PRELIMINARY DESIGN OF A SUPERSONIC SHORT-TAKEOFF AND VERTICAL-LANDING (STOVL) FIGHTER AIRCRAFT

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A preliminary design study of a supersonic short-takeoff and vertical-landing (STOVL) fighter is presented. Three configurations (a lift + lift/cruise concept, a hybrid fan-vectored thrust concept, and a mixed-flow-vectored thrust concept) were initially investigated with one configuration selected for further design analysis. The selected configuration (the lift + lift/cruise concept) was successfully integrated to accommodate the powered-lift short takeoff and vertical landing requirements as well as the demanding supersonic cruise and point performance requirements. A supersonic fighter aircraft with a short takeoff and vertical landing capability using the lift + lift/cruise engine concept seems a viable option for the next generation fighter.

NOMENCLATURE

BAI	Battlefield Air Interdiction
CA	Counter Air
c.g.	Center of Gravity
FS	Fuselage Station
HFVT	Hybrid Fan-Vectored Thrust
LIFT	Lift + Lift/Cruise
MFVT	Mixed-Flow-Vectored Thrust
n.m.	Nautical Mile
STOVL	Short Takeoff, Vertical Landing

INTRODUCTION

The survivability of long, hard-surface runways at Air Force Main Operating Bases is fundamental to the current operations of the Air Force Tactical Air Command. Without the use of these runways, the effectiveness of the Tactical Air Command is severely degraded[1]. One possible solution to this runway denial situation is to include a short takeoff and vertical landing capability in a supersonic fighter/attack vehicle. An aircraft with this capability is envisioned as the next multirole fighter to replace the F-16 in the 2000-2010 time period[2].

Design teams at the University of Kansas, through the sponsorship of the NASA/USRA Advanced Design Program, have completed a conceptual design study of a supersonic STOVL aircraft. Phase I of the study began with a brief historical survey of powered-lift vehicles followed by a technology assessment of the latest supersonic STOVL engine cycles under consideration by industry and government in the U.S. and U.K. A survey of operational fighter/attack aircraft and the modern battlefield scenario was completed to develop, respectively, the performance requirements and mission profiles for the study[3,4]. Three aircraft were considered for initial investigations[5-7]. They employed the following engine cycles: a lift + lift/cruise cycle, a hybrid fan-vectored thrust cycle, and a mixed-flow-vectored thrust cycle. Phase II of the study consisted of comparing the three configurations of Phase I and selecting one configuration for further design analysis. This paper (1) briefly presents the results of the Phase I aircraft study; (2) discusses the considerations for the selection of and modifications made for the Phase II aircraft; and (3) presents the design analysis performed on the Phase II aircraft.

PHASE I AIRCRAFT STUDY

Mission Profiles and Specification

The mission profiles for the Phase I study (Figs. 1 and 2) show the design defensive counter air superiority mission and the fallout battlefield air interdiction mission. The mission specification (Table 1) shows the armament carried for each mission and the point performance requirements.

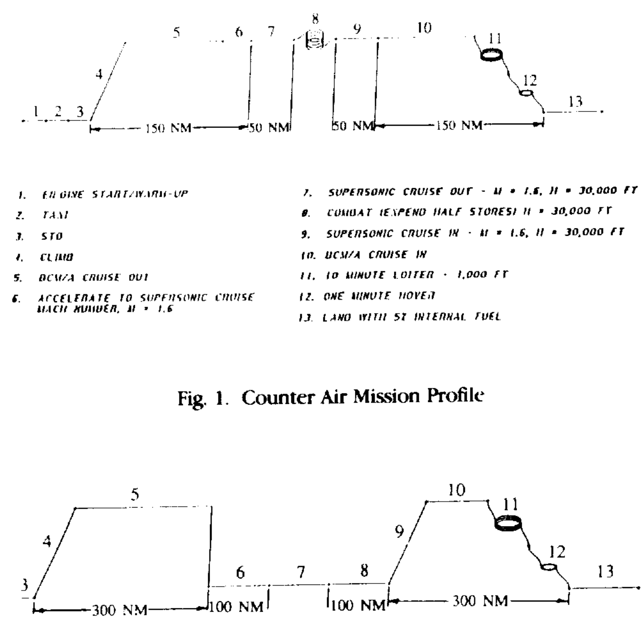

Fig. 1. Counter Air Mission Profile

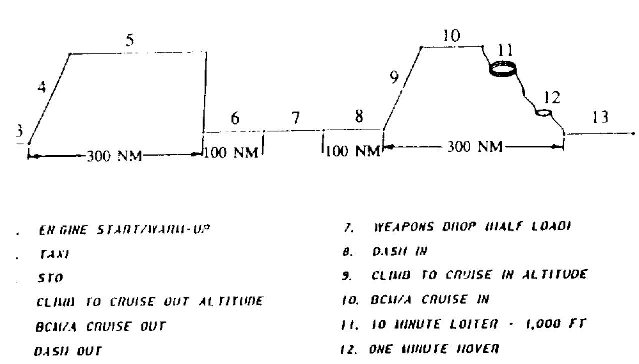

Fig. 2. Battlefield Air Interdiction Mission Profile

Table 1. Mission Specifications

Crew:	One Pilot (225 lb)
Armament:	One internal M61A1 Vulcan cannon and 400 rounds of 20 mm ammo
Payload:	Counter Air
	Two ASRAAMs (stored internally) and two AMRAAMs (stored internally)
	Battlefield Air Interdiction
	Six Mk 82 Bombs (externally stored), or
	Six AGM-65 Mavericks (externally stored)
	Four AGM-88A HARMs (externally stored)
Performance:	
Performance Characteristic	*Value*
Time to Climb	40K in 2 min
1 g Specific Excess Energy	
(2A) 30K Mach 0.9	500 ft/sec
(2B) 10K Mach 0.9	1000 ft/sec
Sustained Turn Rate	
(3A) Mach 0.8/15K ft	15°/sec
(3B) Mach 0.9/30K ft	9°/sec
(3C) Mach 1.2/30K ft	8°/sec
(3D) Mach 0.9/15K ft	6.5 g
(3E) Mach 1.6/30K ft	4.5 g
Acceleration	
(4A) 30K ft Mach 0.9 to Mach 1.6	70 sec
(4B) Mach 0.5 to Mach 1.4	80 sec
(4C) 10K ft Mach 0.3 to Mach 0.9	22 sec
Landing Distance	
Without Chute	2200 ft
Groundrun: Takeoff - 300 ft, Vertical Landing	
Certification: Military	

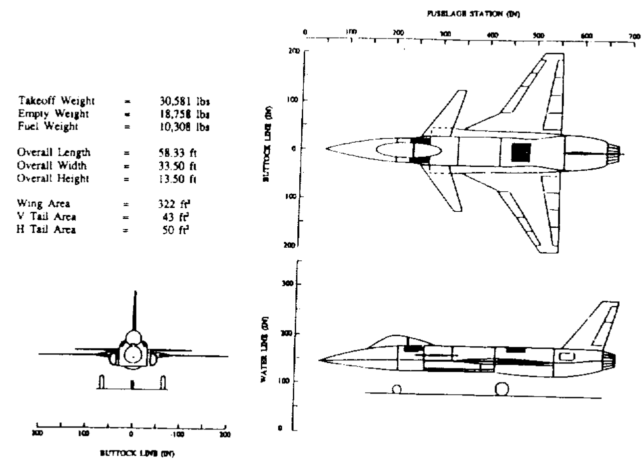

Fig. 3. Lift + Lift Cruise Configuration Three View

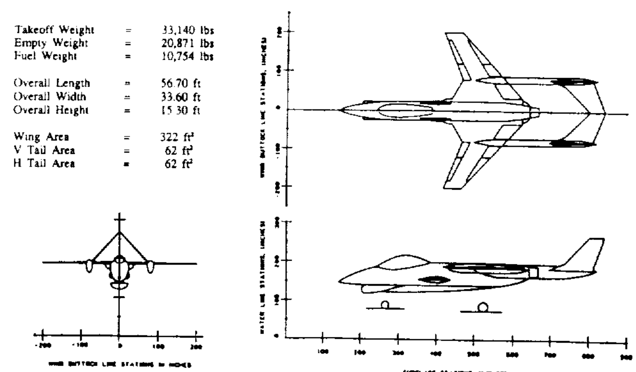

Fig. 4. Hybrid Fan-Vectored Thrust Configuration Three View

Lift + Lift/Cruise Configuration Description

The LIFT configuration consists of a conventional wing and fuselage with a canard and strake. Figure 3 shows a three-view drawing of the LIFT configuration. The mid-fuselage-mounted wing, using full-span leading and trailing edge surfaces to provide for high lift and lateral control, incorporates a strake allowing for delayed wing stall at high angles of attack. The empennage consists of an all-moving canard and a single vertical fin using a two-surface rudder to enhance redundancy against battle damage. Considerations for the fuselage layout included internal packing of the counter air mission weapons and lift engine, as well as shaping for reduced wave drag.

The engine cycle of the LIFT configuration consists of a 28:1 thrust-to-weight lift engine just aft of the cockpit and a conventionally located lift/cruise engine. The lift/cruise engine employs a single ventral nozzle that opens aft of the last turbine stage. The afterburner flame holders double as turning vanes for the flow. Flow turning is also enhanced by a main nozzle capable of choking down its exit area. A three-axis reaction control system is required for hover and transition control. An auxiliary inlet on the upper surface of the fuselage is opened to reduce hot gas reingestion and foreign-object damage.

Hybrid Fan-Vectored Thrust Configuration Description

The HFVT configuration consists of a twin boom, high forward swept wing, and an aft swept inverted vertical tail.

Figure 4 shows a three-view drawing of the HFVT configuration. The combined vertical thrust of the two forward posts and single aft post of the HFVT engine cycle (described below) acts at approximately one-third of the engine length. The resulting hover balance lends itself to the engine being driven forward to the middle of the aircraft, thus the twin boom configuration. The forward swept wing and inverted vertical tail are aimed to achieve structural synergism. The wing rear main spar is synergistic with the main engine mount and the inverted vertical tail acts as an efficient structural tie between the booms.

The HFVT engine cycle consists of a mixed augmented turbofan driving a remote front fan through a shaft. The front fan is connected to the rest of the engine by an interduct. At the forward end of the interduct is a diverter valve to allow two modes of operation for the engine: (1) Parallel—the front fan flow is diverted to a plenum and fed to two unaugmented, fully vectoring front nozzles. The core air is fed by a ventral auxiliary inlet behind the cockpit. (2) Series—the auxiliary inlet and front nozzles are shut off and the front fan air passes through the valve to the rest of the engine for maximum power. The parallel mode is used for the powered lift requirements and subsonic cruise where the higher bypass ratio may improve the specific fuel consumption. The series mode is for point performance and supersonic flight where the front nozzles are faired in by a retractable ramp to minimize drag. A two-axis reaction control system is required as the front nozzles differentially vector to provide lateral control.

Mixed-Flow-Vectored Thrust Configuration Description

The MFVT configuration consists of a high aft swept wing, twin vertical tails, and all moving horizontal stabilators. Figure 5 shows a three-view of the MFVT configuration. The large flow transfer ducts required for the MFVT engine cycle (described below) dictated the middle and aft fuselage width, while the cockpit and radar volume sized the forward fuselage. Fuel volume and internal bays for the medium-range missiles sized the fuselage length. Volume beneath the engine inlet and ducts was dedicated to the main landing gear and internal short-range missiles. A conventional aft swept wing was selected for simple construction with adequate performance. The strake provides improved aircraft lift and maintains adequate airflow to the bifurcated inlet at high angles of attack.

The MFVT engine cycle consists of a single cruise engine with a block-and-turn main nozzle and two flow transfer ducts. In powered-lift operation, the mixed turbine and bypass flow, completely blocked by the main nozzle, is transferred forward to the c.g. of the aircraft and exhausted. The two-variable area, vectoring exhaust nozzles, along with the 5%-thrust, longitudinal trim valve, provide complete control in hover, eliminating the need for a reaction control system. In up-and-away flight, the forward exhaust nozzles are stowed and the transfer ducts are closed off to allow for conventional operation.

PHASE II AIRCRAFT STUDY

Selection of Phase II Aircraft

The LIFT configuration was selected for the Phase II aircraft study based on a comparison of the Phase I aircraft using the following considerations: (1) aircraft weight and cost, (2) aircraft area rule distribution, and (3) aircraft components required for STOVL capability.

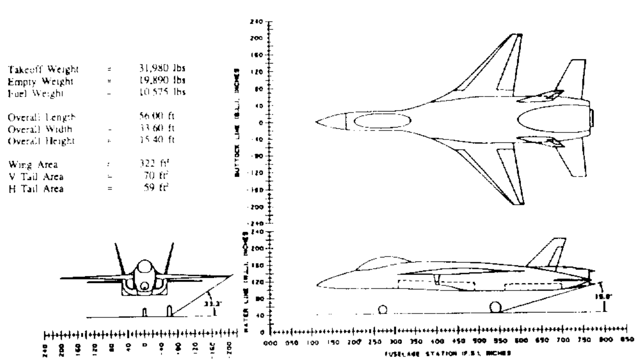

Fig. 5. Mixed-Flow-Vectored Thrust Configuration Three View

The LIFT configuration was 1400 lb lighter than the MFVT and 2400 lb lighter than the HFVT. The added cost of the lift engine negated its lighter weight as the cost of the three configurations was similar.

The more conventional internal packaging of the LIFT configuration compared to the other concepts allowed it a favorable area rule distribution. The HFVT configuration area distribution suffered due to the large loss of cross-sectional area in the boom region. The large transfer ducts required by the MFVT cycle increased the mid and aft fuselage width resulting in a large gap in cross-sectional area between the canopy and mid fuselage.

The component weights and volumes required for the short takeoff and vertical landing capability of each configuration were estimated. The results are shown in Table 2. The HFVT configuration suffers the most from the STOVL equipment for two reasons. First, the engine components required for flow shifting are heavy and require a large volume (the annular inverter valve and interduct). Second, the engine thrust split requires a mid-aircraft-mounted engine and thus some sort of boom configuration. The LIFT and MFVT configurations have similar weight penalties but the MFVT has a larger volume penalty due to the transfer ducts.

Modifications for the Phase II Study

The lessons learned in Phase I were adapted to the study plan of Phase II. Modifications were made regarding (1) the mission profiles and specifications and (2) the overall configuration of the lift + lift/cruise aircraft.

The fuel fractions (fuel weight/takeoff weight) for the Phase I aircraft were unrealistically high[8]. The design CA mission was scaled down to a 100-n.m. subsonic cruise with a 50-n.m. supersonic cruise. The fallout BAI mission was scaled to a 200-n.m. subsonic high-level cruise with a 80-n.m. low-level dash.

Table 2. Weights and Volumes for Components Required for STOVL Capability

	Volume (ft^3)	Weight (lb)
Lift		
Lift Engine	21	647
Ventral Nozzle and Turning Vanes	*	300
RCS System	8	390
Total	29	1337
HFVT		
Flow Switching Mechanism and Extended Power Shaft	83	1351
Front Vectoring Nozzles	2	*
Rear Vectoring Nozle	*	*
Penalty for Booms	117	1112
RCS System	6	423
Total	208	2886
MFVT		
Block and Turn Nozzle	*	450
Transfer Ducts	92	465
Front Clamshell Nozzles	2	450
Total	94	1365

The BAI mission payloads were changed to reflect more realistic missions[9]. The mission payloads were changed to allow carrying radar-guided weapons along with unguided weapons, thus having the aircraft able to deliver munitions if the target shuts off its radar. The BAI missions (two of them) were changed to (1) BAI Mission #1: Four Mk-82s and two HARMs; and (2) BAI Mission #2: Four AGM-65s and two Mk-82s.

A horizontal stabilator replaced the canard on the LIFT configuration to reduce the complexity in the main and lift engine inlet region, to provide more favorable stability margins (less trim drag), and to move the hover c.g. further aft. Moving the hover c.g. aft (or moving the rear thrust post forward) decreases the thrust required of the lift engine. Toward this end, the avionics were moved aft behind the internal weapons bay. The internal short-range missile requirement was dropped and the missile was wingtip mounted since (1) prelaunch target acquisition is required and (2) the wingtip launchers provide the missile with a larger field of view. The final modification of the LIFT configuration was replacing the single ventral nozzle with two variable-area ventral nozzles allowing for a three-post configuration, reducing the suckdown, and providing lateral control in hover. The effect on suckdown of a two- vs. three-post configuration was estimated and is shown in Fig. 6.

CONFIGURATION DESCRIPTION

The Phase II lift + lift/cruise aircraft consists of a mid-wing with split leading and trailing edge flaps, an all moving horizontal stabilator, and a single vertical fin. Figure 7 shows a three view of the configuration. The internal layout is shown in Fig. 8 with the resulting cross-sectional area distribution as shown in Fig. 9. The configuration highlights are discussed below.

The lift engine and lift/cruise engine combine to decouple the short takeoff and vertical landing requirements from the supersonic-cruise and point-performance requirements. The configuration is area ruled to closely match the ideal Sears-Haack shape considering the two internal medium-range missiles, the lift engine volume, and the large soft-field capable and high-sink-rate (17 ft/sec) landing gear. The high main inlet placement provides for less severe hot gas reingestion and reduces foreign-object damage. The pitch and yaw vectoring main engine nozzle allows for the removal of the rudder, a reduction in the vertical tail size, and for enhanced maneuverability at post-stall angles of attack.

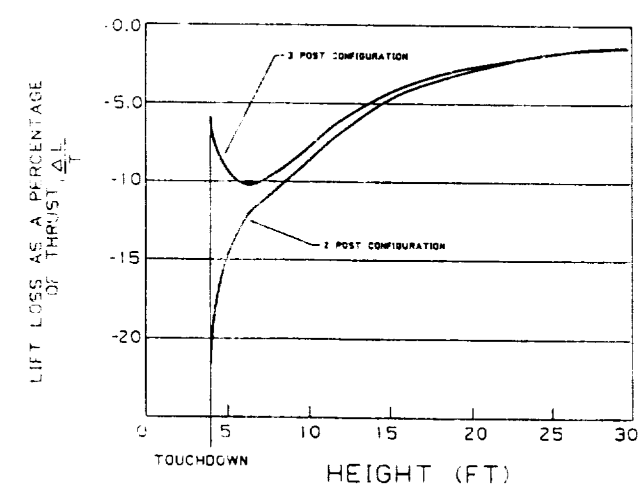

Fig. 6. Effect of Number of Thrust Posts on Suckdown

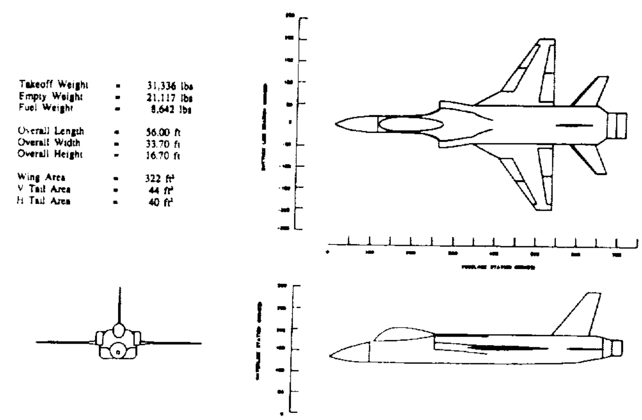

Fig. 7. Lift + Lift/Cruise Configuration Three View

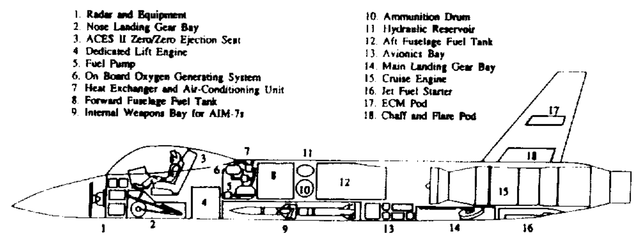

Fig. 8. Lift + Lift/Cruise Configuration Internal Layout

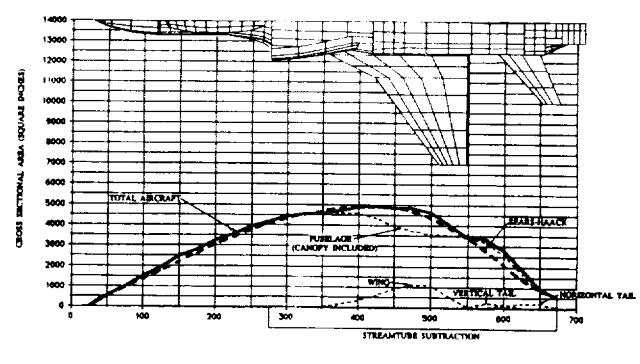

Fig. 9. Lift + Lift/Cruise Configuration Cross-Sectional Area Distribution

WEIGHT DATA

The weight data are shown in Table 3. STOVL equipment weight includes that of the lift engine and nozzles, the lift/cruise engine nozzles, the reaction control system ducting and nozzles, and the lift/cruise engine tailpipe extension.

Table 3. Weight Statement (lb)

	CA	BAI #1	BAI #2
Structure	(9,498)		
Fuselage	4,385		
Wing	2,490		
Tails - Vertical	256		
- Canard	295		
Landing Gear - Main	1,249		
- Nose	220		
Launch Mechanisms (Int. Weap)			
ASRAAM	40		
AMRAAM	262		
Ventral Clamshell Nozzles	300		
Propulsion	(6,139)		
Cruise Engine	3,557		
Lift Engine	480		
Cruise Engine Tailpipe Ext	300		
Cruise Engine Nozzle	420		
Air Induction	773		
Fuel Bladder	415		
Fuel Dumping	24		
Engine Controls	45		
Starting System	125		
Fixed Equipment	(5,480)		
Flight Control	1,021		
Avionics	1,517		
Electrical System	596		
Air Conditioning	301		
Oxygen System	17		
APU	298		
Furnishings	277		
Gun and Provisions	630		
Auxilary Gear, Paint	418		
RCS Ducting and Nozzles	405		
Total Empty Weight	21,117	21,117	21,117
Crew	225	225	225
Total Fuel	8,642	8,642	8,642
Armament	(1,196)	(4,074)	(3,316)
ASRAAMS	332		
AMRAAMS	654		
HARM		1,614	
Mk-82s		2,240	1,120
Mavericks			1,976
Ammo - (200 rounds)	220	220	200
Takeoff Weight	31,336	34,400	33,642

PROPULSION SYSTEM INTEGRATION

The overall propulsion system integration is shown in Fig. 10. The integration consists of a lift/cruise engine with two ventral nozzles and a main pitch and yaw vectoring nozzle, and a lift engine with a pitch vectoring nozzle. Auxiliary inlets are used for the lift/cruise engine to accommodate the increased mass flow required for powered-lift operation.

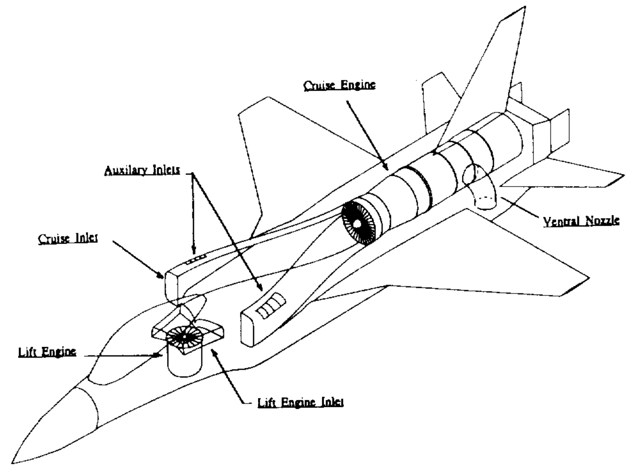

Fig. 10. Propulsion System Integration

The lift/cruise engine,[10] sized by the point-performance requirements, has a maximum sea-level static thrust of 35,573 lb. For hover, the dry thrust required included the following: (1) 1.00 g to counter the aircraft weight, (2) 0.10 g to arrest a sink rate, (3) 0.13 g to counter suckdown (assumed), and (4) 0.07 g to support reaction control (assumed). The calculated required thrust loss due to suckdown and bleed required for reaction control were less than that assumed and so resizing was not required.

The ventral nozzles are of the clamshell type. Figure 11 shows the integration of the ventral nozzles and the tailpipe extension. In powered-lift operation, while the main nozzle blocks the flow, the turning vanes direct the flow through the transfer ducts to the clamshells. In conventional flight, the turning vanes block off the transfer ducts and the clamshell nozzles are retracted into the fuselage. This nozzle arrangement allows for a three-post configuration as well as lateral control in hover, thus reducing the required reaction control bleed.

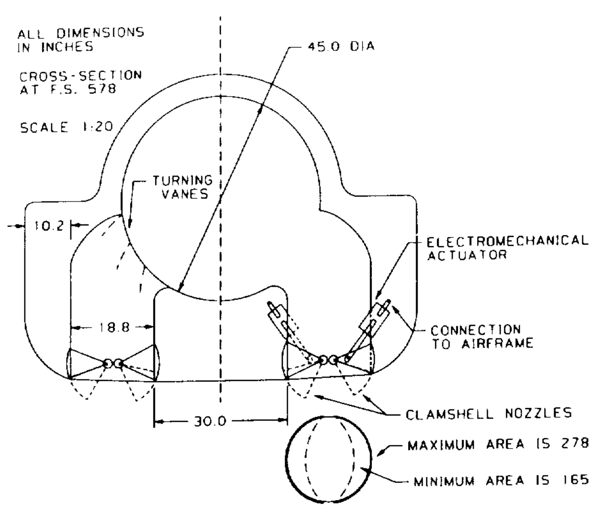

Fig. 11. Lift/Cruise Engine Ventral Nozzles

The lift/cruise engine main nozzle has 20° pitch vectoring and 25° yaw vectoring, with a block and turn capability. Figure 12 shows the lift/cruise engine main nozzle. The yaw capability of the nozzle was calculated to have enough control power to eliminate the rudder and to provide adequate stability to reduce the size of the vertical tail by 30%. Removing the rudder reduces the complexity and cost of the flight control system and reducing the vertical tail size allows a more favorable aft end area distribution. The pitch vanes of the nozzle close together to block the flow and turn its direction for hover and transition.

The lift engine[11], sized by the hover balance, has a maximum installed thrust of 12,105 lb. The lift engine along with its nozzle arrangement is shown in Fig. 13. The unmixed turbofan employs a large amount of advanced composites, which enables the uninstalled thrust-to-weight to reach 28. To achieve the lightest possible engine while maintaining acceptable jet exhaust conditions, a high bypass ratio (1.5) is implemented. A smaller diameter engine with a higher specific thrust could have been used to decrease the engine volume, but this would have led to an increase in engine weight and/or more severe exhaust conditions.

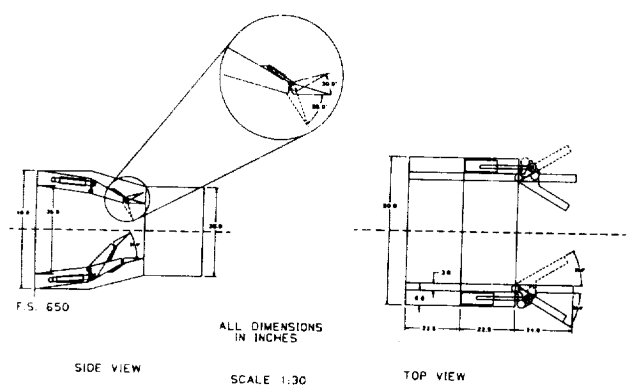

Fig. 12. Lift/Cruise Engine Main Nozzle

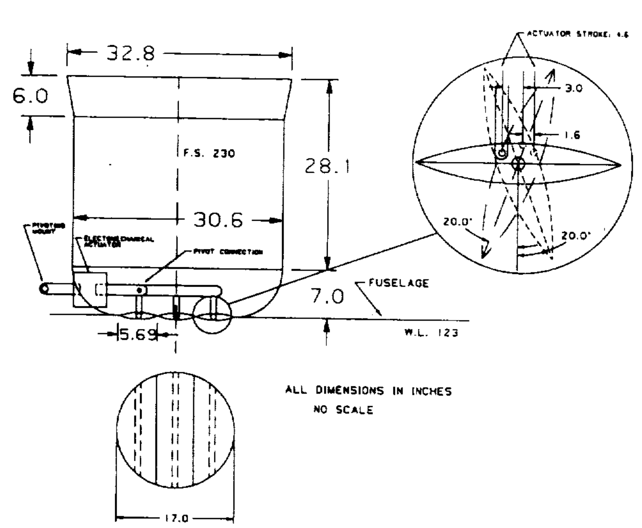

Fig. 13. Lift Engine Nozzle Arrangement

In conventional flight, the lift engine nozzle vanes were designed to fold into the fuselage underside to avoid fuselage doors. The 20° fore and aft capability of the nozzle was included to assist in pitch control in takeoff and transition.

TAKEOFF, TRANSITION, AND HOVER ANALYSIS

Takeoff

At brake release the main engine, operating at maximum dry thrust, has its nozzle vectored slightly downward to balance the thrust of the idling lift engine. During groundroll the lift engine reaches maximum thrust while the main engine thrust is shifted from the main nozzles to the ventral nozzles. When the combined lifting force of the engines and wing reaches the weight of the aircraft, the lift engine retards its thrust while the main engine thrust is shifted back to the main nozzle. During the groundroll, the composite thrust forces are balanced independently of the aerodynamic forces on the aircraft. Rotation was not investigated since the ventral nozzles, not capable of vectoring, would produce a component of thrust to counter the forward motion of the aircraft.

The resulting takeoff groundroll distances for CA, BAI, and an overload mission are shown in Fig. 14.

Transition

The transition of the aircraft between powered-lift and wingborne flight was investigated using a time-stepping technique. Figure 15 shows an example of the transition between powered-lift to wingborne flight, starting with takeoff. An effort was made to achieve gross thrust vectoring with the combination of the lift/cruise engine main and ventral nozzles and the lift engine nozzle. Idling back the lift engine thrust and transferring the main engine thrust from the ventral to main nozzle occurs at a rate at which the aircraft remains at a constant altitude since the decrease in vertical thrust equals the increase in lift from the wing.

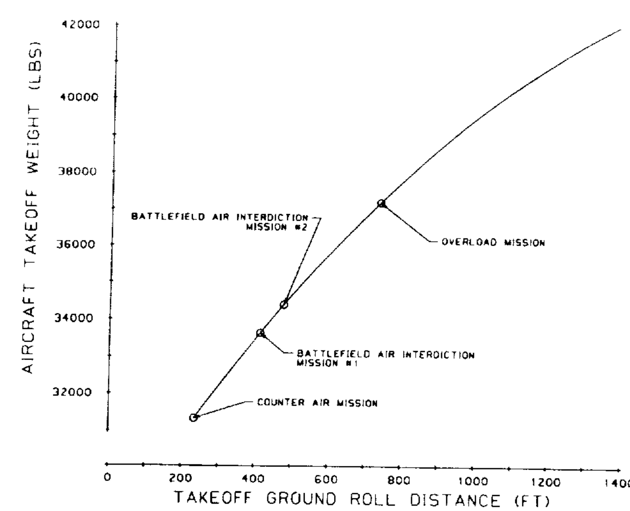

Fig. 14. Takoff Ground Run Distances

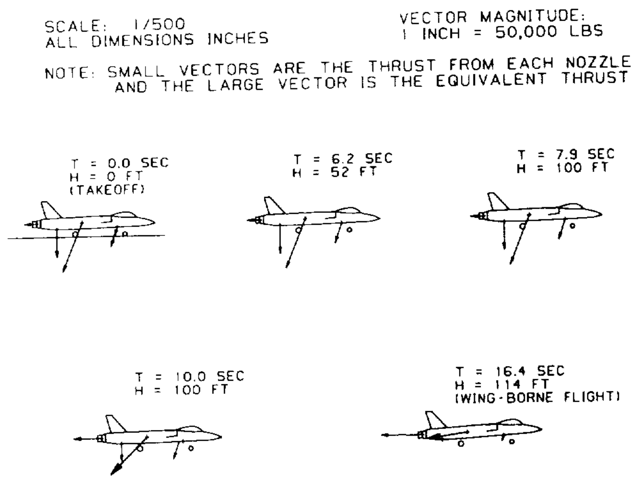

Fig. 15. Takeoff to Wingborne Transition

Control requirements and the pilot workload for STOVL aircraft are higher than that of conventional aircraft, thus a digital fly-by-wire flight-control system with advanced software and integrated propulsion control is required.

Hover

A reaction control system maintains control about the pitch and yaw axes in hover. The Level 1 flying qualities for hover control from AGARD 577 and MIL-F-83300 were used to calculate the required engine mass flow bleed rate. A total of 2% of the lift/cruise engine mass flow rate is required for adequate control in hover, 1.2% for pitch control and 0.8% for yaw control. The reaction control system layout is shown in Fig. 16.

The hot gas reingestion (HGR) problem is very configuration-dependent and thus difficult to identify without extensive theoretical research and experimentation. However, major determinants of the severity of HGR are the number and location of the vertical jet exhaust nozzles. Figure 17 shows a top view of the aircraft with the location of its nozzles and the fountain created by the jet exhaust. The flow walls do not concentrate themselves in an inlet region and thus it is predicted that the aircraft will not have severe HGR problems.

STABILITY AND CONTROL

The stability and control derivatives were calculated for seven flight conditions that were selected to represent critical points in the flight envelope. Pitch trim diagrams were plotted to assure that the aircraft was longitudinally trimmable at each flight condition. The aircraft was verified to not have severe spin-departure characteristics and the inertia coupling of the aircraft was alleviated with feedback to compensate the short period and dutch roll frequencies and damping ratios. A low-level ride qualities analysis indicated that the aircraft may need a ride quality augmentation system throughout most of the flight envelope.

Digitally controlled stability augmentation systems were designed for each of the three aircraft axes: pitch, roll, and yaw. A sampling frequency of 100 Hz was implemented for the digital controllers. The directional stability augmentation system block diagram is shown in Fig. 18. As shown, yaw rate is derived by (1) the deflected thrust of the yaw vanes and (2) the aerodynamic force produced by the yaw vanes as they are deflected. The unaugmented z-plane root locus, shown in

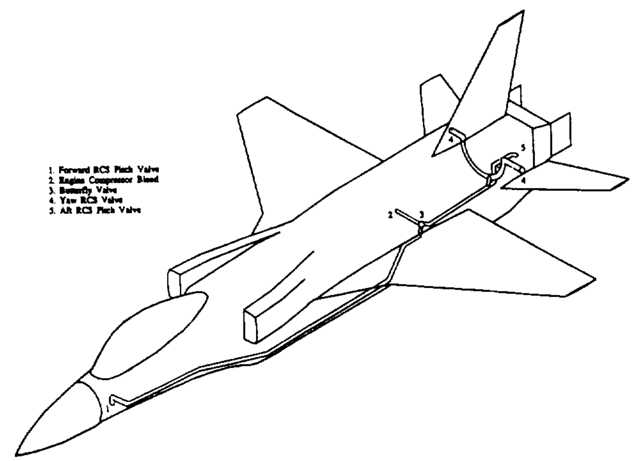

Fig. 16. Reaction Control System Layout

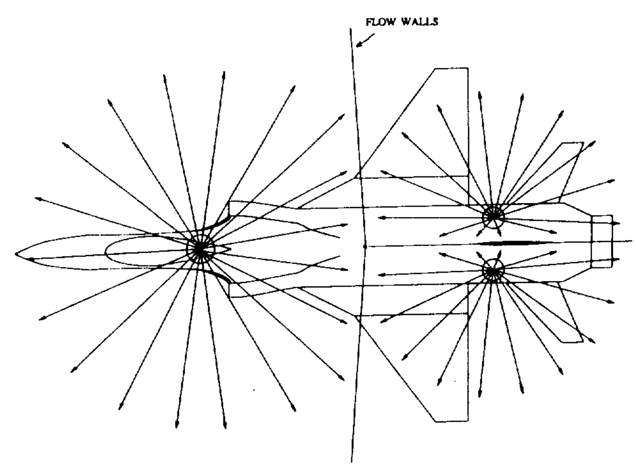

Fig. 17. Flow Walls of the Jet Exhaust

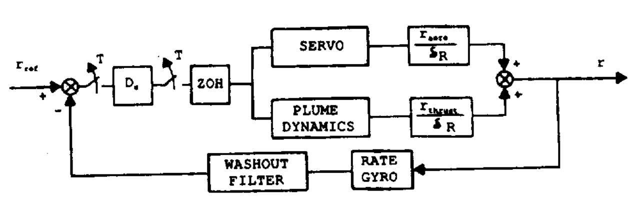

Fig. 18. Directional Stability Augmentation System Block Diagram

Fig. 19, indicates that the dutch roll is neutrally stable. The digital compensator selected is shown below.

$$D_c(Z) = \frac{Z^2 - 1.9978Z + 0.9978}{Z^2 - 1.9766Z + 0.9773}$$

The augmented dutch roll z-plane root locus, shown in Fig. 20, shows that for a gain of -0.1, the dutch roll meets the Level 1 requirements with a damping ratio of 0.6 and a frequency of 2.25 rad/sec.

MATERIALS SELECTION

Weight savings, damage tolerance, and cost were the primary considerations for the materials selection, with the material mechanical properties and fabrication characteristics being secondary considerations. An exploded view showing the material selection is given in Fig. 21. Weight savings are achieved through the use of composite materials and materials with high strength-to-weight ratios. Damage tolerance is achieved by using materials having high toughness and redundant structure. Although many of the materials selected have high initial cost, the good fatigue properties of the materials (reduced maintainence) may allow the costs to be regained throughout the aircraft's life cycle.

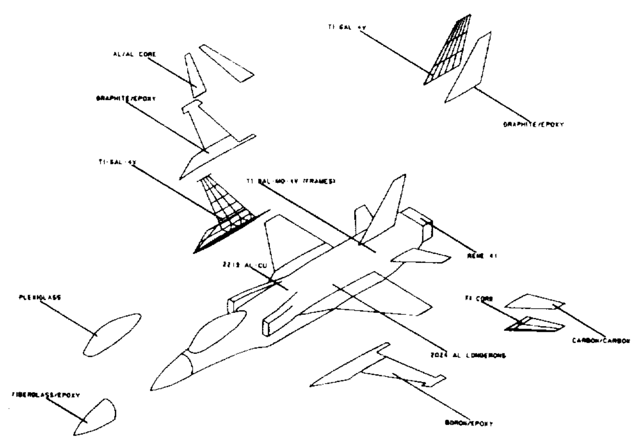

Fig. 21. Materials Selection Exploded View

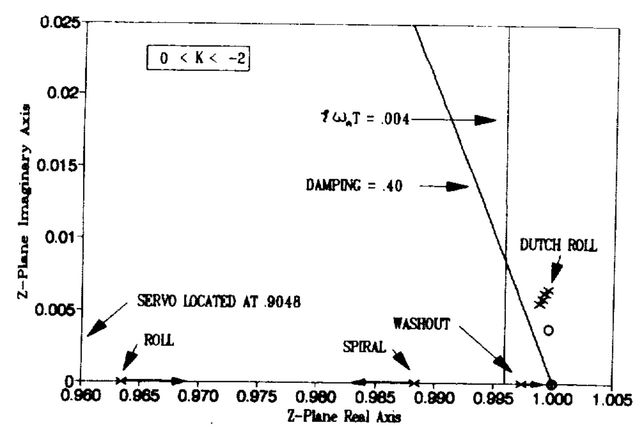

Fig. 19. Unaugmented Z-Plane Root Locus

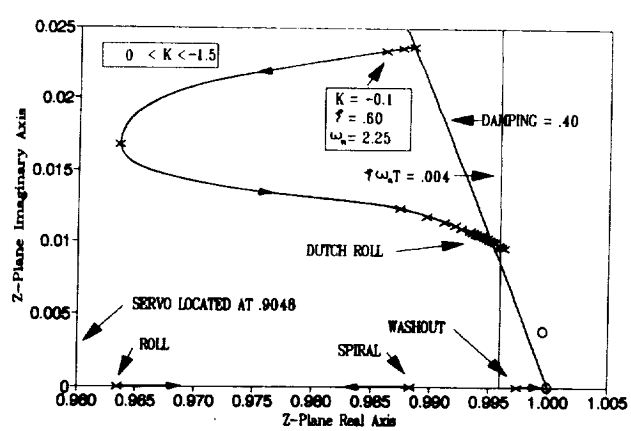

Fig. 20. Augmented Z-Plane Root Locus

PERFORMANCE AND MISSION CAPABILITY

The point-performance requirements of the mission specification were met, as shown in Table 4, with the exception of the very demanding 1000-ft/sec specific excess energy requirement. The point performances were specified at half fuel, two short-range missiles, and half ammo resulting in a performance wing loading of 76 lb/ft^2. The turn performance of the aircraft is shown in Fig. 22. The aircraft sustains high rates of turn over the operating Mach number range due to its high thrust engine. The maximum sustained turn rate at 15,000 ft for the aircraft is 16.9°/sec (thrust limited) and the maximum instantaneous turn rate is 17.3°/sec (lift/load factor limited).

Table 4. Point Performance Verification

Performance Requirement	Required Value	Monarch Value
Time to Climb	40K in 2 min	1.75 min
1 g Specific Excess Energy		
(2A) 30K Mach 0.9	500 ft/sec	505 ft/sec
(2B) 10K Mach 0.9	1000 ft/sec	920 ft/sec
Sustained Turn Rate		
(3A) Mach 0.8/15K ft	15°/sec	15°/sec
(3B) Mach 0.9/30K ft	9°/sec	10°/sec
(3C) Mach 1.2/30K ft	8°/sec	9.9°/sec
(3D) Mach 0.9/15K ft	6.5 g	7.75 g
(3E) Mach 1.6/30K ft	4.5 g	8.70 g
Acceleration		
(4A) 30K ft Mach 0.9 to Mach 1.6	70 sec	47.3 sec
(4B) Mach 0.5 to Mach 1.4	80 sec	62.1 sec
(4C) 10K ft Mach 0.3 to Mach 0.9	22 sec	18.4 sec
Landing Distance (ground roll)		
Without Chute	2200 ft	2100 ft

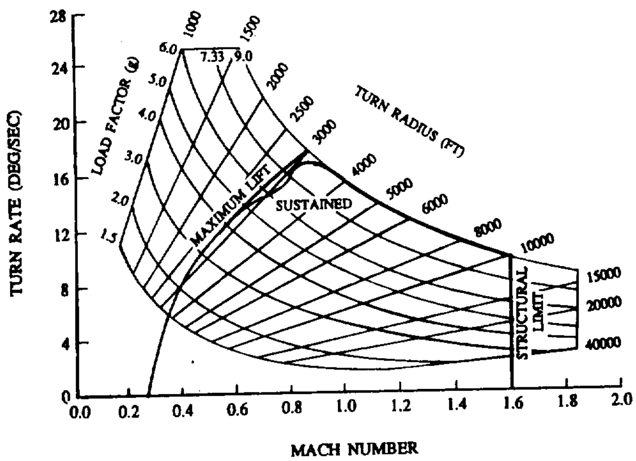

Fig. 22. Turn Performance at 15,000 ft

The 1-*g* specific excess energy for the flight envelope is shown in Fig. 23. The aircraft has a 1000 ft/sec specific excess energy capability at high subsonic Mach numbers and altitudes below 10,000 ft. As shown, a specific excess energy of 600 ft/sec is achievable over a wide portion of the flight envelope.

The mission capability of the aircraft was measured by (1) verifying the CA and BAI mission profiles and (2) taking the aircraft through typical fighter/attack missions to determine the aircraft's capability as a multirole fighter. Tables 5 and 6, respectively, show the CA and BAI (heaviest ordnance) mission fuel usage. As shown, the supersonics (acceleration to and sustaining supersonic flight) of the CA mission and the low-level dash of the BAI mission dominate the aircraft fuel usage. Figures 24 and 25, respectively, show the aircraft's capability in a mass intercept mission and a STOVL two-stage mission. The two-stage mission shows the advantage of a STOVL aircraft in that it can operate from dispersed bases and thus save fuel and cut down on response time.

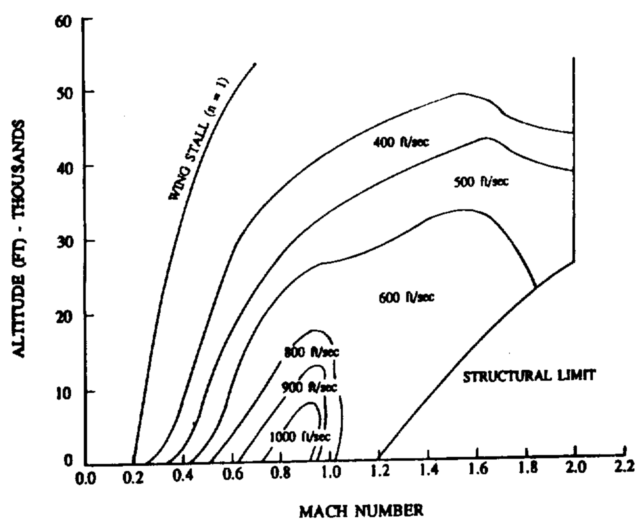

Fig. 23. Specific Excess Energy

Table 5. CA Mission Fuel Usage

Phase	Fuel Burn (lb)
Engine Start/Warm Up	327
Taxi	307
Short Takeoff	376
Acceleration to Climb Speed	308
Climb	538
Subsonic Cruise - 200 n.m.	1331
Sea Level Dash In - 80 n.m.	1204
Strafe Run	864
Sea Level Dash Out - 80 n.m.	1110
Climb	326
Subsonic Cruise - 200 n.m.	1124
Hover	246
Landing	121
Reserves	432
Total	8614

Table 6. BAI Mission Fuel Usage

Phase	Fuel Burn (lb)
Engine Start/Warm Up	314
Taxi	279
Short Takeoff	360
Acceleration to Climb Speed	313
Climb	485
Subsonic Cruise - 100 n.m.	531
Acceleration to Supersonic Cruise	620
Supersonic Cruise - 50 n.m.	1334
Combat	1728
Supersonic Cruise - 50 n.m.	1325
Subsonic Cruise - 100 n.m.	571
Hover	227
Landing	114
Reserves	432
Total	8634

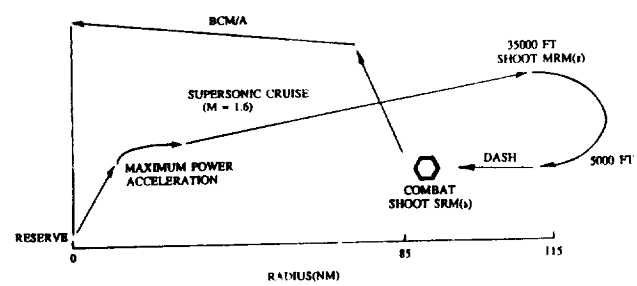

Fig. 24. Mass Intercept Mission

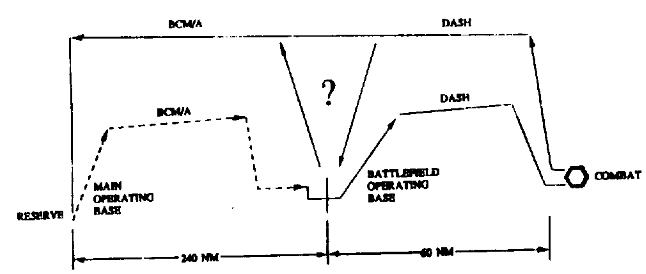

Fig. 25. STOVL Two-Stage Mission

LIFE CYCLE COST ANALYSIS

The life cycle cost of the aircraft was estimated. The results are summarized in Table 7 with a life cycle cost breakdown shown in Fig. 26. The results shown are for a production run of 500 aircraft and in 2005 dollars. The average estimated price per fighter is $32.6 million.

Table 7. Summary of Life Cycle Cost

Research, Development, Test, and Evaluation
Number of Airplanes Built for RDTE = 10
Engineering Manhour Rate = $105.00
Manufacturing Manhour Rate = $68.00
Tooling Manhour Rate = $83.00
RDTE Cost = $3.716 Billion
Acquisition
Number of Aircraft Produced Per Month = 10
Test Flight Hours Before Delivery = 20
ACQ Cost = $12.206 Billion
Operating
Number of Flight Hours Per Year = 325
Number of Years in Active Duty = 25
OPS = $28.88 Billion
Disposal
1% Program Life Cycle Cost
DISP = $0.456 Billion

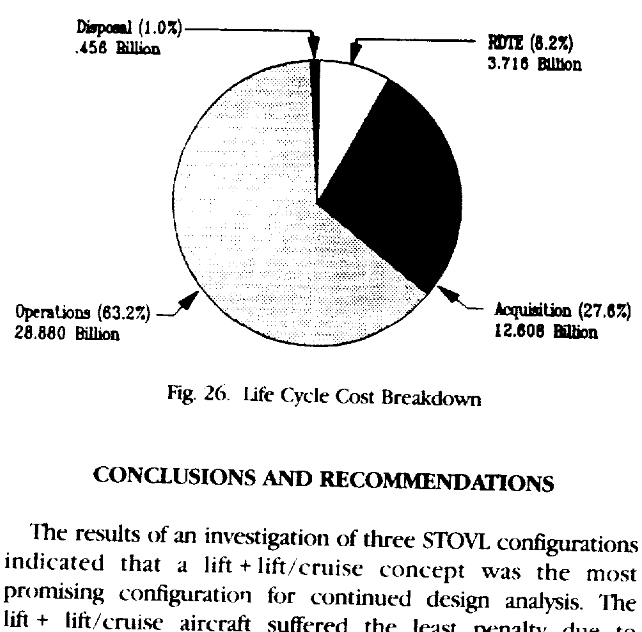

Fig. 26. Life Cycle Cost Breakdown

CONCLUSIONS AND RECOMMENDATIONS

The results of an investigation of three STOVL configurations indicated that a lift + lift/cruise concept was the most promising configuration for continued design analysis. The lift + lift/cruise aircraft suffered the least penalty due to equipment required for STOVL capability. The aircraft's engine cycle, consisting of a lift engine and a lift/cruise engine, decouples the short takeoff and vertical landing requirements and the supersonic requirements. Flexible nozzle integration allows for a three-post design that is critical to acceptable suckdown and to control power requirements in powered-lift operation. The aircraft has the ability to take off in short distances, transition to wingborne flight, complete its mission, transition to powered lift, and land vertically. Inertial coupling and spin departure tendencies were reduced via the digital fly-by-wire flight control system. Materials for the aircraft were selected by balancing their high initial cost with their increased performance throughout the aircraft's life cycle. The aircraft does not suffer from the STOVL requirement as shown by its high level of performance. Also, the aircraft's mission capability is adequate to the point that it may be considered a multirole fighter.

Further design analyses are necessary to determine if the hot exhaust gases interfere with the engine operation in close proximity to the ground and to develop highly redundant integrated flight and propulsion controls to assure successful takeoff and transition of the aircraft.

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