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DESIGN DEFINITION STUDY OF NASA/NAVY LIFT/CRUISE FAN V/STOL AIRCRAFT VOLUME II - SUMMARY REPORT OF TECHNOLOGY AIRCRAFT

By Robert L. Cavage, et al

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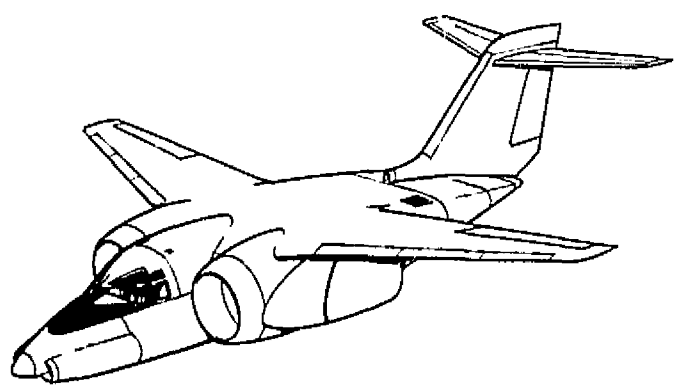
SUMMARY

This report presents results of a study by the Rockwell International Corporation for the NASA Ames Research Center and the Naval Air Systems Command. The study investigated three alternate approaches to the design of a test aircraft to verify emerging lift-cruise fan V/STOL technology via a flight test program. The three alternate approaches addressed were (1) an all new airframe concept capable of demonstrating all essential performance features of an operational airplane, (2) a full performance modified airframe capable of flying in all the operational flight regimes, and (3) a low speed only modified airframe capable of exploring the low speed regime where the unique V/STOL phenomena and technical concerns are most concentrated. The study concluded that the full performance modified airframe would be the most cost-effective approach. The recommended configuration is illustrated below.



The configuration features two 1.3 design fan pressure ratio lift-cruise fans driven by three currently available J97-GE-100 gas generators. The basic airframe consists of a Rockwell International Sabreliner business jet with a relocated wing, and a modified T-tail empennage using the vertical tail from an F-101 Voodoo fighter. Selected fairings, etc., are incorporated to integrate the lift-cruise fan system into a clean aerodynamic shape capable of high subsonic speeds. The aircraft has a vertical takeoff weight of 28,000 pounds. Its STOL takeoff distance with maximum internal fuel is less than 200 feet. Cruise test times up to two hours are available and the test envelope includes test times of 45 minutes or better up to speeds of 0.85 mach number and altitudes to 45,000 feet. A two aircraft flight test program was recommended.

INTRODUCTION

Prior government sponsored studies have identified remote tip turbine driven lift-cruise fan V/STOL systems as having advantages for both commercial applications and Navy military missions for the 1980-1985 time period, References 1 through 4.

The purpose of this study was to define and evaluate three alternative approaches to the necessary test aircraft to verify emerging lift-cruise fan technology such that operational aircraft procurement programs and detailed system design may be pursued with confidence and acceptably low risk. The three approaches investigated covered a wide range of flight demonstration capabilities and potential program costs. The approaches considered were: (1) all new airframe, (2) full performance modified airframe, and (3) low speed only modified airframe. The all new airframe concept was to be based on the operational multi-mission aircraft configuration defined by Reference 4. The modified aircraft approaches were to be defined by the contractor.

The selection of lift-cruise fan propulsion system characteristics was limited by the guideline to select fan systems that could be developed in the short time span of a few years and which would minimize the costs of preliminary flight rating tests (PFRT). Following the selection of lift-cruise fan technology based on J97/LF460 technology, as represented by the data of References 5 and 6, the selection of fan characteristics was further limited to single stage fans to assure low propulsion program costs and risks. Specific data on the selected fan technology was prepared on a parallel government contract by the General Electric Company of Evendale, Ohio.

The scope of the study included technical definition and evaluation of the three alternate approaches to the technology aircraft, estimation of the program schedule and costs for a one airplane and two airplane flight test program for each approach and identification of related technology support or technical development programs required to implement the basic technology aircraft program.

The study identified a technology aircraft configuration meeting the guideline requirements for each of the three alternate approaches. Evaluation of the three approaches indicated that the full performance modified airframe with two flight test airplanes would be the most cost-effective and low risk program.

CONTENTS

SYMBOLS

A/C	Aircraft
APU	Auxiliary Power Unit
AR	Aspect Ratio
b	Span, Ft (0.3048 meters)
C_D	Drag Coefficient, D/qS
CG	Center of Gravity
C_L	Lift Coefficient, L/qS
$C_{L_{max}}$	Maximum Lift Coefficient, L/qS
C/O	Checkout
CONTR	Control
CU	Cubic
DBL	Double
DIA	Diameter, In. (0.0254 meters)
DIST	Distance, Ft (0.3048 meters)
DLC	Direct Lift Control
ETC	Energy Transfer Control
FLT	Flight
FPR	Fan Pressure Ratio
FPS	Feet Per Second (0.3048 meters/second)
g, G	Acceleration of Gravity 32.3 ft/sec^2 (9.815 m/sec^2)
HR, HRS	Hour, Hours
GE	General Electric Company

GG	Gas Generator
°F	Temperature in Fahrenheit, Degrees (5/9 (°F+459.67))°K
GND	Ground
INCL	Including, includes
KN, KTS	Knot(s) (0.5144 meters/sec)
LAT	Lateral
L/D	Lift-To-Drag Ratio
M	Mach Number
MAC	Mean Aerodynamic Chord
MAX	Maximum
Min	Minimum, minute(s)
MOD	Modified, modification
N M	Nautical Mile(s) (1852 meters)
PERF	Performance
PGM, PGRM	Program
P/L	Payload, Lb (4.44822 Newtons)
PSF	Pounds per Square Foot, lb/ft^2 (47.88024159 Newton/m^2)
q, Q	Dynamic Pressure, Lb/Ft^2 (47.88024159 Newton/m^2)
RAD	Radians
RES	Reserve
RPM	Revolutions Per Minute (0.016666 Rev/Sec)
S, S_W	Wing Area, Ft^2 (0.09290304 meters^2)
SP	Span
SL	Sea Level
STOGW	Short Takeoff Gross Weight, LB (4.44822 Newtons)

STOL	Short Takeoff and Landing
T	Thrust, LB (4.44822 Newtons)
t/c	Thickness to Chord Ratio, %
TECH	Technology
T.O.	Takeoff
TOGW	Takeoff Gross Weight, LB (4.44822 Newtons)
T/W	Thrust-to-Weight Ratio
VEL	Velocity
V/STOL	Vertical/Short Takeoff and Landing
VTO	Vertical Takeoff
VTOGW	Vertical Takeoff Gross Weight, LB (4.44822 Newtons)
VTOL	Vertical Takeoff and Landing
WOD	Wind Over Deck
W/S	Wing Loading, Lb/Ft^2 ($47.88024159\ Newtons/m^2$)
WT, W	Weight, LB (4.44822 Newtons)
W/U	Warm Up
α	Angle-of-Attack, Degrees (0.017453 radians)
δ_F	Flap Deflection Angle, Degrees (0.017453 radians)
$\Lambda_{c/4}$	Sweep Angle of Quarter Chord Line, Degrees (0.017453 radians)
Λ_{LE}	Leading Edge Sweep Angle
λ	Taper Ratio, Tip Chord to Root Chord

ILLUSTRATIONS

LIST OF TABLES

STUDY GUIDELINES

The major design guidelines established to direct the design of the technology aircraft are summarized in figure 1. The design criteria were established to assure that the aircraft would provide reasonable V/STOL regime flight demonstration capability. Design VTOL and STOL horsetrack pattern test mission profiles were established as shown in figure 1. Because of the higher fuel consumption and steeper climbout and approach paths typical of VTOL operations, the VTOL test mission profile was set at a shorter distance than the STOL mission and five rather than 11 continuous circuits were prescribed.

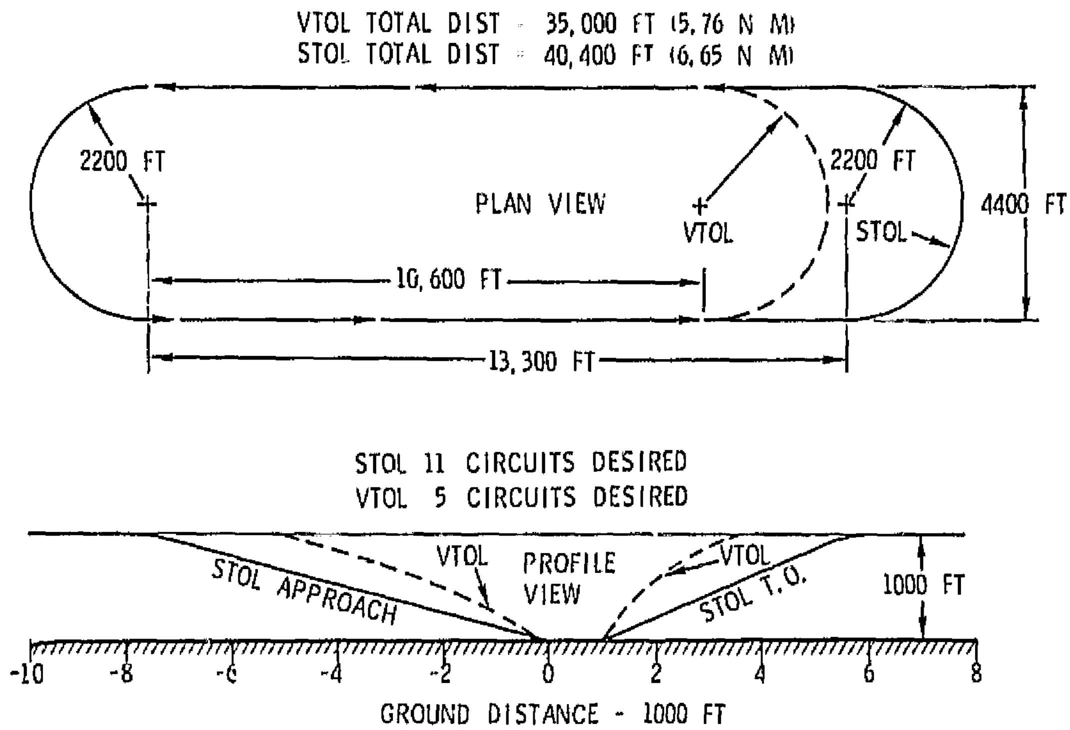
A major emphasis of the study was to identify low cost approaches to the technology aircraft in each of the three categories without compromising flight safety. The minimum acceptable positive maneuver load factor was established as +2.5 but a load factor of +3.0 was indicated to be highly desirable.

The minimum attitude control power and flight safety criteria consisted of an extensive array of criteria for both normal and emergency operations in VTOL, STOL and cruise operating regions and treated the individual requirements for control about all three control axes of the aircraft. The criteria included:

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

The guidelines provided adequate low speed margins to handle the large angle of attack changes due to gust encounters when flying at very low speeds. These included the requirement for transition speeds of $\geq$120% of wing borne stall speed and an operational $C_{L_{MAX}}$ limit of 0.8 times the maximum available $C_{L_{MAX}}$. The aircraft was to be capable of completing a STOL mode takeoff after any reasonable failure of a gas generator or a control system component. Similarly, a maximum vertical landing weight was to be established where after a failure, a controllable landing could be completed without exceeding the design gear limit sink speed. New component design life, minimum mission times, research payload provisions, crew provisions, and maximum design gear limit sink speed were specified as noted in figure 1. The cockpit was to provide maximum practical visibility and stick and pedal primary flight controls. Minimum cockpit environmental control was acceptable as an economy measure. For the low speed only approach, fixed landing gear were acceptable and the speed and altitude were to be limited to 160 knots and 15,000 feet respectively to minimize structural modification costs, including elimination of the need for pressurization.

TEST MISSIONS



- <u>LOW COST</u> WITHOUT COMPROMISING SAFETY
- LIMIT LOAD FACTORS +2.5, -0.5 G
- SPECIFIED MINIMUM ATTITUDE CONTROL POWER
- NEW COMPONENTS DESIGN LIFE, 500 FLT HRS
- MINIMUM MISSION TIMES:

  VTOL - 0.5 HR
  STOL - 1.0 HR
  CRUISE - 2.0 HR
- PAYLOAD, 2500 LB / 50 CU. FT.
- CREW OF TWO WITH EJECTION SEATS
- MAX LANDING TOUCHDOWN SINK RATE, 12 FPS
- MAX POSSIBLE VISIBILITY
- LOW SPEED ONLY APPROACH:
  - 160 KNOTS
  - 15,000 FT CAPABILITY (UNPRESSURIZED)

Figure 1. Summary of Major Design Requirement Guidelines

RECOMMENDED FULL PERFORMANCE MODIFICATION AIRPLANE

Based on comparative evaluations, the full performance modified airframe approach configuration was recommended as the most cost-effective technology aircraft concept. The specific configuration was evolved from trade and configuration development studies as presented in a later section of the report. The following paragraphs present the features and characteristics of the selected final representative configuration.

Configuration Definition

Figure 2 presents a design brief of the full performance modification configuration. The airframe was derived through modification and addition

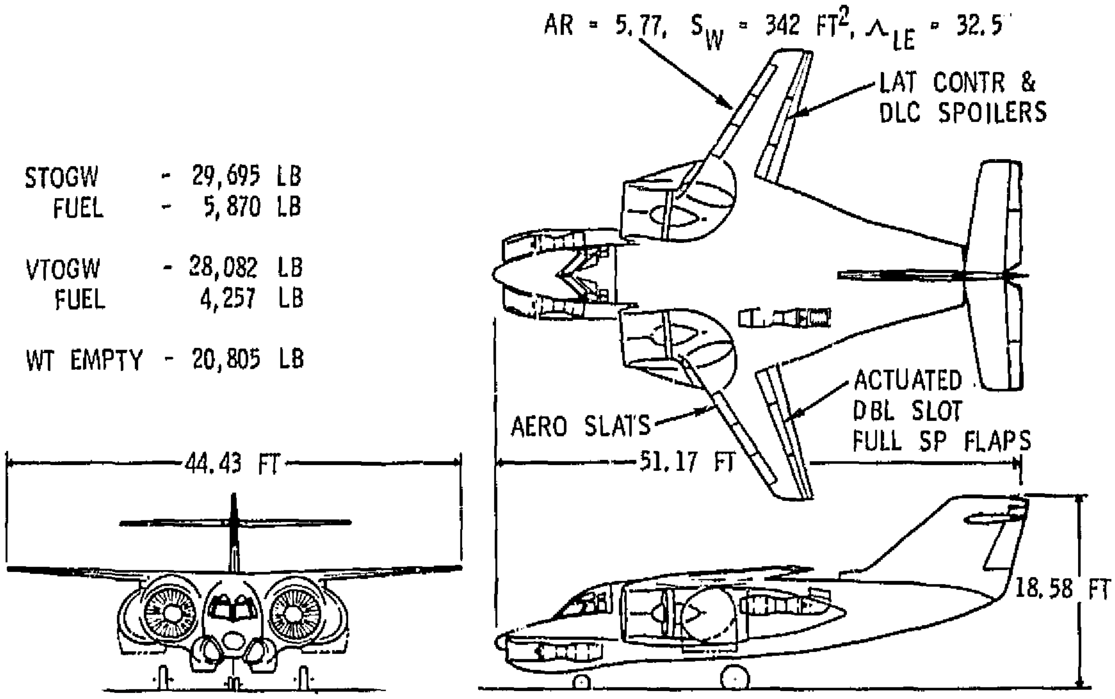


Figure 2. Design Brief - Full Performance Modification Approach

of new features to a Rockwell International Sabreliner business jet. The low mounted Sabreliner wing was moved to the top of the fuselage to allow nesting of the new lift-cruise fan system components below the wing in the area of the wing/fuselage juncture. Full-span double-slotted fowler flaps and spoilers replaced the single-slotted flap and aileron aft of the wing rear spar. The original empennage was replaced with a vertical tail from the F-101 Voodoo supersonic fighter and on all new horizontal tail. The nose landing gear from the F-100 supersonic fighter and the main gear from the Navy RA-5C reconnaisance bomber were adapted to the configuration to provide adequate ground clearance and structural strength to withstand the design sink rates at higher design gross weights. The nose of the aircraft, from the cockpit forward, was canted down 5° to provide 20° over the nose vision directly in front of the pilots. These modifications increased the empty weight by 7555 pounds and the design gross weight by 6695 pounds.

The high subsonic speed capability of the basic wing was retained by maintaining a smooth upper wing surface and by providing well faired flap hinging and actuation mechanisms beneath the wing, similar to the DC-10 airplane. The fuselage fairings behind the lift-cruise fan system components were shaped to prevent flow separation below the design high subsonic cruise speed. High lift devices include the double slotted flaps and aerodynamically operated leading edge slots. Spoilers provide conventional lateral control and direct lift control in the low speed flight regime. A segmented elevator on a trimmable all moving horizontal tail provides aerodynamic pitch control. The rudder of the Voodoo vertical tail provides aerodynamic yaw control. The rudder has a duel operating mode: at low speed, it operates through its full deflection range but at high speed, deflection is limited to eliminate control oversensitivity.

The major geometric features of the lifting surfaces of the vehicle are presented in Table 1. The fuselage maximum length is 47.33 feet. The maximum fuselage height is 7.5 feet and the maximum width, including the fairings behind the fans but not the nozzles, is 18.58 feet. The maximum width including the nozzles is 23.0 feet. The total wetted area of the configuration is 2289 square feet.

Table 1. Wing and Tail Surface Geometry

	Wing	Horizontal Tail	Vertical Tail
S - ft	342	100	100
AR	5.77	4.84	0.743
λ	0.321	0.62	0.486
b - ft	44.43	22	8.62
$\Lambda_{c/4}$ - deg	29.0°	8.2°	43.9°
t/c - %	12%	10%	6%
Airfoil	64A212 Mod	64A010	Symmetrical
MAC - ft	8.38	4.63	12.06

Performance & Research Capability

The capabilities of the full performance modified airplane configuration are reasonably similar in the cruise mode regime and slightly superior to the target operational aircraft configuration of reference 4 in the low speed regime. Figure 3 shows the STOL takeoff performance characteristics of the full performance modification aircraft configuration. Because of its lighter weight, the full performance airplane can lift-off in shorter distances and at lower airspeeds than required to meet the design operational capabilities. At reduced thrust settings, however, it can investigate the flight characteristics with T/W ratios bracketing the operational aircraft T/W and thus perform STOL regime flight investigations with high fidelity to the operational situations but with significant reserve margins for added safety.

The takeoff capability and fuel capacity of the full performance airplane allows performance of the required low speed horsetrack pattern test missions with fuel to spare. Figure 4 summarizes the low speed test mission performance.

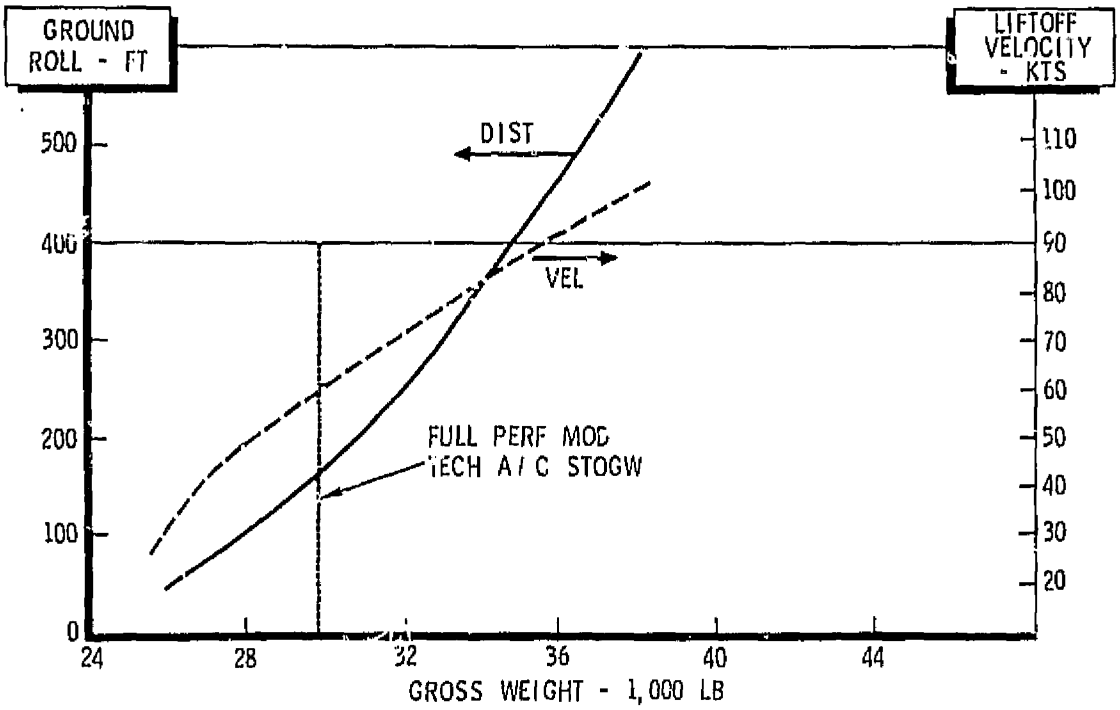


Figure 3. Full Performance Aircraft STOL Takeoff Characteristics

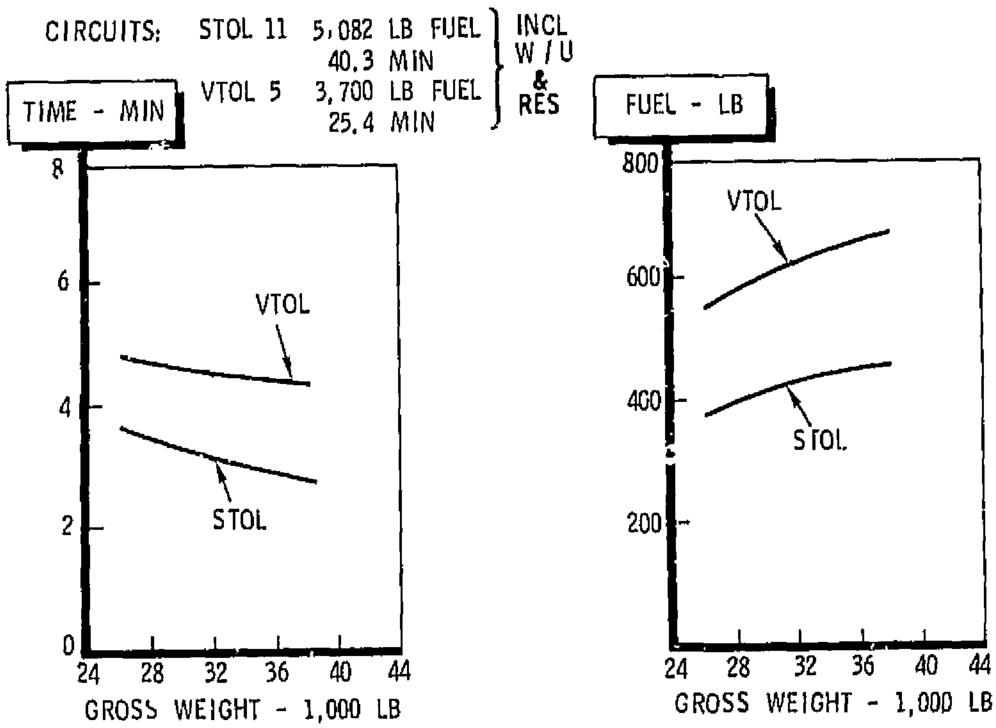


Figure 4. Full Performance Aircraft Low Speed Test Mission Performance, per Test Mission Field Circuit

The data of figure 4 indicate the time and fuel used to complete an individual touch and go test mission circuit as a function of the initial gross weight. The VTOL missions, because of lower initial effective horizontal accelerating T/W, consume more time and fuel.

The total fuel and time required to complete the eleven STOL circuits and five VTOL circuits are shown at the top of figure 4. These total fuel/time figures include the time and fuel for an initial warmup and checkout of 2.5 minutes and also allow for a 10 percent initial fuel reserve and a one minute taxi back after the final landing. Because the aircraft has a basic internal fuel capacity of 5870 pounds of JP-4, additional STOL circuits or a higher research payload can be carried than specified by the guidelines if desired. Because the vehicle can perform a vertical takeoff at a gross weight of 28,000 pounds including 4257 pounds of fuel, versus 3700 pounds required, and the 2500 pound research payload, it also has excess capacity over the minimum VTOL test mission guideline requirements.

The aircraft cruise and propulsion system flight test time capability versus mach-altitude flight condition is shown in figure 5.

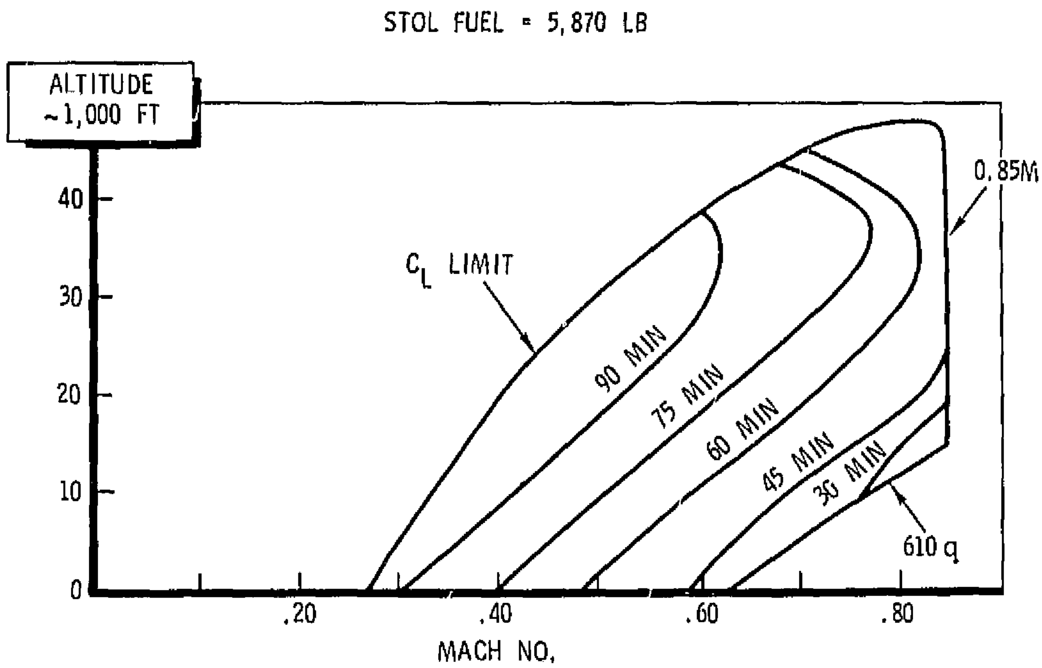


Figure 5. Full Performance Aircraft Cruise/Propulsion Test Time

The test times of figure 5 are based on a takeoff with the maximum STOL fuel load with a minimum fuel climb accelerate to the test point, a no distance credit loiter at the test flight condition and a minimum fuel cruise back to the point of origin. Fixed allowances are provided for warmup, takeoff and landing reserves. The majority of the test envelope shown is accomplished with two of the available gas generators driving the two lift-cruise fans. The maximum cruise test time with this propulsion system operating mode is approximately 110 minutes at speeds of 0.4 to 0.5 mach number near 30,000 feet. Additional test time at these conditions, beyond the desired 2 hour period, can be obtained by operating with one gas generator driving both fans for increased cruise efficiency. The test times and envelope provided are adequate to allow testing of a development lift-cruise fan system throughout most of its expected operating regime including speeds above 0.8 mach number and altitudes to 45,000 feet.

Figure 6 presents the aerodynamic characteristics of the configuration in the low speed operating regime.

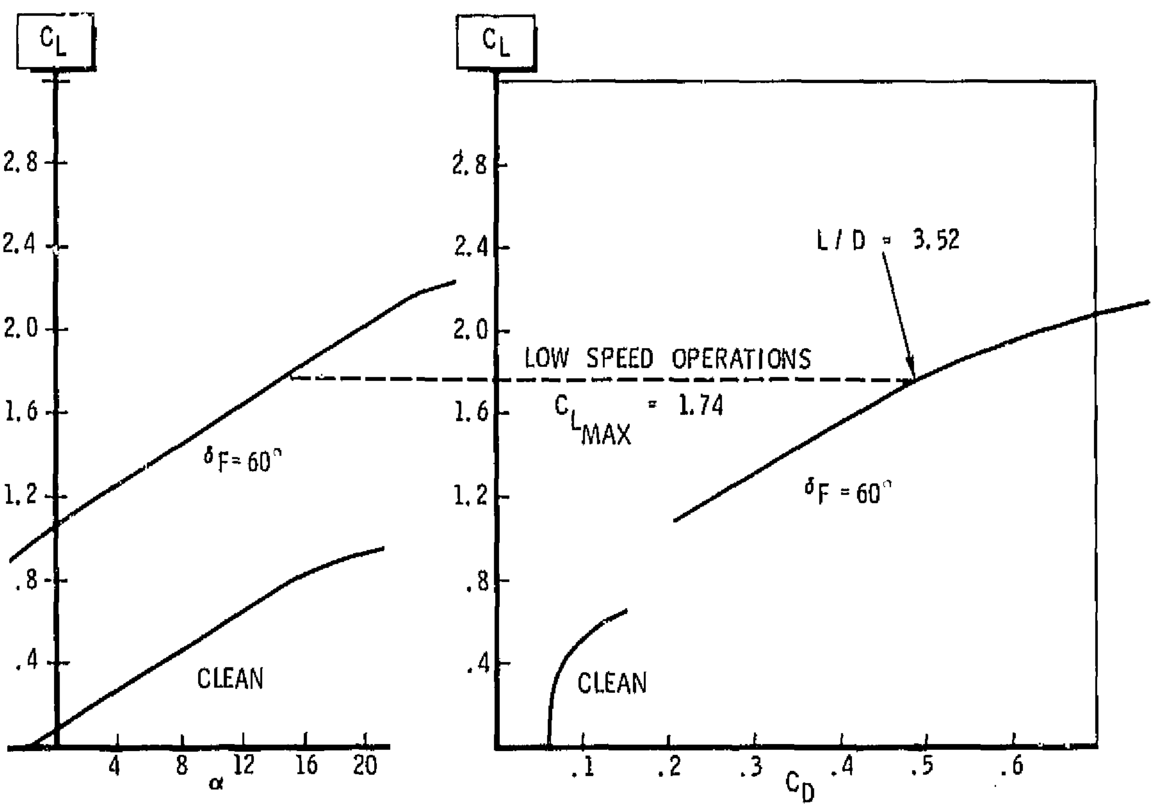


Figure 6. Full Performance Aircraft Low Speed Aerodynamic Characteristics

The data of figure 6 shows that the configuration can develop a $C_{L_{max}}$ of 2.18 with full flap deflection. Also significant, for system test purposes, is the capability to fly angles of attack up to 26 degrees if necessary. The basic low speed capability of the aircraft, however, with consideration for the desired low speed flight safety margins, would allow routine operations with a C_L of 1.76 where the L/D of the system is about 3.52. These characteristics allow adequate coverage of the low speed flight regime for test purposes. The low speed operating velocities permitted are indicated by the data of figure 3.

Propulsion/Hover Control

The propulsion and hover control systems are designed as an integrated system. Figure 7 shows the basic lift-cruise fan system installation. Two 1.3 design fan pressure ratio single stage VTO design fans are mounted vertically on either side of the fuselage. Two J97-GE-100 gas generators drive the fans through a common interconnect duct system. Integrated single swivel nozzles downstream of the fan exhausts direct the fan flow aft for cruise or downward as required for STOL or VTOL operations. The system uses the Energy Transfer Control (ETC) method of providing hover and low speed control forces.

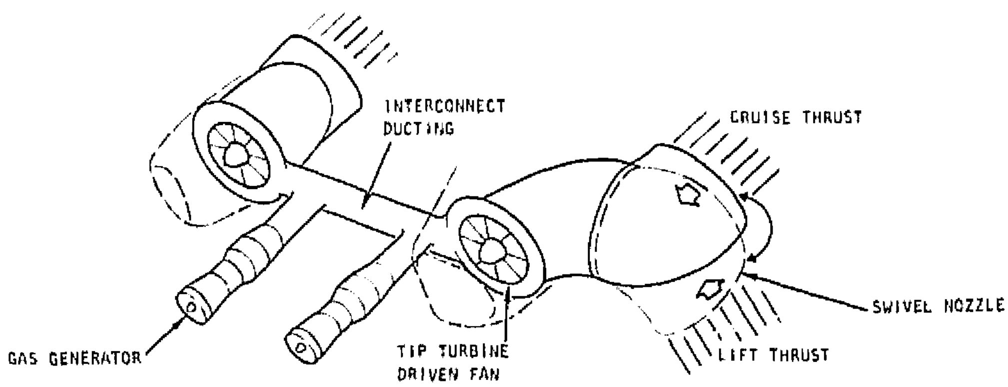


Figure 7. Basic Lift-Cruise Fan System Installation

The sytem is basically simple and lightweight and provides an interconnect system for VTOL engine out safety and control. An additional benefit of the arrangement is the ability to perform loiters and low speed cruises with one gas generator driving both fans. The ETC thrust modulation provides vehicle hover and low speed roll control and differential operation of the swivel nozzles provides yaw control. Pitch control is provided by a separate system described in the following paragraph.

To provide a proper level of engine out safety and simultaneously provide the vehicle with a fast acting pitch control system, a third gas generator and a fore and aft pitch pipe control system are installed along with the basic lift-cruise fan system of figure 7. Figure 8 illustrates the total propulsion/hover control system as installed in the vehicle. The third gas generator and pitch pipe system normally operate independently of the lift-cruise fan system and gas generators.

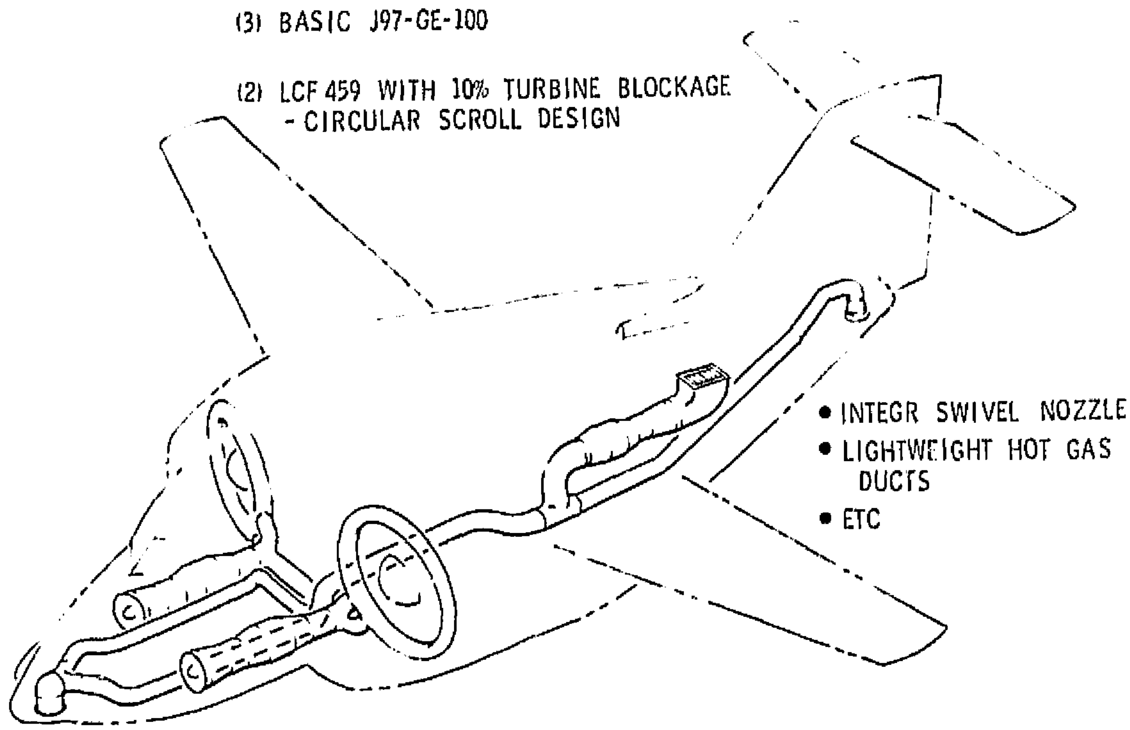


Figure 8. Complete Propulsion/Hover Control System Installaion

The third gas generator system provides nominal V/STOL lift to the system and fast acting pitch control forces with large moment arms. Thrust modulation in the third gas generator system is fast because no fan inertia is involved in raising or lowering the thrust. The lift-cruise fan system and the third gas generator system can be interconnected in the event of a gas generator failure in either system. This interconnection allows the gas from the remaining two gas generators, operating at their emergency ratings, to be distributed to both systems in a manner that will bring about the most desirable results after the failure.

As indicated by figure 7, the system can be assembled using existing J97-GE-100 gas generators. The LCF459 fans as designed have alternate capability for use as cruise designed fans with a growth version of the J97. With simple blockage of a portion of the scroll arc, the LCF459 performs well as a VTO designed fan matched to the basic J97-GE-100. A scroll with a circular cross-section and an included butterfly valve (to allow the percent of the scroll arc activated to be matched to the system requirements) are desired features of the LCF 459 for integration with the above system.

The integrated single swivel nozzle and light weight hot gas ducts that are essential parts of the propulsion system are unique designs developed by the contractor. The integrated single swivel nozzle has variable exit area to optimize the propulsion system performance over a wide speed range and has thrust spoiling features to allow it to efficiently use the Energy Transfer Control (ETC) method of low speed control.

The propulsion/hover control system operation is most critical in the VTOL modes. Figure 9 shows the pitch and roll hover control power capability of the system compared to the guideline requirements for the critical takeoff and emergency landing conditions for the conservative situation where 100 percent of guideline yaw control is simultaneously being commanded. The data shows, that at the design vertical takeoff weight and simultaneous 1.1 g upward flight path control condition, that the system has a wide margin of pitch control power and nominally acceptable roll control.

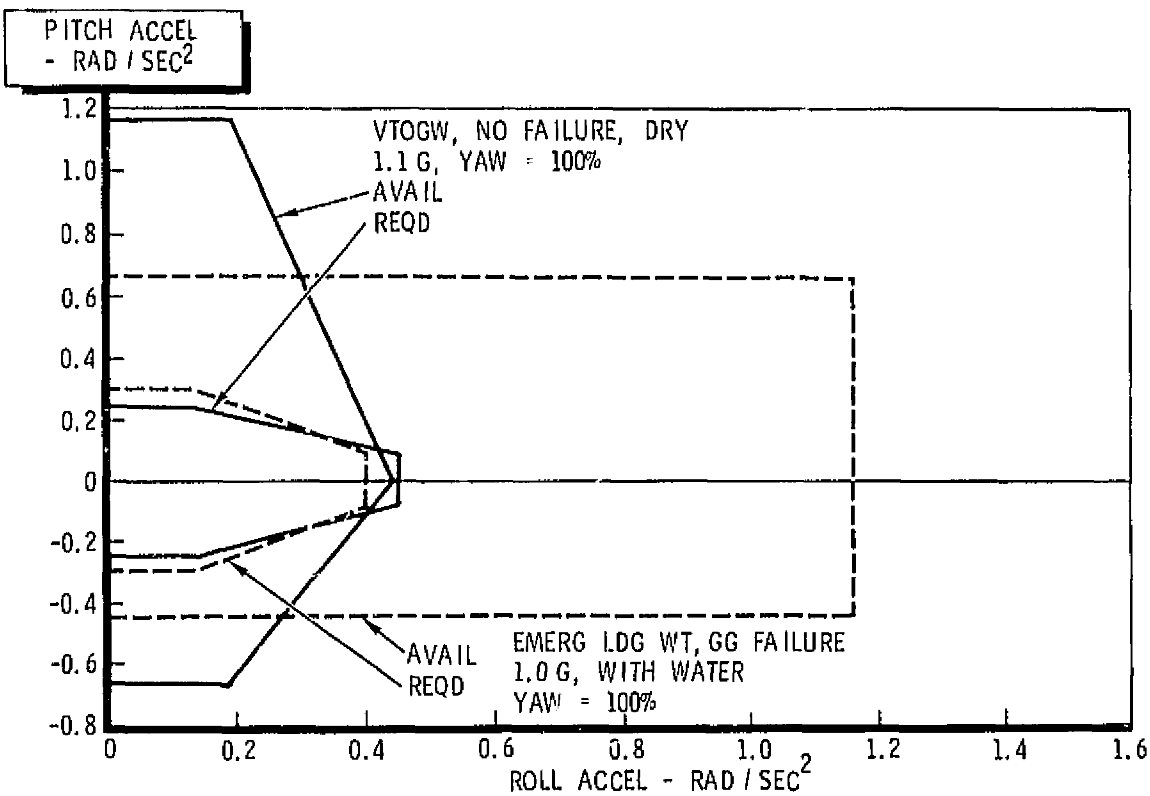


Figure 9. Full Performance Aircraft Hover Control Capability

In the emergency landing case illustrated on figure 9, after a gas generator failure and while maintaining a thrust to weight ratio of 1.0, the aircraft has a comfortable margin of pitch attitude control power and a huge surplus of roll control power. This emergency landing performance was obtained with 40 percent of the flow of one of the remaining gas generators allocated to the pitch control system. Other flow split options are available. By judicious selection of the emergency flow split design option and conducting early VTOL testing at light weights, it is possible for the full performance modified airplane to have pitch and roll control prowers of double the guideline VTOL requirements if necessary. This capability would assure that early VTOL testing could be conducted with adequate control safety margins until confidence in the system and its relationship to true operational requirements would allow operation at higher weights and lower control margins.

Structure

The structure of the full performance technology aircraft consists of modified conventional aluminum Sabreliner business jet structure plus selected items of Government Furnished Equipment (GFE) and new structure as required to fully adapt the basic airframe to the requirements of the lift-cruise fan technology aircraft configuration. Figures 10 and 11 illustrate the major features. Figure 10 summarizes the structural design approach and modifications required to the basic airframe structure. The shaded area of the figure indicated as "off shelf/mod" structure will be modified in local areas only,

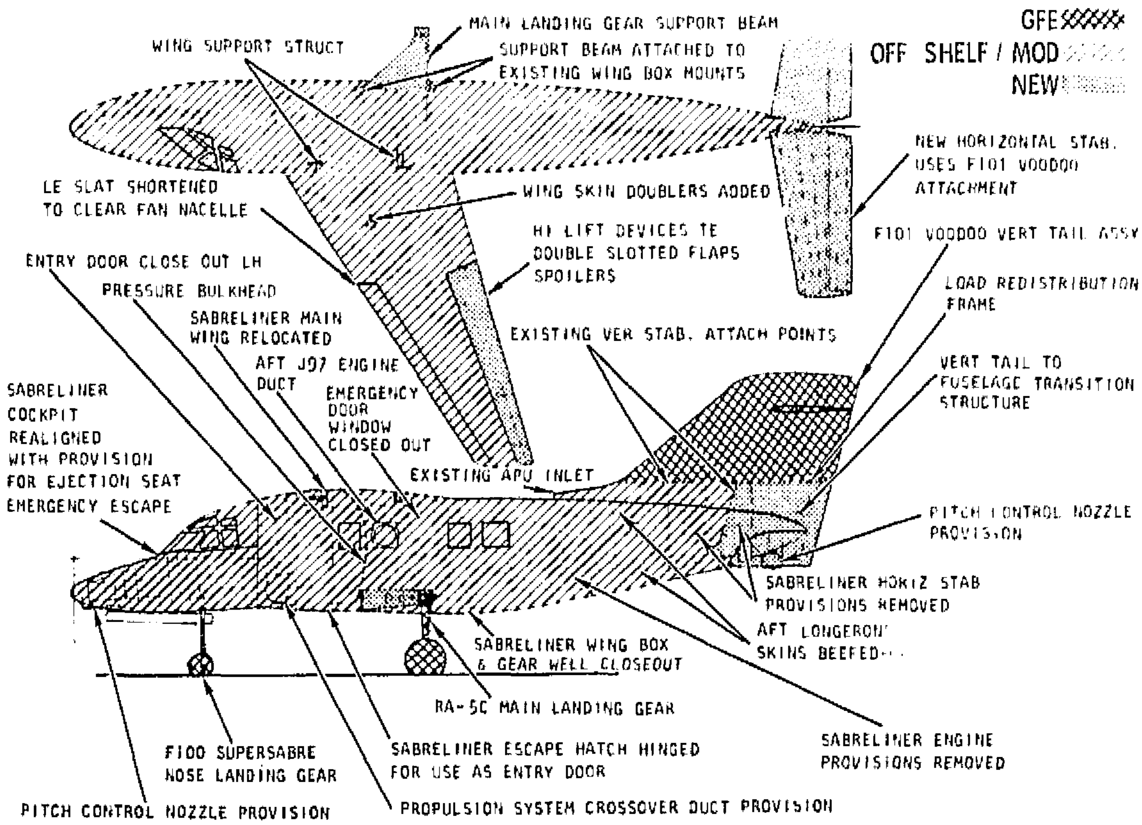


Figure 10. Full Performance Aircraft Basic Structural Modifications

as necessary, to carry the higher loads of the V/STOL technology aircraft configuration. The new support beam required to attach the RA-5C landing gear is secured to the fuselage at the points of the original wing mount fittings. The gear retracts into the space earlier provided for the wing carry through box. The fuselage aft pressurization bulkhead is installed well forward in the vehicle, near fuselage station 220 to minimize the fuselage area that must be resealed and pressure tested after modification. The pressurized area provided can be adjusted to meet specific research payload volumes as required. The horizontal tail and aft portion of the fuselage tail cone are new structures required to meet aerodynamic requirements. The exposed portion of the outer wing panel aft of the rear spar will be replaced with a new integrated double slotted Fowler flap and upper surface spoiler system installation. The design will provide a smooth upper wing surface mating with the existing upper wing surface and faired housings under the wing similar to the DC-10 airplane for the flap hinge and actuation installations.

Figure 11 shows the fan and aft fuselage fairing structure that is added on to the basic structure and provides a smooth aerodynamic shape around the lift-cruise fan propulsion system components. This structure can cover

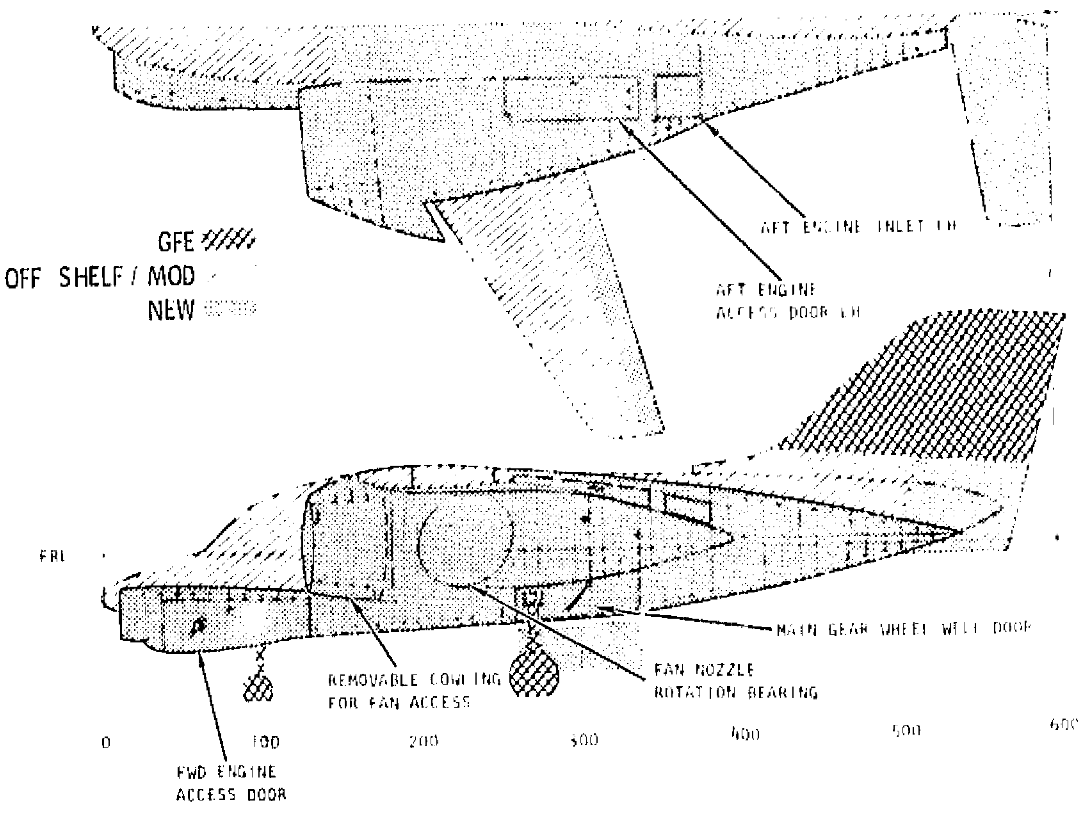


Figure 11. Full Performance Aircraft Structural Fairing Additions

structurally efficient external doublers placed over the basic fuselage structure and provide much of the detailed propulsion system installation features, such as access doors and mounts, without modifying internal elements of the basic structure as well as providing the proper aerodynamic shape.

The structure modifications and new elements are designed to provide the new vehicle with at least a +3,-1g structural load factor capability at the new design gross weights. All structure is also designed to withstand the 610 lb/ft^2 dynamic pressure capability of the basic Sabreliner structure. In addition to these provisions, an additional weight growth factor has been included in the structural weight estimates to account for the use of short cut experimental shop design and fabrication methods that will provide cost savings at some expense to the vehicle fabricated empty weight.

Subsystems

The subsystems of the technology aircraft are all conceived as off-the-shelf available hardware except for selected specialized requirements and detailed installation provisions required to adapt the major components to the specific airframe.

The flight control system is a multiple redundant fly-by-wire system breadboarded together from existing or slightly modified existing components that are currently being developed as a result of the several fly-by-wire technology development programs being pursued by the government and within industry. Many automatic functions will be included to keep pilot workload within practical limits for both normal and emergency operating modes. The flight control system will use hydraulic actuation primarily but other systems will be considered if hardware is available and the chracteristics are more beneficial to the overall system operation and cost. The manual/mechanical flight control system linkages of the basic Sabreliner will be removed from the modified airframes because adequate backup capability will be inherent in the basic fly-by-wire system.

An off-the-shelf auxiliary power unit (APU) of adequate size to provide starting and checkout power and provide all the air for the onboard environmental control system requirements will be provided. An APU very close to the current Sabreliner APU size is estimated to be sufficient pending more detailed definition of specific requirements.

An electrically driven, state of the art 3000 psi hydraulic system was selected to perform the major flight control and selected utility actuation functions. Several off-the-shelf components are expected to be useable in the system with the line routings being tailored to the vehicle.

The DC electrical system of the basic Sabreliner will be removed and be replaced by an AC system driven by two fan mounted primary generators. An AC system was selected because of better overall total system characteristics. Most of the available components for the avionics, fly-by-wire and electrical system control elements, of the type required for the technology aircraft, are designed for use in an AC system.

The avionics and flight instrument system will use off-the-shelf components or slightly modified components in a breadboarded total system. The electronic portions of the fly-by-wire system are mechanized as a part of the avionics system. The avionics system is a full V/STOL capability system that would allow the airplane to fly anywhere in US airspace in addition to performing the specialized functions needed for flying steep and high performance V/STOL approach and climbout profiles. Installation provisions will provide necessary structural support, power, cooling and vibration isolation as required but repackaging of individual components is not planned other than to accommodate necessary functional performance requirements. If special provisions are required for carrier suitability tests not included in the basic system, they can be accommodated as a portion of the 2500 pound research payload provisions.

The furnishings provided for the technology aircraft include the basic cockpit and crew items and two zero-altitude, zero-velocity capable ejection seats. Additional thermal and acoustic insulation are provided to satisfy minimum crew environment design criteria within the environment induced by the lift-cruise propulsion system components.

The environmental control system is an air cycle system fed by the onboard APU. Pending more detailed definition of the specific requirements, the current Sabreliner system is estimated to be adequate with a change in the distribution system. The cabin cooling requirements are reduced significantly by the reduction in the cabin pressurized and controlled volume. The cooling capability thus freed is available to cool the avionics and provide cooling flows to control air vehicle structure and systems that otherwise might be adversely affected by external temperatures of the hot gas duct system or other propulsion system components. The need for forced cooling flows is most critical during hover mode operations when normal ram air cooling and ventilating flows are not available. The APU driven environmental control system provides the necessary cooling and does not draw power or bleed air from the main engines during these critical maneuvers.

Mass Properties

The concept adopted for the technology aircraft was to minimize the necessary fixed weight items such that the thrust to weight ratio of the technology aircraft could be significantly above the levels expected for the operational aircraft. The high thrust to weight ratio then provides significant margins of added safety and performance such that the technology aircraft flight program can be undertaken with less risk and has greater flexibility. The objective is to permit investigation of flight regimes and operating modes greater than the minimums currently identified for the likely operational aircraft, such that the requirements and advantages can be assessed in terms of optimum capabilities for given applications. The weights and associated inertias achieved in the design of the full performance modified aircraft configuration met these objectives.

Table 2 below shows the weights of the major groups and their percentage of the maximum STOL takeoff weight. The group weight percentage distribution of the operational aircraft is shown for comparison.

Table 2. FULL PERFORMANCE MODIFIED AICRAFT WEIGHT PERCENTAGE DISTRIBUTION

	Wt-Lb	%	Oper A/C %
Propulsion	6825	22.98	17.00
Structure	9984	33.62	23.50
Equipment	3996	13.46	18.44
Useful Load	3020	10.18	12.43
Fuel	5870	19.76	28.63
Max STOL Wt	29,695	100.00	100.00 (38,727 LB STOL Wt)

The operational aircraft used for comparison with the full performance modified technology aircraft in Table 2 is an antisubmarine warfare aircraft version of a Navy multi-mission V/STOL airplane designed with advanced technology for the 1980's. The full performance technology aircraft, though it uses state of the art conventional structure and subsystems, achieves a lower takeoff weight primarily through reduced equipment, useful load and fuel provisions relative to the operational aircraft. The structure and propulsion fractions of the technology aircraft are higher than the comparable fractions of the operational aircraft. Since the propulsion system to be demonstrated in the technology aircraft is essentially the same as the system planned for the operational aircraft, and the thrust capability is nearly equal, the technology aircraft has a significant T/W advantage because of its lighter takeoff weight. This T/W advantage permits the technology aircraft to provide excellent VTOL capability for technology development and demonstration purposes.

A more detailed group summary weight breakdown of the vehicle is presented in Table 3. The vehicle inertia and the center of gravity locations resulting from these weights referenced to the fuselage station versus gross weight are presented in figure 12.

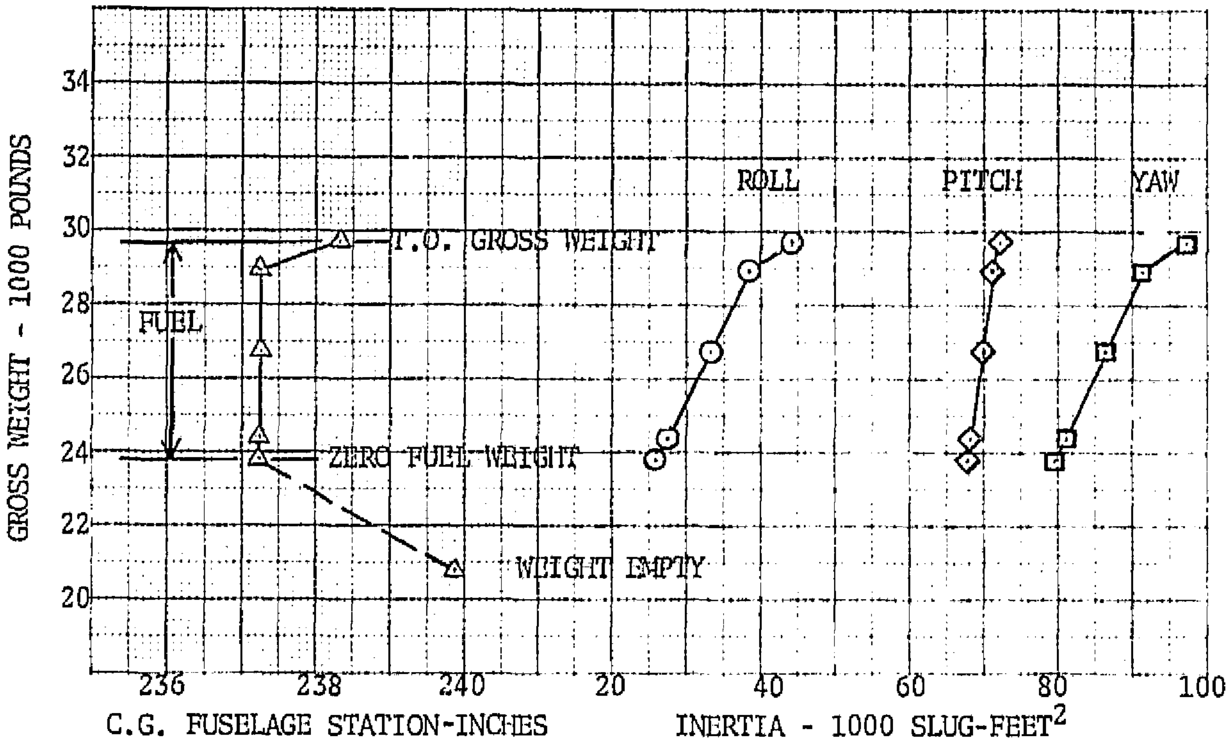


Figure 12. Center of Gravity And Inertia

Figure 12. Full Performance Aircraft Center of Gravity and Inertia

The inertias indicated in figure 12 near the zero fuel weight for the technology aircraft are only about 75 percent of the corresponding inertia of the operational airplane. These lower inertias are due to the lighter weights and the lower aspect ratio wing on the technology airplane relative to the operational airplane. The operational airplane has a wing with an aspect ratio of 9.0; this compares with the 5.77 aspect ratio of the full performance technology aircraft. The lower inertia of the technology airplane relative to the operational configuration indicates that the technology aircraft will have significant margins in low speed attitude control power to provide flight test program safety and research versatility.

TABLE 3. FULL PERFORMANCE AIRCRAFT GROUP WEIGHT BREAKDOWN

Structure	
Wing	2065
Empennage	841
Fuselage	4458
Landing Gear	2074
Engine Section	307
Air Induction System	154
Exterior Finish	85
Propulsion	
Gas Generators	2265
Exhaust System	1129
Cooling and Drain Provisions	31
Engine Controls	95
Starting System	148
Fuel System	266
Fans	1700
Hot Gas Duct System	1191
Equipment Groups	
Flight Controls	570
Auxiliary Power Plant	350
Hydraulics & Pneumatics	225
Electrical	625
Avionics/Instruments	1135
Furnishings	741
Air Conditioning	350
Weight Empty	20,805
Crew	400
Oil and Unuseable Fuel	120
Operating Weight Empty	21,325
Fuel	5870
Payload	2500
STOL Takeoff Gross Weight	29,695

LOW SPEED ONLY MODIFICATION AIRPLANE

The low speed only modified aircraft approach to the technology aircraft was studied as the lowest cost approach to providing a technology test vehicle. The low speed flight regime contains the most unique V/STOL phenomena that would be of interest in a flight test program, thus it is a valid approach to consider if total program cost becomes a major criteria in the selection of a viable approach. Several existing airframes were investigated for potential application as the low speed technology aircraft. The results of these studies indicated that a suitably simplified adaptation of the full performance modification aircraft, based on the Rockwell International Sabreliner business jet, showed more promise than adaptation of other available airframes. The following paragraphs present the characteristics and features of the final selected low speed only Sabreliner modification approach configuration.

Configuration Definition

Figure 13 presents the design brief of the low speed only modification configuration. A majority of the airframe features are identical to the full

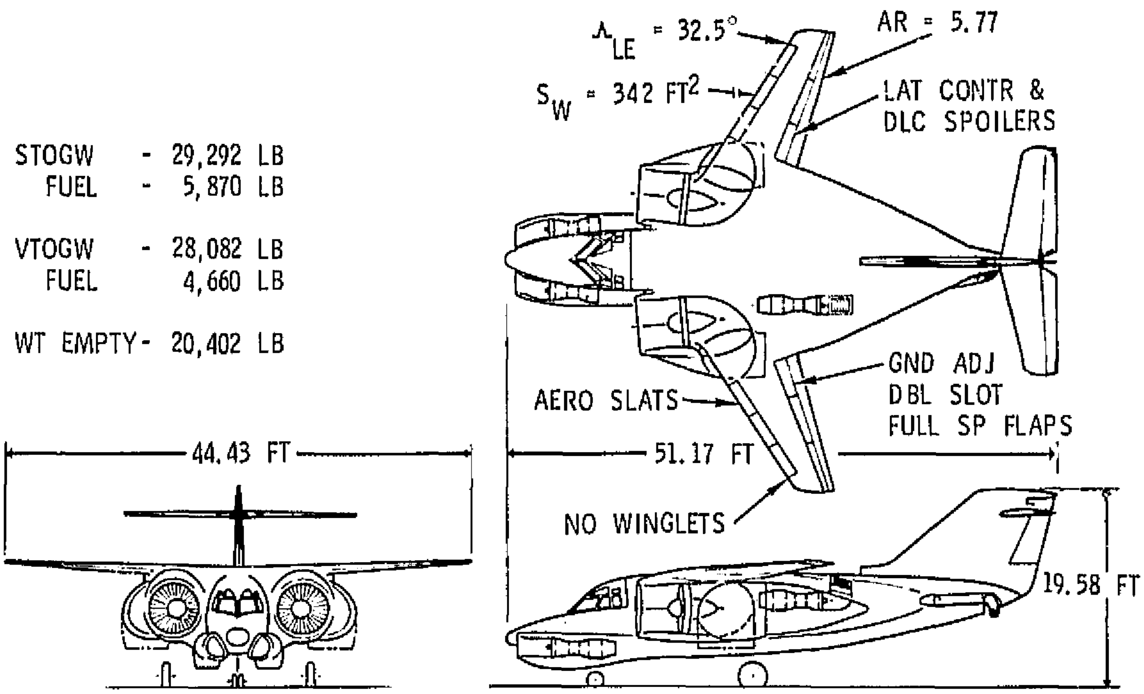


Figure 13. Design Brief-Low Speed Only Modification Approach

performance Sabreliner modification approach from which the low speed only approach was derived. Only the differences relative to the full performance approach described earlier will be enumerated here.

The most significant changes to the full performance Sabreliner configuration to represent the low speed only approach result from the relaxation of the high subsonic speed capability requirement. Fixed non-retracting landing gear, ground-adjustable-only flaps with unfaired underwing hinge and actuation provisions, strap on rather than integrated faired wing spoilers and actuation, partially exposed ducting and minimum aerodynamic smoothness criteria on modified or new structure are notable among these changes. The most significant and meaningful change is the allowed reduction in the fairings behind the lift-cruise fan installation on the aft fuselage. Significant weight reduction and reduced skin friction drag result from this simplification. Also a single segment elevator design is permissible because of the low speed only operating regime of the aircraft. Also, the single segment rudder can be designed for the full deflection low speed operating mode only since high speed oversensitivity will not be a consideration. In the propulsion system, the narrower operating speed regime will allow a fixed area swivelling nozzle design rather than a variable exit area design. These modifications reduce the technology aircraft empty weight and maximum STOL takeoff weight each by a net of approximately 400 pounds relative to the full performance modification approach.

The major geometric features of the low speed only modification approach are presented in Table 4. The fuselage maximum length is 47.33 feet. The maximum fuselage height is 7.5 feet and the maximum width, including the fairings behind the fans but not the nozzles, is 18.58 feet. The maximum width including the nozzles is 23.0 feet. The total wetted area of the configuration is 2193 square feet.

TABLE 4. LOW SPEED ONLY AIRCRAFT WING AND TAIL SURFACE GEOMETRY

	Wing	Horizontal	Vertical
S - ft	342	100	100
AR	5.77	4.84	0.743
λ	0.321	0.62	0.486
b - ft	44.43	22	8.62
$\Lambda_{c/4}$ - deg	29.0°	8.2°	43.9°
t/c - %	12%	10%	6%
Airfoil	64A212 Mod	69A010	Symmetrical
MAC - ft	8.38	4.63	12.06

Performance & Research Capability

The performance of the low speed only configuration is limited by its concept as an aircraft designed for approximately 160 knots of forward flight speed and 15,000 feet altitude. Its takeoff performance, however, because of its lower weight is somewhat better than the full performance modified airplane as shown in figure 14.

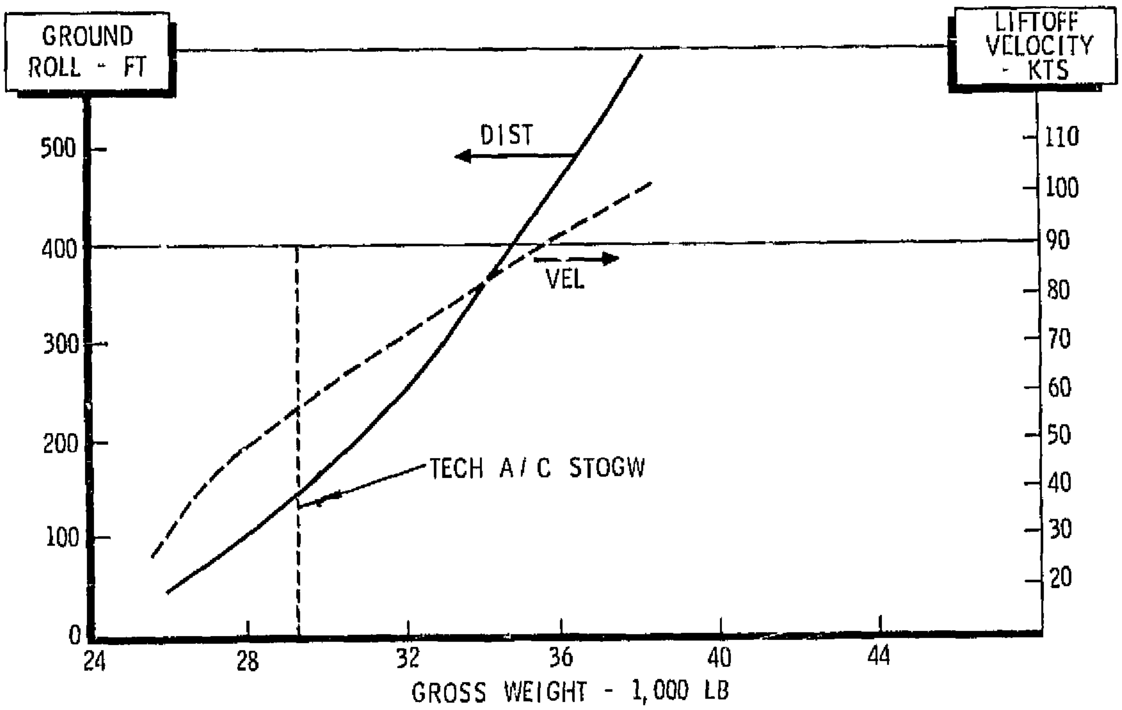


Figure 14. Low Speed Only Aircraft STOL Takeoff Characteristics

The improved STOL takeoff performance is not a significant advantage of the low speed only approach because the STOL takeoff performance of the full performance modification airplane is already significantly superior to the estimated minimum requirements.

Figure 15 presents the performance of the low speed only airplane on the low speed horsetrack pattern test missions. The data show that the low speed airplane requires just a slightly longer time and higher fuel quantity to complete the required test mission circuits. This is due to the restricted speed of the aircraft in the downwind legs relative to the full performance aircraft which can retract its gear and flaps and increase speed somewhat when desired. The performance differences between the two aircraft in this respect are quite small and the low speed only aircraft has enough fuel capacity to fly more than the guideline required number of circuits or increase the research payload somewhat if desired also.

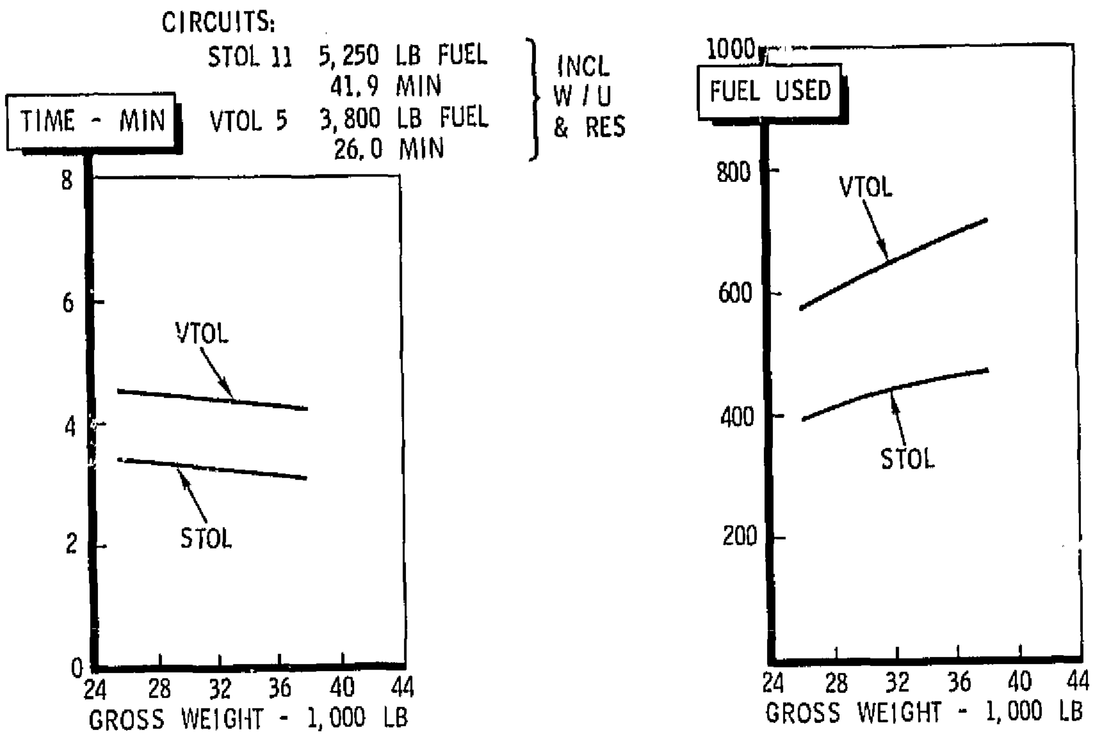


Figure 15. Low Speed Only Aircraft Low Speed Test Mission Performance, Per Test Mission Circuit

The limiting performance capabilities of the low speed only aircraft are inherent in its conceptual approach. If the purpose of the flight program can appropriately be limited to the unique V/STOL low speed phenomena, the approach is valid and attractive because of its minimum cost characteristics. If, however, a requirement of the technology aircraft flight program is to address the development and verification of the lift-cruise fan propulsion system, the low speed approach is at a disadvantage. Figure 16 shows the approximate conventional speed attitude operational limts of the low speed only airplane. While adequate for the unique V/STOL low speed phenomena

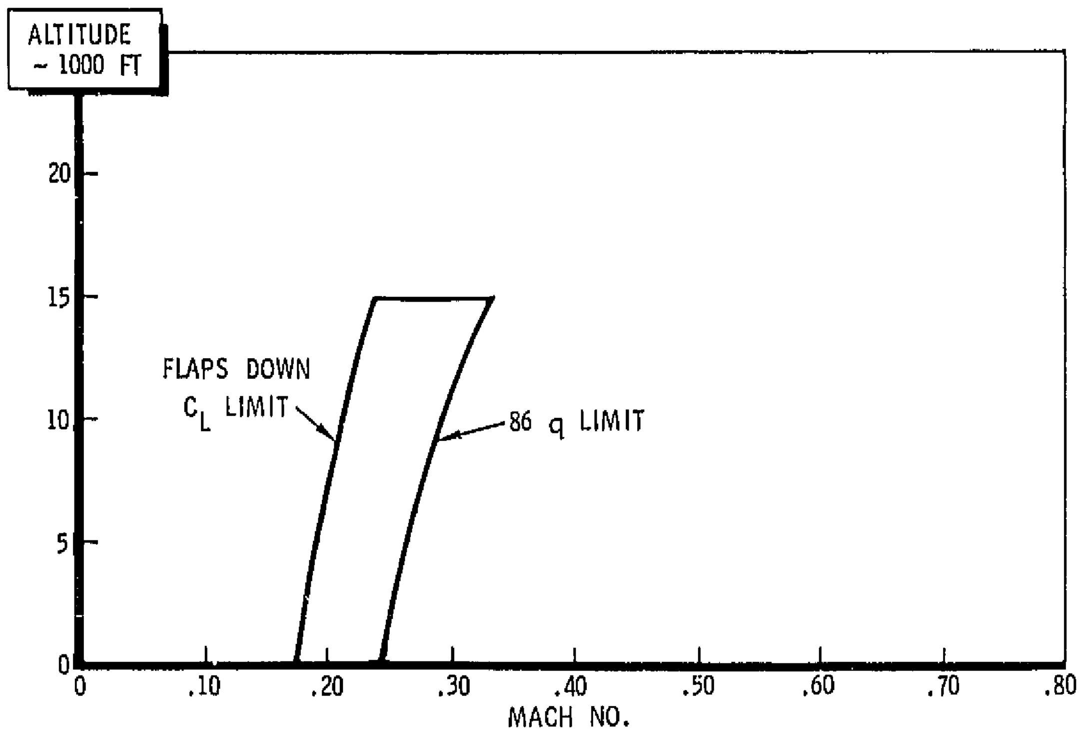


Figure 16. Low Speed Only Aircraft Operational Speed Altitude Envelope

investigations, the indicated speed altitude capability would not allow verification of the lift-cruise fan system performance at high dynamic pressure, high mach number or high altitude flight.

Figure 17 illustrates the approximate low speed lifting and drag characteristics of the low speed only airplane. The low speed only configuration has a net drag of 11 counts less than the full performance airplane at very low speeds. This reduction of drag is of minor importance however because of the typical high drag levels in this region due to gear and flap drag plus typical operations are at high lift coefficients which also significantly increase the drag coefficient.

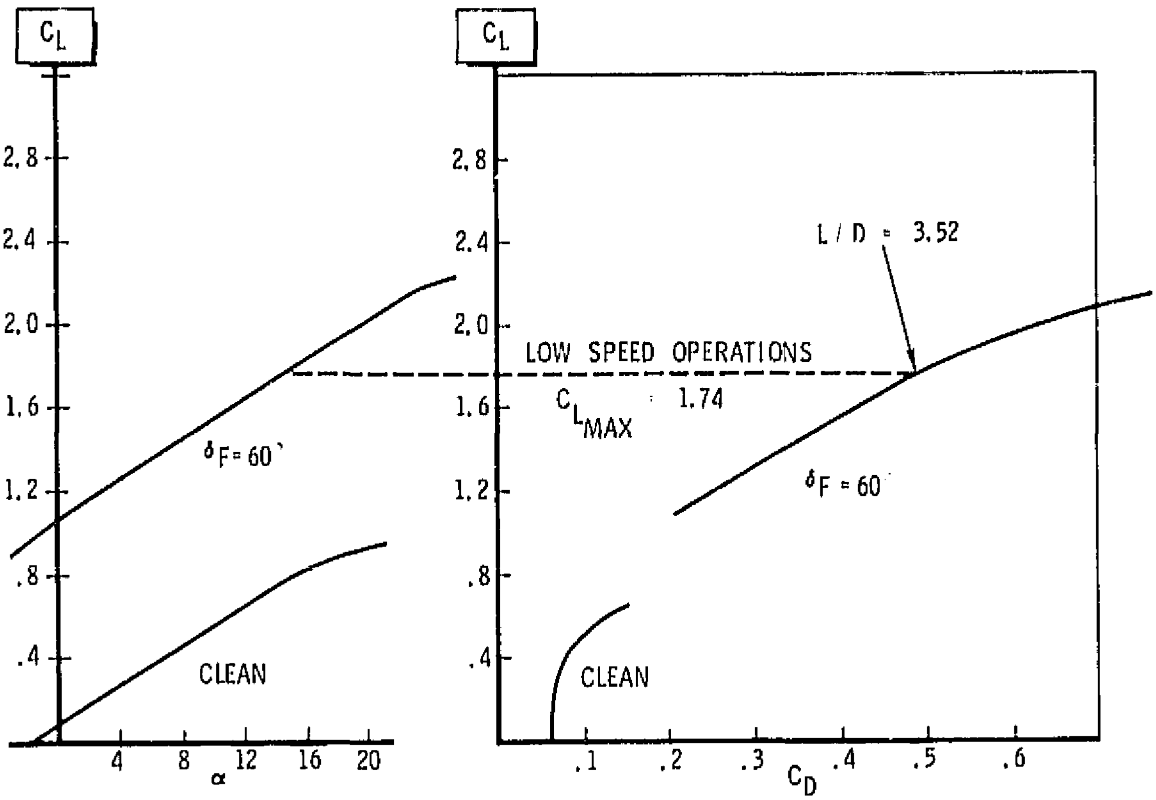


Figure 17. Low Speed Only Aircraft Low Speed Aerodynamic Characteristics

In general, however, the low speed characteristics of the low speed only configuration are excellent for low speed testing. Very low operating velocities can be sustained as illustrated by the data of figure 14 and high lift coefficients can be obtained as well as operations at high angles of attack up to 26 degrees as shown on figure 17.

Propulsion/Hover Control

The propulsion and hover control system of the low speed only aircraft is essentially identical to the system installed in the full performance modification airplane at low speeds. The low speed only aircraft has a fixed area swivel nozzle, whereas, the full performance airplane has a variable exit area nozzle. At low speeds the full performance aircraft nozzle area would closely approximate the fixed area of the low speed only airplane such that the performance of the two systems would be essentially identical.

Because of the slightly lighter fixed weight of the low speed only aircraft, its inertias are from 2 to 4 percent lower than the corresponding values for the full performance airplane near zero fuel gross weight. This reduction provides the low speed only aircraft with about the same percentage of improved low speed attitude control power relative to the full performance airplane. Thus the hover control power of the low speed airplane is roughly 2 to 4 percent higher than the control powers presented in figure 9 for the full performance modification airplane.

Structure

The structural concept of the low speed only aircraft is similar to that adopted for the full performance modification airplane except that the design loads are significantly reduced because of the lower dynamic pressure design requirements. The maneuver load factor capability is retained at +3 and -1 g but the design dynamic pressure is only about 86 lb/ft^2 instead of the 610 lb/ft^2 requirement for the full speed airplane. Since this relaxation of requirements only affects the modified structure and the new structural fairing designs, the effect is not as dramatic as it might be if both aircraft were redesigned in total. Because of the reduced dynamic pressure and aerodynamic requirements, the manufacturing techniques and quality control requirements can be relaxed somewhat to reduce fabrication costs. The experimental shop weight growth factor was applied in estimating the weights of the low speed only aircraft structure to allow the use of these low cost design and fabrication methods.

Subsystems

The subsystems of the low speed only aircraft configuration are very similar to the systems used in the full performance configuration. The major difference is due to the elimination of some of the flight control and hydraulic system components because of the reduction in actuated components, e.g., flaps, landing gear, single segment elevator versus dual segment and elimination of the requirement for nozzle area variation features.

The ejection seats used with the low speed only aircraft could be of a lower capability design such that some weight and cost could be reduced for the qualification and procurement of the seat system.

In general, the changes in subsystems relative to the full performance airplane are not large, but they are in the direction to allow some reduction in the cost of procuring and qualifying the air vehicle systems affected by the changes.

Mass Properties

The mass properties data for the low speed performance only airplane are very similar to the chracteristics identified earlier for the full performance modified airplane. The changes reflect the approximate net 400 pound reduction in fixed weight on the airplane and the beneficial effects this has on the vehicle inertia characteristics.

Table 5 presents the major group weight percentage distribution.

Table 5. LOW SPEED ONLY AIRCRAFT WEIGHT PERCENTAGE DISTRIBUTION

	Wt-Lb	%	Oper A/C %
Propulsion	6775	23.13	17.00
Structure	9766	33.34	23.50
Equipment	3861	13.18	18.44
Useful Load	3020	10.32	12.43
Fuel	5870	20.03	28.63
Max STOL Wt.	29,292	100.00	100.00 (38,727 lb STOL Wt)

Table 6 presents the more detailed group weight breakdown. Figure 18 presents the center of gravity and inertia data as a function of gross weight.

TABLE 6. LOW SPEED ONLY AIRCRAFT GROUP WEIGHT BREAKDOWN

Structure	
Wing	2026
Empennage	841
Fuselage	4421
Landing Gear	1942
Engine Section	307
Air Induction System	144
Exterior Finish	85
Propulsion	
Gas Generators	2265
Exhaust System	1079
Cooling and Drain Provisions	31
Engine Controls	95
Starting System	148
Fuel System	266
Fans	1700
Hot Gas Duct System	1191
Equipment Groups	
Flight Controls	470
Auxiliary Power Plant	350
Hydraulics & Pneumatics	210
Electrical	605
Avionics/Instruments	1135
Furnishings	741
Air Conditioning	350
Weight Empty	20,402
Crew	400
Oil and Unuseable Fuel	120
Operating Weight Empty	20,922
Fuel	5820
Payload	2500
STOL Takeoff Gross Weight	29,292

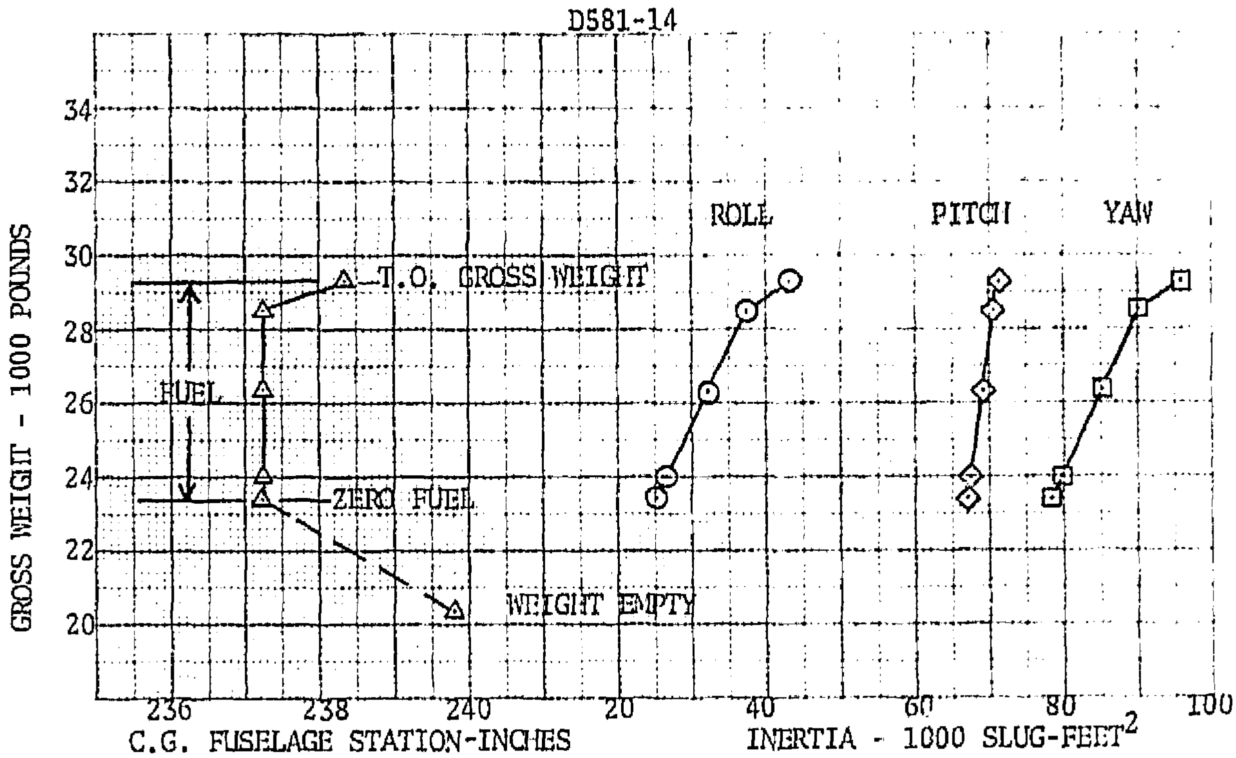


Figure 18. Low Speed Only Aircraft Center of Gravity and Inertia

ALL NEW AIRFRAME APPROACH AIRPLANE

The all new airframe concept approach to the technology demonstrator was investigated with the objective of defining a low cost flight test vehicle with a high degree of direct applicability to operational requirements. As such, it was conceived to have the identical propulsion system estimated to be required for the operational airplane and the identical external vehicle aerodynamic shape and control components. Other than these items, the system was to be designed to minimize the technology aircraft program acquisition cost. The following paragraphs are a summary of the characteristics of the configuration that was developed to these criteria.

Configuration Definition

Figure 19 presents a design brief of the all new airframe approach configuration. Having the aerodynamic configuration of the target operational

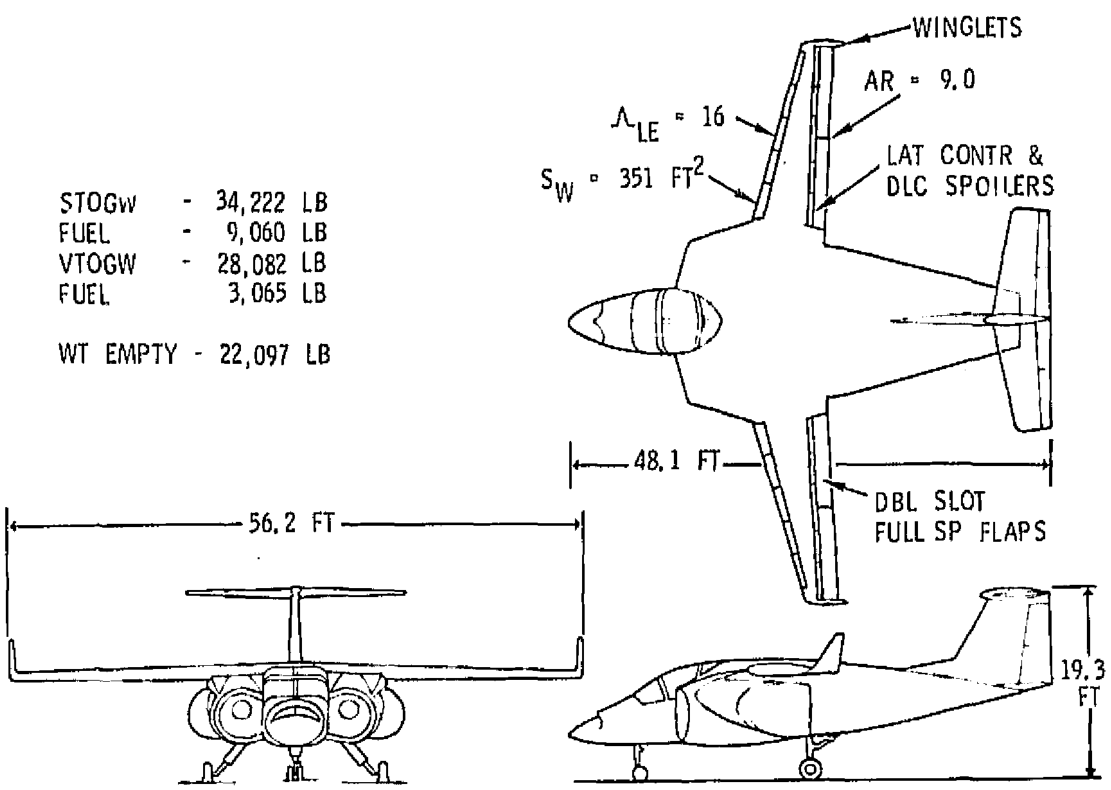


Figure 19. Design Brief-All New Airframe Approach

aircraft, this version of the technology aircraft has an aspect ratio 9.0 wing with emerging NASA technology winglets, a more streamlined fuselage shape and a more highly integrated lift-cruise fan propulsion system installation. Since the propulsion system aerodynamic configuration and controls are identical to those on the operational aircraft, this configuration would provide the best simulation of the operational vehicle and resulting program data would have the highest degree of applicability to operational requirements of the three approaches investigated. The weight and cost growth of the configuration relative to the modification approaches to the technology aircraft was minimized by eliminating all non-essential mission oriented features that would be included if the aircraft were being developed to perform a specific operational mission. Cost was also limited by using only state of the art subsystems throughout the airplane except for the new elements of the propulsion/hover control system. The large fuel capacity of the all new airframe configuration provides over 50 percent more STOL fuel than is available in the modification approach configurations.

The major geometric features of the lifting surfaces of the vehicle are presented in Table 7. The winglets used each have a plan area of 6.5 ft^2 and a height of 3.92 feet. The fuselage maximum length is 44.83 ft. The

TABLE 7. ALL NEW AIRFRAME AIRCRAFT WING AND TAIL SURFACE GEOMETRY

	WING	HORIZ. TAIL	VERT. TAIL
S - ft	351	100	87.5
AR	9.0	4.84	2.37
λ	0.3	0.62	0.50
b - ft	56.2	22	10
$\Lambda_{c/4}$ - deg	12.9°	8.2°	23.75°
$t/_c$ - %	17	10	10
Airfoil	Supercrit	64A010	64A010
MAC-ft	6.85	4.43	9.49

maximum fuselage height is 8.33 feet and the maximum width, including the fairings behind the fans but not the nozzles is 17.67 ft. The maximum width including the nozzles is 19.17 ft. The total wetted area of the configuration is 2159 ft^2.

Performance & Research Capability

Having virtually the same propulsion system and aerodynamic characteristic as the operational airplane, the all new airframe configuration has significantly better cruise and low speed performance than the modification approaches to the technology aircraft. Because of its high aspect ratio wing and higher weights and inertias, however, it has slightly less hovering attitude control power.

The STOL takeoff performance of the all new airframe approach is illustrated in figure 20 and compared to the operational aircraft capability. The operational aircraft takeoff performance is estimated with all engines operating with 10 knots of wind over the decks (WOD). The technology airplane takeoff performance is estimated with one gas generator failed and is presented for the same wind condition for comparison purposes.

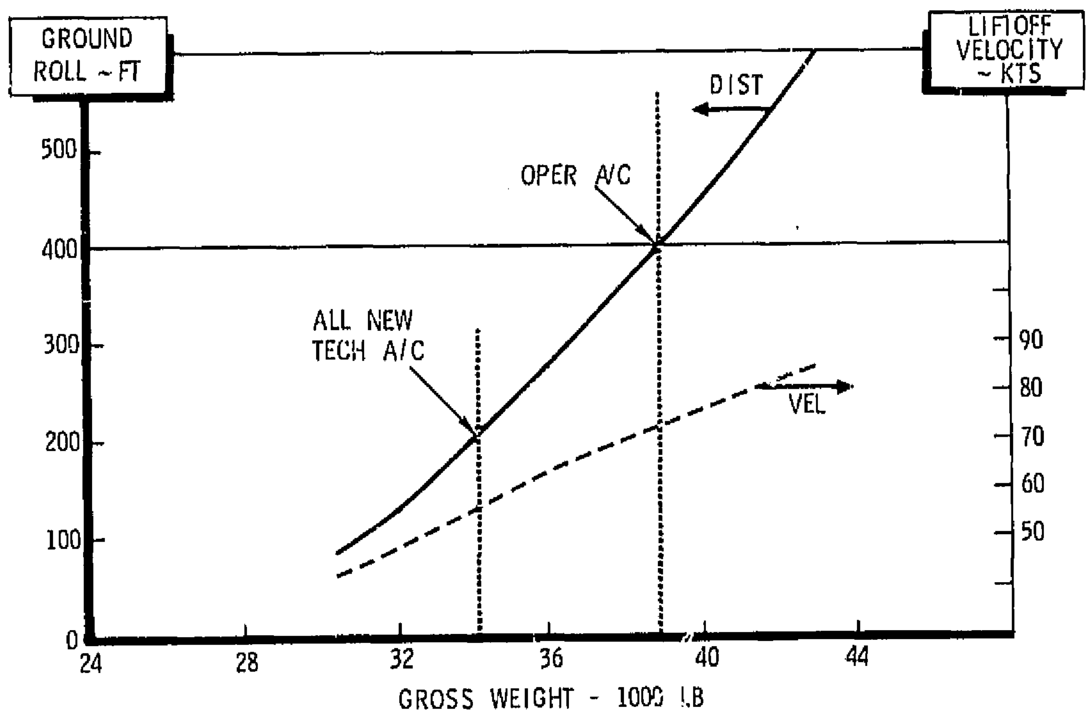


Figure 20. All New Airframe Aircraft STOL Takeoff Characteristics

Because of its lighter STOL takeoff weight relative to the operational aircraft, the STOL takeoff distances are about half those expected with the operational configuration. The takeoff distance is slightly higher, but in the same class as is achieved by the lighter modification technology aircraft. At takeoff weights similar to the modification configurations (about 29,000 pounds) the takeoff distance would be about half the distance required by the modification airplanes.

During light weight STOL operations, the all new aircraft can fly slow, 40 to 50 knot flight speeds, which are somewhat lower than are achievable by the modification approaches.

One of the significant advantages of the high efficiency, high aspect ratio of the operational aircraft, as reflected in the performance of the aerodynamically similar all new airframe technology aircraft configuration, is shown in figure 21.

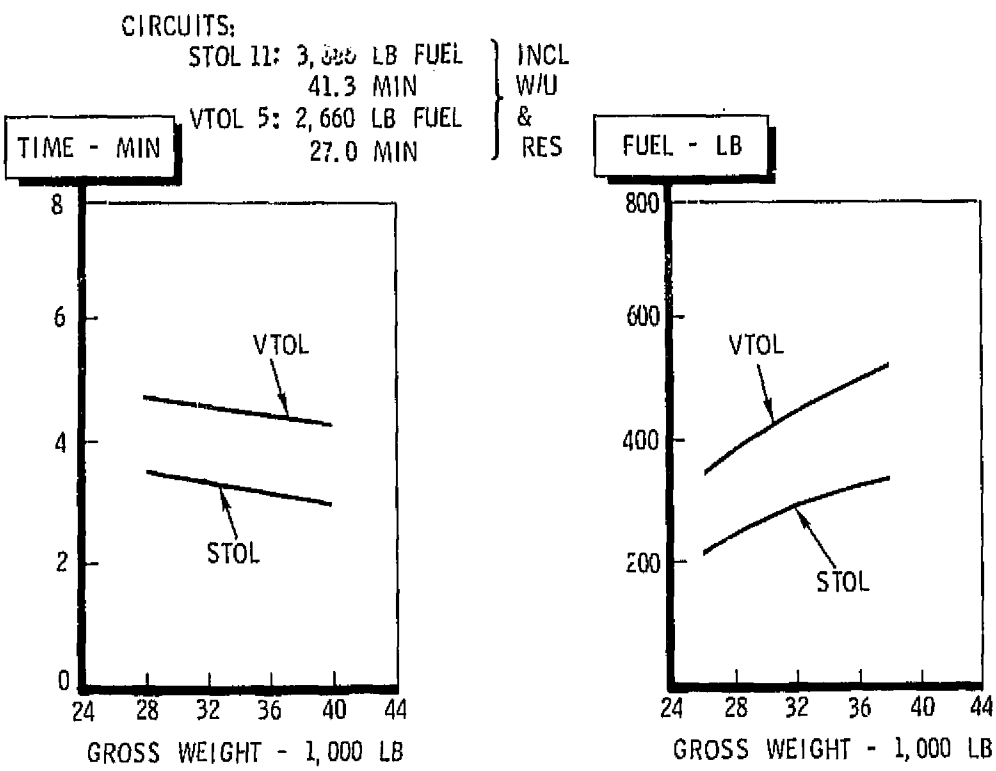


Figure 21. All New Airframe Aircraft Low Speed Mission Performance, Per Test Mission Field Circuit

While the time to fly the horsetrack circuits is slightly longer due to the lower speeds, the fuel required by the all new airframe aircraft to perform the missions is significantly less than for the low aspect ratio modified aircraft approaches, without winglets. Figure 22 illustrates the low speed aerodynamic characteristics of the all new airframe configuration that explains the differences in performance.

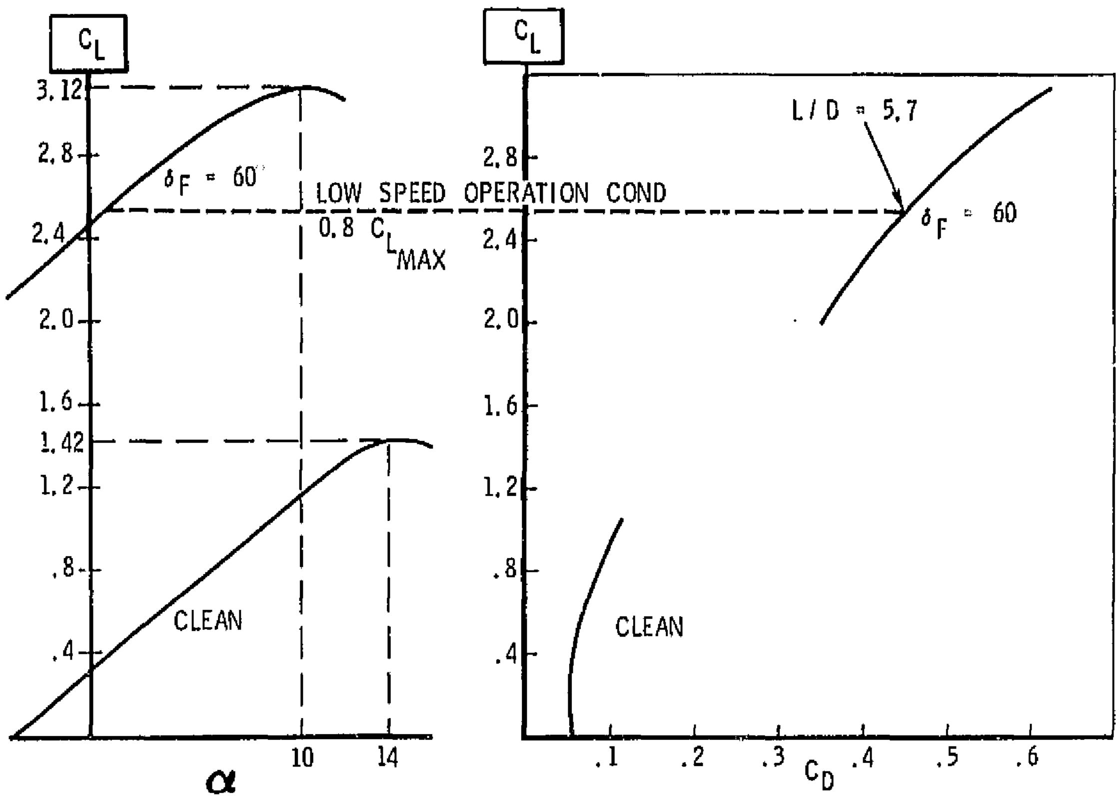


Figure 22. All New Airframe Aircraft Low Speed Aerodynamic Characteristics

The reason for the difference in low speed fuel consumption is the low speed configuration L/D. The higher aspect ratio wing with winglets provides a much more efficient aircraft for low speed, high lift coefficient operations.

The higher wing efficiency, higher fuel load and more sophisticated propulsion system of the all new airframe approach combine their characteristics to give the all new aircraft approach very satisfactory cruise and propulsion flight test capabilities as illustrated in figure 23.

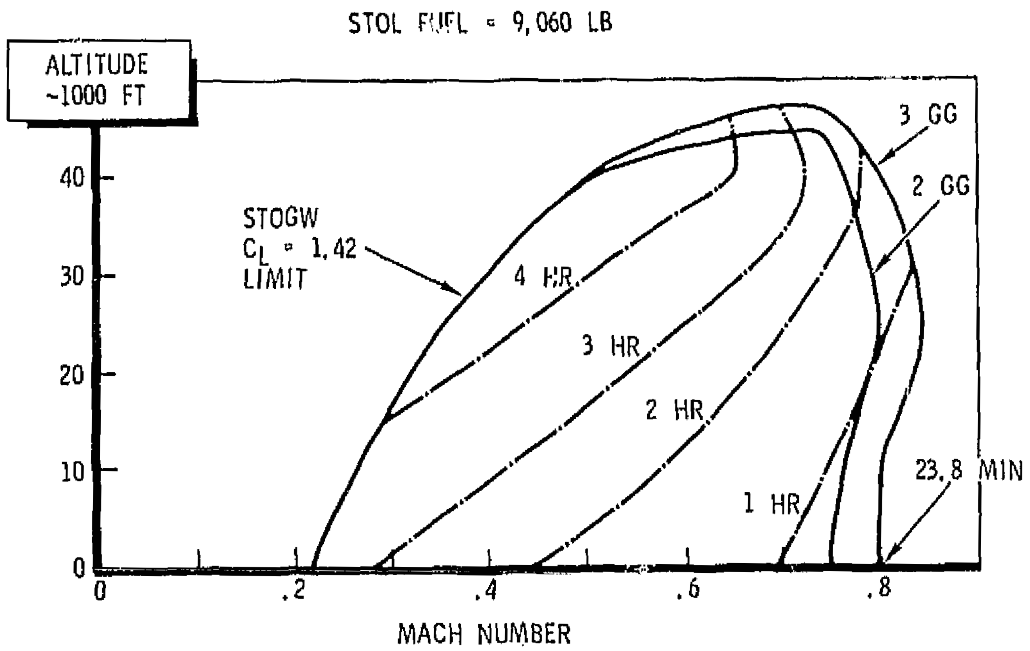


Figure 23. All New Airframe Aircraft Cruise/Propulsion Test Time

Long test times are provided throughout the wide operational envelope. Using the turbojet thrust of the third gas generator via auxiliary nozzles, the configuration can test the propulsion system at the highest dynamic pressures required of the operational system as well as high mach number flight above 45,000 feet.

In addition to the excellent low speed, high dynamic pressure and cruise performance capabilities, the all new airframe approach configuration has the excellent cockpit visibility characteristics of the operational configuration which is important to safe V/STOL operations.

Propulsion/Hover Control

The all new airframe technology aircraft approach has the identical propulsion system installation as intended for the operational aircraft. As such it has the same basic lift-cruise fan installation as the modification approach configurations as presented in figure 7 and the third gas generator pitch control system. The all new aircraft configuration also has the main gas generator inlets located inboard and on the upper portion of the nose of the aircraft which offers higher protection from hot gas reingestion. Also the propulsion system includes auxiliary nozzles on either side of the fuselage just aft of the wing that can be used to employ the flow of the third gas generator as a turbojet for cruise and dash mode operations when desired. Figure 24 illustrates the complete, highly integrated propulsion system installation in the all new airframe approach configuration.

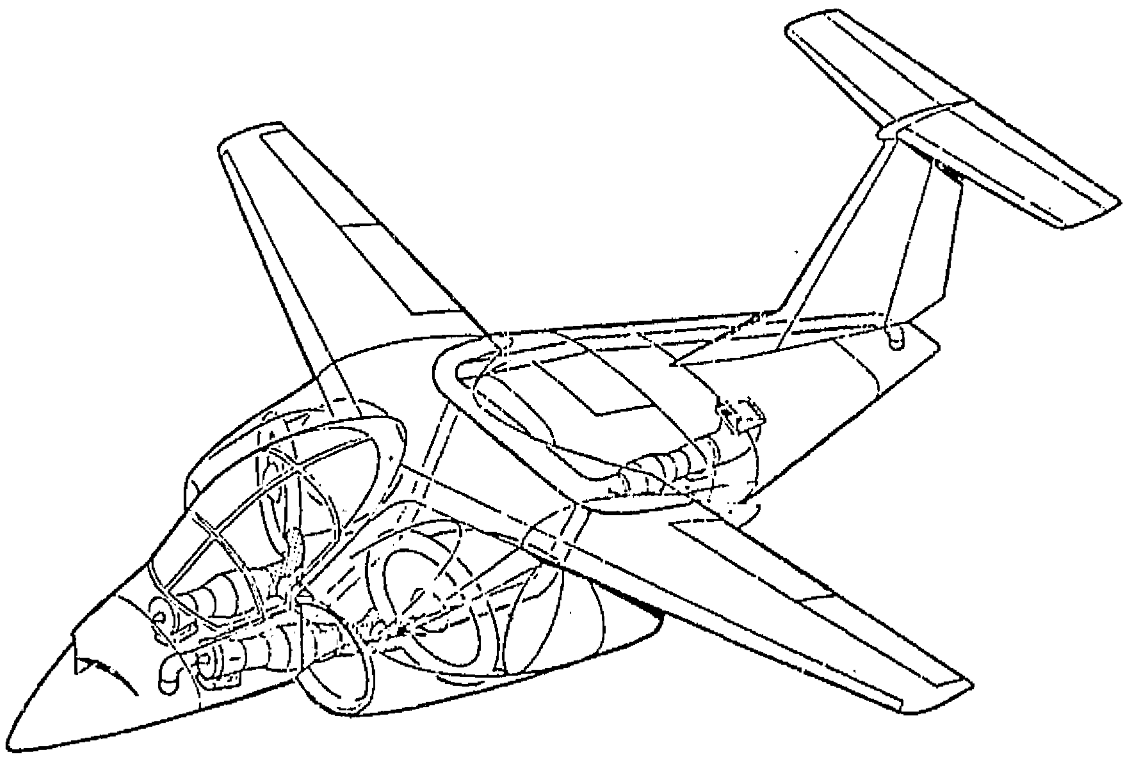


Figure 24. All New Aircraft Propulsion/Hover Control System Installation

The all new aircraft configuration has adequate margins of hover control power but, because of the higher weights and inertias, the configuration has slightly less hover control power than the modified aircraft approaches. The hover control power for the two critical conditions is illustrated in figure 25.

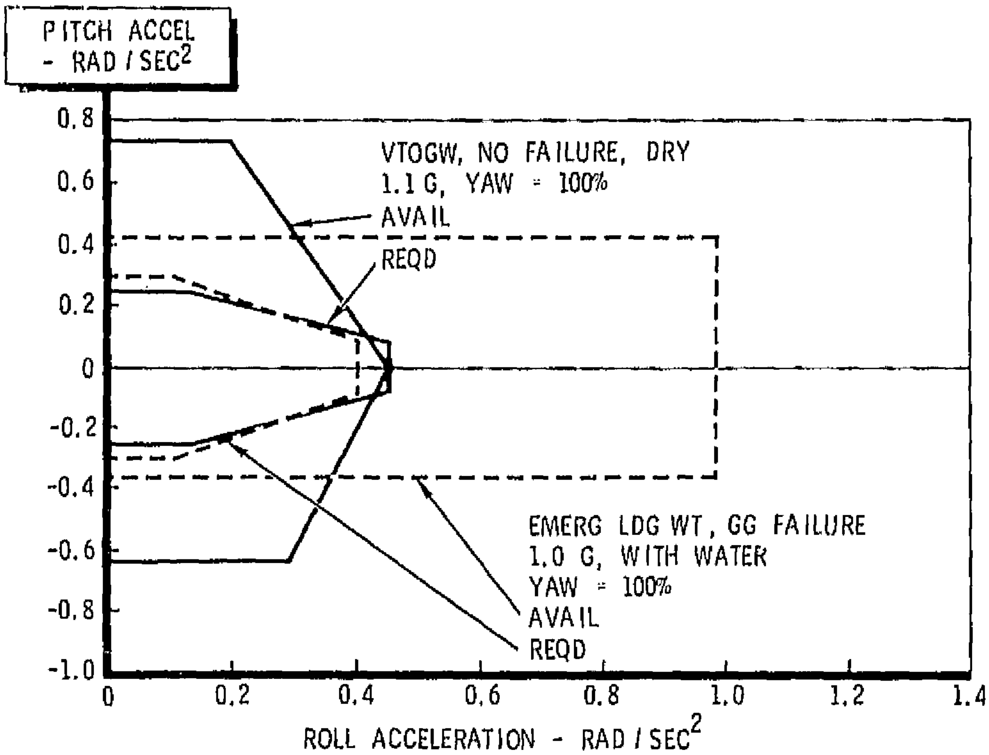


Figure 25. All New Aircraft Hover Control Capability

Structure

The structure of the all new airframe approach is conventional metal structure to save cost. The structure is designed to 1000 pounds per foot squared dynamic pressure and +3, -1g maneuver load factor requirements. A weight growth factor was used in estimating the weights to allow cost cutting experimental shop techniques to be used.

Subsystems

The air vehicle subsystems used in the all new airframe configuration approach are state-of-the-art concepts very similar to those described for the full performance modification airplane. Because of the higher sophistication of the all new airframe flight control system, e.g., five segment spoilers and leading edge deivces, the detailed sizing and numbers of components are somewhat different but the technology and basic design approach are equivalent.

Mass Properties

The mass properties data for the all new airframe approach are presented in tables 8 and 9 and figure 26.

Table 8

ALL NEW AIRFRAME AIRCRAFT WEIGHT PERCENTAGE DISTRIBUTION

	Wt-lb	%	Oper A/C %
Propulsion	6,970	20.37	17.00
Structure	11,184	32.68	23.50
Equipment	3,943	11.52	18.44
Useful Load	3,065	8.96	12.43
Fuel	9,060	26.47	28.63
Max STOL Wt	34,222	100.00	100.00 (38,727 lb STOGW)

TABLE 9. ALL NEW AIRFRAME AIRCRAFT GROUP WEIGHT BREAKDOWN

Structure	
Wing	3075
Empennage	971
Fuselage	5400
Landing Gear	1279
Engine Section	307
Air Induction System	152
Propulsion	
Gas Generators	2265
Exhaust System	1129
Cooling and Drain Provisions	31
Engine Controls	95
Starting System	153
Fuel System	237
Fans	1700
Hot Gas Duct System	1360
Equipment Groups	
Flight Controls	539
Auxiliary Power Plant	350
Hydraulics & Pneumatics	366
Electrical	590
Avionics/Instruments	1124
Furnishings	672
Air Conditioning	271
Weight Empty	22,097
Crew	400
Oil and Unuseable Fuel	165
Operating Weight Empty	22,662
Fuel	9060
Payload	2500
STOL Takeoff Gross Weight	34,222

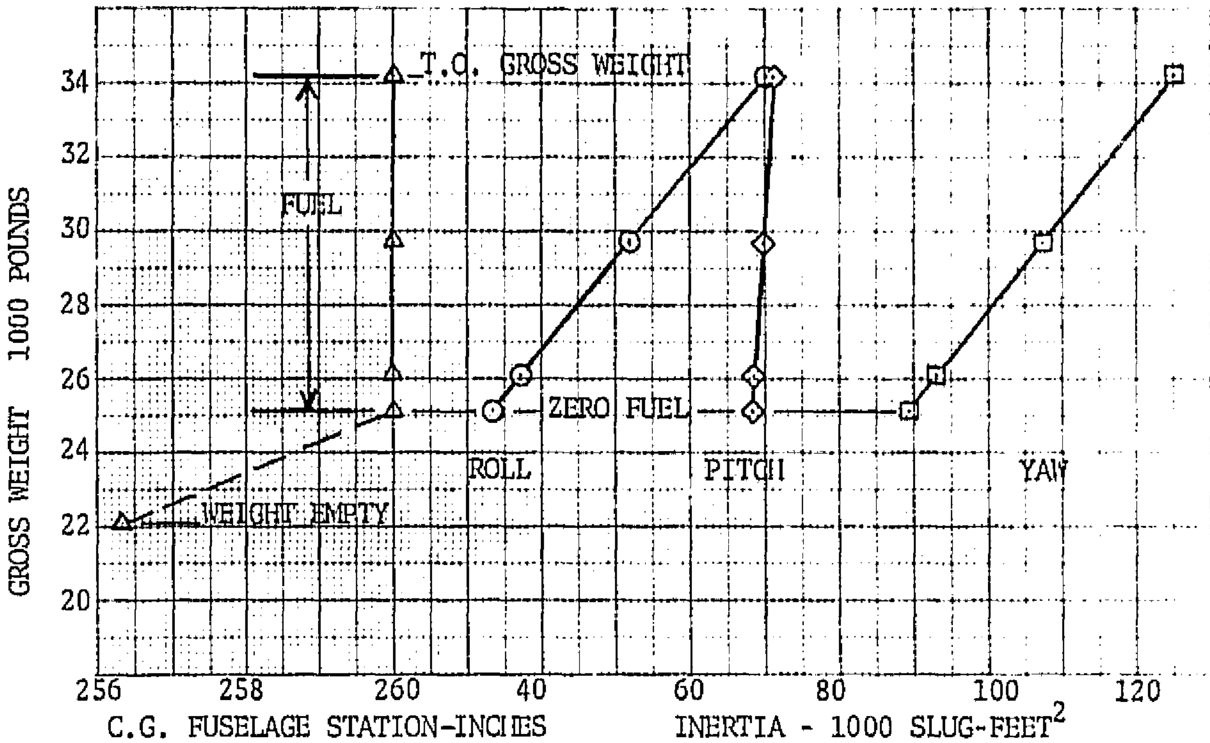


Figure 26. All New Aircraft Center of Gravity and Inertia

CANDIDATE AIRCRAFT EVALUATIONS & TRADE STUDIES

Candidate airframes for the modification approach technology aircraft configurations were selected and evaluated for their suitability in a two step process.

Initially, a search for potential candidates was initiated by a level of effort review of the industry historical and reference documents for airframes of suitable characteristics which had first flight dates within the past 20 years. By comparison of an individual aircraft's characteristics with the nominal characteristics of the target operational aircraft, with respect to gross weight, empty weight, wing area, maximum speed and overall physical dimensions, potential candidates were significantly narrowed. Any airframe suggestions from the government project monitors or study participants were considered. Approximately 10 potential candidates each resulted from this initial effort to identify suitable airframes for both the full performance and low speed only modification technology aircraft.

At the second stage of review and evaluation of the candidates, limited preliminary analyses and, in some cases, layout drawings were made to evaluate and rank a given candidate's potential relative to the others. The main evaluation tools used at the second level were determinations or estimates of the candidates modified fuel capacity, overload design requirements, physical capability to integrate with the lift-cruise fan system, amount of structural modification required, availability and probable cost of airframe acquisition. Several of the preliminary candidates were of foreign origin and therefore would have posed cost and administrative difficulties. Tables 10 and 11 present a summary of the evaluations performed on the candidates that had reached the second level of evaluation.

Reviewing the full performance candidates of table 10 shows that the majority of the candidates passing the first level of evaluation were relatively late model, low wing business jets which would classify them as expensive procurements. All would require modification to correct the wing location and ground clearance integration requirements with the lift-cruise fan propulsion system. Three of these aircraft were judged to be too large for efficient matching with the lift-cruise fan system and three were evaluated as too small. Two otherwise excellent technical candidates were eliminated because they were late model foreign business jets which would be costly to procure and create long lead time technical data acquisition problems. The LTV F-8J was considered a candidate because of good weight range and its high speed capability. However, a review of the modifications required to overcome its limited aspect ratio, aft mounted wing, low fuselage volume and balance difficulties with a lift-cruise fan system caused it to be passed over for the Rockwell International Sabreliner business jet. The Sabreliner was selected because it had fewer major modification requirements and could be more effectively evaluated in depth by the contractor.

Review of the summary of the results of the evaluation of the low speed only candidates, table 11, indicated proper physical size was a significant evalaution criteria for those aircraft. The Rockwell International Sabreliner was selected again in this category primarily because of its size.

TABLE 10. FULL PERFORMANCE MODIFICATION CANDIDATES

	DESIGNATION	EMPTY WEIGHT	GROSS WEIGHT	V_{MAX}	MOD EMPTY WEIGHT	MOD STOL OVER-LOAD	REMARKS
1	RI SABRELINER-80	13,250	23,000	0.8M	20,805	6,695	SELECTED
2	LTV F-8J	18,000	29,500	2.0M	22,400	4,000	WING, VOL, BAL
3	FALCON 20F	16,000	28,700	0.88M	23,800	6;100	FOREIGN, COST
4	HS 125-600	12,850	25,000	0.78M	20,550	6,550	FOREIGN, COST
5	LEARJET 35/36	8,800	17,000	0.83M	16,300	10,300	TOO SMALL
6	1123 WESTWIND	11,600	21,000	0.77M	20,200	10,200	TOO SMALL
7	HFB 320	11,950	20,300	0.83M	20,450	11,150	TOO SMALL
8	GRUMMAN A-6A	26,350	55,000	0.90M	28,750	0	TOO LARGE
9	JETSTAR II	24,200	44,000	0.82M	30,550	0	TOO LARGE

* PRELIM DATA EXCEPT FOR SABRELINER

TABLE 11. LOW SPEED ONLY MODIFICATION CANDIDATES

	DESIGNATION	EMPTY WEIGHT	GROSS WEIGHT	V_{MAX}	MOD EMPTY WEIGHT	MOD STOL OVERLOAD	REMARKS
1	RI [illegible]BRELINER-80	13,250	23,000	0.8 M	20,402	6,292	SELECTED
2	DHC-4 CARIBOU	17,600	28,000	188 KT	22,500	5,000	STR WG, LARGE
3	B-25J	21,100	33,500	175 KT	23,700	1,200	TOO SMALL
4	GRUMMAN S2F	19,000	26,900	240 KT	23,100	7,100	TOO SMALL
5	AJ-1 SAVAGE	27,000	55,000	370 KT	29,600	0	TOO LARGE
6	FAIRCHILD F-27	23,100	35,600	265 KT	28,700	4,100	TOO LARGE
7	FR SUPER BROUSSARD	12,350	20,700	205 KT	19,450	9,750	TOO SMALL, FOR**
8	SCOTTISH TWIN PIONEER	10,200	14,600	143 KT	17,400	13,800	TOO SMALL, FOR
9	TWIN OTTER	6,700	12,500	182 KT	14,300	12,800	TOO SMALL, FOR

*PRELIM DATA EXCEPT FOR SABRELINER ** FOR = Foreign

The DHC-4 Caribou was a close second choice because of its weight characteristics and physical fuselage proportions, however, it was passed over because of poorer overall simulation of the operational aircraft than the Sabreliner. The Caribou has a straight wing and fairly large phys'cal dimensions relative to the target operational airplane.

Selected design trade studies and design approach layouts were made of alternate means of integrating the lift-cruise fan propulsion system to the Sabreliner airframe to enhance the simulation fidelity of the oeprational aircraft installation and to minimize the costs of the modification. The best of these configurations were defined in greater detail to support program cost estimates. One configuration each was selected for the full performance and the low speed only modification approaches as described earlier in the report.

DEVELOPMENT PROGRAM FEATURES & REQUIREMENTS

The major technology aircraft program elements and a representative schedule are shown in figure 27.

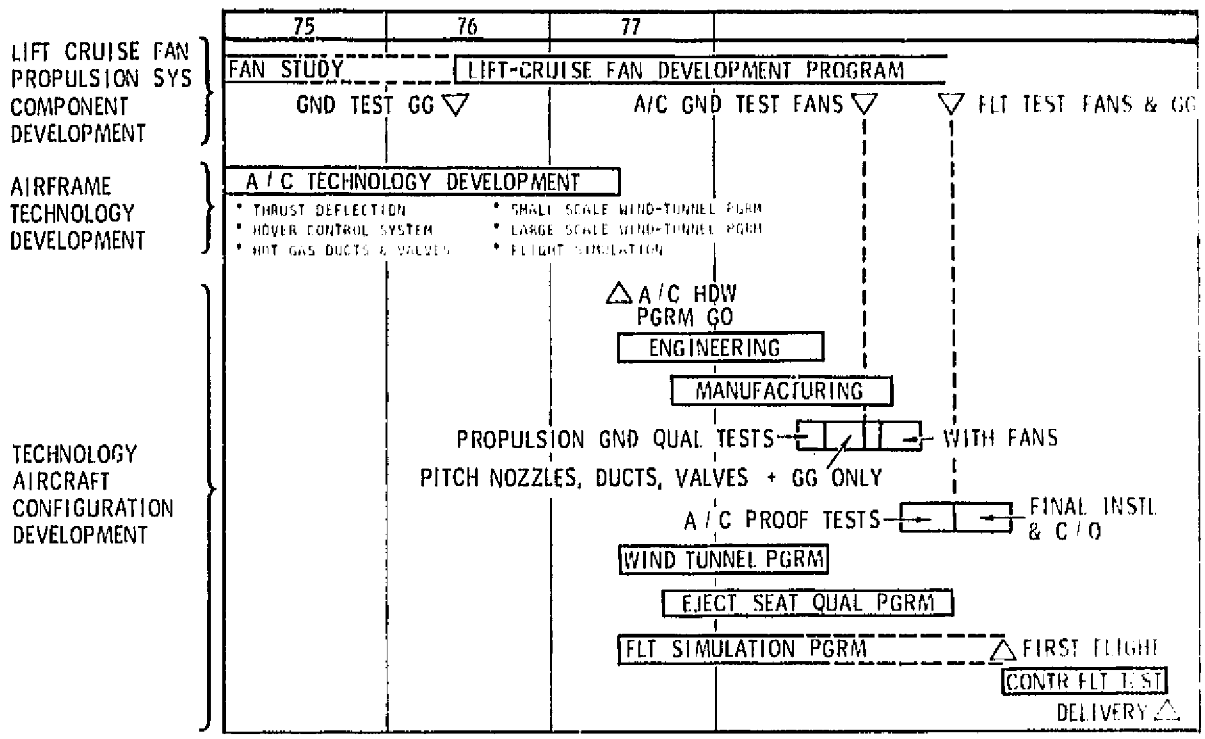


Figure 27. Technology Aircraft Program Schedule

As shown in figure 27, there are three major components to the technology aircraft program: (1) development of a suitable lift-cruise fan; (2) completion of development of the necessary airframe component technologies; and (3) development of the selected technology aircraft configuration.

The lift-cruise fan development program will complete the fan detail design, qualify fan hardware through Preliminary Flight Rating Tests (PFRT), and supply test hardware to the aircraft portions of the program. Currently, it is estimated that this program could begin about 1 June 1976 and deliver ground test fans in 30 months and the first set of flight test fans in about 36 months. In addition to the fans, gas generators would be required early in the program to support aircraft hover control system and hot gas duct and valve technology development efforts. The gas generators may be required to be modified and qualified to operate with water injection to provide proper test conditions and emergency gas horsepower.

The airframe technology development program elements are required to complete the development of selected technologies to be incorporated into the technology aircraft and provide the design data base that will allow selection and definition of a low risk technology aircraft configuration prior to initiation of the hardware program. Items included in this area are the novel thrust deflection systems, hover control systems and hot gas duct systems being developed by the industry contractors. Additional technology development work is required on these propulsion/hover control elements to assure that the design criteria are adequately described and that the mechanizations available will allow the system to perform as desired in all normal and emergency operating modes.

Selected items of long lead applied research specifically directed to the needs of high bypass ratio lift-cruise fan V/STOL aircraft configurations need to be completed to support detailed design requirements. For example, small scale wind tunnel tests, in and out of ground effect, are needed to provide basic design data and preliminary substantiation of analytical performance estimating methods in the hover, low-speed and high subsonic speed operating regions. A large scale model program is required for high confidence in the absolute level of the estimated aerodynamic performance parameters by providing extrapolation data for scale effects. To accomplish this objective, the large scale model must be similar to one tested at lower scale. Together, the large and small scale data provide substantiated methodology for predicting full scale performance of similar lift-cruise fan V/STOL configurations. A flight simulation program will be required to establish the flight control requirements of specific lift-cruise fan aircraft configuration types to meet normal and emergency operating requirements in proximity to the ground in a variety of operational environments including cross winds, etc.

With the assumption that the lift-cruise fan and airframe technology developments as described above will be provided, the technology aircraft hardware configuration can be developed as shown in the lower portion of figure 28. Technology aircraft program go-ahead is assumed to be given on 1 June 1977. Depending on which technology aircraft configuration is selected, the timespans for individual tasks vary somewhat but they generally retain the relationship shown. The engineering task shows the timespan for the preliminary and detail design and analysis of modified or new structure and subsystems through basic drawing release. Selected lower levels of sustaining engineering continue beyond the timespan shown in support of qualification and flight testing.

The propulsion ground qualification tests will be conducted in two phases on a full scale iron bird type test set-up using flight weight hardware. In the first phase, before fans are available, the system will consist of the gas generators, ducts, valves and simulated fan loads. Steady state and transient operation of the entire system will be accomplished over the whole operating range of the system. The structural integrity of the integrated system will be verified and the control system mechanization and system response time constants will be evaluated and refined as necessary. Any changes required based on the latest wind tunnel and flight simulator data available at that time will be incorporated. When the ground test fans become available, they will be added to the propulsion ground test system for final checkout and tuning of the propulsion and flight control systems.

Following structural completion of the vehicle, structural proof loading of the first airplane will be performed to verify the basic structural integrity of the airframe. Special loading fixtures, loading straps, air bags, etc., will be used to statically test the airframe to limit loads conditions. Following completion of the structural proof tests, all final subsystems installations including the flight test fans, gas generators and fully qualified ejection seats will be installed. With all flight subsystems and installations complete -- ground vibration, taxi and all other preflight checks will be made.

The wind tunnel program directly supporting the technology aircraft configuration development will be tailored to take maximum advantage of the preceding technology development wind tunnel program results and will focus on flight safety aspects of configuration development and performance verification. Approximately 1000 wind tunnel hours will be devoted to this program at the contractor's facility, the remainder will be performed at government facilities. Both powered and unpowered full airplane configuration and specialized propulsion system tests will be conducted. The data will be used to refine the aerodynamic and propulsion/flight control system features of the configuration.

The ejection seat qualification program will fully qualify the selected ejection seats for both zero altitude, zero speed and full flight spectrum operation from both pilot and copilot stations. A special sled containing the essential elements of the cockpit and forward portions of the airplane will be constructed to perform the necessary testing. The testing will be conducted at an appropriate government operated rocket sled test site.

The flight simulation program conducted as a portion of the technology aircraft configuration development program will be directed toward investigating and providing assurance of the acceptability of the specific characteristics of the developed configuration. It will be used to establish suitable flight control system mechanization gains and constants, etc., and provide assurance that the normal and failure mode characteristics meet the technology aircraft program requirements and objectives. In the period following basic drawing release, as hardware becomes available, the simulator will be connected into the breadboarded flight control system to checkout the airborne hardware components. Training of the contractor and government pilots will also be accomplished as a part of the flight simulation program task.

The contractor's flight test program will be conducted in four phases and will be directed primarily at establishing general flight safety and satisfactory operation of all flight systems for the operating regimes rather than full exploration of the extremities of the flight envelope. The initial tests will evaluate conventional flight mode characteristics. The second phase of testing will make use of a pedestal type ground restrained flight setup to evaluate the low-speed/hover control system characteristics of the aircraft. The third phase of testing will evaluate the low speed STOL characteristics and the final phase will evaluate VTOL characteristics. When all operations and systems have been demonstrated to be operating satisfactorily, the aircraft will be delivered to the procuring agency.

To provide a technology aircraft for government flight evaluations by 1980, the long lead applied research, new technology developments and lift-cruise fan hardware development must begin soon to support the aircraft configuration development as indicated by figure 27.

TECHNICAL, SCHEDULE & COST COMPARISON

Technical Comparison

A summary comparison of the technical features of the representative technology aircraft in each of the three approach categories is presented in table 12.

TABLE 12. TECHNOLOGY AIRCRAFT TECHNICAL COMPARISON SUMMARY

TECHNOLOGY AIRCRAFT APPROACH	RESEARCH CAPABILITY INDICATORS						
	AVAIL. VTOL FUEL (5 CIRCUITS)	AVAIL. STOL FUEL (11 CIRCUITS)	(FLAPS / CLEAN) $C_{L_{MAX}}$	(FLAPS / CLEAN) α_{MAX}	STOGW LIFTOFF VELOCITY (DISTANCE)	PROPULSION & CRUISE TEST CAPABILITY	OPERATIONAL CONFIG SIMULATION
ALL NEW STOGW (34, 222 LB)	3, 065 (2, 660)	9, 060 (3, 886)	3. 12 / 1. 42	10. 5°/ 14. 5°	56. 5 KTS (208 FT)	EXCELLENT HIGH ALTITUDE 0. 8M / SL	EXCELLENT
FULL PERF STOGW (29, 695 LB)	4, 257 (3, 700)	5, 870 (5, 082)	2. 18 / 0. 95	26°/ 20°	59 KTS (155 FT)	EXCELLENT HIGH ALTITUDE 0. 64M / SL	GOOD
LOW SPEED STOGW (29, 292 LB)	4, 660 (3, 800)	5, 870 (5, 250)	2. 18 / 0. 95	26°/ 20°	56. 5 KTS (142 FT)	LOW SPEED ONLY LOW ALT ONLY	GOOD

The parameters compared for each vehicle approach are maximum STOL takeoff weight, maximum VTOL and STOL fuel capability, fuel requirements for the low speed test mission circuits, $C_{L_{max}}$ and angle of attack for $C_{L_{max}}$ for flaps down and clean configurations, maximum STOL weight liftoff velocities and takeoff ground roll distances, propulsion and cruise test capability and operational aircraft configuration simulation fidelity.

The maximum STOL takeoff weights of the modified aircraft approaches are within 400 pounds of each other, but, the all new airframe approach, because of heavier structure and a larger fuel capacity, is about 4900 pounds heavier than the modified airframe configurations. The all new configuration has less VTOL mission fuel capacity than the modified aircraft because, with lift capacity limited by the common propulsion system capabilities, its higher empty weight displaces fuel carriage capacity. In the STOL mode however, where the fuel load is limited only by the wing fuel volume capacity, the all new aircraft provides a fuel load of over 50 percent greater than that provided by the modified aircraft. The fuel available is greater than required to perform the test mission circuits for all three aircraft approaches.

Because of the differences in the wing designs, the low speed maximum lift coefficients and angles of attack for maximum lift are significantly different for the all new airframe relative to the modified aircraft. The STOL liftoff velocities and ground roll distances, however, are very similar because of compensating differences in STOL takeoff weights. The modification approaches can fly and test the propulsion system to angles of attack of from 5 to 15 degrees higher than the all new airframe in the low speed regime.

Relative to general propulsion system and cruise test capability, the all new airframe has excellent capabilities. The all new airframe has virtually the same speed altitude capability as the goal operational airplane, including the ability to fly at 0.8 mach number at sea level. Its large fuel load allows continuous cruising flights of over 4 hours if desired. The full performance modified airplane has speed altitude performance that is very nearly comparable to the operational aircraft, but the reduced fuel load reduces the test times available. The test times available at the extremes of the envelope, however, are more than adequate to obtain good steady state propulsion performance data. The desired steady state cruise times of 2 hours, or better, can be obtained by cruising on one gas generator. The maximum speed altitude capability meets or exceeds the capabilities of the operational aircraft at all altitudes above 13,000 feet. The maximum speed at sea level is 0.64 mach number which limits the testing to less than the maximum flight dynamic pressures that will be experienced by some versions of the operational aircraft. The combat search and rescue and surface attack mission versions of the operational airplane will be capable of speeds to 0.8 mach number at sea level. The antisubmarine warfare, vertical onboard delivery and surveillance mission versions, however, are limited to about 0.58 mach number at sea level. Thus the full performance technology aircraft covers the testing need to verify the performance capabilities over a substantial portion of operating envelope of all versions of the operational aircraft. The concept of the low speed only technology aircraft limits its operational envelope to speeds below 160 knots and altitudes of 15,000 feet, thus it does not have the capability to explore the cruise regimes or the extremes of the operational envelope.

In terms of simulation of the operational aircraft configuration, all three approaches to the technology aircraft have been designed to closely represent the low speed aerodynamic/propulsion interface features of the operational aircraft configuration. The sizing and relationship of the propulsion system inlets and exhausts and their relationship to the fuselage and inboard wing geometry has been preserved with reasonable fidelity on all three approaches. This assures the prime objective of getting the proper evaluation of the low speed propulsion/aerodynamic interactions which are unique to the operational lift-cruise fan V/STOL aircraft. Because of its exact duplication of the operational aircraft geometry, the all new aircraft must be rated excellent, particularly because of the high applicability of all handling qualities data to be acquired and the exact duplication of the pilot vision which can influence pilot opinion of the aircraft's low speed performance acceptability. The modified aircraft are rated good because of their close representation of the critical low speed propulsion/aerodynamic features and characteristics and because the 20° over the nose vision provided directly in front of the pilots will also assure similarity of this important characteristic. All three aircraft exhibit more than the minimum guidelines for hover control power at selected practical test weights.

Schedule Comparison

Based on the same assumptions of preceding airframe technology programs and a parallel lift-cruise fan development program, as discussed relative to figure 27, the estimated development schedules required for the modified aircraft and the all new airframe approaches to the technology aircraft are presented in figures 28 and 29.

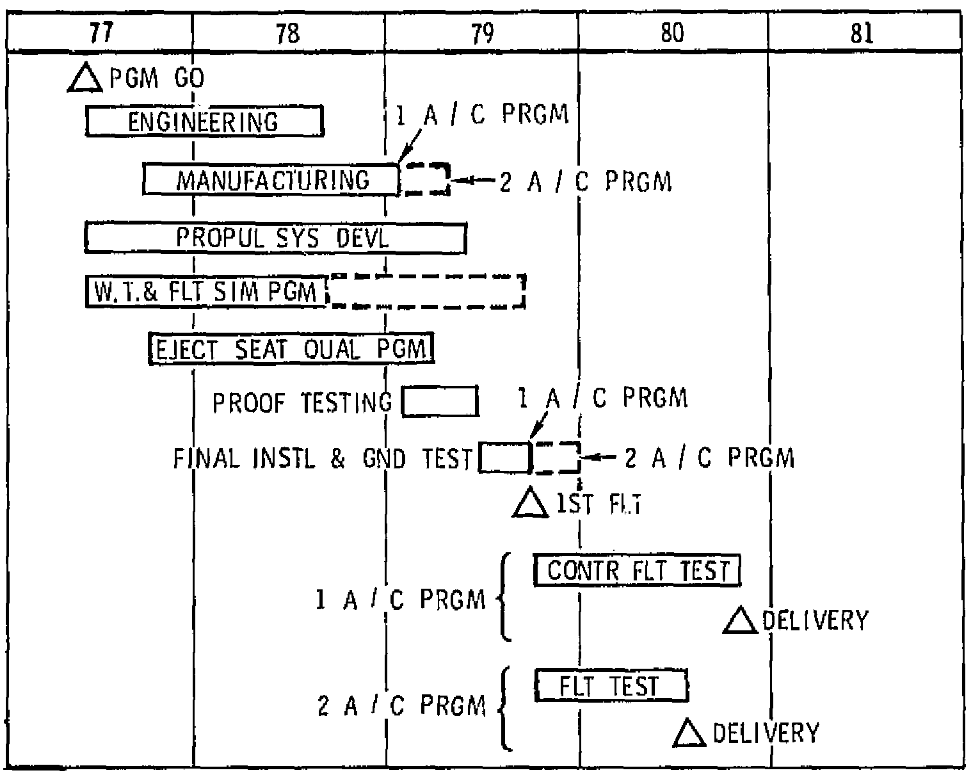


Figure 28. Modified Aircraft Configuration Development Schedule

Both the full performance modification and low speed only modification aircraft configurations can be developed according to the schedule of figure 28. The propulsion system development and ground qualification tests are the pacing items. The other engineering design/development and manufacturing activities can be accomplished within the timespans thus allowed for either configuration. Preliminary and detailed engineering design, through basic drawing release, can be accomplished in 15 months from go ahead. The manufacturing activities start 4 months after go ahead and complete the first aircraft structural assembly at 20 months after go ahead. The second aircraft of a two aircraft program would be completed three months after the first aircraft. The design and development phases of the wind tunnel, flight simulation and ejection seat qualification programs can be easily accommodated within the timespans provided by the basic engineering and structural assembly activities. Selected flight simulation program activities related to flight control system hardware validation and pilot training continue intermittently after drawing release until first flight. Structural proof testing can be accommodated in the time period allowed between structural completion and completion of the propulsion system development and ground qualification testing. Four months are then allowed for final installation of the flight test propulsion system hardware and the air vehicle subsystems and completion of the ground vibration, taxi and other preflight ground testing of the first aircraft. This schedule allows the first flight to occur 28 months after go ahead. In a one aircraft program, the contractor flight tests would require approximately 13 months to complete validation of the air vehicle and its subsystems prior to delivery to the government at 41 months after go ahead. In a two aircraft program, the testing can be accomplished in shorter time allowing delivery three months earlier, at 38 months after go ahead.

Figure 29 presents the development schedule requirements for the all new airframe configuration. Because of the larger efforts associated with the all new structure design and development, the required timespans are slightly longer than for the modified aircraft. Engineering basic drawing release would be completed in 19 months after go ahead and structural assembly of the first aircraft completed in 24 months. Structural proof loading will require 6 months. Final installation of subsystems and completion of preflight ground tests can then be completed in time to allow first flight at 34 months after go ahead. Contractor flight test programs of 13 and 10 months for one and two aircraft programs would allow the deliveries to occur at 47 and 44 months after go ahead respectively.

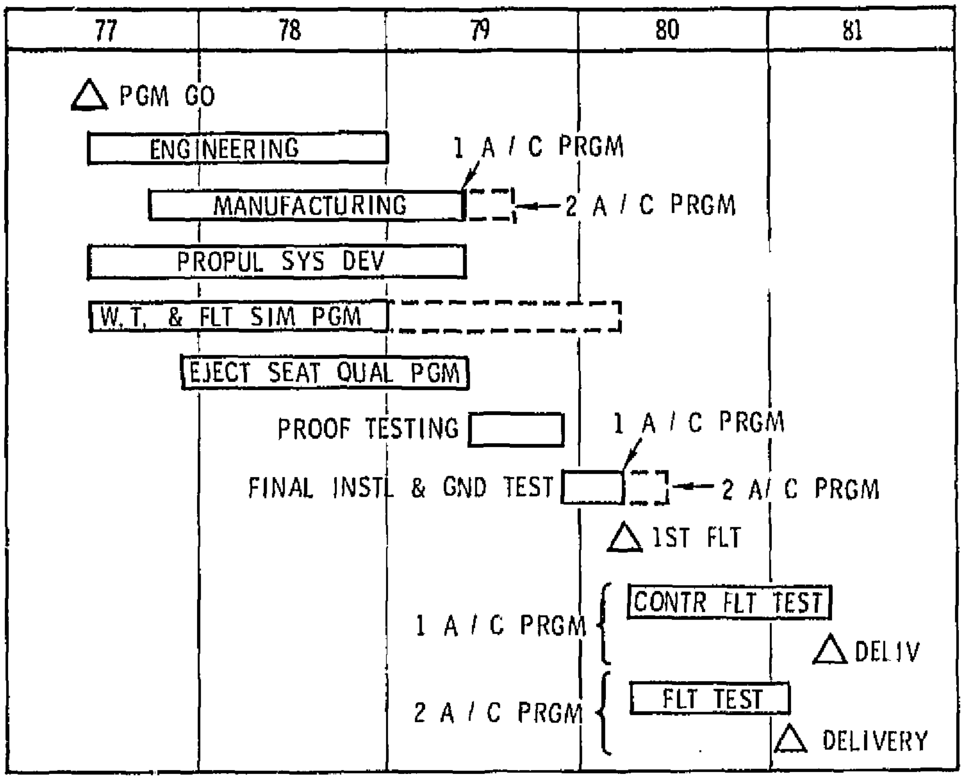


Figure 29. All New Airframe Configuration Development Schedule

Cost Comparison

The relative costs of developing each of the three technology aircraft configuration approaches for one and two aircraft programs were estimated. Figure 30 presents the results of the cost analysis. The costs are presented relative to the cost of a full performance modification, one test airplane program. The costs for the representative configurations of each category as described in this report are shown in the center of each category band. By adding or deleting selected features of these aircraft, the cost (and research capability) could be varied somewhat within each technology aircraft approach category as shown. The significant result of the cost analysis, however, is that the low speed only modified technology aircraft would be only about 8 percent less expensive than a full performance modification approach and the all new airframe approach would be about 120% more expensive. The cost of a second test aircraft over that of a one test airplane program of the same type would only be about 20 percent for the modified aircraft approaches and 17 percent for the all new airframe approach. Since each test

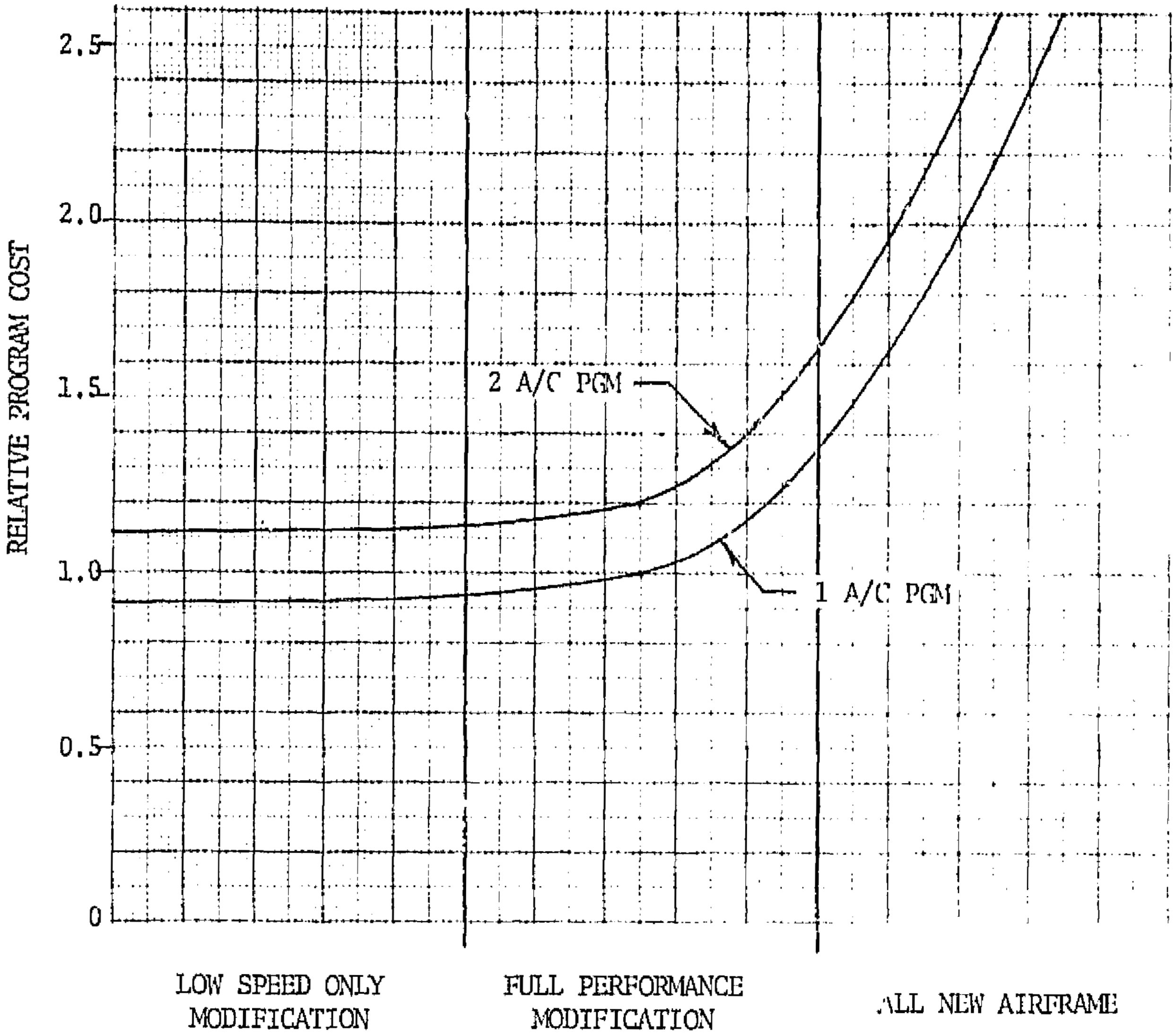


Figure 30. Relative Program Cost vs Technology Aircraft Approach

aircraft will provide 500 hours of flight test time, it is noted that a second test aircraft will increase the test time available by 100 percent while increasing the program cost by only about 20 percent. A two airplane program thus would provide two times the test time at 1.2 times the cost or 66 percent more test time per dollar invested. A two airplane program also provides insurance and reduced risk that a single accident early in the flight test program could nullify the entire opportunity to provide useful test data to the program.

Comparison Summary

A review of the technical, schedule and cost comparisons presented above for the three technology aircraft approaches leads to the following summarizations:

The technical features comparison of the three approaches indicates that the all new airframe approach provides the best simulation of the goal operational aircraft because of its similar geometry. The full performance modified aircraft provides very nearly the same capability as the all new aircraft except for limited sea level top speed capability and second level differences in handling qualities due to the structural and geometry differences. The low speed only approach, while providing test capability in the unique V/STOL low speed regime, cannot provide cruise or propulsion system test capability at the extremes of the operational speed altitude envelope.

The development schedule comparisons showed that there was an insignificant difference in the schedules required for the low speed only and full performance modified aircraft approaches. The all new airframe approach would require only an additional 3 months or 7 percent more elapsed time for aircraft delivery relative to the modified aircraft approaches. Selection of a two airplane program relative to a single aircraft program shortens the delivery time by 3 months for all approaches because it shortens the contractor flight test time requirements.

The cost comparisons indicated that the low speed only aircraft approach would cost about 8 percent less than the full performance modified aircraft and that the all new airframe would cost about 120 percent more. Two aircraft programs would cost only about 20 percent more than a one aircraft program.

From consideration of the above, the full performance modified aircraft approach was selected as the recommended approach for the technology aircraft. This approach, while demonstrating technical features and capabilities close to the all new airframe approach, is significantly less expensive. The low speed only approach, while only slightly less expensive than the full performance modified aircraft, has significantly less capability to test all operating regimes of the aircraft or the development propulsion system. Thus the full performance modified aircraft was selected because of its high technical capabilities and modest cost relative to the other approaches. A two airplane program was also selected for recommendation relative to a one airplane program because of the significant improvement in test time provided, the reduction in program risk and the modest cost increase relative to the program gains.

CONCLUSIONS

The major conclusions of the lift-cruise V/STOL technology study are:

- Of the three technology aircraft approaches investigated, the full performance modified aircraft configuration approach appears to provide the most research value and operational suitability evaluation potential relative to the number of dollars that must be invested.

- A two airplane flight research program significantly reduces the total program risk and provides about 66 percent more flight test hours per dollar invested and is therefore preferred over a one aircraft program. The program cost of a two aircraft program is only 20 percent more than a one aircraft program.

- Long lead applied research, new technology developments and lift-cruise fan hardware development must begin soon to maintain the program schedule required for the aircraft to enter flight status by 1980.

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