Missions, Total (hr)	1
Cruise/Endurance, Total (hr)	2
Airframe	
Flight Load Factor	+2.5, -0.5 g
Sink Rate at Touchdown (Max. Landing Weight)	12 fps
Cockpit Pressurization	Full Envelope Configuration Only
Crew	2 Pilots with Ejection Seats
Visibility	Maximum Possible

3.2 CANDIDATE AIRCRAFT

Candidates for a technology flight vehicle were defined for each of the three approaches:

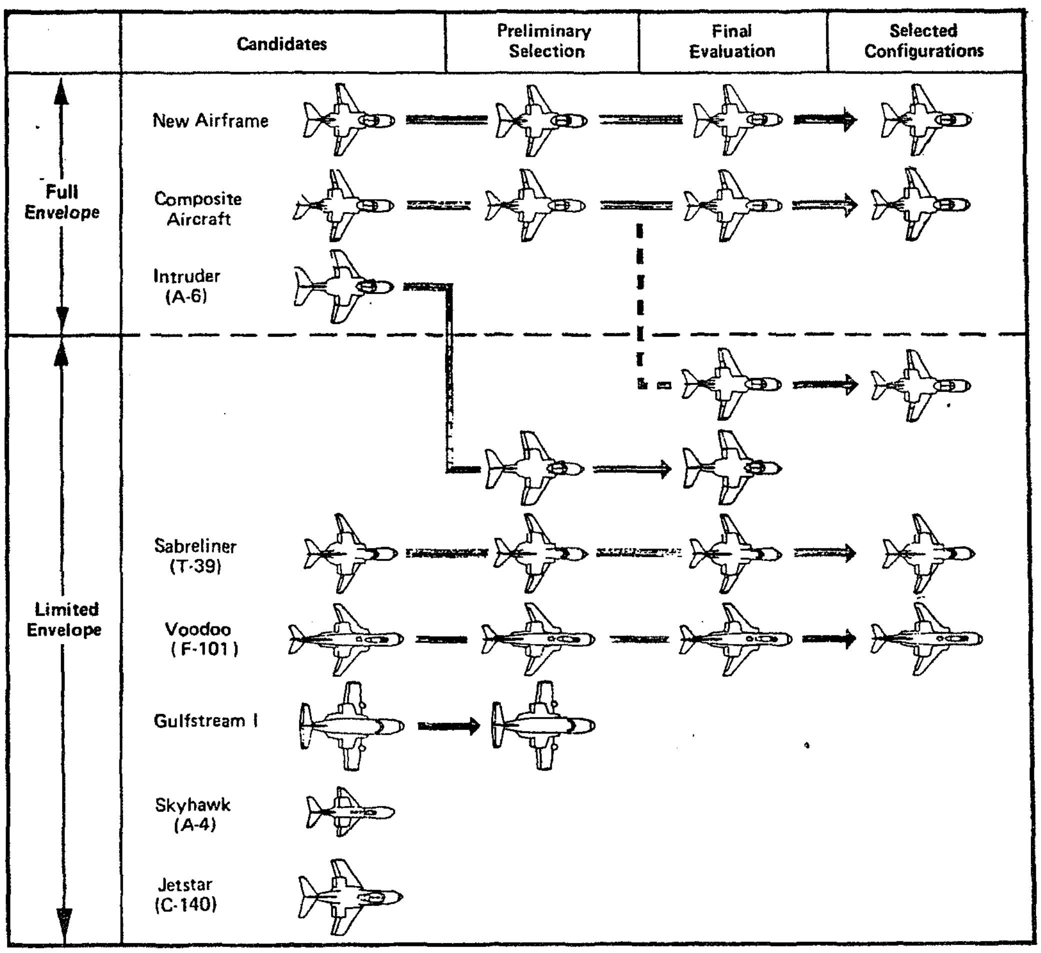
- o Approach 1: New Airframe - Full Flight Envelope
- o Approach 2: Modified Aircraft - Full Flight Envelope
- o Approach 3: Modified Aircraft - Limited Flight Envelope

Based on the design guidelines and selected propulsion system, a large number of existing aircraft were evaluated to establish candidates for Approaches 2 and 3.

Preliminary Selection

Figure 3-2 is a matrix showing the original candidates considered for the technology aircraft. They are divided into full and limited envelope categories to reflect the performance requirements specified in the Statement of Work. The Skyhawk (A-4) and the JetStar (C-140) were eliminated early in the selection process. The Skyhawk lacked the space required for a third engine, flight test

FIGURE 3-2
CANDIDATE AIRCRAFT STUDY MATRIX



equipment, and mission fuel, as well as requiring major airframe modifications. The JetStar was eliminated because of major changes required to the wing, cockpit, and landing gear, and because of the limited number in the military inventory. The Sabreliner required less modification, had an OWE approximately 6000 lb less than the JetStar, was more available, and offered adequate useful load capability for the guideline missions. Therefore, the JetStar was removed from the final list to be evaluated. Because of the complexity of modification to the Gulfstream 1, MCAIR was requested to delete this configuration from the list to be evaluated and priced, and to consider instead a low speed version of the Composite aircraft.

Side views of the five basic technology aircraft evaluated and priced are shown in Figure 3-3. Weights shown correspond to preliminary layouts of the configurations. The New Airframe most nearly reflects the multipurpose aircraft with the exception that it has three gas generators, utilizes an A-6 cockpit and stabilizer, and an A-4 landing gear. The Composite design incorporates a greater number of existing aircraft components, and the remaining aircraft are existing aircraft with varying degrees of modification or component substitutions. All versions have two pilots with the exception of the Voodoo, which is single place.

Configuration Refinement

The technology aircraft configurations were analyzed for stability and control requirements and adjusted accordingly. This consisted primarily of shifting the thrust center, center of gravity, and aircraft neutral point relationships to be within acceptable limits.

Additional changes to the New Airframe design included relocation of the main landing gear aft to improve tip-over angle, and relocation of the third engine exhaust to the lower surface with reaction loads passing through the center of gravity.

The Composite aircraft design underwent three basic changes; namely, the addition of a plug in the forward fuselage to improve stability, relocation of the third engine to the center section (facing forward), and payload repositioning. The above changes resulted in the desired forward shift of the center of gravity and thrust center. As mentioned earlier, a low speed version of the Composite aircraft was introduced, which differs from the full envelope design only in the landing gear installation. The same A-4 gear is installed in the locked-down position as opposed to being retractable and enclosed (faired) for cruise flight.

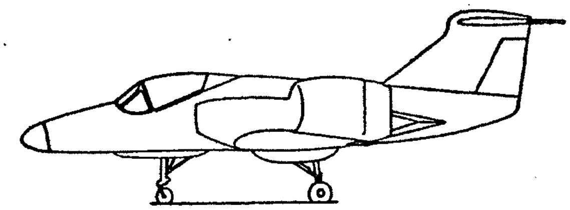
In the case of the Intruder the lift/cruise fans were moved forward to achieve the desired thrust center, and the fan scroll was placed above the wing mold line in order to avoid extensive wing modifications. Because of the reduction in inlet performance resulting from this change, the Intruder configuration was transferred to the limited flight envelope category. The Sabreliner configuration did not require further modification, and the lift/cruise fans on the Voodoo were shifted forward to attain proper cg/thrust center relationship.

Figure 3-4 is a summary of the major airframe components used in configuring the final six candidates. Annotations are included to indicate usage of existing or modified components.

FIGURE 3-3
FINAL EVALUATION
Technology Aircraft
VTOGW = 28,000 Lb

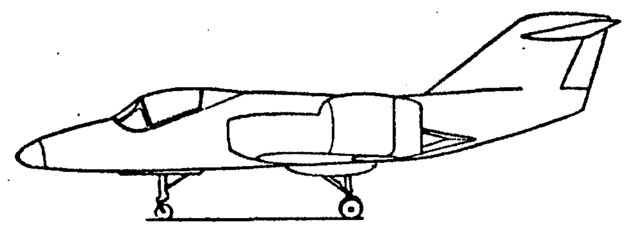
NEW AIRFRAME

Wing Area	368 ft^2	(34.19 m^2)
O.W.E.	18,247 lb	(81,163 N)
U.L.	9,753 lb	(43,381 N)



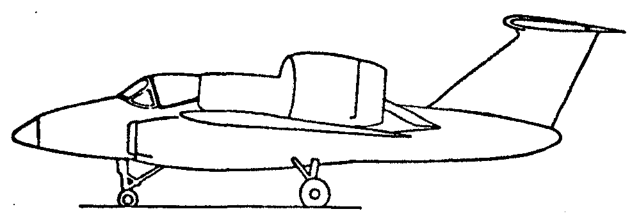
COMPOSITE AIRCRAFT

	High Speed	
Wing Area	368 ft^2	(34.19 m^2)
O.W.E.	21,116 lb	(93,924 N)
U.L.	6,884 lb	(30,620 N)
	Low Speed	
Wing Area	368 ft^2	(34.19 m^2)
O.W.E.	20,774 lb	(92,403 N)
U.L.	7,226 lb	(32,141 N)



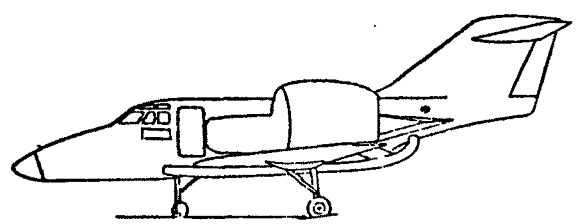
INTRUDER (A-6)

Wing Area	368 ft^2	(34,19 m^2)
O.W.E.	23,700 lb	(105,418 N)
U.L.	4,300 lb	(19,126 N)



SABRELINER (T-39)

Wing Area	342 ft^2	(31.77 m^2)
O.W.E.	18,640 lb	(82,911 N)
U.L.	9,360 lb	(41,633 N)



VOODOO (F-101)

Wing Area	368 ft^2	(34.19 m^2)
O.W.E.	21,899 lb	(97,407 N)
U.L.	6,101 lb	(27,137 N)

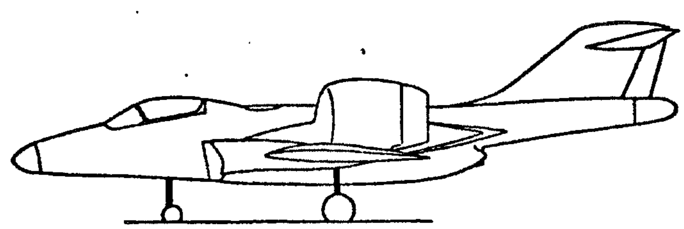


FIGURE 3-4
TECHNOLOGY AIRCRAFT CONFIGURATIONS
Major Component Summary

ALTERNATE CONFIGURATIONS	NOSE (FAN)	COCKPIT (NOTE 1)	FUSELAGE			VERTICAL TAIL	HORIZONTAL TAIL	LANDING GEAR	WING
			FWD	CTR	AFT				
NEW AIRFRAME	NEW	A-6	NEW	NEW	NEW	NEW	A-6 (MOD)	A-4	NEW
COMPOSITE	NEW	A-6	NEW	NEW	F-101	F-101	F-101	A-4	A-6 (MOD)
COMPOSITE (LOW SPEED)	NEW	A-6	NEW	NEW	F-101	F-101	F-101	A-4 (NOTE 5)	A-6 (MOD)
MODIFIED INTRUDER	NEW	EXISTING	EXISTING	MOD	NEW	NEW	MOD	EXISTING	MOD (NOTE 4)
MODIFIED SABRELINER	NEW	EXISTING (NOTE 2)	EXISTING (NOTE 2)	MOD	F-101 (MOD)	F-101	F-101	A-4 (NOTE 5)	MOD
MODIFIED VOODOO	NEW	EXISTING (SINGLE SEAT) (NOTE 6)	MOD (NOTE 3)	EXISTING	EXISTING	EXISTING	EXISTING	EXISTING	EXISTING

NOTES:
(1) NEW CONTROLS AND EQUIPMENT INSTALLATIONS REQUIRED FOR ALL VERSIONS. TWO PILOTS EXCEPT AS NOTED.
(2) OPTIONAL 2 ZERO/ZERO EJECTION SEATS. REQUIRES NEW COCKPIT AND FORWARD FUSELAGE
(3) 6.3 FT REMOVED AFT OF COCKPIT
(4) 6 FT REMOVED EACH WING TIP
(5) LANDING GEAR FIXED IN DOWN POSITION
(6) ZERO-ZERO SEAT REPLACES EXISTING EJECTION SEAT.

Final Evaluation

As shown in Figure 3-4, the New Airframe and Composite designs were considered as full envelope candidates while the Composite (low speed), Sabreliner, Intruder, and Voodoo were considered limited envelope candidates. A Sabreliner with zero-zero seats was included as an alternate version.

Figure 3-5 compares the "V" mission capability of the candidates when operating within the engine out VTOGW of 28,000 lb and carrying the 2500 lb payload. As noted, the Intruder is severely limited in total mission time, which results in an unacceptably low number of "V" circuits. Based on the results of this analysis, the Intruder was eliminated from the list of acceptable candidates for a technology aircraft.

FIGURE 3-5
"V" MISSION CAPABILITY
VTOGW (SL 89.8°F) = 28,000 Lb
Payload 2,500 Lb

	OWE LB	FUEL LB	VTOL MISSION TIME MIN. NOTE (1)	APPROX. NO. OF "V" CIRCUITS
NEW AIRFRAME	18,247	7,253	42	8
COMPOSITE	21,116	4,384	25	4
INTRUDER	23,700	1,800	9	1
SABRELINER	18,640	6,860	38	7
VOODOO	21,899	3,601	20	3

NOTE: (1) TOTAL TIME - VTOL MISSIONS

The characteristics of the remaining four basic aircraft are summarized in Figure 3-6. The STOGW's were determined by the maximum internal fuel capability plus the 2500 lb payload. With the exception of the Sabreliner, all have the same wing area as the multipurpose aircraft. The maximum control modulations are within acceptable limits in all cases. The pilot's visibility in each case exceeds that of the Harrier, which is 11 degrees over the nose and 40 degrees over the side.

FIGURE 3-6
CHARACTERISTICS SUMMARY
Final Evaluation

	New Airframe	Composite Aircraft	Sabreliner	Voodoo
STOGW (lb)	32,247	34,216	30,240	32,789
(N)	143,435	152,193	134,508	145,845
VTOGW (lb)	28,000	28,000	28,000	28,000
(N)	124,544	124,544	124,544	124,544
OWE (lb)	18,247	21,116	18,640	21,899
(N)	81,163	93,924	82,911	97,407
Wing Area (ft^2)	368	368	342	368
(m^2)	34.19	34.19	31.77	34.19
Internal Fuel Capacity (lb)	11,500	10,600	9,100	8,400
(N)	51,152	47,149	40,477	37,363
Visibility (deg)				
Over the Nose	16.5	16.5	15	15 (max)
Over the Side	53	53	53	44 (max)

3.3 NEW AIRFRAME - FULL FLIGHT ENVELOPE

The general arrangement of the New Airframe designed for the technology aircraft, Approach 1, is shown in Figure 3-7, and the principal weights and geometric characteristics are presented in Figure 3-8. With the exception of the third engine and deletion of wing fold, the configuration and geometry are essentially identical to that of the multipurpose aircraft. The three fans and three gas generators are interconnected into a duct and valve system identical in concept to the multipurpose aircraft. The thrust vectoring and control systems are also essentially identical to those of the operational aircraft.

FIGURE 3-7
NEW AIRFRAME

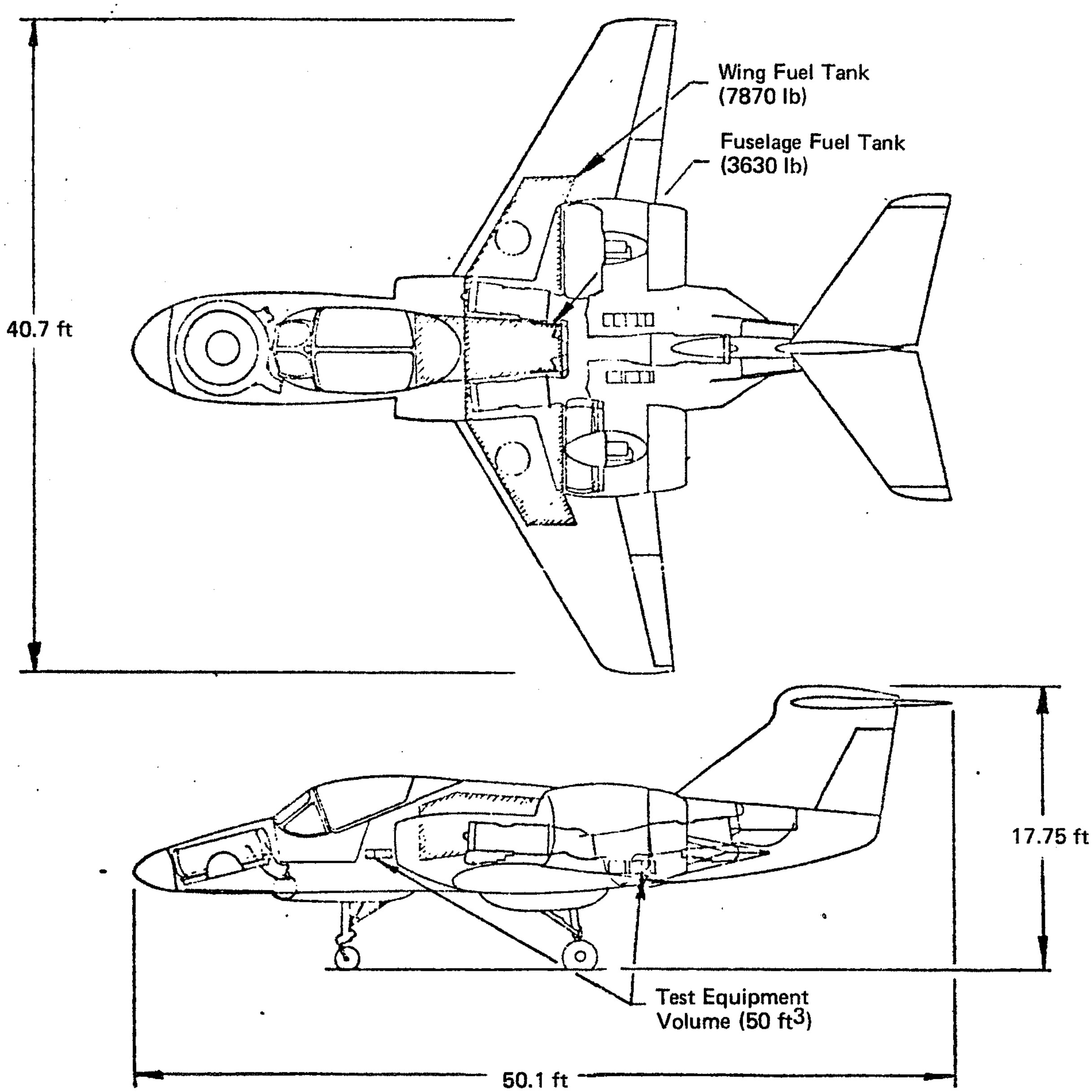


FIGURE 3-8
DIMENSIONAL AND DESIGN DATA
New Airframe Technology Aircraft

STOGW	(lb)	32,247
	(N)	143,435
VTOGW	(lb)	28,000
	(N)	124,544
OWE	(lb)	18,247
	(N)	81,163
Overall Length	(ft)	50.1
	(m)	15.27
Wing Span	(ft)	40.7
	(m)	12.41
Height	(ft)	17.75
	(m)	5.41
Crew Provisions	(No.)	2
Max. Internal Fuel	(lb)	11,500
	(N)	51,152

	Wing	Horizontal Tail	Vertical Tail
S (ft^2)	368	107.1	68.0
(m^2)	34.19	9.95	6.32
AR	4.5	3.38	0.69
λ	0.3	0.42	0.43
b (ft)	40.7	19.0	6.83
(m)	12.41	5.79	2.08
$\Lambda_{c/4}$	25.0	30.0	45.5
t/c (% Root/Tip)	17.38/8	A-6	10
Airfoil	Supercritical (Modified)	A-6	63AXXX

<u>Propulsion System</u>

The propulsion system is composed of three GE LF459 fans, three GE-J97-100 gas generators, and an interconnecting gas ducting system with valves for distribution control as presented in Section 2. Two gas generators are enclosed in nacelles adjacent to the center fuselage and in close proximity to the lift/cruise fans. The third engine is located in the aft fuselage on the aircraft centerline, facing aft. A plenum chamber is provided for air induction and a firewall is incorporated for engine isolation. The lift/cruise fans are fitted with inlets that enclose the fan scrolls, and a rotating hood vectors thrust from horizontal through vertical for cruise and "V" flight modes respectively. Vanes are incorporated in the exit for yaw control. The lift fan in the nose receives air through an inlet in the upper mold line and exhausts through a set of louvers to provide fore and aft thrust vectoring. Yaw vanes are used to vector thrust sideways. The thrust vectoring systems are illustrated in Section 2.

Each of the three gas generators is equipped with an air turbine starter that can be driven either by a pneumatic ground cart source or by bleed air from the J97 gas generators in flight. In the event the third engine is shut down in aerodynamic flight, start air is supplied by the lift/cruise engines.

Flight Controls

Dual sets of conventional stick and rudder controls are provided in a side-by-side arrangement and are supplemented by power and transition control levers. The flight control baseline system is a triplex control-by-wire system referred to as an Active Control System (ACS) and is described in Section 5. Three electrical power supplies and three hydraulic systems are provided. Switching valves are used between the hydraulic systems at all flight critical power actuators. The hydraulic flight control actuators are of the dual tandem type. The power management controls are mechanical.

Fuselage

The fuselage and engine nacelles are conventional all metal semimonocoque structure. The center fuselage incorporates a carry-through wing and attach points for the cruise fans. Space is provided for flight test equipment aft of the cockpit and in the center fuselage. A fuel tank with capacity of 3630 lb is also installed in the center fuselage.

Cockpit System - The A-6 cockpit system is utilized in this configuration. This includes the canopy, canopy tracks, and locks as well as the two Martin-Baker seats relocated from a staggered to a side-by-side arrangement. Removal of consoles and most instrumentation is necessary to provide space for the dual installation. Pressurization is provided for the full operating envelope of the multipurpose aircraft. Visibility of 16.5 degrees over the nose and 53 degrees over the side is provided for both pilots.

Empennage

The vertical stabilizer and rudder are conventional all metal structure, and the horizontal stabilizer is an adaptation from the A-6. The A-6 torque tube is shortened approximately 16 inches and the surfaces faired to fit the vertical contours.

Wing

The wing, which has a modified supercritical airfoil, is conventional metal three spar construction with a carry-through torque box that serves as the main fuel tank. It has a capacity of 7870 lb. Conventional flaps and ailerons cover the entire span from nacelle to wing tip. Main gears are retracted into pods external to the mold line.

Landing Gear

Both the main and nose gears of the A-4 are adapted by attachment fittings external to the mold line. The attachment fittings are designed to provide the proper ground clearance and aircraft attitude. The A-4 retraction mechanism and control system are used without modification.

Fuel System

The fuel system employs a single point refueling arrangement. Double ended boost pumps assure fuel flow to the engines under all flight conditions and tanks are vented through merging pipes and a vent tank located in the vertical tail. The wing fuel tank, which serves as the feed tank, is partitioned by rib bulkheads located at the fuselage-wing junction and at the centerline. The juncture bulkheads are fitted with interconnect flapper check valves which limit the lateral excursion of fuel, and trap fuel in the center wing section when the wing is not level. The fuel system is configured for pressure fueling and defueling.

Hydraulic Systems

Three independent 3000 psi hydraulic systems are provided to support the triplex Active Control System (ACS) and utility requirements of the aircraft. Pumps are mounted on gas generators and/or lift/cruise fan accessory drive pads. Dual hydraulic actuators are provided for control of ailerons, flaps, rudder, stabilator, engine throttles, as well as all powered lift functions (pitch, roll, yaw, power, and vectoring).

Electrical Systems

Three independent electrical power supplies are provided to support the triplex Active Control System (ACS), utilities, avionics, and test instrumentation. AC generators (and CSD's) are mounted on gas generators and lift/cruise fan accessory drive pads. Transformer/rectifiers are used for DC power.

Avionics and Test Equipment

Avionics equipment is installed to perform communications and navigation functions required for the flight test program, and space is provided for future installation of equipment for experiments related to V/STOL terminal area operation, including advanced stabilization, guidance and navigation systems. The basic avionics selected are presented in Section 3.6.

Approximately 50 cu ft of space is provided in the fuselage to install the 2500 lb of test equipment specified in the guidelines.

Fire Detection and Extinguishing System

Fire warning sensors and extinguishing agent are installed in critical heat zones of the aircraft.

3.4 MODIFIED AIRCRAFT - FULL FLIGHT ENVELOPE

The general arrangement of the Composite aircraft designed for Approach 2 is shown in Figure 3-9, and its principal weights and geometric characteristics are presented in Figure 3-10. With the exception of the third engine and the increased fuselage length, the geometry closely approximates that of the multipurpose aircraft. The increased length is the result of using an existing (A-6) wing, which resulted in increased fan spacing, for tri-center coincident locations. In addition to the A-6 wing, the design also uses the A-6 cockpit system, the landing gear and engine

FIGURE 3-9
COMPOSITE AIRCRAFT

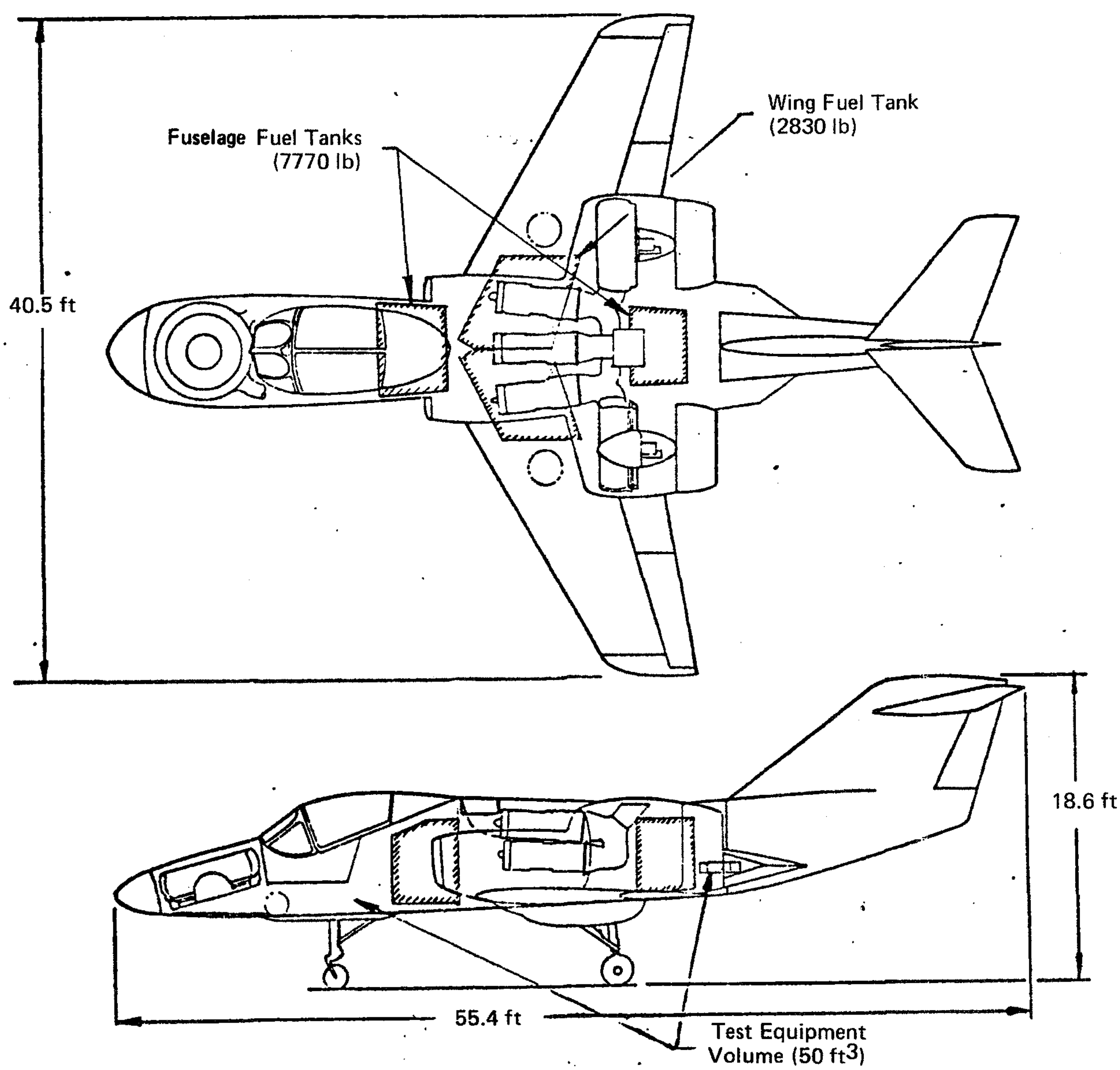


FIGURE 3-10
DIMENSIONAL AND DESIGN DATA
Composite Technology Aircraft

STOGW	(lb) (N)	34,216 152,193
VTOGW	(lb) (N)	28,000 124,544
OWE	(lb) (N)	21,116 93,924
Overall Length	(ft) (m)	55.4 16.89
Wing Span	(ft) (m)	40.5 12.34
Height	(ft) (m)	18.6 5.67
Crew Provisions	(No.)	2
Max. Internal Fuel	(lb) (N)	10,600 47,149

	Wing	Horizontal Tail	Vertical Tail
S (ft^2) (m^2)	368.0 34.19	75.1 6.98	84.88 7.89
AR	4.45	3.3	0.66
λ	0.39	0.46	0.51
b (ft) (m)	40.5 12.34	15.75 4.80	7.5 2.29
$\Lambda_{c/4}$ (deg)	25	35 3/4	46
t/c (% Root/Tip)	8.7/6.0	7.0/6.0	7.0/7.0
Airfoil	64A0XX Modified	65A0XX Modified	65A0XX

inlets of the A-4, and the F-101 empennage. Figure 3-11 indicates the new airframe required to integrate these components.

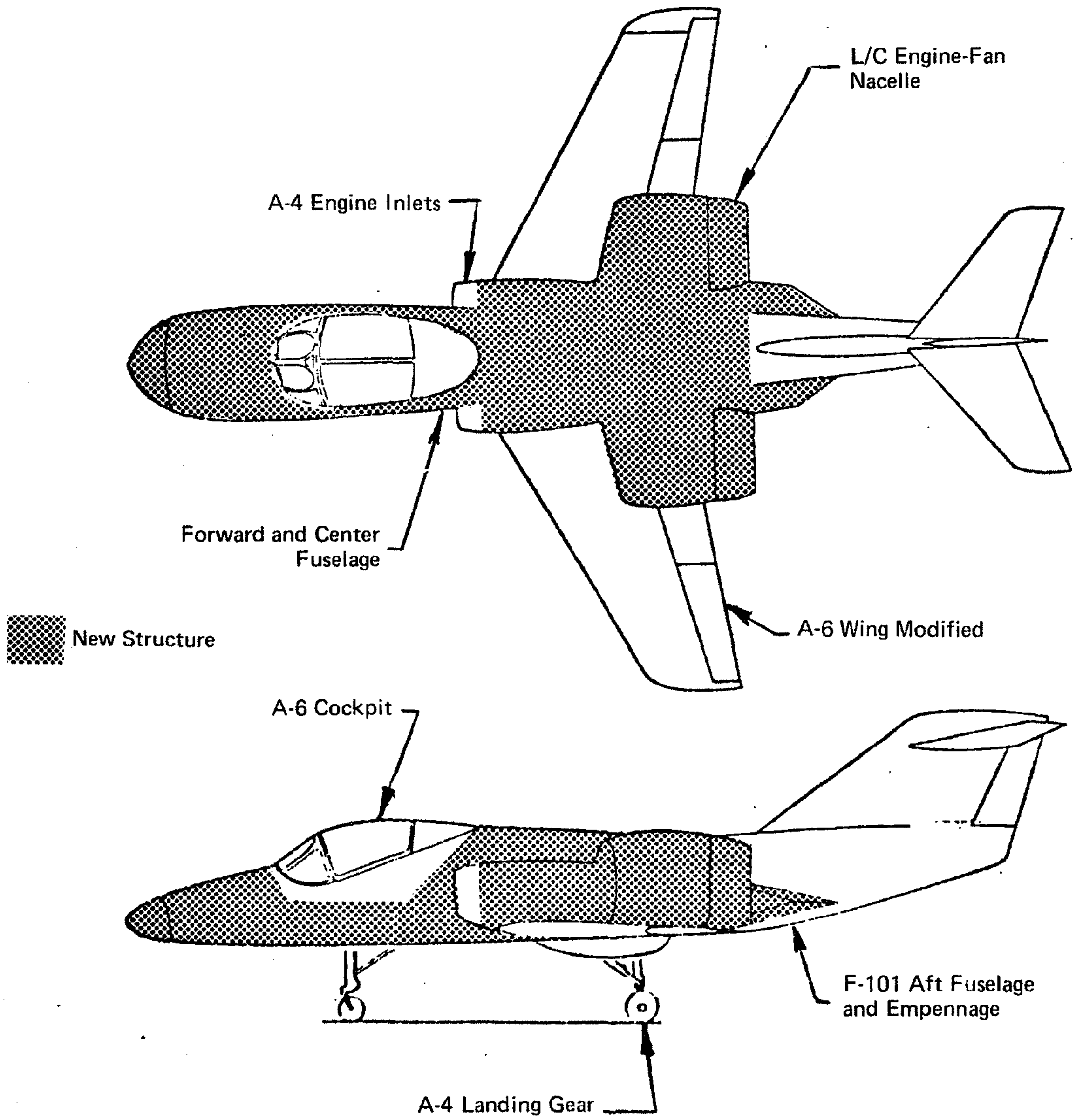
Propulsion System

The propulsion system is functionally identical to that described in Section 2. The primary difference is location of the third engine, which is installed in the center fuselage to improve cg and also to avoid rework of the F-101 aft fuselage. Thrust vectoring and control systems are identical to those of the multipurpose aircraft.

Flight Controls

The flight control system for the Composite aircraft is as described for the New Airframe in Section 3.3.

FIGURE 3-11
COMPONENT INTEGRATION
COMPOSITE AIRCRAFT



Fuselage

The forward fuselage, except for slight mold line differences, is the same as that of New Airframe. The forward and center fuselage are new structure which join together the existing A-6 cockpit system and F-101 aft fuselage, and the A-6 wing. The center fuselage structure incorporates attachment points for the lift/cruise fans and mounting fittings for the third engine. The air inlet is located on the upper fuselage surface. Space is provided in the forward and center fuselage sections for installation of the flight test payload (50 ft^3). Two fuel tanks with a total capacity of 7770 lb are carried in the fuselage.

Cockpit System - The cockpit provisions and rework required to convert the A-6 system are as described in Section 3.3. Pilot visibility is the same as for the New Airframe.

Empennage

The F-101 empennage, including horizontal and vertical tail planes, and aft fuselage are used essentially without modification. Since the center fuselage is new, it includes the major splice details, thus minimizing the rework required on the F-101 aft fuselage. It is anticipated that some new supports or modifications will be required to accommodate the ACS requirements.

Wing

The A-6 wing was modified in the following manner:

(a) Approximately 11 feet of the center section of the torque box was removed, and the resulting sections rejoined at the aircraft centerline with skin and spar straps and shear ties. The resulting fuel capacity is 2830 lb.

(b) The wing tips, which include speed brakes, are replaced by simple fairings.

(c) Wing fold mechanism was removed.

(d) Leading edge flaps and actuators, fences, and spoilers are deleted.

(e) Trailing edge flaps and flaperons are removed and replaced by flaps and ailerons. Existing flaps are converted to the maximum practicable extent.

(f) Pods are added external to the mold line to house the main gear in the retracted position.

Landing Gear

The A-4 main and nose gears are adapted to the airframe as in the case of the New Airframe. The A-4 retraction mechanism and control system are used without modification.

Subsystems

Except for tank configuration and plumbing differences, the fuel system of the Composite aircraft is as described in Section 3.3. The hydraulic system, electrical system, avionics and test equipment, and fire protection system are also as defined in Section 3.3.

3.5 MODIFIED AIRCRAFT - LIMITED FLIGHT ENVELOPE

Three candidates were selected for the limited flight envelope category, Approach 3, and are as follows:

- o Composite Aircraft (Low Speed Version)
- o Sabreliner (T-39)
- o Voodoo (F-101)

The Composite (low speed version) configuration differs from the Composite aircraft described in Section 3.4 only in adaptation of the landing gear and the removal of the aft fuselage fairing. The A-4 landing gear is locked in the down position, and all related gear accessories including doors, fairings, and power and control for retraction are deleted. Its configuration is as described in Section 3.4, and with the exception of weights its dimensions and characteristics are as shown in Figures 3-9 and 3-10.

The propulsion system, flight control system, and subsystems are all functionally identical to those described in Section 3.3. Major differences are in component locations and routing of ducts and plumbing.

Sabreliner (T-39)

The modified Sabreliner design proposed for the technology aircraft is shown in Figure 3-12, and the principal weights and geometric characteristics are presented in Figure 3-13. Its overall length is 2.8 ft greater and its wing span 3.5 ft more than the comparable dimensions of the multipurpose aircraft. The new structure, areas of rework, and usage of existing components from other aircraft are shown in Figure 3-14. The latter includes the F-101 aft fuselage, empennage, and the A-4 landing gear. An optional installation of two zero-zero ejection seats as shown in Figure 3-15 has the same overall dimensions and fan spacing. Movement of the windshield forward and installation of ejection seats results in an increase of 416 lb in weight empty and some degradation in forward visibility.

Airframe - A new nose section was required forward of the cockpit to accommodate the nose fan installation. In the interest of minimizing cost, the existing pilots' compartment (including seats) was utilized. Downward and over the side vision are improved by the installation of transparent panels below existing side transparencies.

The two J60 turbojet engines mounted on the rear of the fuselage were removed and replaced with two J97-GE-100 gas generators and lift/cruise fans enclosed in nacelles. The third gas generator faces forward and is located in the aft portion of the passenger cabin. It has an inlet located on top the fuselage. The center fuselage section was modified to provide a separate compartment for the third gas generator and the related systems. In addition, the fuselage center section was strengthened to accommodate external attachment of two lift/cruise fans and two gas generators. The aft fuselage of the T-39 was removed and replaced with an aft fuselage and empennage assembly of the F-101. Minor modifications of the empennage were required in addition to the aft fuselage splice joint. A fuel tank with capacity of 5410 lb is installed in the center fuselage and adequate space is provided in the forward portion of the cabin for the flight test equipment.

FIGURE 3-12
MODIFIED SABRELINER (T-39)

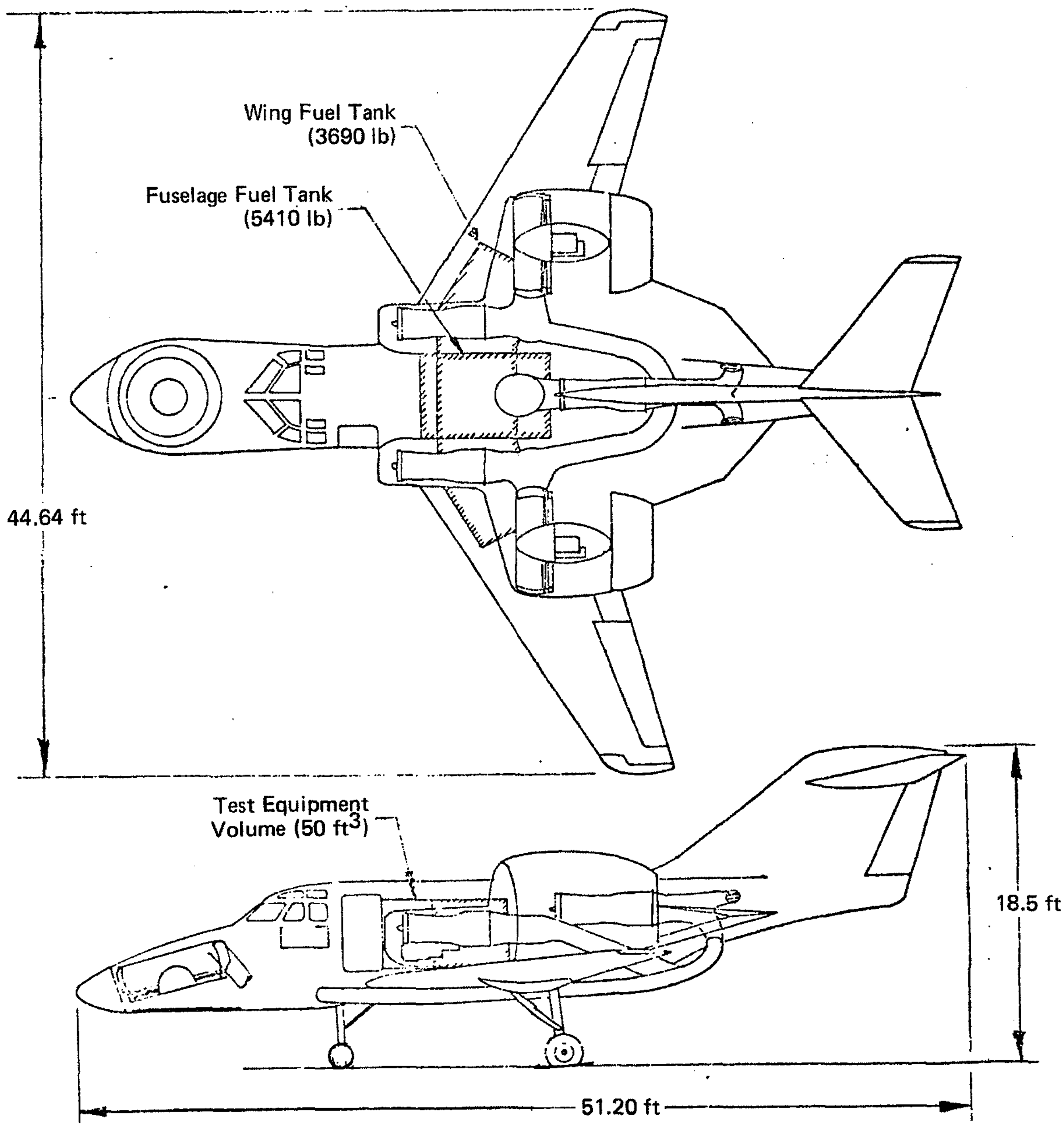


FIGURE 3-13
DIMENSIONAL AND DESIGN DATA
Modified T-39 Aircraft

STOGW	(lb) (N)	30,240 134,508
VTOGW	(lb) (N)	28,000 124,544
OWE	(lb) (N)	18,640 82,911
Overall Length	(ft) (m)	51.2 15.61
Wing Span	(ft) (m)	44.64 13.61
Height	(ft) (m)	18.5 5.64
Crew Provisions	(No.)	2
Max. Internal Fuel	(lb) (N)	9,100 40,477

	Wing	Horizontal Tail	Vertical Tail
S (ft^2) (m^2)	342.05 31.78	75.1 6.98	84.88 7.89
AR	5.77	3.30	0.66
λ	0.32	0.46	0.51
b (ft) (m)	44.64 13.61	15.75 4.80	7.50 2.29
$\Lambda_{c/4}$	28.5	31.25	46.0
t/c (% Root/Tip)	11.30/9.4	7.0/6.0	7.0/7.0
Airfoil	64A0XX Modified	65A0XX Modified	65A0XX

FIGURE 3-14
MAJOR MODIFICATIONS TO SABRELINER (T-39)

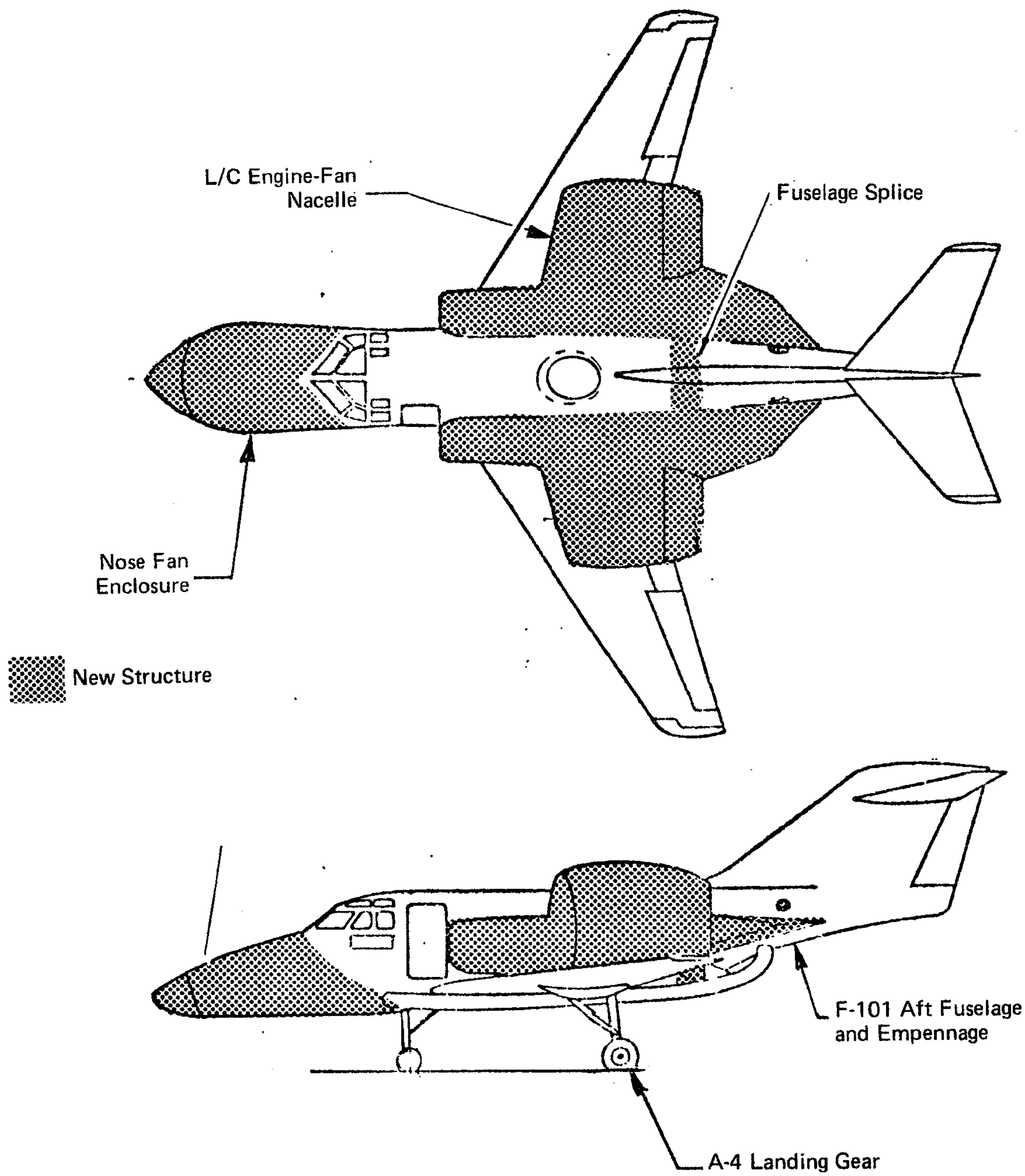
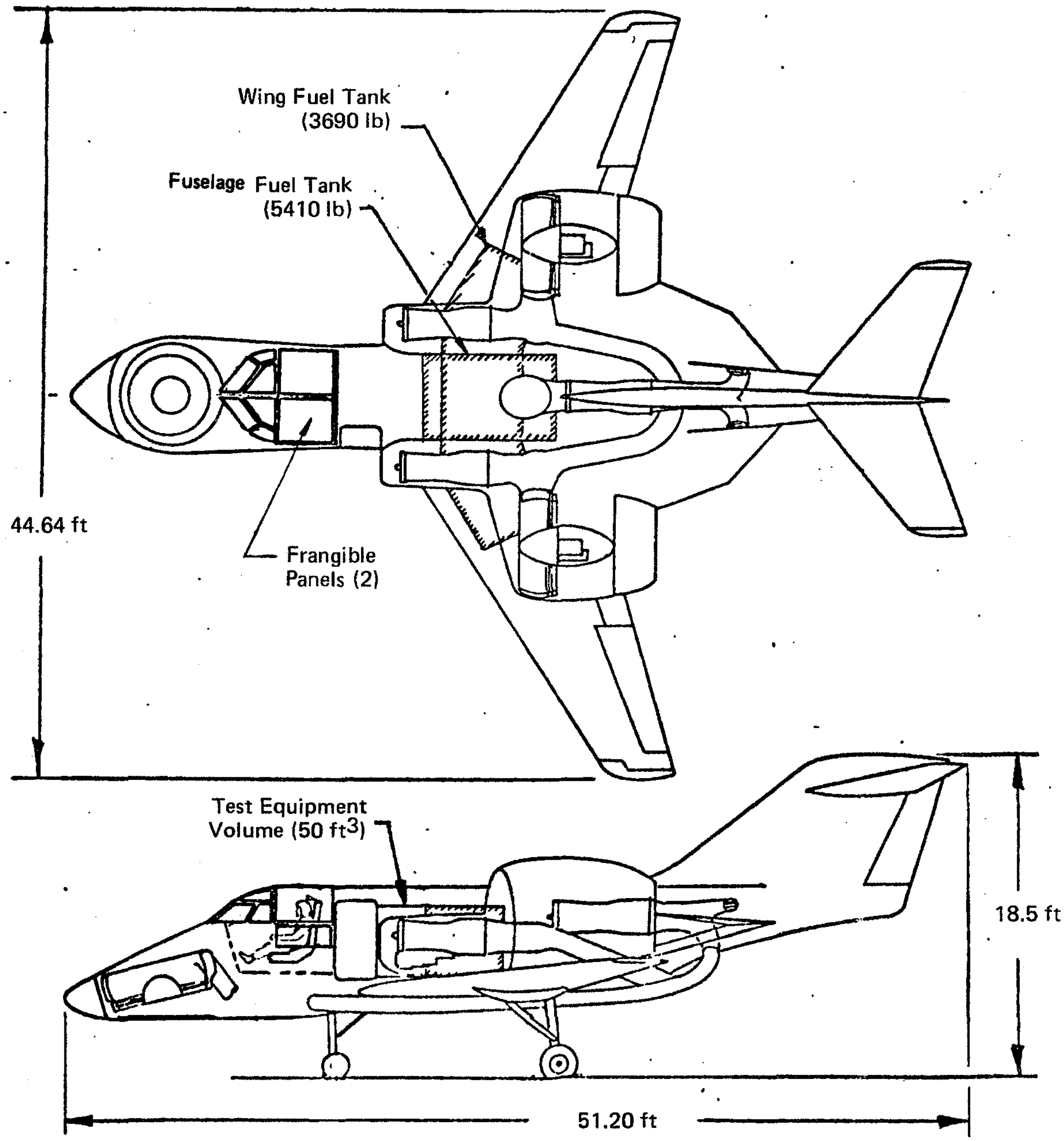


FIGURE 3-15
MODIFIED SABRELINER (T-39)
WITH EJECTION SEATS



The existing wing was used with local structural changes and strengthened as needed for the A-4 landing gear and lift/cruise fan attachments. Removal of part of the inboard flap section was required. The upper surface of the inboard wing section is faired to provide a smooth transition to the fan inlet. Fuel carried in the wing (3690 lb) is reduced from that of the Sabreliner by sealing off ribs at Wing Rib 106. The purpose of this modification was to reduce the roll moment of inertia for VTOL operation.

The A-4 main landing gear, which is longer than the T-39 gear, provides the proper ground clearance with lift/cruise thrust vectoring hoods deflected. The main gear attach points were moved outboard on the wing to improve the turnover angle. Both the nose and main gear are mounted in the "locked down" position. The A-4 brake and nose gear steering systems are utilized as is. Items associated with retraction and stowage of the gears were deleted.

Ejection Seat Installation - The optional installation of two zero-zero seats, shown in Figure 3-16, was accomplished by moving the windshield forward 20 inches and adding a frangible transparent enclosure for egress. The forward movement of the windshield is required for ejection clearance. As in the case of the basic version described above, the nose fan enclosure is faired into the Sabreliner fuselage, and additional transparent panels are installed for improved pilot vision.

Voodoo (F-101)

The modified Voodoo design proposed for the technology aircraft is shown in Figure 3-17, and the principal weights and geometric characteristics are presented in Figure 3-18. Its wing area, aspect ratio, and span are essentially the same as the multipurpose aircraft, and has an overall greater length of 12.7 ft. Because of the fan spacing ratio desired, and the complexity of structural modification required, the aircraft is configured with a single rather than a two place cockpit. As shown in Figure 3-19, aside from the installation of the propulsion system, shortening of the center fuselage constituted the greatest modification to the existing airframe.

Airframe - A new nose section was required forward of the cockpit to accommodate the nose fan installation. A section 75 inches in length was removed from the basic aircraft and the forward cockpit section rejoined to the center fuselage. The existing cockpit system was used except that the F-101 ejection seat was replaced by a zero-zero type. The existing equipment bay located aft of the pilot's compartment was reserved for flight test equipment.

The two J57 turbojets were removed and replaced with two J97-GE-100 gas generators. Existing inlets were adapted. Fuel cells in the center fuselage were removed to permit installation of the third gas generator and ETaC ducting system. The inlet for the third gas generator is located on the upper fuselage surface aft of the canopy. The center section structure was reinforced to accommodate external attachment of two lift/cruise fans and two gas generators. Two fuel tanks with a total capacity of 7770 lb were installed in the aft fuselage. Minor modifications were required in the empennage to provide for installation of the flight control actuation components.

FIGURE 3-16
EJECTION SEATS FOR SABRELINER

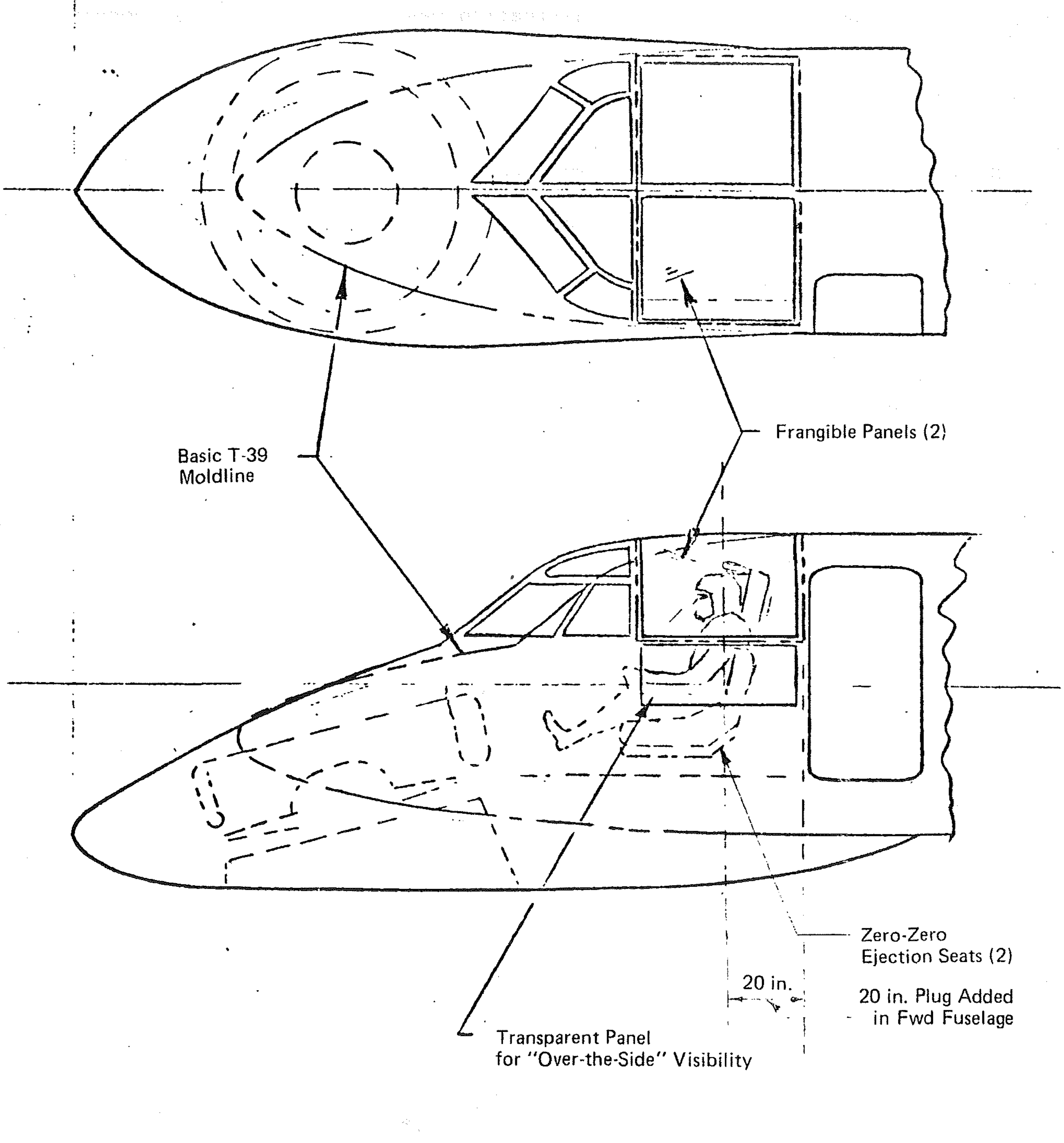


FIGURE 3-17
MODIFIED VOODOO (F101)

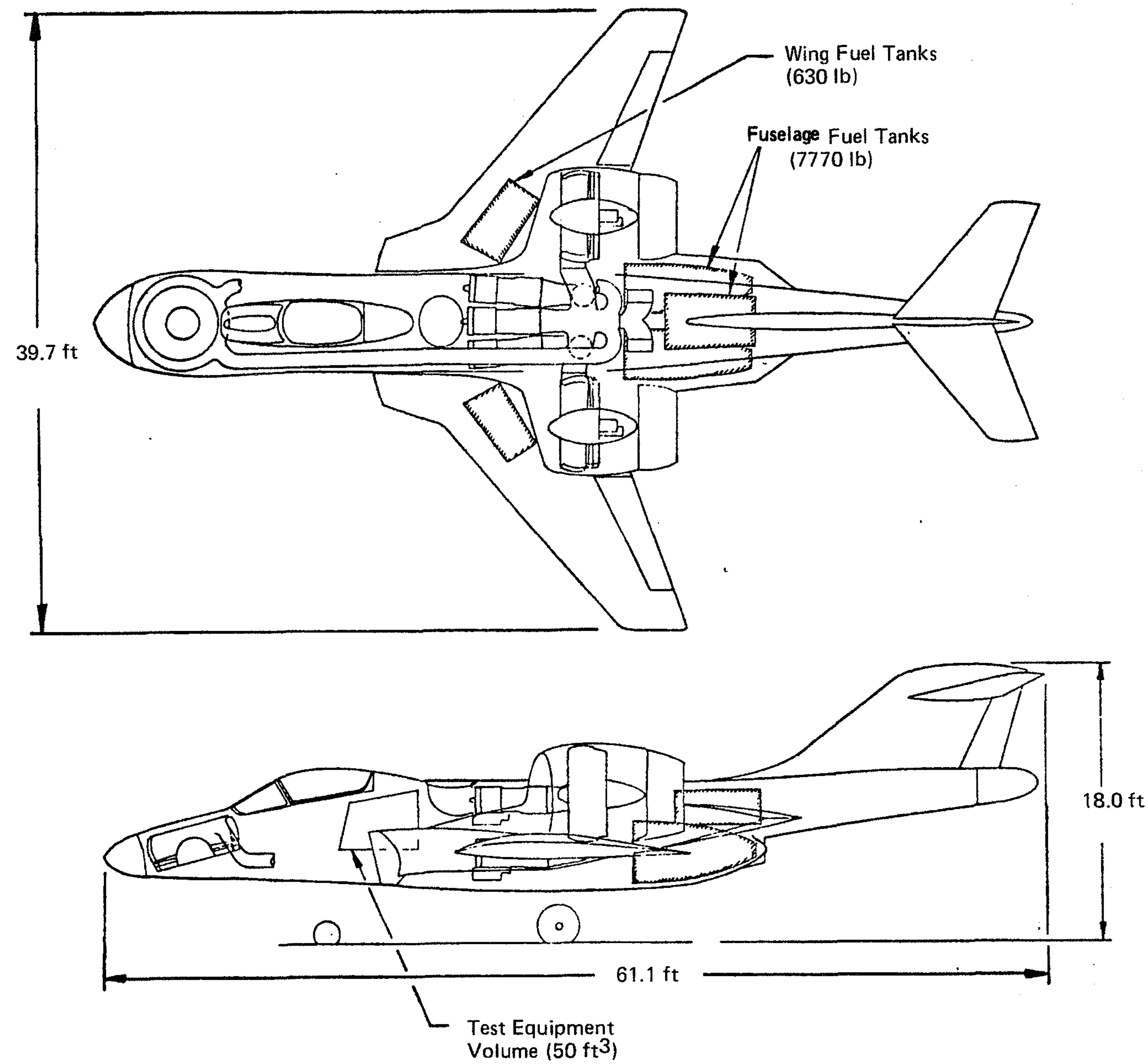
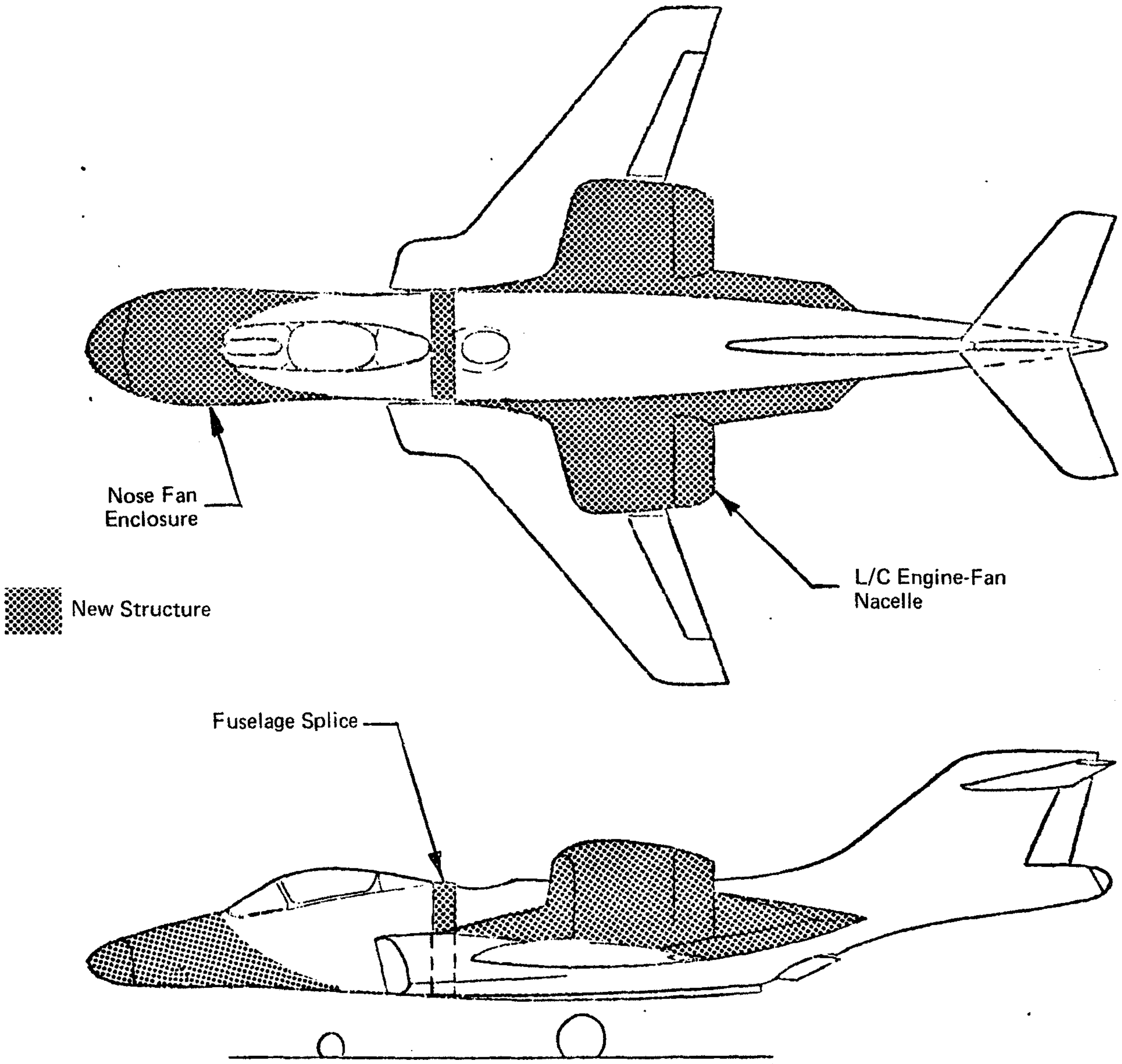


FIGURE 3-18
DIMENSIONAL AND DESIGN DATA
Modified F-101 Aircraft

STOGW	(lb) (N)	32,789 145,845
VTOGW	(lb) (N)	28,000 124,544
OWE	(lb) (N)	21,899 97,403
Overall Length	(ft) (m)	61.1 18.62
Wing Span	(ft) (m)	39.7 12.10
Height	(ft) (m)	18.0 5.49
Crew Provisions	(No.)	1
Max. Internal Fuel	(lb) (N)	8,400 37,363

	Wing	Horizontal Tail	Vertical Tail
S (ft^2) (m^2)	368.0 34.19	75.1 6.98	84.9 7.89
AR	4.28	3.2	0.66
λ	0.28	0.46	0.51
b (ft) (m)	39.69 12.10	15.51 4.73	7.5 2.29
$\Lambda_{c/4}$	36.61	35.74	45.97
t/c (% Root/Tip)	6.67/5.70	7.0/6.0	7.0/7.0
Airfoil	65A0XX Modified	65A0XX Modified	65A0XX

FIGURE 3-19
MAJOR MODIFICATIONS TO VOODOO (F-101)



No change was required to the basic wing torque box structure. Local modifications to the wing were required, however, for lift/cruise fan secondary attachments. In order to provide a smooth transition to the fan inlet, a fairing was built up on the upper surface from the leading edge to the fan scroll. The existing ailerons were adapted to be used as flaperons.

The landing gear system will be used as is; however, the wheel base was changed somewhat, due to shortening of the nose, and resulting aft movement of the nose gear and wheel well.

3.6 AVIONICS SYSTEM

The avionics equipment for the technology flight vehicle is comprised primarily of off-the-shelf GFE sets, as shown by the listing in Figure 3-20. The avionics accomplishes communications, navigation, display and control functions representative of those required for the flight test demonstration program. Optional equipment can be added at a later date to fulfill specific objectives, such as a Head-Up display for V/STOL terminal area guidance and control evaluations. A brief summary description of technology flight vehicle avionics appears in the following paragraphs.

FIGURE 3-20
TECHNOLOGY AIRCRAFT AVIONICS

Equipment Function	Nomenclature	Uninstalled Weight (Lb)
Communication, Radio Nav and Identification		
UHF AM Transceiver	AN/ARC-159	9.0
Intercomm	AN/AIC-25	7.0
IFF Transponder	AN/APX-100	6.5
TACAN	AN/ARN-84(v)	31.0
Antennas		
*UHF/L Band	AS-2718/ARC	3.0
*Transponder	AT-741/A	1.0
	Subtotal	57.5
Navigation		
Attitude and Heading Reference (2)	AN/ASN-120 Type	60.0
Magnetic Azimuth Detector(2)	ML-1	3.2
Air Data System		
*Air Data Computer	AN/ASK-6 Type	16.2
Pitot Static Probe (2)	Rosemount 855 CG	5.0
Alpha/Beta Sensors (2)	Rosemount 861 E	5.0
Total Temp Sensor (2)	Rosemount A-2-18001A	1.2
*Low Velocity A/S System (2)	J TEC	10.3
	Subtotal	100.9
Displays		
Attitude Director Indicator	ARU-39/A	8.0
Horizontal Situation Indicator	AQU-12A	7.0
Altimeter	ID-1818/ASN	4.0
Standby Attitude Indicator	ID-1791	2.3
	Subtotal	21.3
*Flight Control Avionics	New	127.0
	Total	306.7

Note: All Items GFE Except as Noted by *

Communications, Radio Navigation and Identification Equipment

Radio set AN/ARC-159 is a solid state UHF transceiver that provides two-way amplitude modulated, double-sideband, full carrier, radio telephone communication. The radio set permits transmitting and receiving on any of 7000 frequencies spaced 25 kHz apart in the 225 to 399 MHz frequency range, with transmitter output of 10 watts minimum.

The AN/AIC-25 intercommunication system provides headset amplification for the UHF radio and audio warning signals as well as microphone preamplification control of the UHF radio transmission, cockpit communications, and cockpit-to-ground crew voice communications.

The AN/APX-100 panel mounted transponder provides positive identification whenever interrogated and, in conjunction with the air data system, has provisions for altitude reporting. System operation in Modes 1, 2, 3/A, 4, C and Test is augmented by a built-in test capability in all modes. Mode 4 operation is possible with the addition of the optional KIT-1A/TSEC unit.

The AN/ARN-84(v) tactical air navigation set provides bearing, distance, and tone identity information to indicate the location of selected complementary surface stations with respect to the aircraft. It operates in the L-band frequency range with 252 channels available from 962 MHz to 1213 MHz. TACAN bearing and range information is displayed on the Horizontal Situation Indicator (HSI).

Navigation Equipment

The Attitude Heading Reference Set (AHRS) provides pitch, roll, and heading information for the displays and the Flight Control System electronics set. Dual AHRS are provided for fail-operate automatic hover flight control. The magnetic azimuth detector (flux valve or compass transmitter) measures the heading of the vehicle with respect to the direction of the earth's magnetic field, providing a magnetic heading reference for the AHRS.

The Air Data System computes and outputs aircraft altitude, indicated airspeed, and true airspeed. Altitude information is provided to the transponder equipment for the altitude reporting function. Dual air data sensors allow one fail-operate of air data inputs to the flight control system electronics. Backup air data computation capability is contained within the flight control system electronics units.

The J TEC low velocity airspeed system yields accurate airspeed information for the very low velocities that are below the air data sensors' lower limit of operation (approximately 40-50 knots).

Display Equipment

The Attitude Director Indicator (ADI) displays aircraft pitch, roll, heading, and turn rate. The Horizontal Situation Indicator (HSI) displays aircraft heading and TACAN information. The Standby Attitude Indicator provides the pilot with information on aircraft pitch, roll, turn rate, and sideslip in the event of AHRS malfunctions.

Flight Control Avionics Equipment

The flight control avionics equipment contains sensors and electronics to properly shape, schedule, amplify, and monitor the input signals supplied for use in driving the appropriate control system surface actuators and for supplying control signals to the power management servoactuators. The electronics utilize multiple redundancy channel techniques in conjunction with redundant signal conversion mechanisms (servos) to provide fail operational flight control, as necessary to meet the operational and safety requirements of the flight control system. The equipment comprising the indicated 127 lb of hardware includes:

- Interchangeable computers containing all necessary input/output circuitry, memory, power supply, and processors
- Flight control panel providing mode select and preflight test initiate capability
- Status/reset panel showing system modes and operational status
- Sensor packages for rate and acceleration sensing
- Pilot input transducers

3.7 WEIGHTS

The weight and balance summaries for the selected technology configurations are shown in Figures 3-21 and 3-22 resepctively. All aircraft are designed for a VTOGW of 28000 lb which includes the payload of 2500 lb of electronic flight test instrumentation. With the exception of the Sabreliner, the limit load factor for all configurations exceeded the desired 2.5 g specified in the guidelines (at VTOGW). The limit load factor for the Sabreliner is 2.1 g at the VTOGW of 28000 lb, which was considered acceptable for a technology demonstrator. This load factor could have been increased by structural modifications; however, additional modification costs would have been incurred. The following rationale was used to derive weight statements for the four selected technology aircraft.

New Airframe

The New Airframe configuration, although similar to the multipurpose aircraft defined in Part I, is actually a much simplified, all-metal vehicle that has been further modified to accept certain structural and subsystem components from existing aircraft. This configuration utilizes the canopy/windshield, ejection seats. and modified horizontal tail of the A-6 and the landing gear from the A-4. Another major change to the configuration was the incorporation of a third gas generator into the propulsion system. A minimum CNI electronics group is installed while the flight control system reflects the weights of a FLY-BY-WIRE Active Control System.

Composite Aircraft

This configuration was based on the New Airframe design but uses a modified A-6 wing and an F-101 aft fuselage/empennage in lieu of new structure. The A-6 wing assembly is extensively modified with the center section and major portion of the outer panel removed. The forward and center fuselage of the New Airframe vehicle was retained, but a three-foot fuselage plug is added forward of the wing. Incorporation of the F-101 aft fuselage necessitated addition of fairing structure to approximate the New Airframe moldline. Subsystem weights differ between this and other configurations essentially because of geometric dissimilarities.

A low speed version of the Composite configuration was also studied. This aircraft is identical to the full envelope configuration except that the landing gear is fixed in the down position and the fairing structure on the F-101 aft fuselage is removed. Weight empty was reduced by 342 lb with these changes.

Sabreliner

Configuration weights are based on those of the T-39 Sabreliner modified to accept the F-101 aft fuselage and A-4 landing gear. The Sabreliner wing was changed to adapt the A-4 gear for use, and fuel was limited to the volume inboard of B.L. 105. This wing fuel capacity limitation reduced the roll and yaw inertias for this configuration. Subsystems are modified T-39 with changes made to incorporate the 3 gas generator/3 fan propulsion system and Active Control System.

An optional configuration utilizing ejection seats was also evaluated. Replacement of the T-39 crew station seats with A-6 ejection seats was accompanied by a revision to the T-39 forward fuselage and addition of a frangible canopy.

Voodoo

Weights for this configuration result from modifications to the F-101, the largest of which is the removal of a 75-inch forward fuselage section and incorporation of the 3 gas generator/3 fan propulsion system. An inboard aft section of the wing was removed to facilitate mounting of the lift/cruise fan and nacelle assembly. The subsystems were based on the basic F-101 but modified to suit the revised configuration. This is the only technology aircraft to have provisions for a one man crew. The existing ejection seat was replaced with a zero-zero seat.

FIGURE 3-21
GROUP WEIGHT STATEMENTS
TECHNOLOGY AIRCRAFT

ITEM	NEW AIRFRAME	COMPOSITE AIRCRAFT	SABRE-LINER	VOODOO
Wing	1392	3709	1680	3300
Vertical Tail	218	471	471	471
Horizontal Tail	500	366	366	366
Fuselage	3364	3727	3551	4502
Nose Landing Gear	220	220	220	187
Main Landing Gear	670	670	670	1409
Surface Controls	835	835	730	1000
Engine Section	180	180	180	180
Propulsion				
Gas Generators	2217	2217	2217	2217
Air Induction	375	302	237	280
Fuel System	557	649	417	722
Controls	60	60	60	60
Lift Fan	700	700	700	700
Lift Fan Louvers	200	200	200	200
Lift/Cruise Fans	1400	1400	1400	1400
L/C Fan Deflectors	1300	1300	1300	1300
Ducting	630	693	867	675
Valves	650	650	700	650
Starting	100	100	100	100
Instruments	257	257	227	283
Hydraulics	260	260	200	309
Electrical	400	400	400	400
Electronics	230	230	230	230
Armament	---	---	---	---
Furnishings	568	568	459	325
Air Conditioning	250	250	250	250
Auxiliary Gear	7	7	3	7
Manufacturing Variation				-59
Weight Empty	17540	20421	17835	21464
Crew	360	360	360	180
Trapped Fuel	72	60	170	50
Oil	135	135	135	135
O_2 & Miscellaneous	140	140	140	70
Operating Weight Empty	18247	21116	18640	21899
Fuel	7253	4384	6860	3601
Payload	2500	2500	2500	2500
Takeoff Gross Weight	28000	28000	28000	28000

FIGURE 3-22
TECHNOLOGY AIRCRAFT BALANCE SUMMARY

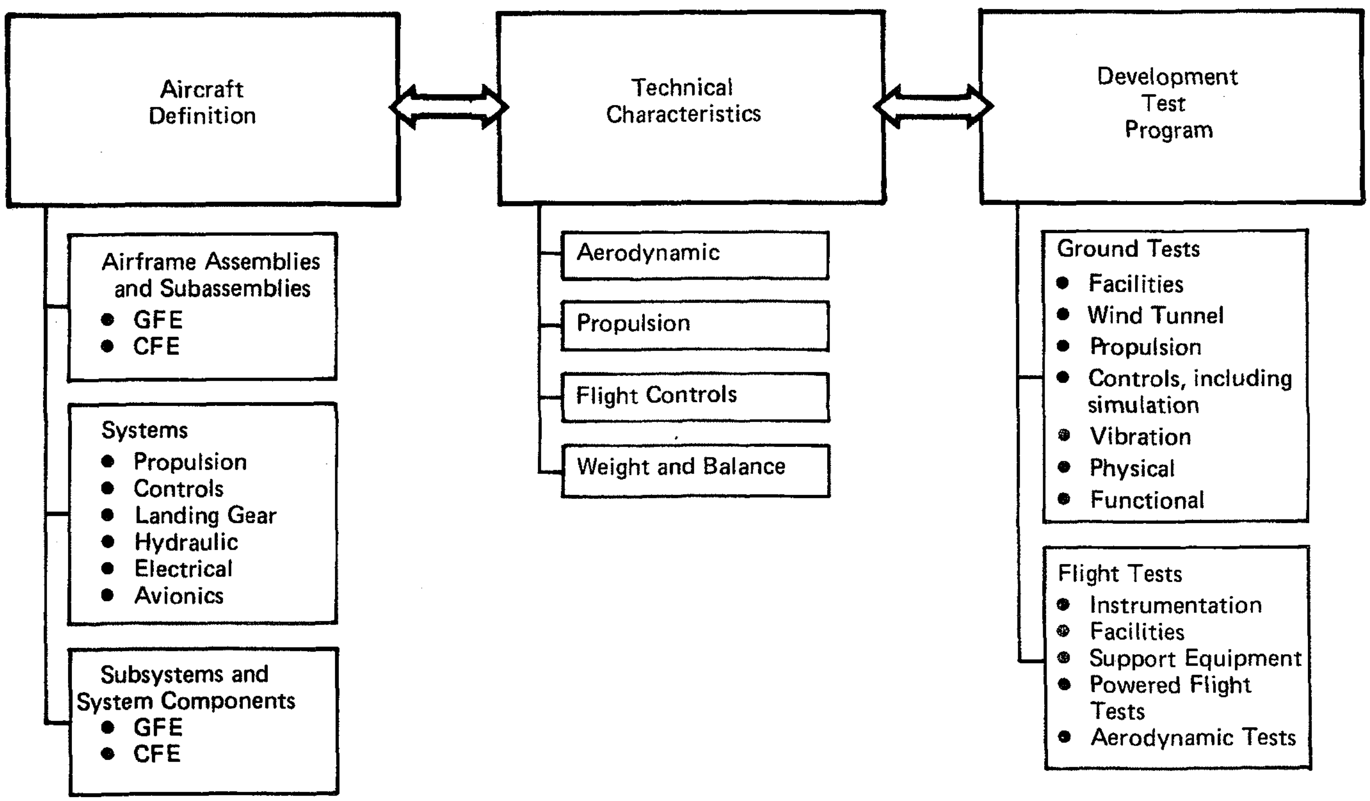
Configuration	Condition	Weight ~lb	Fuselage Sta. ~Inches	W.L. ~Inches
1. New Airframe	V.T.O.G.W.	28000	394.8	113.0
	Landing G.W.	21547	397.1	118.0
2. Composite	V.T.O.G.W.	28000	387.7	115.5
	Landing G.W.	24416	379.9	114.1
3. Sabreliner	V.T.O.G.W.	28000	252.6	92.2
	Landing G.W.	21940	256.0	97.2
4. Voodoo	V.T.O.G.W.	28000	431.1	54.4
	Landing G.W.	25199	423.3	53.6

Note: Landing Gross Weight = O.W.E. + 2500# (payload) + 800# (landing reserve fuel)

3.8 DATA BASE SUMMARY

Figure 3-23 shows the various data elements used as a basis for analysis and budgetary cost estimates of the selected program and aircraft approaches. The candidate aircraft selections for the three specified approaches are described in Section 3.2. The major airframe components required for each aircraft and their required modification/integration are discussed in detail in Sections 3.3, 3.4, and 3.5 and summarized in Figure 3-4. Weight, aerodynamic, propulsion, and controls characteristics are summarized in Sections 2, 3, 4, and 5, respectively. The technical development program, including both ground and flight test programs, is summarized in Section 6. Systems requiring development are identified together with test objectives, instrumentation, and facilities required. A milestone schedule shows the integration of development tests for systems and aircraft and dock dates of major contractor and Government furnished items.

FIGURE 3-23
DATA BASE–TECHNOLOGY AIRCRAFT PROGRAM



The major Government furnished airframe components of the four basic selected candidates are identified in Figure 3-24.

The major equipment items common to all candidates (except as noted) are listed in Figure 3-25. Flight test onboard requirements are included under "Miscellaneous". Items are identified as GFE, CFE, and CFE off-the-shelf.

Ground Support Equipment

It is assumed on-site GSE at contractor or Government test facilities will suffice for the major support needs of the technology aircraft. This includes support for the various subsystems such as hydraulics, electrical, fuel, landing gear and brakes, and CNI. Existing GSE will be identified for the particular aircraft selected.

Special support equipment, such as required for the Automatic Flight Control Set, will be furnished by the contractor. Certain Government furnished special GSE will be required for the propulsion system components, including checkout and handling equipment. The latter includes slings and transport adapters for the gas generators and fans. A preflight console for the instrumentation data system will also be required as GFE.

FIGURE 3-24
MAJOR GFE AIRFRAME COMPONENTS

New Airframe	Composite Aircraft	Sabreliner	Voodoo
A-6 Fwd Fus.	A-6 Fwd Fus.	Complete T-39 Airframe	Complete F-101 Airframe
A-6 Horiz. Tail	F-101 Aft Fus. and Empennage	F-101 Aft Fus. and Empennage	
A-4 Ldg. Gear	A-6 Wing	A-4 Ldg. Gear	
	A-4 Ldg. Gear		

FIGURE 3-25
MAJOR SUBSYSTEMS/EQUIPMENT

	Per A/C	CFE	GFE
PROPULSION SYSTEM			
J97-GE-100 Gas Generator	3		X
LF 459 Lift Fan (G.E.)	3		X
Air Turbine Starter	3		X
L/C Vectoring Nozzle Assembly	2	X	
Interconnect Ducts	1 Set	X	
Nose Fan Vectoring Nozzle Assembly	1	X	
Gas Generator Isolation Valve	3	X	
System Isolation Valve	2	X	
ETaC Mod/Shutoff Valve (Nose)	2	X	
ETaC Mod/Shutoff Valve (L/C)	2	X	
Diverter Valve	1	X	
FLIGHT CONTROL SYSTEM			
Automatic Flight Control Set	1	X	
Flight Control Actuators	1 set each		
Aileron, Stabilizer, Rudder, Flap		X (1)	
Thrust Reduction		X (1)	
Transition Thrust Deflection		X	
Transition Schedule		X (1)	
ETaC Valve		X	
Secondary Actuators (SCM)		X (1)	
Engine Throttle		X (1)	

(Continued)

(1) Off the Shelf

(Figure 3-25 Continued)

UNDERCARRIAGE	Per A/C	CFE	GFE
Main Ldg Gear and Mechanism	2		X
Main Wheel, Brake, Tire	2		X
Nose Wheel, Tire	1		X
Brake Control Valve	2		X
FUEL SYSTEMS			
Boost Pumps, Transfer Pumps	1 Set	As Available GFE or Off-the-Shelf CFE	
Miscellaneous Valves and Regulators, Gaging Systems	As Required		
HYDRAULIC SYSTEMS			
Variable Displacement Pump	3		X
Reservoir	3		X
Miscellaneous Valves and Components for Power Control System	3 Sets	As Available GFE or Off-the-Shelf CFE	
ELECTRICAL SYSTEMS			
AC Generator	3		X
Constant Speed Drive	3		X
Transformer Rectifier	4		X
3ϕ Power Monitor	2	X (1)	
General Control Unit	3	X (1)	
Miscellaneous Relays, Contactors etc.	1 Set	X (1)	

(Continued)

(1) Off the Shelf

(Figure 3-25 Continued)

AVIONICS		Per A/C	CFE	GFE
Communication, Radio Nav and Identification				
UHF AM Transceiver	AN/ARC-159	1		X
Intercomm	AN/AIC-25	1		X
IFF Transponder	AN/APX-100	1		X
TACAN	AN/ARN-84(v)	1		X
Antennas				
UHF/L Band	AS-2718/ARC	1	X	
Transponder	AT-741/A	1	X	
Navigation				
Attitude and Heading Ref. Set	AN/ASN-120 Type	2		X
Magnetic Azimuth Detector	ML-1	2		X
Air Data System				
Air Data Computer	AN/ASK-6 Type	1	X	
Pitot Static Probe	Rosemount 855GG	2		X
Alpha/Beta Sensors	Rosemount 861E	2		X
Total Temp Sensor	Rosemount A-2-18001A	2		X
Low Velocity A/S System	J TEC	2	X	
Displays				
Attitude Director	ARU-39/A	1		X
Horizontal Situation Indicator	AQU-12A	1		X
Altimeter	ID-1818/ASN	1		X
Standby Attitude Indicator	ID-1791	1		X
Flight Control Avionics	(See Flight Controls)			

(Continued)

(Figure 3-25 Continued)

MISCELLANEOUS	Per A/C	CFE	GFE
Environmental Control System (Modified)	1		X
Fire Detection and Exting. System	1 Set	X	
Miscellaneous Flight Instruments	1 Set		X
Ejection Seat (zero-zero)	As Req'd (1)		X
100 Channel PCM Tape and Telemetry	1 System		X
Measureands	80	X	

(1) One Required for Voodoo

4. PERFORMANCE ANALYSES

4.1 BASIC AERODYNAMIC DATA

Performance and mission evaluations of the technology aircraft required the establishment of the takeoff gross weight levels that provide safety of operation. Emergency operational capabilities are specified by the design guidelines in the event of failure of a gas generator or control system component (excluding fans). Design to these emergency criteria required the installation of excess lift. It was decided, as discussed in Section 2, that the technology aircraft would be designed with a three gas generator system and operated at gross weight levels established by two gas generator capability. Consequently, performance is presented for gross weights determined from the emergency capabilities of the propulsion system with one gas generator inoperative. Sea level, 89.8°F was assumed to be the appropriate takeoff condition per the safety and operating criteria of the design guidelines. The VTOGW is 28,000 lb under these conditions.

STO performance at gross weights greater than VTOGW is a function of the installed thrust level which is defined by the design thrust/VTOGW ratio (T/W = 1.05). Thus, the STO performance is presented in terms of the STOGW/VTOGW ratio. Selection of the 28,000 lb VTOGW based upon two gas generator operation provided the desired safety and performance levels throughout the powered lift flight regime. The STO, transition, and conversion can be completed in the event of a gas generator failure since the thrust/weight ratios are maintained at levels equivalent to a two gas generator configuration operating at takeoff weights established by full installed power, as was the case for the multipurpose aircraft. The technology aircraft are flown with three gas generators operating at part throttle during powered lift flight and with two gas generators for aerodynamic flight. The throttle is advanced to maintain the flight condition in event of gas generator failure.

The basic aerodynamic data required for performance calculations are estimated through use of advanced design techniques, MCAIR lift/cruise fan aircraft technology base, and technical data reports pertaining to existing aircraft components that were used for the candidate vehicle. The integration of available aircraft components into a lift/cruise fan V/STOL configuration means acceptance of their geometric and aerodynamic characteristics. Generally, this results in reduced buffet onset, reduced maximum lift, and increased interference effects relative to the multipurpose aircraft.

Lift-Drag Polars

Mission performance capabilities of the candidate technology aircraft are based on the estimated low speed drag characteristics presented in Figure 4-1. The minimum profile drag consists of component skin friction drag modified for shape, roughness, and interference plus incremental drag for appendages and trim. Incremental appendage and trim drags are based on previous lift/cruise fan aircraft R&D efforts. This drag estimation approach is consistent with the Part I Design Definition Study, Volume I presentation. The equivalent skin friction coefficient (C_{D_f}) is referenced to the total wetted area of each aircraft. The high drag level for the modified Sabreliner is caused by the fixed landing gear and external routing of the propulsion system gas transfer ducts.

FIGURE 4-1
TECHNOLOGY AIRCRAFT POLARS

Aircraft	Zero Lift Drag f (ft^2)	C_{D_f}	Drag Polar $C_D = C_{D_o} + KC_L^2$
New Airframe	10.29	0.0054	$0.0280 + 0.094\ C_L^2$
Composite	10.22	0.0052	$0.0278 + 0.095\ C_L^2$
Sabreliner	22.80	0.0109	$0.0667 + 0.075\ C_L^2$
Voodoo	11.95	0.0050	$0.0325 + 0.101\ C_L^2$

The trimmed drag polars for low speed performance estimates are defined by a two-term parabolic equation, $C_D = C_{D_o} + KC_L^2$, for C_L values below the lift curve break. Minimum drag is assumed to occur at zero lift, and a lift dependent drag factor (e) of 0.75 is estimated for Mach number below approximately 0.70. Wind tunnel tests of a similarly configured model indicated this value was conservative at low Mach numbers, but insufficient data are available to substantiate use of a higher value. The low speed two-term polars are adequate for estimating the mission performance of the technology aircraft.

4.2 FLIGHT ENVELOPES

Technology aircraft flight envelopes are shown in Figures 4-2 and 4-3 for 28,000 lb TOGW, intermediate thrust, in a standard atmosphere. The powered-lift and aerodynamic envelopes are typical of the unrestricted technology aircraft since all are designed to a common propulsion system and wing loading. Figure 4-2 compares the powered-lift speed-altitude capability for two and three gas generator operation at intermediate thrust. The three gas generator hover ceiling is 9000 ft since the aircraft is operated at a gross weight established by two gas generator emergency (dry) operation at sea level, 89.8°F. The sea level standard day thrust/weight ratio is 1.33 at the 28,000 lb TOGW, intermediate thrust rating. The hover ceiling for two gas generator emergency operation is approximately 2000 ft. The emergency rating provides capability for either an emergency vertical landing or the establishment of flight in the two gas generator, intermediate thrust, powered-lift envelope. Hovering at altitudes greater than 2000 ft reduces the gas generator out safety margins. The maximum speed capability in powered-lift flight is defined by a thrust deflection angle of 30 degrees relative to the cruise position; the remaining 30-degree deflection to the cruise position is quite rapid during conversion to aerodynamic flight. The powered-lift and aerodynamic envelopes overlap to provide conversion capability. The requirement is a minimum of a 20% velocity margin over the aerodynamic flight stall speed. The unrestricted technology aircraft, at 28,000 lb gross weight, meet this requirement for altitudes up to 23,000 ft with three gas generator operation and 16,000 ft with two gas generator operation. As the takeoff gross weight increases by STO operations, the conversion velocity overlap and altitude capability decrease.

FIGURE 4-2
TECHNOLOGY AIRCRAFT
POWERED-LIFT FLIGHT ENVELOPES

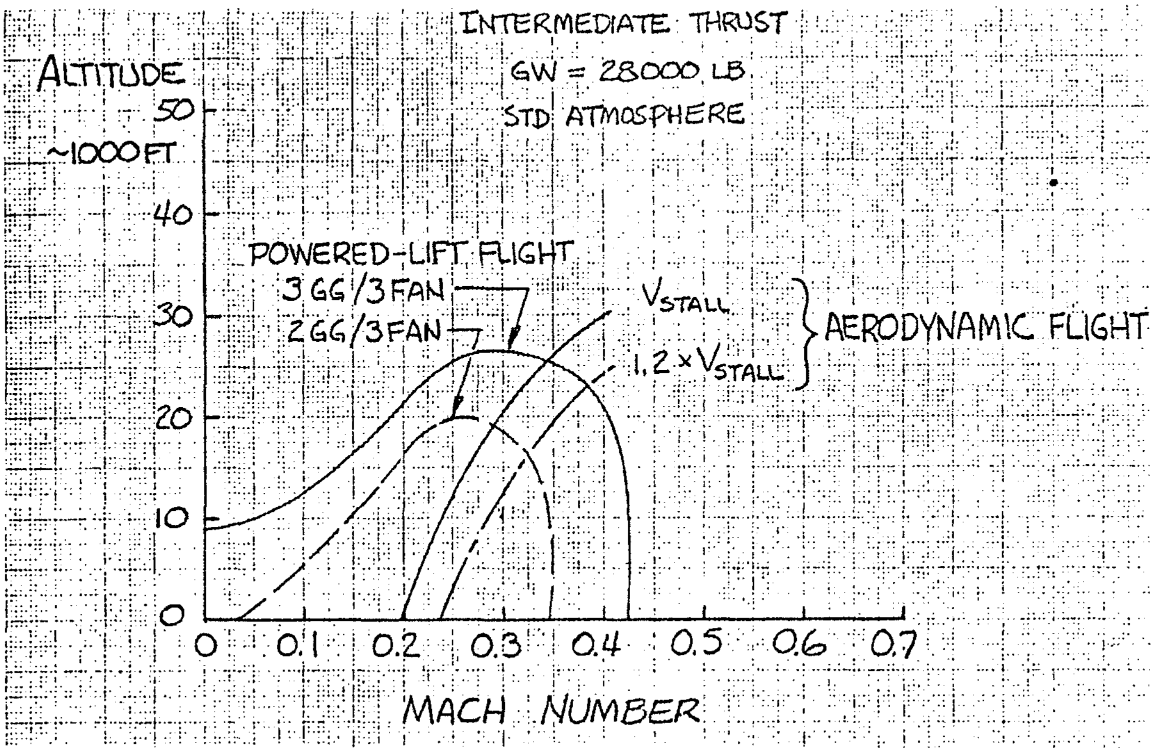
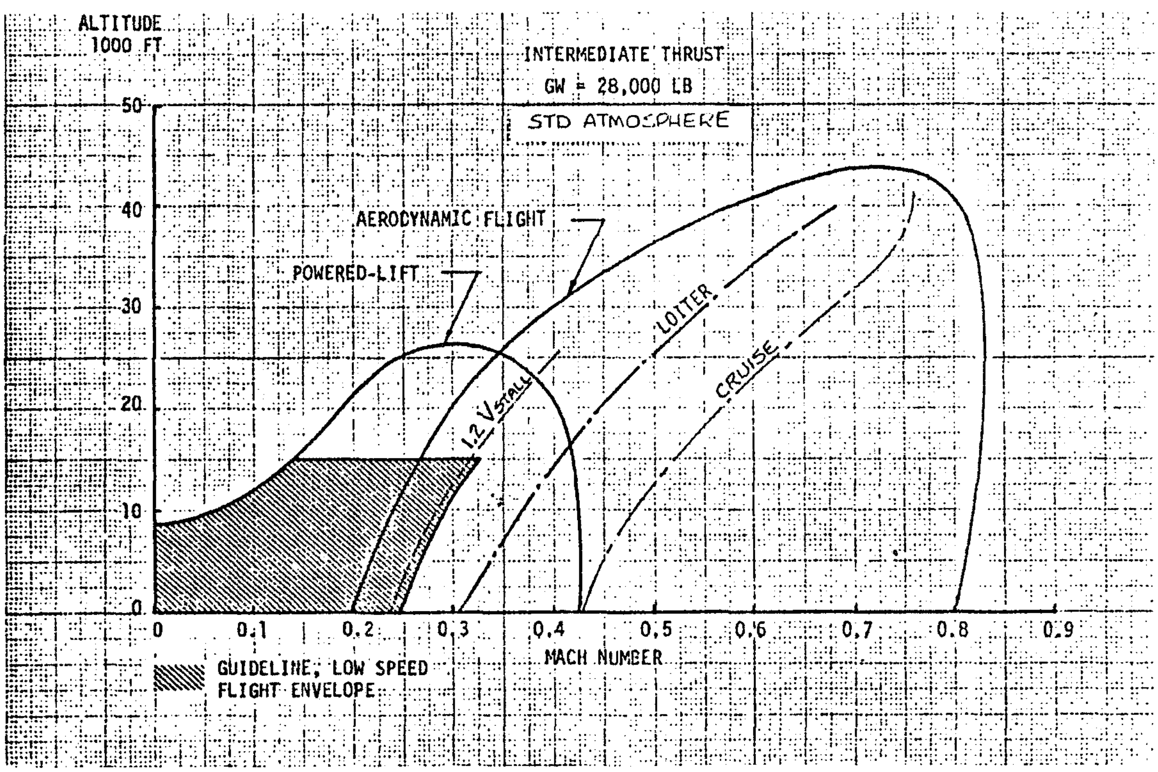


FIGURE 4-3
TECHNOLOGY AIRCRAFT
FLIGHT ENVELOPES



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The aerodynamic flight envelope, Figure 4-3, shows the maximum (0.83 M), minimum (0.25 M), cruise (0.70 M to 0.75 M at altitude) and loiter (0.30 M to 0.60 M as a function of altitude) Mach numbers for two gas generators, two fan operation. Below 20,000 ft the minimum speed is defined by the power off, maximum usable lift coefficient.

The guideline limited flight envelope, superimposed on the typical flight envelope for comparison, is applicable to configurations defined for Approach 3, Sabreliner and Voodoo. This envelope is limited to 15,000 ft and 160 KEAS and does not permit demonstration of the loiter (maximum L/D) and cruise characteristics in aerodynamic flight. The 160 KEAS placard is equivalent to the 20% margin requirement at the 28,000 lb gross weight. As gross weight increases, the stall speed increases, and the 160 KEAS placard does not meet the conversion overlap requirement. However, the low speed configurations are capable of increased velocity performance to provide the required conversion margins.

4.3 MISSION CAPABILITY

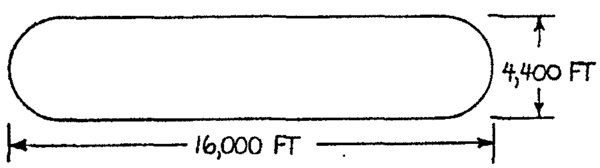
Addendum II of the Statement of Work gives specific requirements for VTOL, STOL, and cruise/endurance type missions with a minimum "payload" (flight test equipment) of 2500 lb. The VTOL and STOL missions demonstrate takeoff, conversion, reconversion, and landing around an oval course. The requirements are five circuits and a total mission time of 30 minutes for the VTOL mission, and eleven circuits and one hour for the STOL mission. The cruise/endurance mission demonstrates the aircraft characteristics in aerodynamic flight with a minimum requirement of two hours mission time. For analysis purposes, the time on station is defined as loiter at either optimum altitude or 15,000 ft depending on the configuration.

A typical fuel breakdown for one lap of the oval course for the VTOL mission is shown in Figure 4-4 for the New Airframe configuration. This breakdown is representative of the various candidate configurations because of the common TOGW and propulsion system. The warmup allowance at the start of the mission is equivalent to one minute of intermediate thrust. The fuel for one circuit is 800 lb and includes 1 1/2 minutes at intermediate thrust for takeoff and conversion to aerodynamic flight, and a one-minute allowance for landing. The reserve fuel allowance (800 lb) is equivalent to four minutes of hover at the landing gross weight. The VTOL mission capabilities of each of the candidate configurations is shown in Figure 4-5. The number of circuits and total mission time are directly related to the fuel available at the TOGW of 28,000 lb (Fuel = TOGW less OWE and Payload). The performance estimates are slightly conservative since a certain amount of overlap exists between the final landing and the reserve allowance. The conservatism provides a margin for variance in pilot technique and time spent in powered-lift flight. The New Airframe configuration and the modified Sabreliner meet the requirement of five circuits and thirty minutes mission time.

The STOL mission requirement is less stringent than the VTOL requirement since the gross weight increase is used for additional fuel. The fuel breakdown for the VTOL mission is assumed typical of the STOL mission; the added fuel required at greater weights being less than the conservatism in the VTO estimate. Figure 4-6 summarizes the STOL mission capabilities and takeoff distances for the candidate configurations using full internal fuel. Two of the candidate configurations, the New Airframe and the Composite aircraft, can meet the STOL mission requirements using full internal fuel. The modified Voodoo can fly nine circuits on internal fuel, and can meet the requirement if external fuel is carried. The modified Sabreliner cannot meet the requirement since there are no external fuel stations, and internal fuel capacity is insufficient for eleven circuits in one-hour mission time. The STO distances are less than the 400 ft specified (with a 10 kt wind) by the design guidelines.

The two-hour requirement for the cruise/endurance mission can be met by all four candidate configurations with full internal fuel and a short takeoff run. Figure 4-7 shows the loiter capability of each of the configurations at a radius of 20 nm, an assumed climb distance to the loiter altitudes. The New Airframe and Composite aircraft loiter at maximum L/D and optimum altitude and have 4.2 and 3.5 hours time on station, respectively. The modified Sabreliner and the modified Voodoo are restricted to the guideline low speed envelope and loiter at 15,000 ft and 160 KEAS. The restricted aircraft are capable of 2.7 and 2.3 hours time on station, respectively. Figure 4-8 shows the VTO time on station capability of each of the candidate configurations. The New Airframe and modified Sabreliner meet the two-hour requirement with a vertical takeoff at radii of 150 and 10 nm, respectively. Figure 4-9 shows the time on station capabilities with STO gross weights shown in Figure 4-7 (full internal fuel). All candidates exceed the two-hour guideline requirement.

FIGURE 4-4
TECHNOLOGY AIRCRAFT
VTO MISSION FUEL BREAKDOWN
New Airframe (NNV-014)



WARMUP FUEL, 1 MIN INTERMEDIATE THRUST		260 LB
FUEL FOR EACH CIRCUIT		800 LB
VTO, CLIMB ACCEL TO 1000 FT, 210 KT, 1½ MIN INT. THRUST	385 LB	
180° TURN AT 210 KT (2 G'S)	27 LB	
DOWNRANGE CRUISE	29 LB	
180° TURN AT 210 KT (2 G'S)	27 LB	
POWERED-LIFT DESCENT, DECEL TO V=O	132 LB	
1 MIN FOR VERTICAL LANDING	200 LB	
RESERVES, 4 MIN HOVER AT LGW		800 LB

5% SERVICE TOLERANCE ON FUEL FLOW

FIGURE 4-5
TECHNOLOGY AIRCRAFT
"V" MISSION CAPABILITY
VTOGW (S.L. 89.8°F) = 28,000 Lb
Payload = 2,500 Lb

Configuration	O.W.E. (lb)	Fuel (lb)	Reserve Fuel (lb)	Fuel Per Circuit (lb)	No. of Circuits	Time Per Circuit (Min)	Mission Time (Min)
New Airframe	18,247	7253	800	800	8	4.4	39
Composite	21,116	4384	800	800	4	4.4	23
Sabreliner	18,640	6860	800	800	7	4.4	37
Voodoo	21,889	3601	800	800	3	4.4	19

FIGURE 4-6
TECHNOLOGY AIRCRAFT
STOL MISSION CAPABILITY
S.L. 89.8°F Takeoff Payload = 2,500 Lb

Configuration	TOGW (lb)	Fuel (lb)	STO Distance (ft)		No. of Circuits	Mission Time (Min)
			Zero WOD	10 kt WOD		
New Airframe	32,247	11,500	210	170	13	63
Composite	34,216	10,600	430	330	12	58
Sabreliner	30,240	9,100	200	160	10	49
Voodoo	32,789	8,390	320	250	9	45

FIGURE 4-7
TECHNOLOGY AIRCRAFT
STO CRUISE/ENDURANCE MISSION
S.L. 89.8°F Takeoff Payload = 2,500 Lb, Distance During Climb = 20 NM

Configuration	TOGW (lb)	Fuel (lb)	STO Distance (ft)		Time On Station (hr)
			Zero WOD	10 kt WOD	
New Airframe	32,247	11,500	210	170	4.2
Composite	34,216	10,600	430	330	3.5
Sabreliner	30,240	9,100	200	160	2.7
Voodoo	32,789	8,390	320	250	2.3

FIGURE 4-8
TECHNOLOGY AIRCRAFT
VTO CRUISE/ENDURANCE MISSION
VTOGW (S.L., 89,8^{o}F) = 28,000 Lb
Payload = 2,500 Lb

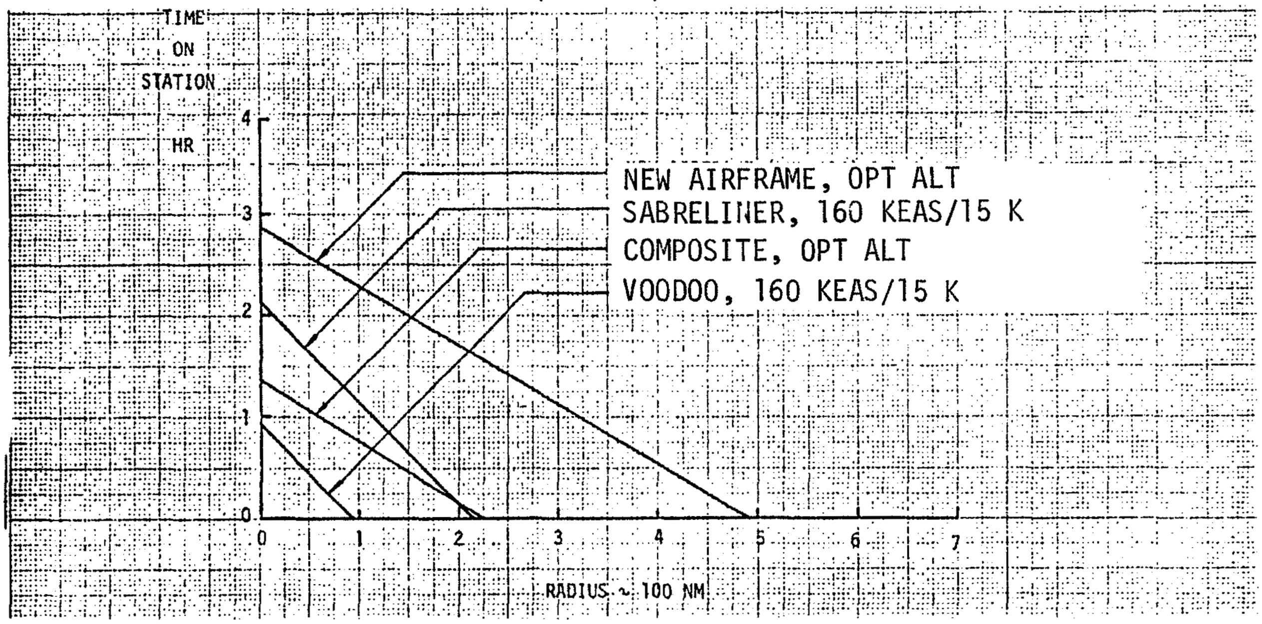
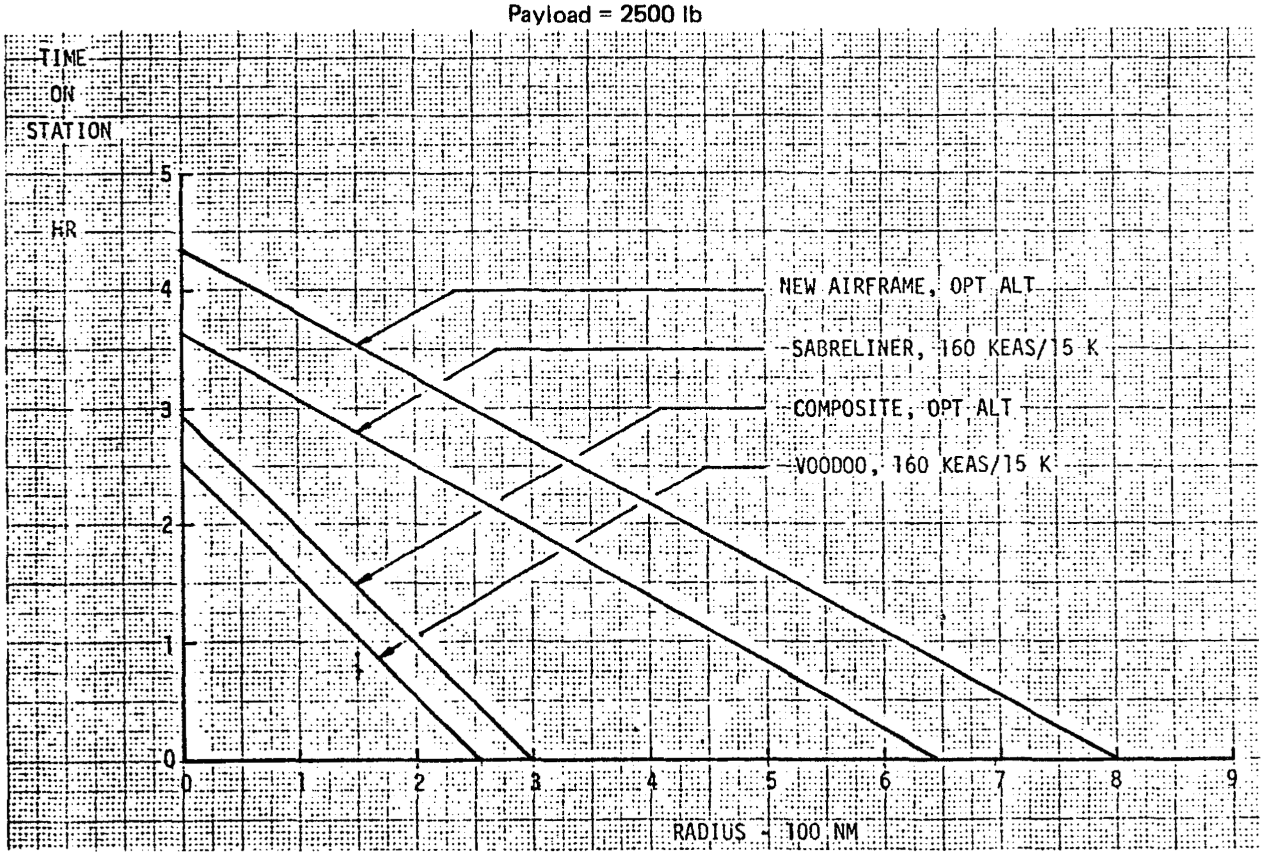


FIGURE 4-9
TECHNOLOGY AIRCRAFT STO CRUISE/ENDURANCE MISSION
Full Internal Fuel
Payload = 2500 lb



5. AIRCRAFT CONTROL AND HANDLING QUALITIES

5.1 AIRCRAFT CONTROL

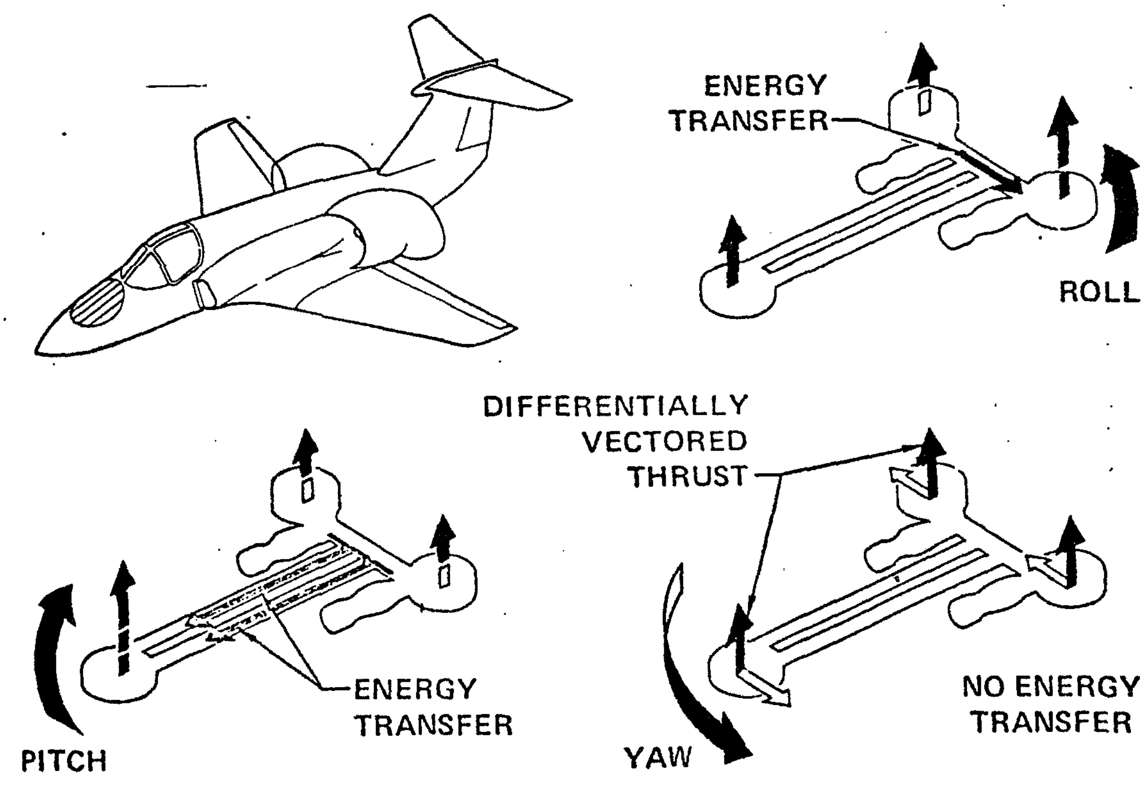
The technology aircraft candidates have functionally identical control systems, and the description in this section is applicable to all aircraft configurations presented. Control capabilities of each configuration have been analyzed individually and are discussed and compared to the requirements.

Basic Control Concept

Aircraft control is provided by aerodynamic control surfaces and powered lift controls. Stabilator, ailerons, and rudder provide all of the pitch, roll, and yaw control throughout aerodynamic flight and part of the control in the powered lift flight regime depending on the airspeed. These control surfaces are actuated by irreversible, hydraulically powered actuators and remain operational throughout the flight envelope. The powered lift controls, which function through fan thrust modulation and vectoring, generate the necessary attitude control moments as shown in Figure 5-1. Differential thrust modulation between the forward fan and the two lift/cruise fans provides aircraft pitch control, while differential thrust modulation between the left and right lift/cruise fans provides roll control.

Thrust modulation is achieved by means of the Energy Transfer and Control (ETaC) system. Valves, located at the inlets to the tip turbine of each fan, control transfer of energy through the interconnecting ducts between fans to accomplish the desired thrust changes. The ETaC system operation involves partial

FIGURE 5-1
VTOL CONTROL



closing of an ETaC valve at one fan to cause the thrust of all the other fans to increase, without a substantial change of thrust at that fan. The result is a net increase in total lift. The ETaC system is implemented with fan thrust reduction modulation (TRM) to provide greater thrust differential for control moments and better control response while maintaining constant total lift. All three ETaC and TRM devices are coordinated to achieve aircraft control without coupling between attitude and height control.

Yaw control is provided by laterally deflecting the thrust of the lift and lift/cruise fans differentially, such that the side force components of the lift vectors at each fan produce a yaw moment on the aircraft. To yaw right, for example, the exhaust flow of the forward fuselage fan is deflected to the left so that the horizontal component of thrust is a force which moves the nose of the aircraft to the right. Simultaneously, the flow of the lift/cruise fans is deflected to the right such that the side forces move the aft fuselage to the left. The effective deflection angles required are small so that negligible total lift losses result during yaw control inputs. Separate actuation of the thrust deflection for yaw at each fan provides high reliability and safety by virtually excluding the chance of losing all yaw control.

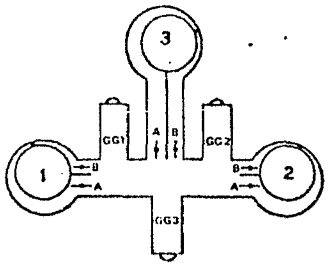
Height control in VTOL is synonymous with total lift control and is accomplished by modulation of gas generator power. Manual control is by means of a power lever located on the power management quadrant on the left side of the pilot's seat. The power management quadrant also contains the transition lever, or thrust vector control, which is linked with thrust vectoring devices at each fan. A set of vectoring louvers at the lift fan and vectoring nozzles at the lift/cruise fans provide the means for vectoring the aircraft thrust for VTOL, STOL, and transition.

Powered Lift Control Safety

The redundant actuation and control systems provide for safe operation in the powered lift mode. In addition, the complementary functions of ETaC and TRM (ETaC for thrust increase and TRM for thrust reduction) provide an inherent safety feature by nature of the separate actuation of these devices at each fan. Loss of an ETaC function at a fan does not interfere with the TRM operation and conversely loss of the TRM does not interfere with the ETaC operation. This feature provides for excellent survivability when multiple failures or battle damage are considered. When a total loss of a TRM or ETaC function at a fan is considered, adequate aircraft control is still maintained with some degradation in handling qualities resulting from reduction in control power in the affected axis. The estimated control power remaining after a total loss of the control moment producing function is shown for each axis in Figure 5-2. As discussed in subsequent sections, the installed control power exceeds the study guideline requirements. Therefore, after a complete loss of ETaC, TRM or yaw vanes at a fan, the control power remaining related to the requirements is still adequate for safe aircraft control.

FIGURE 5-2
CONTROL POWER REMAINING FOLLOWING LOSS OF CONTROL MOMENT PRODUCING FUNCTION IN HOVER

Based on 30% Thrust Modulation



AFFECTED AXIS	AFFECTED FUNCTIONAL ELEMENT / SENSE	CONTROL POWER REMAINING — % LEVEL 1 GUIDELINE											
		ETaC VALVES						T R M*			YAW VANES		
		1A	1B	2A	2B	3A	3B	1	2	3	1	2	3
ROLL	RIGHT WING UP	79						73					
	RIGHT WING DOWN			79					73				
PITCH	NOSE UP												
	NOSE DOWN									66			
YAW	NOSE RIGHT												
	NOSE LEFT												

(Shaded) **ABOVE LEVEL 1 GUIDELINE**   *TRM = THRUST REDUCTION MODULATION

Control Requirements

The control design requirements were established not only to insure good maneuvering capability, but also to provide adequate forces and moments to stabilize the aircraft and to control aircraft disturbances and cross-coupling effects. The primary control design guidelines for the technology demonstration aircraft, as summarized in Figure 5-3, show only the maneuver control power requirements. Design control power, however, is interrelated with the aircraft stability requirements inasmuch as the characteristics of the stability augmentation system affect the installed control power requirement. To achieve the specified hover stability, aircraft attitude and rate feedback loops are closed through appropriate gains to produce specific damping and natural frequency characteristics for satisfactory handling qualities. The closed loop pitch and roll control powers are dictated by the requirement of attitude change in one second per inch of control displacement. Yaw control power, however, was determined based on the specified moment/inertia (M/I) ratio because the yaw axis is rate stabilized which makes the M/I a dominating design requirement.

FIGURE 5-3
PRIMARY VTOL CONTROL GUIDELINES
Lift Cruise Technology Aircraft

		LEVEL 1	LEVEL 2
ATTITUDE CONTROL			
ACCELERATION (RAD/SEC^2)	ROLL	± 0.90	±0.40
	PITCH	± 0.50	±0.30
	YAW	± 0.30	±0.20
ANGLE IN 1 SEC (DEGREES)	ROLL	±15	±7
	PITCH	± 8	±5
	YAW	± 5	±3
COMBINED CONTROL		100% + 30% + 30%	
HEIGHT CONTROL			
WITH 50% ATTITUDE CONTROL (g)		±0.1	−0.1, +0.05
TRANSIENT RESPONSE (TIME CONSTANT)			
ATTITUDE CONTROL (SECONDS)		0.2	0.3
HEIGHT CONTROL (SECONDS)		0.3	0.5

Control During Normal Operation

Each of the technology candidates was analyzed to determine the thrust modulation necessary for attitude control. Attitude control in hover was determined to be more demanding of thrust modulation than control in transition or STOL. Thrust modulation levels required for each configuration to satisfy the most critical combination of control inputs specified by the design guidelines are shown in Figure 5-4. Available thrust modulation levels are defined by a temperature limit and practical considerations which are also shown in Figure 5-4. A 3-second 1600°F EGT rating provides a modulation capability in excess of 40% of nominal thrust at VTO gross weight condition. However, 25%-30% thrust modulation represents a practical design goal which insures better control characteristics with respect to cross-coupling effects and control response. Control capabilities in pitch and roll based on 25% thrust modulation are shown in Figure 5-5. All four aircraft configurations are well above the guideline and therefore attain the practical design goal.

The relationship of thrust modulation for attitude and height control to the propulsion system capabilities is shown in Figure 5-6. Aircraft operation at VTO gross weight is well below the intermediate engine power setting.

Yaw vector angle requirements are generally highest at the landing gross weight, because the thrust to be deflected is reduced while the aircraft yaw inertia exhibits only a small relative change with gross weight. The thrust deflection angles were computed at both takeoff and landing weights for each of the candidate aircraft and are summarized in Figure 5-7. The side force produced by the forward fan must balance the side force of the two lift/cruise fans for pure yaw moment without side force coupling. The thrust deflection angles of the lift/cruise fans are therefore approximately half of the forward fan thrust deflection angles.

FIGURE 5-4
THRUST MODULATION REQUIREMENTS
Level 1

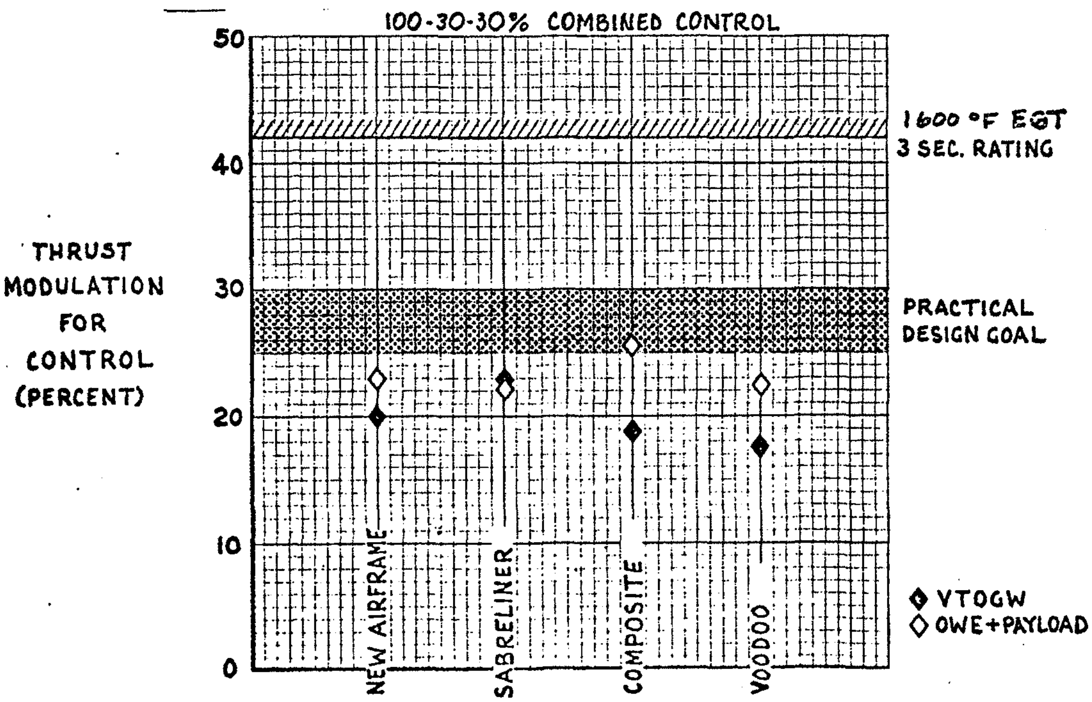


FIGURE 5-5
ATTITUDE CONTROL CAPABILITY WITH 25% MODULATION
Level 1

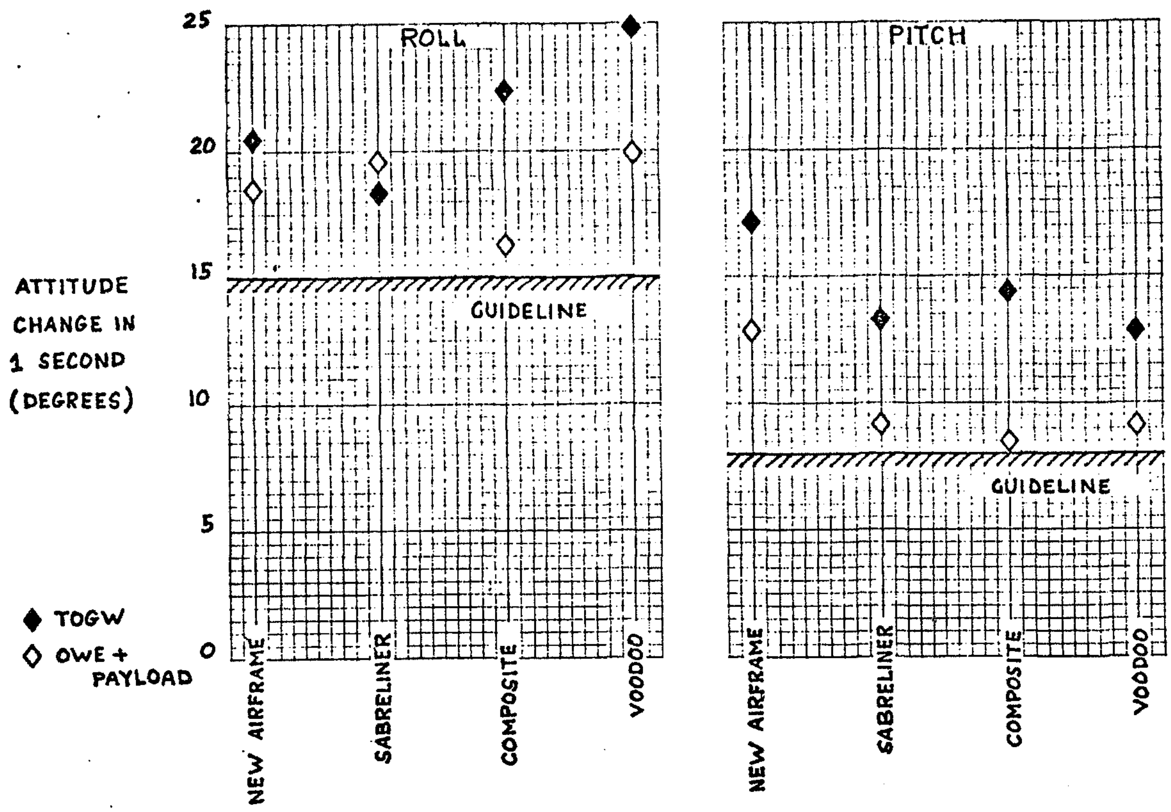


FIGURE 5-6
LEVEL 1 VTOL CONTROL DEFINITION
VTOGW = 28,000 Lb

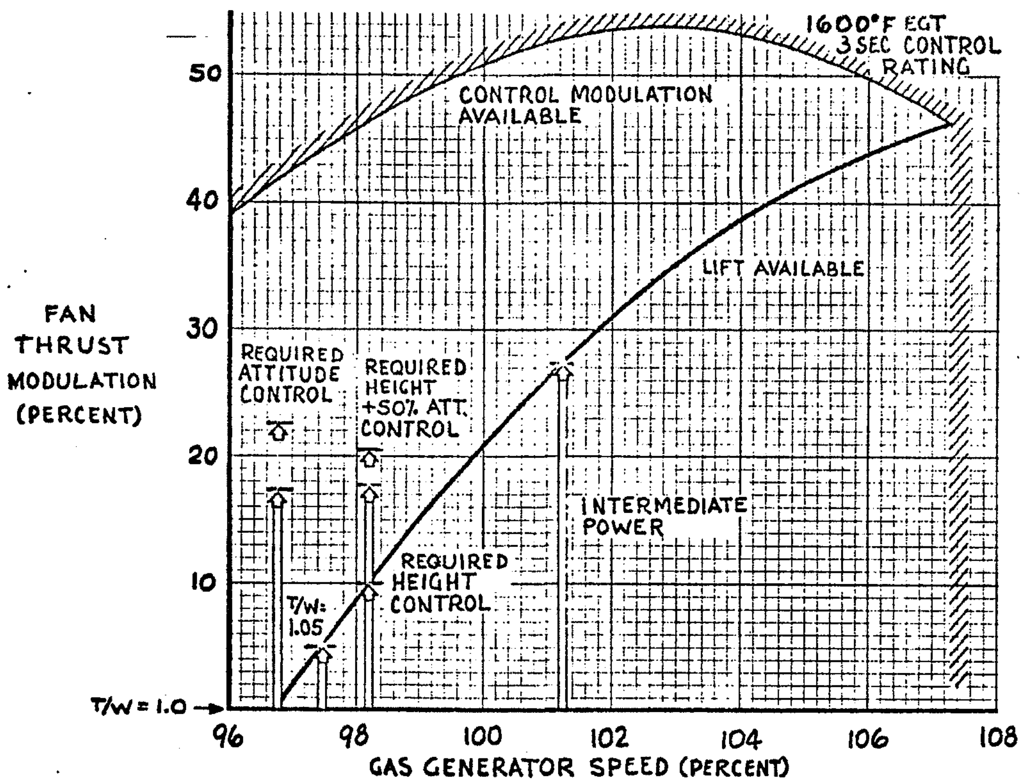
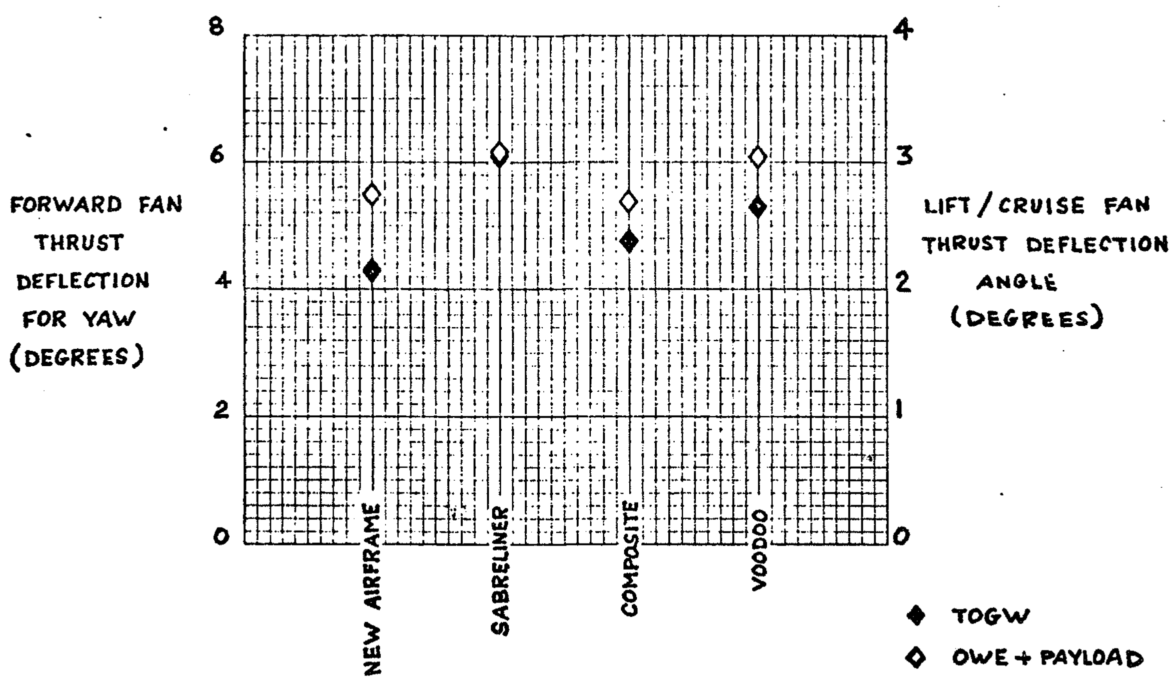


FIGURE 5-7
THRUST DEFLECTION REQUIREMENT FOR YAW CONTROL
Level 1



Control During Engine Out

The thrust modulation required for the specified Level 2 control following a gas generator failure is substantially reduced, and the modulation levels for the four aircraft are shown in Figure 5-8. Control margins are defined by the allowable temperature limits and the nominal thrust levels corresponding to the maximum "one gas generator out" vertical takeoff capability. The relationship of emergency control requirements to the propulsion system capabilities is shown in Figure 5-9, and it is evident that the control capability provided at the dry rating condition is adequate for the selected aircraft VTO gross weight of 28,000 lb. The thrust modulation control margins above guideline for each configuration at 28,000 lb are shown in Figure 5-10.

Gyroscopic Coupling

Gyroscopic coupling occurs between the pitch and roll axes due to the angular momentum of the forward fuselage fan, and between the pitch and yaw axes due to the combined angular momentum of the gas generators and lift/cruise fans. The gyroscopic coupling evaluations were performed at a power setting corresponding to T/W = 1.0 at VTO gross weight. The requirement pertinent to gyroscopic coupling is given as part of the attitude control power requirement and states that at least 90% of the specified normal control power shall be available after compensation for the gyroscopic moments resulting from maneuvers demonstrating the specified control power.

Design control power requirements are specified in terms of instantaneous angular acceleration (moment/inertia ratio) and attitude change in one second for step control input. Achieving the specified attitude change in one second is the dominating requirement in pitch and roll with the attitude stabilization systems engaged. The yaw axis is rate (rather than attitude) stabilized and as a result the 0.3 radians/second^2 requirement is higher than the 5-degree change in one second. The demonstration maneuvers, therefore, consist of step control inputs to achieve 8 degrees pitch attitude change in one second, 15 degrees roll attitude change in one second, and a step input of 0.3 radians/second^2 moment/inertia in yaw. The angular rates encountered during performance of these maneuvers are plotted in Figure 5-11. The gyroscopic coupling moments were computed at the peak angular rates in pitch and roll and the yaw rate at one second as indicated in the figure.

Available control power for the gyroscopic coupling analysis is identified as the amount of attitude change capability in one second corresponding to 25% thrust modulation level in pitch or roll as previously discussed. Yaw control power is the moment/inertia ratio available from 8 degess of forward fan thrust deflection and 4 degrees of lift/cruise fan thrust deflection. Based on these control levels, the control margins remaining after compensation for the gyroscopic moments are summarized in Figures 5-12 and 5-13.

Control in Crosswind

The candidate aircraft were evaluated as to compliance with the requirement that at least 50% of the specified normal control power shall be available for maneuvering after the aircraft is trimmed in a 25 kt crosswind. The available control power corresponds to 25% thrust modulation. The primary sources of the forces and moments in a crosswind are the ram drag effect of inlet mass flows and aerodynamic loads on the fuselage and vertical tail. The maximum trim force and

FIGURE 5-8
LEVEL 2 THRUST MODULATION REQUIREMENTS
VTOGW = 28,000 Lb

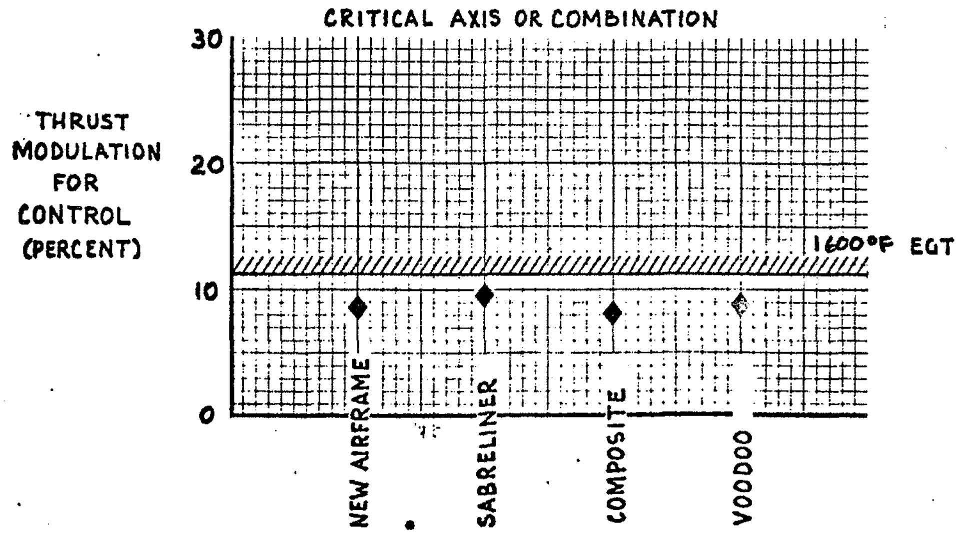


FIGURE 5-9
LEVEL 2 VTOL CONTROL DEFINITION
One Engine Out, Emergency Dry Rating
VTOGW = 28,000 Lb

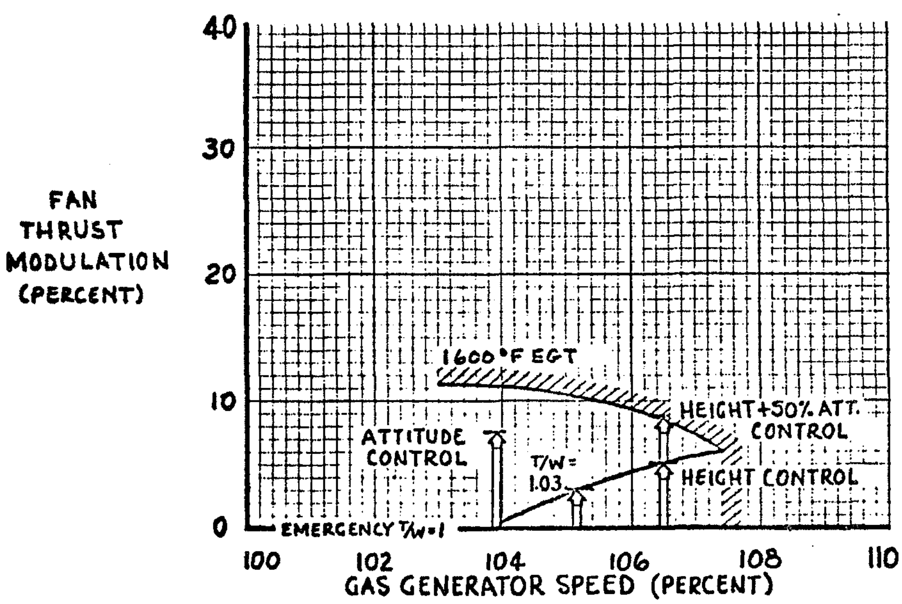


FIGURE 5-10
CONTROL CAPABILITY AFTER ENGINE FAILURE
Level 2
VTOGW = 28,000 Lb

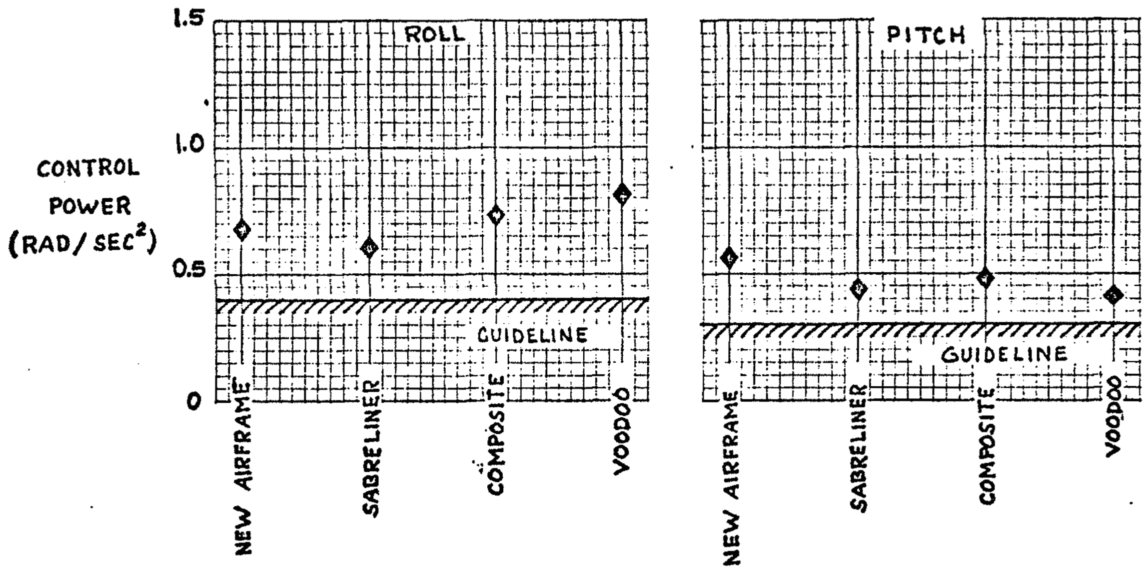


FIGURE 5-11
AIRCRAFT RATE RESPONSE FOR INPUT
OF GUIDELINE MANEUVER CONTROL POWER
Hover

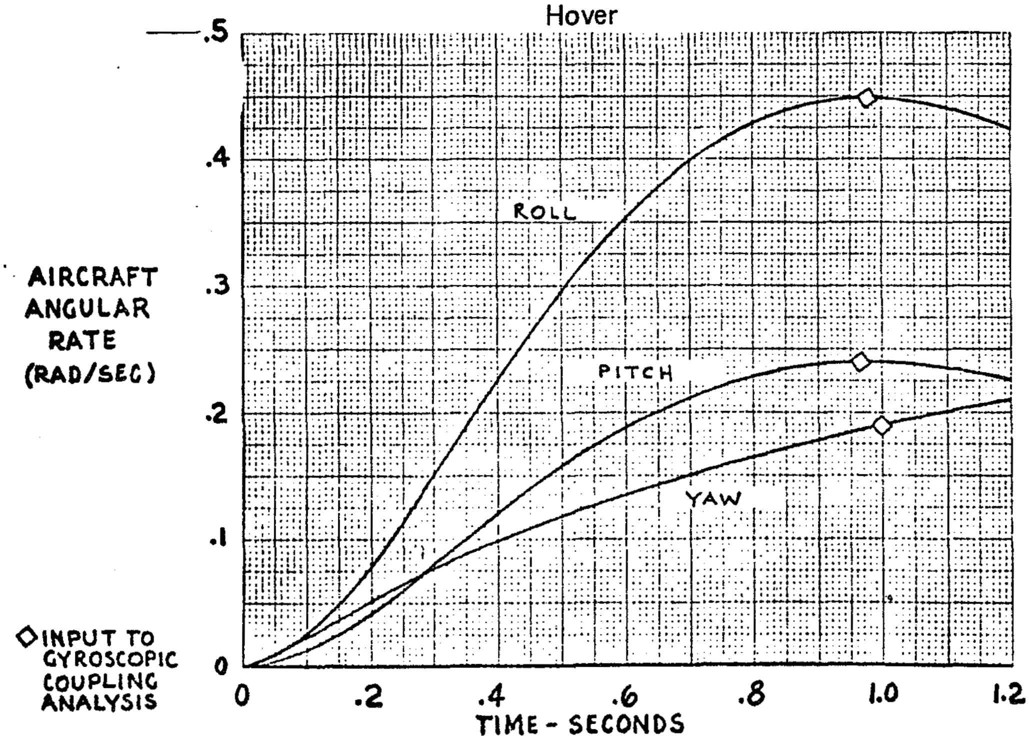


FIGURE 5-12
ROLL/PITCH GYROSCOPIC COUPLING COMPARISON

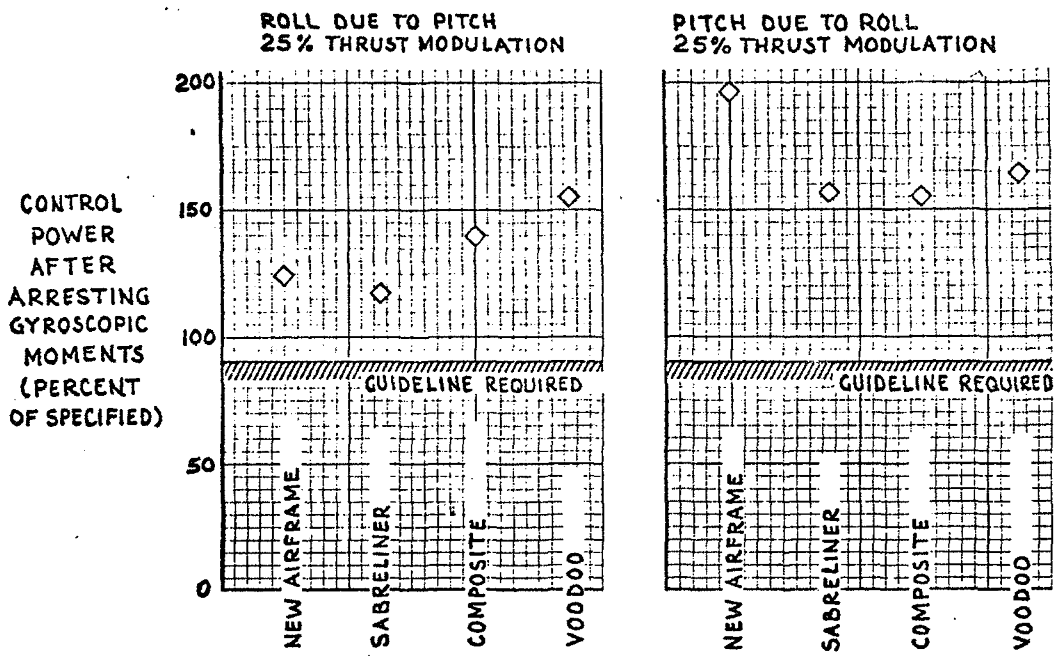
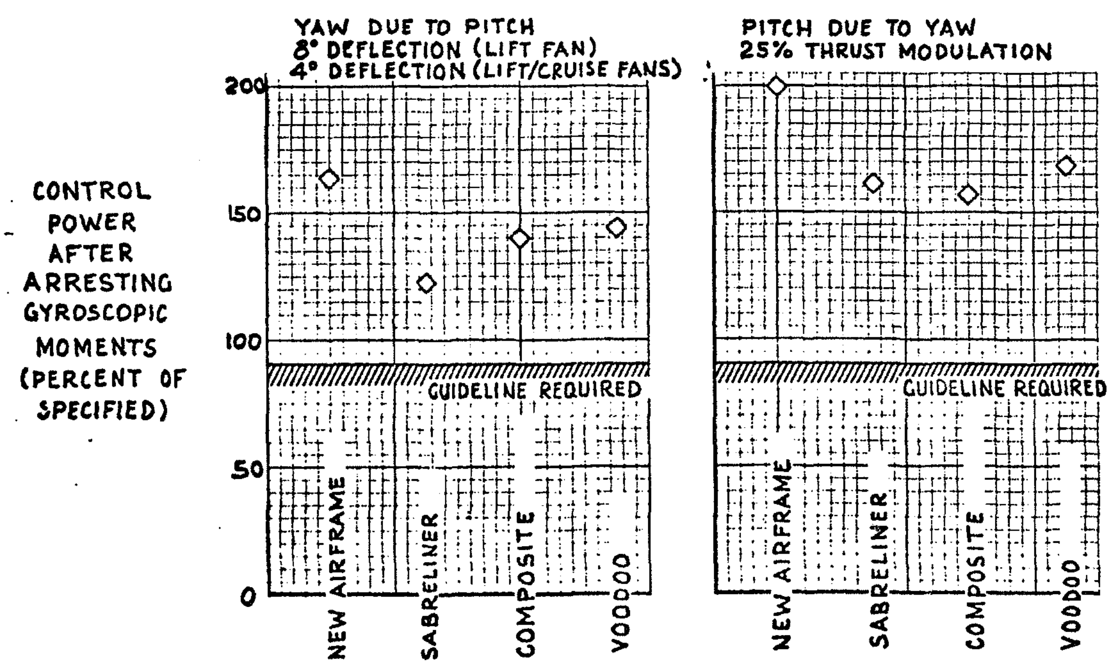


FIGURE 5-13
PITCH/YAW GYROSCOPIC COUPLING COMPARISON



and moment occur when the flow is normal to the aircraft plane of symmetry. Figure 5-13 presents the control margins remaining after trimming in a 25 kt cross-wind; all candidates exceed the design guideline requirement.

Center of Gravity Trim

Coincident center of thrust and center of gravity (cg) at VTO gross weight is a design requirement. This is accomplished by appropriate distribution of installed lift among the three fans. Therefore, cg trim requirements were not considered in computing the thrust modulation margins for control at the VTO gross weight. At lower operational gross weights, the thrust center is controlled with respect to the cg using ETaC, and the computed thrust modulation margins include the trim requirement.

Control Power Capability

All of the technology aircraft candidates have excess control margins for future research programs in the area of control power requirements. The margins available have been computed and are shown in Figure 5-15. Note that margins shown are based on 25% thrust modulation capability and on the 1600°F EGT limit for pitch and roll, and 8 and 10 degrees of thrust deflection for yaw.

Control System Response

Fan speed response varies with fan polar moment of inertia and inversely as the ratio of the accelerating torque to the corresponding speed change increment. Fan thrust response includes the effects of fan speed change, tip turbine thrust fraction, and actuation lags. Control response consists of two components: (1) fan thrust response from the increase of gas energy, and (2) thrust reduction modulation response. Estimated values of each component and their combination are shown in Figure 5-16 based on previous LF460 fan studies and ETaC test results.

As discussed earlier in this section, the normal control thrust modulation capabilities are well in excess of the normal control requirement. The excess modulation margin permits effective use of lead compensation for response improvement. Lead compensation magnifies the control commands and exponentially washes out the magnification. The result is a more rapid rise of the response to the commanded level. With lead compensation, therefore, the control response easily meets the 0.2 second requirement as shown in Figure 5-16. Because the fan thrust output must lift the same vertical takeoff gross weight in emergency as in normal condition, the energy supplied to the fan remains about the same. Also, approximately the same control margin for lead compensation is available in emergency for inputs meeting the Level 2 control power requirements. The response, therefore, is nearly the same in both cases, showing less than 0.2 second time to 63% of commanded change.

Flight Path Control

Figure 5-17 presents the short landing approach speeds required to produce an incremental normal acceleration of 0.15 g by aircraft rotation (pitch attitude change at constant thrust and vector angle) in 1.5 seconds. Data are given as a function of gross weight and descent rate assuming a reasonable rotation angle of 10 degrees which is consistent with the aircraft attitude control power requirement of 6 degrees displacement in one second. The 0.15 g incremental normal acceleration

FIGURE 5-14
TRIM/CONTROL IN HOVER
25 Kt Crosswind

	New Airframe	Composite	Sabreliner	Voodoo
Bank Angle Required - deg	5.0	5.1	5.1	5.2
Yaw Control Available after[(1)] Trimming - % of Guideline Requirement	132	127	96	116
Roll Control Available after[(2)] Trimming - % of Guideline Requirement	118	123	108	145

(1) 100% Available Yaw Control = 8 Deg Fwd Fan, 4 Deg L/C Thrust Deflection

(2) 100% Available Roll Control = 25% Thrust Modulation

Installed control power is in excess of guideline requirement.

FIGURE 5-15
CONTROL POWER CAPABILITY FOR RESEARCH

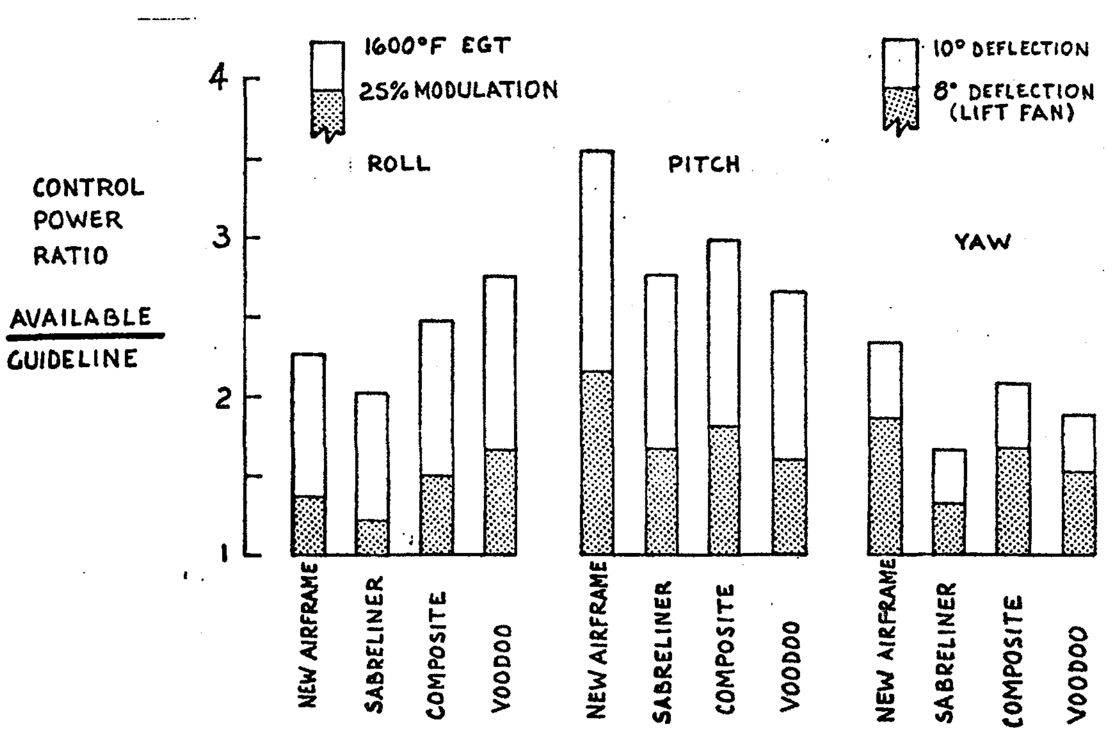
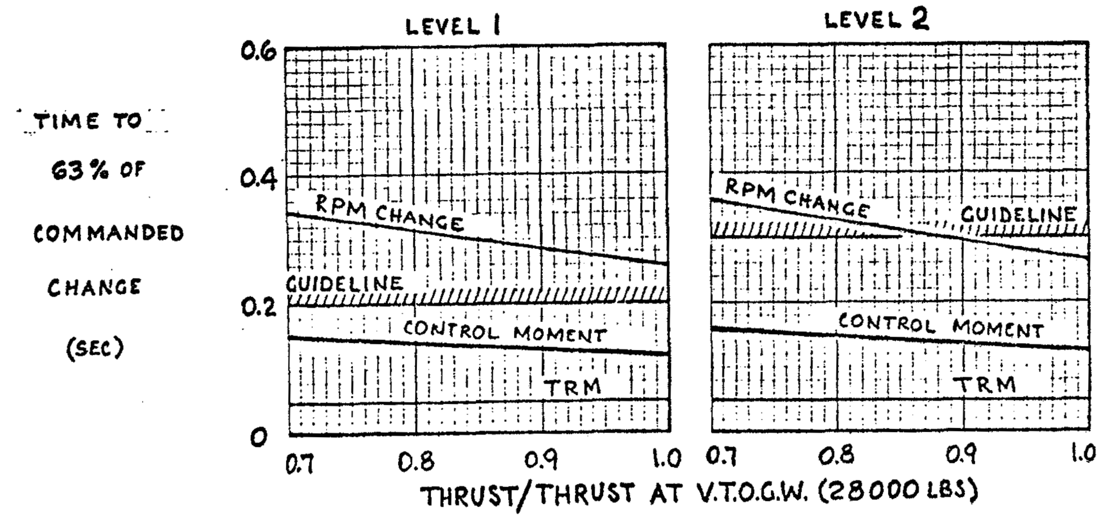
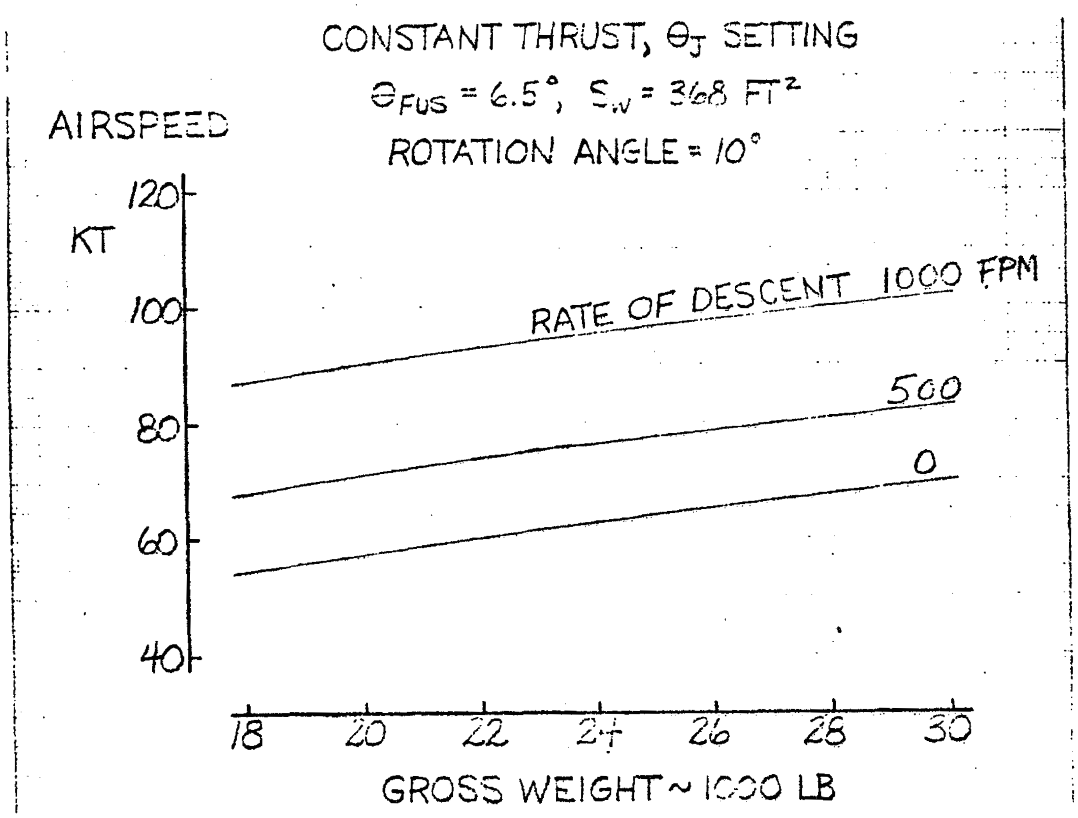


FIGURE 5-16
ESTIMATED CONTROL RESPONSE
Lead Compensation with ETaC



TRM = THRUST REDUCTION MODULATION

FIGURE 5-17
FLIGHT PATH CONTROL
Speed for 0.15 G Normal Acceleration by Rotation



for Level 1 operation can be produced when the approach speed equals or exceeds that shown. The Level 2 requirement of ±0.05 g incremental normal acceleration in 1.5 seconds can be fulfilled at lower velocities since the reduction in delta rotation angle is less than the reduction in acceleration required; i.e. the control power requirement is 5 rather than 6 degrees displacement in one second, thus the rotation angle is approximately 83% of the Level 1 value. As approach speeds are reduced, normal accelerations are obtained to a greater degree by power adjustment.

5.2 STABILITY

The following paragraphs present and discuss the design parameter and fan location effects with respect to the technology aircraft and its demonstration capabilities, and the dynamic stability characteristics in hover.

Design Parameters

The technology aircraft performance is a result of the configuration integration to optimize the aerodynamic-propulsion effects. Figure 5-18 presents a summary of the design parameters that contribute to the aircraft thrust balance, trim and control, and the static longitudinal stability margin. The adaptation of existing hardware to reduce the technology aircraft cost restricts the design freedom to provide thrust center, gravity center, and aerodynamic center coincidence at a given percentage MAC location. However, a tricenter compatibility was achieved to reduce the powered lift trim requirements, thus increasing the control capability of the ETaC system. The estimated neutral points show that the aircraft static longitudinal stability exceeds the requirement for a 0.05 MAC margin. Neutral points are estimated using advanced design methods supplemented by experimental data from wind tunnel tests of flow-through models of similarly configured lift/cruise fan aircraft.

FIGURE 5-18
DESIGN PARAMETER SUMMARY

Configuration	Thrust Center % MAC	CG Position (% MAC) OWE	OWE + Payload	TOGW	Neutral Point (% MAC)	Trim Req'd @ VTOGW (% MAC)	Static Margin @ VTOGW (% MAC)
New Airframe	25.0	26.1	27.4	25.0	40.0	0	15
Composite	29.6	20.5	20.2	29.6	36.0	0	6
Sabreliner	23.5	18.9	27.2	23.5	34.0	0	10
Voodoo	35.0	31.2	23.0	37.3	43.5	2.3	6

Fan Location, Aero/Propulsion Area Ratio

Theoretical and experimental data have verified that the L/C fan nacelle location relative to the wing is of primary importance to the creation of beneficial power induced lift in the STO and transition flight regimes. Fan spacings, which define powered lift control moment arms, and nozzle exit locations are determinants of VTOL power effects, in and out of ground effect. Such power induced effects are key inputs to V/STOL aircraft performance and handling qualities characteristics.

The technology aircraft configurations have been developed with the objective of retaining power induced effects similar to those of the multipurpose aircraft of the Part I study. Figure 5-19 presents the fan location data for the technology versus the multipurpose aircraft. Figure 5-19 also compares an aerodynamic/propulsion area ratio (wing span/fan diameter)^2 which when multiplied by $\rho V/\rho_J V_J$ is proportional to the aerodynamic/propulsion mass flow ratio. Power induced effects in general are similar if this mass flow ratio is duplicated in either demonstration aircraft or wind tunnel model designs.

FIGURE 5-19
FAN LOCATION, AERO/PROPULSION AREA RATIO

Aircraft	Fan Spacing		L/C Nacelle Location		Aero/Prop
	Longitudinal (No. Dia.)	Lateral (No. Dia.)	Inlet (x/c_{Local})	Exit (x/c_{Local})	Area Ratio $(b_W/D)^2$
Multipurpose	5.70	2.48	0.41	1.20	68.5
New Airframe	5.70	2.54	0.30	1.20	68.5
Composite	6.31	2.54	0.53	1.35	67.9
Sabreliner	5.51	3.55	0.26	1.30	82.4
Voodoo	6.35	2.78	0.52	1.36	65.2

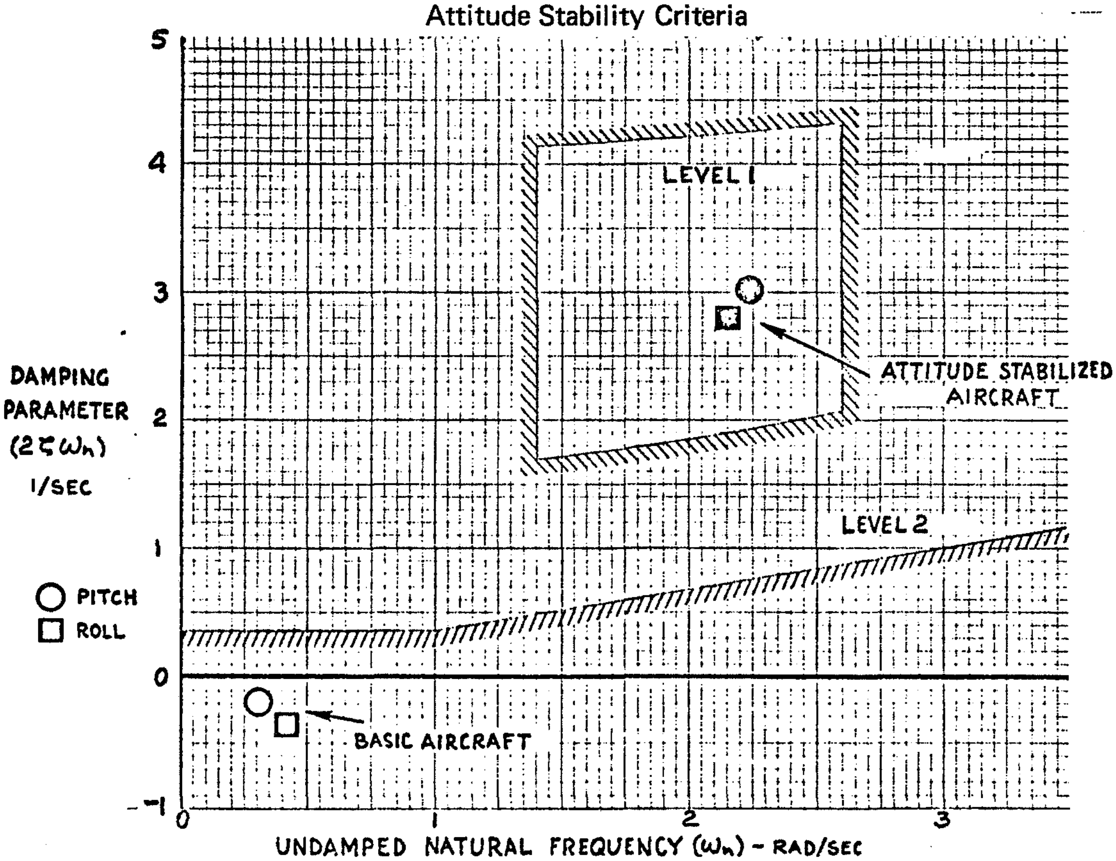
Hover Dynamic Stability

The inherent aerodynamic stability of a V/STOL aircraft decreases with reduction of airspeed until at some low speed approaching hover the aircraft becomes unstable. To stabilize the aircraft and to reduce the pilot's effort, a stability and control augmentation system was provided. The design guidelines with respect to low speed flying qualities address the aircraft's response and the dynamic stability characteristics. A dynamic stability criterion, expressed in desirable frequency and damping characteristics (Figure 5-20), is provided that is applicable to pitch and roll attitude stabilization.

The basic inherent dynamic characteristics of the technology aircraft in hover were evaluated and found to possess a low frequency divergent oscillatory mode as shown in Figure 5-20. The primary stability and command augmentation requirements in the powered lift regime were analyzed and the basic control loops determined for the hovering vehicle. These analyses were performed using root locus techniques which led to the selection of appropriate feedback gains to achieve the desired frequency and damping characteristics. The pitch and roll dynamic characteristics with the attitude and rate feedback loops closed are indicated by the symbols located within the design area in Figure 5-20.

Command of rate, rather than attitude, is required in yaw and the damping and frequency criterion for pitch and roll is not applicable. Yaw rate feedback gains are selected to provide rapid but comfortable aircraft response which meets the M/I and angle in one second guideline requirement. By means of a root locus

FIGURE 5-20
HOVER STABILITY CHARACTERISTICS
Attitude Stability Criteria



analysis, a rate feedback gain was selected which results in a yaw damping level of 1.12 sec^{-1} and which also satisfies the MIL-F-83300 yaw damping requirement.

5.3 FLIGHT CONTROL SYSTEM

Extensive consideration of the technology vehicle's stability and control functional requirements and a sound design philosophy with respect to operational reliability and flight safety dictate the flight control system characteristics as described in this section.

Basic Control Functional Requirements

Pilot command of pitch and roll attitude provides superior VTOL handling characteristics at airspeeds near hover. In this mode pitch and roll attitude changes are proportional to control stick displacements. Feedback signals of pitch and roll attitude and pitch and roll rate are used to effect attitude stability and proper aircraft attitude response. At speeds of 30-40 knots and above, the pilots prefer to command aircraft rate rather than attitude. Pitch and roll rate feedback signals are used to provide aircraft rate response proportional to stick displacement during maneuver control inputs. The attitude feedback signals are used only during steady state flight to provide attitude hold for pilot workload reduction. The flight control system operation is mechanized through the powered lift control and the aerodynamic control surfaces. This provides a smoother transition, as the powered lift controls are phased out and the aerodynamic controls become more effective, and insures continuation of good control and stability through conversion.

Directional control is augmented by a yaw rate command system which provides lateral/directional stabilization and good directional control characteristics at hover and low speeds when the system operates mainly through the lift fan thrust deflection system. After conversion to conventional flight, yaw command augmentation is provided through the rudder only.

Roll to yaw system interconnects coordinated with feedbacks of lateral acceleration, bank angle, and yaw rate are used to provide turn coordination signals. This mechanization is particularly important because the turn coordination requirements change drastically with airspeed, particularly in the 0 to 100 knot range At some speed approaching hover, coordinating of turns must yield to a pure sideslip mode of control.

These functional requirements combined with the multitude of control elements influence the selection of the flight control system.

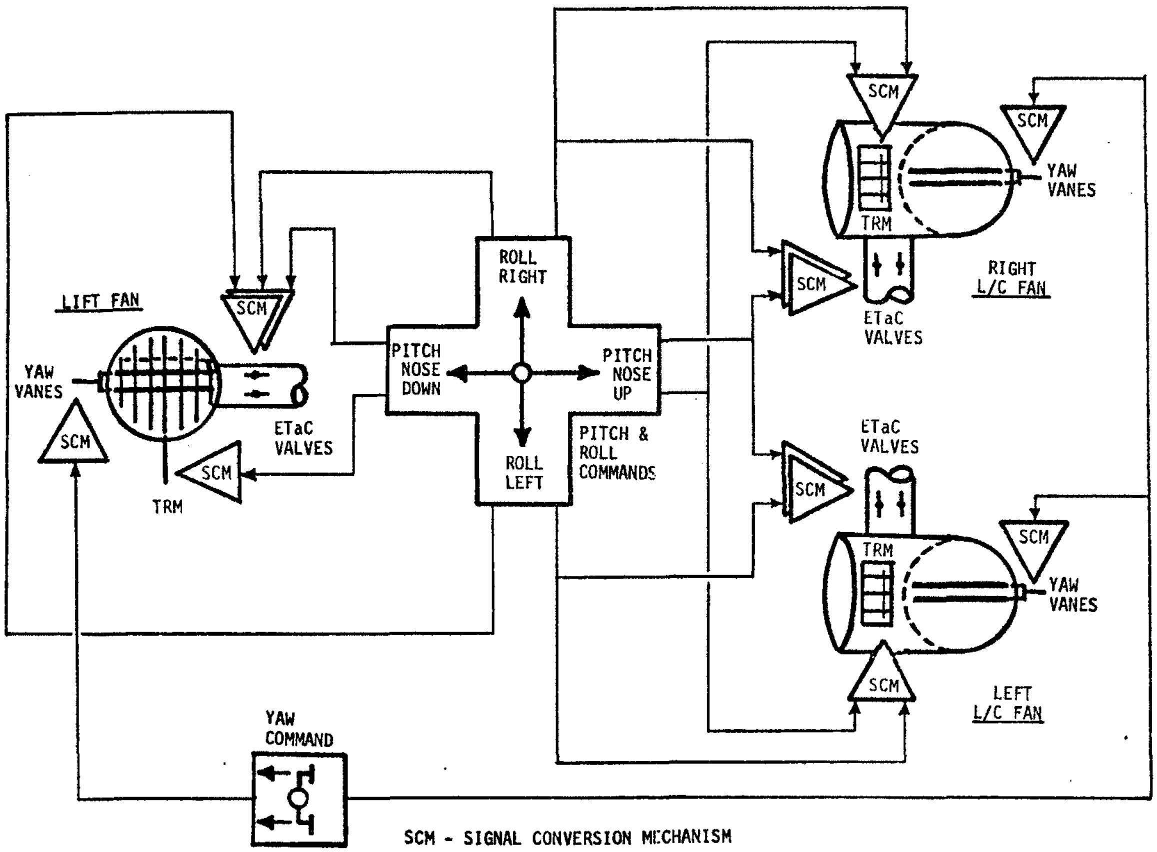
Flight Control System Description

The selection of a suitable flight control system for the technology demonstration aircraft is based on the premise that the aircraft should demonstrate all aspects of the technology which it represents. The technology aircraft flight control system is related, as much as possible, to the system selected for the operational aircraft within the constraints of cost, risk, and schedule. The elements and functions of the powered lift control system, as shown by the implementation of control logic diagram in Figure 5-21, and the characteristics of V/STOL operation in general require a control system which is highly flexible. To satisfy this requirement the Active Control System (ACS) approach was selected. The ACS is defined as a control-by-wire through a dedicated flight control system computer as shown in Figure 5-22.

The ACS is a triplex hybrid implementation of digital and analog functions combined to achieve desired high reliability and flight safety goals. The analog computer provides the minimum flight control functions deemed necessary for safe flight particularly during approach and landing following a complete digital system failure. The digital computer provides the capacity and flexibility required to incorporate many different primary flight modes, which are desirable for widening the scope of research applications. Both the analog and digital computations are performed simultaneously. The redundancy provides capability to land safely in the event of either complete digital or complete analog control function computation failure with reduced performance in either case.

As a technology demonstrator and a research tool, the control modes and functions to be provided are somewhat fewer than those required of an operational aircraft. The modes and functions as planned for the technology aircraft are listed in Figure 5-23.

FIGURE 5-21
IMPLEMENTATION OF POWERED LIFT ATTITUDE CONTROL



SCM - SIGNAL CONVERSION MECHANISM
TRM - THRUST REDUCTION MODULATION

FIGURE 5-22
ACTIVE CONTROL SYSTEM (ACS)

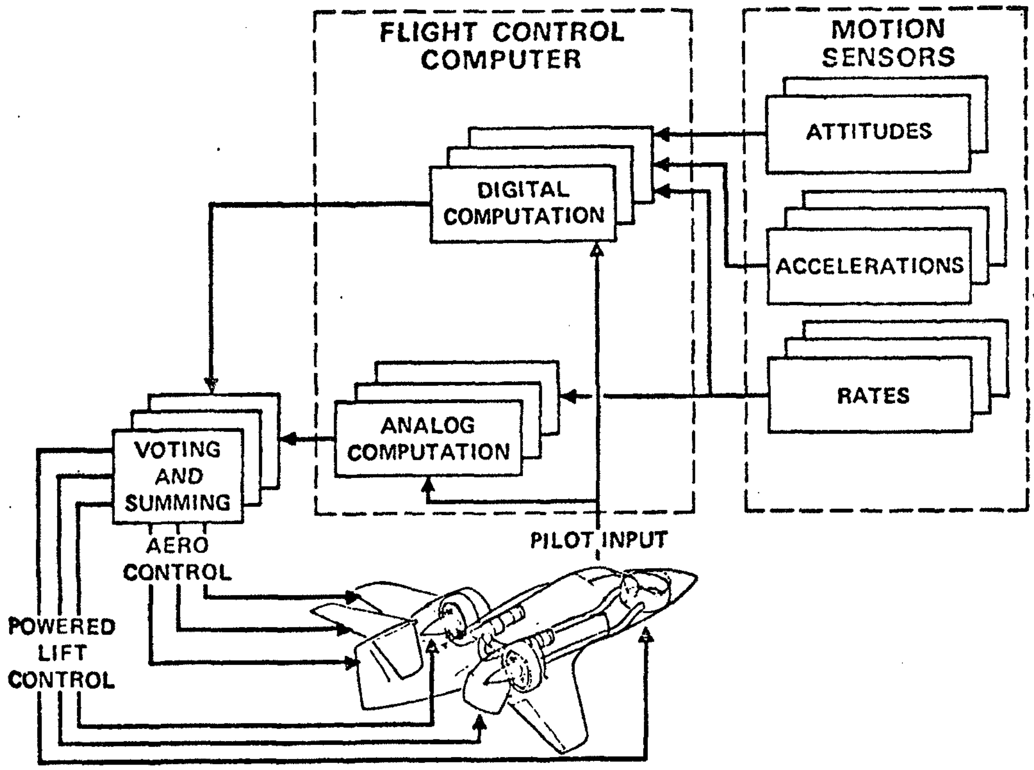


FIGURE 5-23
FLIGHT CONTROL SYSTEM FUNCTIONS/MODES

- CONVENTIONAL FLIGHT REGIME
  - MOTION DAMPING AND COMMAND SHAPING FUNCTIONS
- TRANSITION FLIGHT REGIME
  - PITCH RATE COMMAND/ATTITUDE HOLD
  - ROLL RATE COMMAND/ATTITUDE HOLD
  - YAW RATE DAMPING/TURN COORDINATION
- HOVER FLIGHT REGIME
  - PITCH ATTITUDE COMMAND
  - ROLL ATTITUDE COMMAND
  - YAW RATE COMMAND
- FLIGHT PATH CONTROL MODE
  - AUTOVECTOR
- AUXILIARY FUNCTIONS
  - AUTOMATIC TRIM
  - TAKEOFF TRIM SELECT
  - VERTICAL RATE DAMPER
  - EXHAUST SPLAY (FLOW FIELD EVALUATION)

6. DEVELOPMENT TEST PROGRAM

6.1 GENERAL DESCRIPTION

The ground and flight test development programs described briefly in the following paragraphs are those required to develop and evaluate the selected technology aircraft in the powered lift mode through conversion, and in the conventional flight mode through 200 kt. In all areas, full advantage was taken of the extensive development work MCAIR has accomplished in the past several years, both independently and under contract to NASA, to reduce the cost of the proposed test program. This work, which is a continuing effort, includes wind tunnel tests of similar designs and development tests of ETaC systems, hot gas ducting, thrust vectoring devices, and V/STOL aircraft control systems.

It is anticipated that the ground test program for any of the aircraft under consideration will be similar. In the case of a limited flight envelope aircraft, high speed wind tunnel tests would not be required; and in the case of the several modified existing aircraft, the extent of the proof testing could be minimized. However, the major propulsion system and control system tests would not change appreciably as a result of limiting the design flight envelope. In the flight test area, the contractor's effort for any of the approaches has been limited to a V_{max} of 200 kt IAS and 25,000 ft altitude and the instrumentation system limited in scope to reduce the cost of the contractor's program. Before a meaningful research program could be started, additional flight testing would be necessary.

The proposed development program schedule presented in Figure 6-1 and the discussions in the following paragraphs are for the full flight envelope aircraft design using one aircraft in the limited flight envelope evaluation.

6.2 GROUND TEST PROGRAMS

Wind Tunnel Test

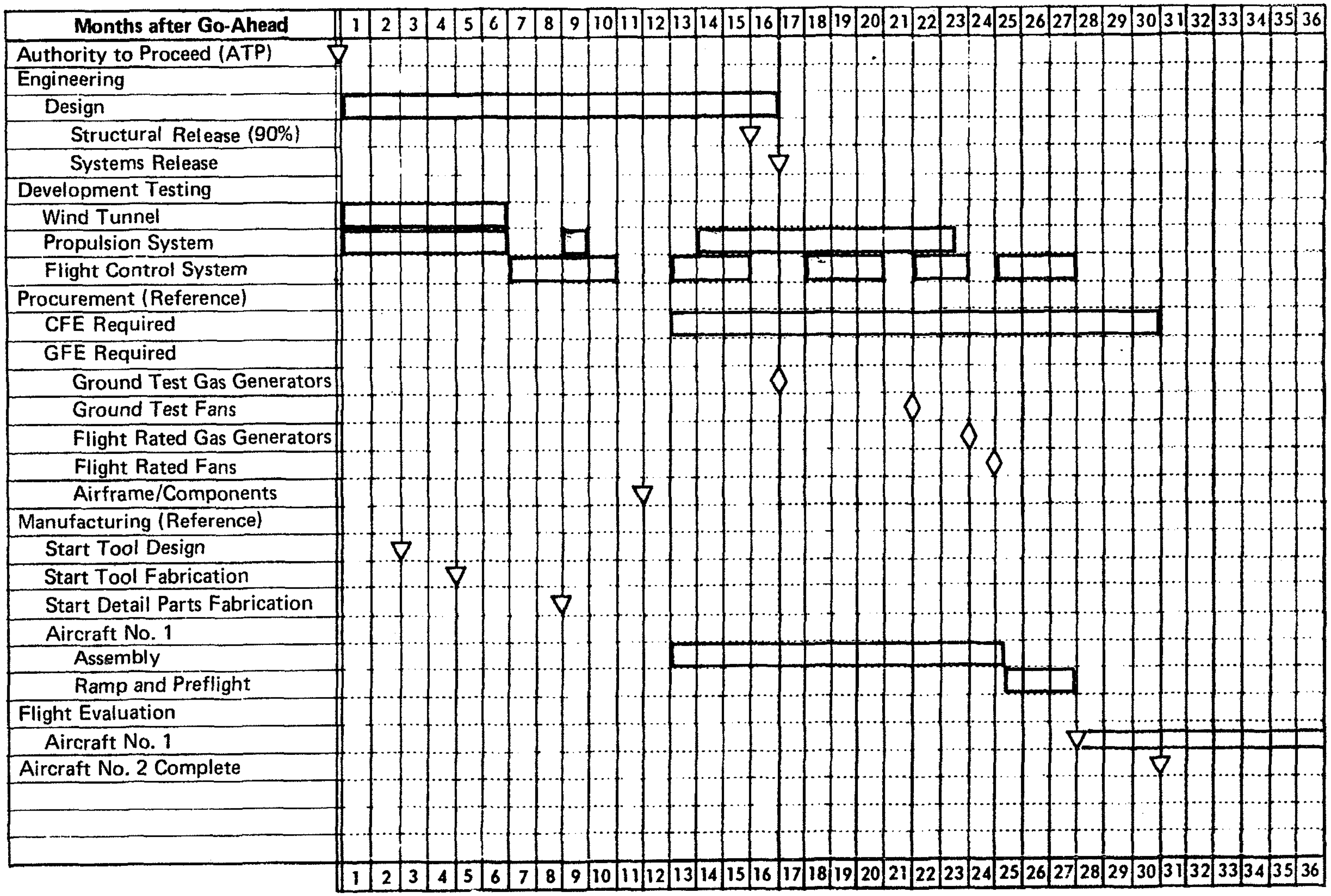
Maximum utilization will be made of experience and data from the Large Scale Lift/Cruise Fan Powered Model tests to be conducted in the NASA-Ames 40-by-80 foot wind tunnel under Contract NAS2-8655 as well as previous MCAIR tests of designs similar to the technology aircraft. In addition, a minimum amount of new low and high speed tests will be required. The low speed tests will be conducted using a new 10% scale unpowered model. The high speed tests will be conducted using an existing 4% scale model modified as required. The general objectives of the wind tunnel programs will be to determine low and high speed aerodynamic force and moment data, control powers, propulsion-aerodynamic interaction effects, ground effects, and flow field effects on forces, moments, and propulsion system recirculation. During the flow field tests the effects of power setting; aircraft heights, altitude, and control application; and forward, aft, and cross winds will be investigated.

Propulsion System Development

As in the case of aerodynamic wind tunnel tests, maximum use will be made of data obtained from various current testing being accomplished both under contract and independently. In addition, a limited amount of subscale and full scale tests will be required to supplement this current testing. These will include:

- <u>Ducting</u> - Subscale cold tests for evaluation of the specific design's internal aerodynamics; subscale hot tests of the specific system as proof of its thermostructural design.

FIGURE 6-1
TECHNOLOGY AIRCRAFT DEVELOPMENT SCHEDULE



- o Thrust Vectoring Devices - Subscale model tests on thrust stand to supplement 36-inch fan tests currently being conducted under Contract NAS2-6883 to NASA-Ames.

- o Valves - Energy Transfer and Control (ETaC), Shutoff, and Isolation: Subscale cold tests in conjunction with the ducting tests and full scale hot tests in conjunction with complete propulsion system tests described below.

- o Inlets - Subscale partial models of fan and gas generator inlets with suction, scaled model fans, or engine simulators tested statically and in conjunction with aerodynamic wind tunnel tests.

- o Total System Integration - Fans will be the pacing item in availability of the propulsion system. Therefore, these integration tests will start with J97 gas generators, ETaC valves, ducts, and fixed nozzles to simulate the fans. Final tests will be run with a complete aircraft propulsion system including the fans and a partial flight control system.

Flight Control Systems Tests

A considerable amount of the data obtained from earlier study and simulation efforts conducted under contract to NASA as well as currently proposed programs are of direct benefit in the development of the flight control system for the technology aircraft. Additionally, further specific development testing would be required by MCAIR to precede and supplement that conducted by the Active Control System (ACS) vendor. These tests would include the following:

- o Simulation - Fixed and moving base simulation early in the development phase with various degrees of actual hardware tie-in - a hybrid approach.

- o Control Subsystem Development - The flight control power components will be tested to determine that they meet the specified performance requirements. Vendor's test results will be accepted where possible.

- o Active Control System (ACS) Development - In addition to the vendor's tests, MCAIR will do the following:

  a. Component tests to check the performance of items such as flight control computers, motion sensors, and position sensors.

  b. Partial system integration tests to check, for example, the stability and response characteristics of some of the basic control loops made up from individual components.

- o Total System Integration Tests - A broad integration program is planned which includes:

  a. Overall system operational, stability, and performance evaluation under load. This will be done after completion of aircraft construction and in conjunction with the proof testing of the flight control devices.

b. Closed loop system integration tests, done in conjunction with the preflight tie-down tests with the propulsion system functioning in place of the usual "iron bird" tests with simulated propulsion system inputs. During these tests the propulsion system forces will be measured by load cells, the resulting aircraft motion computed by a general purpose digital computer, and the results displayed in the cockpit for the pilot in a manner similar to a flight simulation program.

Functional Tests

Although the technology aircraft design will incorporate a high percentage of developed components and subsystems, there will be a limited number of tests required to ascertain proper functioning of these items as installed. The tests, which will be performed as part of the preflight ground test program, will cover the fuel system, hydraulic system, electrical system, CNI avionics, landing gear, environmental control system, and ejection seats.

Physical Test Program

This program will consist principally of element tests of critical elements, and proof loading on the first flight article of aerodynamic control surfaces, engine and fan mounts, and thrust vectoring devices.

Vibration Tests

Vibration tests of the clean aircraft configuration will be performed as part of the ground test program. These tests will identify airframe modes critical for flutter and obtain accurate base data to be used in the flutter analysis. Critical modes will be investigated using conventional ground vibration test techniques including a soft tire suspension test setup.

Preflight Tie-Down Test Program

During the normal ramp checkout of the first airplane after completion of assembly, a thorough test of the propulsion and control system will be performed with the airplane tied down. Satisfactory operation of the gas generators, lift fans, thrust vectoring devices, and the ACS will be verified. The closed loop system integration tests described in the Flight Control System Test section above are part of these tests.

6.3 FLIGHT TEST PROGRAM

The contractor's flight test program has the prime objective of providing a preliminary evaluation of the technology aircraft in the powered lift mode and in the aerodynamic flight mode to a maximum of 200 kt indicated airspeed and 25,000 ft altitude. Additional flight testing will be required prior to the start of the NASA research program (see Section 6.4). The MCAIR flight program will consist of six aircraft months of testing with one instrumented aircraft. The instrumentation system to be furnished GFE will consist of on-board PCM tape recording with telemetry. Approximately 80 measurands are installed as CFE covering the basic parameters required to evaluate the aircraft and its systems. No propulsion system inlet or exit instrumentation will be included in order to reduce program costs. The second aircraft will be for program backup with space provisions for instrumentation.

Aerodynamic Flight Tests

After completion of the tie-down tests described above in the ground test program description, the first airplane will be transported to the remote test facility. Then, following completion of the normal ramp preflight checkout, the aircraft will be flown first in the aerodynamic flight mode using CTOL. Six flight hours are allocated for this phase. In addition to assuring that the aircraft is operationally safe, these flights will provide some flight operating experience with the remote fan propulsion system before start of the powered lift mode testing.

Powered Lift Mode Tests

After completion of the CTOL operational checkout flying, the airplane will be installed on a simple three-degree-of-freedom VTOL test stand for an initial look at the hovering mode handling characteristics. This type of test, with the pilot operating all powered lift mode systems, will be a valuable test procedure before first flight as well as later in the program to obtain a preliminary evaluation of any propulsion or control system changes or adjustments prior to commitment to flight. Upon satisfactory completion of these tests, the remainder of the program will be conducted. First, 18 flights will be devoted to a free-flight investigation of the powered lift hover mode. Then, during the last phase of the MCAIR program consisting of 21 flights, the forward flight speed will be increased in stages to overlap the minimum CTOL mode flight speed. The program will terminate with the first conversion from the powered lift mode to the aerodynamic mode and return.

Evaluation Categories

During the MCAIR flight test program, data will be obtained to evaluate the design in the following general areas of interest:

- Aircraft performance will be evaluated during vertical takeoff, hover, transition to and from aerodynamic flight, cruise to 200 kt indicated airspeed at 25,000 ft altitude, and both conventional and vertical landings. Specific attention will be given to evaluating the high induced lift characteristics for vertical and very short takeoff distances.

- Stability and control, as provided by the ACS, will be evaluated at selected airspeeds, altitudes, gross weights, and cg's in both the powered lift and aerodynamic flight modes to determine handling qualities at several fuselage pitch attitude angles and angles of attack; and longitudinal, lateral, and directional stability. The ACS integration with the propulsion control system will be investigated.

- Propulsion system performance will be evaluated with regard to adequacy of gas generator, fan, and duct installation; gas generator and fan operation including one-gas-generator-out conditions; and fuel system operation.

6.4 ALTERNATE FLIGHT TEST PROGRAMS

Two alternate flight test programs are presented in the following discussion - each with increased goals as compared to the basic program described in the preceding section.

100 Flight Hour Program

The additional test flights in this program would be accomplished on the second aircraft instrumented with the same type system as the first aircraft in the basic program; i.e., on-board PCM tape and telemetry. The added flights would provide an initial cursory look at the entire aerodynamic flight envelope and additional flight time to evaluate the transition flight phase. The aircraft months of test would increase to nine. However, the calendar span time for the program would remain at six months.

210 Flight Hour Program

This program is the minimum that would provide a test aircraft ready to go immediately into a NASA research program. The entire flight envelope would have been examined with sufficient test points to fully define the flight characteristics and performance capabilities of the design. To achieve this the two aircraft would be equipped with a miniaturized instrumentation system with added capabilities over the basic program system. A total of fifteen aircraft months of testing would be accomplished on the two aircraft in nine calendar months. It is proposed that NASA/Navy flight personnel participate on a continuing basis throughout this program.

7. CONCLUSIONS

The lift/cruise fan V/STOL technology demonstrator aircraft defined by this study

- o essentially meet all of the design guideline requirements
- o provide complete engine-out safety
- o can demonstrate Navy operational mission capabilities
- o make maximum utilization of existing components
- o provide excess control power in all axes for research purposes

The full flight envelope aircraft (New Airframe and Composite) designed for Approaches 1 and 2

- o are most representative of the multipurpose aircraft
- o are most relevant to the program intent
- o offer the greatest research productivity
- o provide for demonstrating aero/propulsion efficiencies and cruise fan integrity at cruise and loiter conditions

APPENDIX A

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

ATTACHMENT I

Revised Design Guidelines and Criteria
dated October 21, 1974

Enclosure (1) and (2) to National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California Letter FPL:237-2(037L:5.0) dated Oct 29 1974.

October 21, 1974

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 I 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 that 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 Critieria (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 work load 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 kts); where the STOL values will apply when operating above 40 knots. 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:

Conditions (a) --- to be satisfied simultaneously,

(1) Trim with the most critical CG position.

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

- 3 -

Axis	Maximum Control Moment / Inertia		Attitude Angle in 1 sec after a Step Input	
	VTOL	STOL	VTOL	STOL
Roll	± 0.9 rad/sec²	± .6 rad/sec²	± 15 deg	± 10 deg
Pitch	± 0.5 rad/sec²	± .4 rad/sec²	± 8 deg	± 6 deg
Yaw	± 0.3 rad/sec²	± 0.2 rad/sec²	± 5 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.

Condition (b) - - At least 50% of the above control power shall be available for maneuvering, after the aircraft is trimmed in a 25 knot crosswind.

Condition (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 CG position.

Level 2: The low speed control power shall be sufficient to satisfy, simultaneously, the following:

- 4 -

(1) With the most critical CG position trim after any reasonable single failure of power plant or control system.

(2) 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 Flight Path Control Power (SL to 1000 ft., 90°F).

1.1.2.1 VTOL (0-40 kt TAS 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 ± 0.1g
- (b) With wheels just clear of the ground -0.10g, + 0.05g

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Level 2:

(a) In free air -0.1g, + 0.05g

(b) With wheels just clear of the ground

-0.10g, + 0.00g

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

Level 1: ± 0.15g

Level 2: ± 0.10g

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

Level 1: $\frac{F}{W}$ = 1.05 in free air (Takeoff power rating)

Level 2: $\frac{F}{W}$ = 1.03 in free air (Emergency power rating)

1.1.2.2 VTOL and STOL Approach (40 kts. to V_{CON})

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

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 seconds at the STOL landing approach airspeed where reasonable rotation (angle of attack changes) will produce at least 0.15g's.

Level 1: ± 0.1g

Level 2: ± 0.05g

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

Level 1: ± 0.1g

Level 2: ± 0.05g

1.1.3 VTOL and STOL Low Speed Control System Lags (S.L. to 1000 ft. 90°).

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

	Level 1	Level 2
Attitude Control Moments	0.2 sec	0.3 sec
Flight Path 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 seconds for 0.5 inches of pilot's control
0.5 seconds for full pilot's control

Level 2: 0.5 seconds for full pilot's control

1.1.4 Stability (S.L. to 1000 ft., 90°F)

1.1.4.1 Hovering Stability

The frequency and damping of the airframe/control system dynamics, in the hovering condition, shall be within the following limits:

Level 1: Optimum damping and frequency zone established from the Ames six-degree-of-freedom moving base simulator (figure 1).

Level 2: The zone given in figure 1. The boundary of this zone corresponds to a damping factor of 0.166 for values of ω_n above 1 rad sec.

1.1.4.2 Low Speed Stability

Level 1: The dominant oscillatory modes shall be maintained as close as possible to the optimum zone specified in section 1.1.4.1 while maintaining other oscillatory modes damped. Aperiodic modes, if unstable, shall have a time to double amplitude of greater than 20 sec.

Level 2: The dominant oscillatory modes shall be maintained within the Level 2 zone given in figure 1. Other oscillatory modes may be unstable provided their frequency is less than 0.84 rad/sec and their time to double amplitude greater than 12 sec. Aperiodic modes, if unstable, shall have a time to double amplitude of greater than 12 sec.

1.1.4.3 Cruise Stability

The aircraft as configured for cruise flight shall be statically stable with a stability margin of 0.05 at the critical center of gravity without stability augmentation.

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 stall 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 2 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.

3.0 General Design Guidelines

3.1 Austerity is to be stressed but not by compromising safety.

3.2 The limit load factor will be no less than +2.5g, -0.5g.

3.3 Sufficient attitude control power will be available to perform research on control requirements. The contractor shall indicate those axes where greater control power than required in section 1.0 would be made available for research purposes.

3.4 The modified existing airframe designed with the limited flight envelope should have a maximum flight speed of approximately 160 knots. This aircraft could use a fixed landing gear. A retracting gear would be acceptable if it were available at no cost increase.

3.5 New aircraft components will be designed for approximately 500 flight hours.

3.6 Additional Information

- Minimum Mission Time	
VTOL Missions	1/2 hour
STOL Missions	1 hour
Cruise/Endurance Mission	2 hour
- Pay Load (not including crew)	2500 lbs (minimum) Volume 50 cu ft

- 10 -

3.6 (Continued)

- Crew	2 pilots (flyable by one pilot only, or by either pilot)
- Sink rate at touchdown	12 fps at max landing weight
- Ceiling (Low Speed restrictive configuration)	15,000 ft (Nonpressurized cockpit)
- Cockpit Environmental System	Minimum
- Pilot's Primary Flight Controls	Stick and Pedals
- Ejection System for both pilots	
- Maximum possible visibility	

Further or modified guidelines will be established following Part I of the study per paragraph 2.1 of Attachment 1 of the Statement of Work.

3.7 The contractor shall furnish as a minimum:

a. Conceptual design aircraft layout drawings.

b. Weight and balance summary with empty weight breakdown into usual structual and system groups.

c. Low speed performance envelope at design gross weight.

d. Conceptual definition of proposed aircraft low speed control and stabilization system.

e. Control moment coefficients and control power about each axis with all gas generators operating and with most critical gas generator failed.

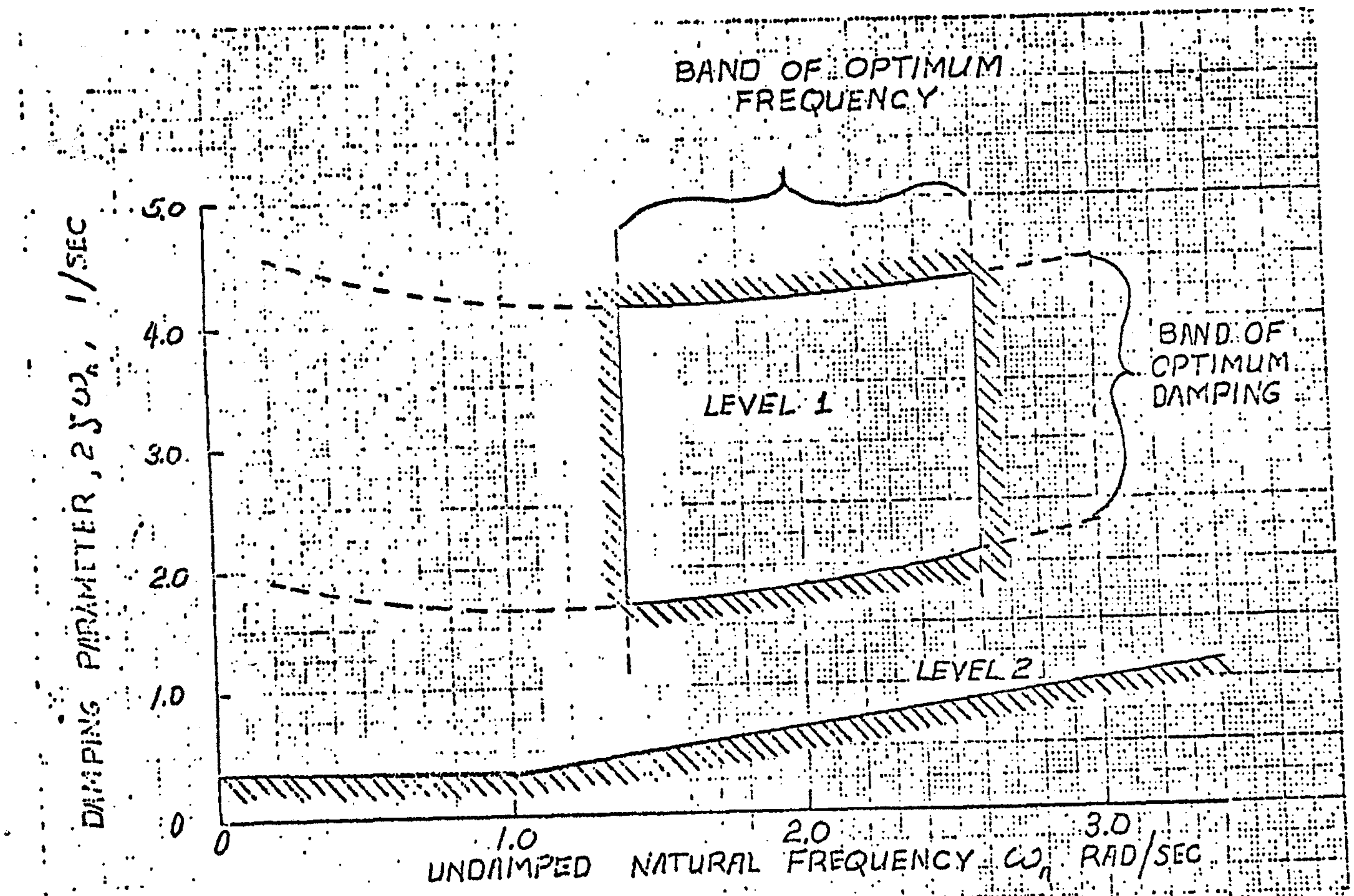
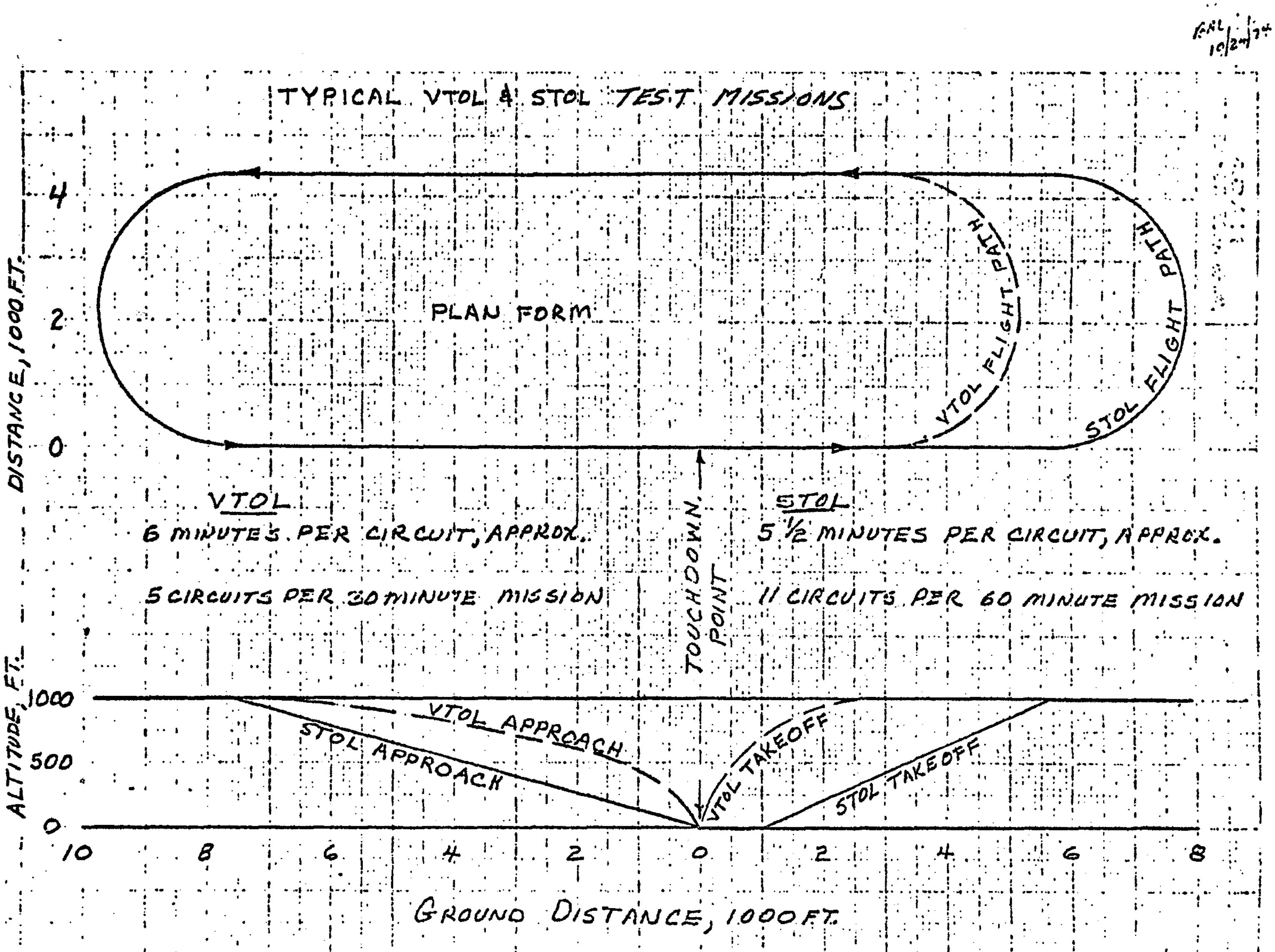


FIGURE 1. DYNAMIC STABILITY CRITERIA


TYPICAL VTOL & STOL TEST MISSIONS
PLAN FORM
DISTANCE, 1000 FT.
VTOL FLIGHT PATH
STOL FLIGHT PATH
VTOL
6 MINUTES PER CIRCUIT, APPROX.
5 CIRCUITS PER 30 MINUTE MISSION
STOL
5 1/2 MINUTES PER CIRCUIT, APPROX.
11 CIRCUITS PER 60 MINUTE MISSION
TOUCHDOWN POINT
ALTITUDE, FT.
VTOL APPROACH
STOL APPROACH
VTOL TAKEOFF
STOL TAKEOFF
GROUND DISTANCE, 1000 FT.

Enclosure 2