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VARIABLE CYCLE ENGINE EVALUATIONS FOR SUPERSONIC V/STOL FIGHTER--ETC(U)

APR 78 J E CUPSTID, D G GLENNIE N00140-75-C-0034

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VARIABLE CYCLE ENGINE EVALUATIONS FOR SUPERSONIC V/STOL FIGHTERS

Phase II and III Technical Report

McDonnell Douglas Corporation
McDonnell Aircraft Company
St. Louis, Missouri

April 1978

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Variable cycle engines (VCE) have been evaluated using advanced V/STOL fighter designs. The VCE payoffs were assessed in terms of total weapon system cost effectiveness and results indicate that they offer potential benefits in supersonic V/STOL fighters. → over

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A systematic engine/airframe evaluation procedure was developed and used to assess interactions for advanced engine concepts in L + L/C aircraft designs. The evaluation procedure provides a rapid and inexpensive technique for evaluating engine concepts considering a large matrix for engine and airframe design and sizing variables. The procedure was used to establish a parametric data base using both fixed cycle turbofans and variable geometry turbine turbojets. Specific engine/airframe designs were then selected for detailed comparisons.

Engine/airframe design evaluations were also conducted using a variable cycle turbofan engine capable of being used with both L + L/C and L/C aircraft. These aircraft designs were compared to the fixed cycle turbofan and variable geometry turbine turbojet aircraft designs in terms of TOGW, performance, life cycle cost and operational flexibility.

FOREWORD

This report was prepared by the McDonnell Aircraft Company (MCAIR), a division of the McDonnell Douglas Corporation, St. Louis, Missouri, for the Naval Air Propulsion Center, Trenton, New Jersey. This study was performed under Navy Contract N00140-75-C-0034, "Variable Cycle Engine Selection Program" from June 1975 through November 1977. Program direction was provided by Mr. J. R. Facey, Program Manager, and Mr. Paul Piscopo of the Naval Air Propulsion Center, and Mr. John Cyrus of the Naval Air Development Center. The program was under the direction of Mr. R. E. Martens, MCAIR Program Manager, and Mr. F. C. Glaser, Technical Director.

The authors of this report, J. E. Cupstid and D. G. Glennie, are indebted to B. T. Phelps, R. L. Crossen, R. W. Holzwarth, and R. E. Smith for their technical assistance. The authors are also indebted to C. W. Miller, H. H. Ostroff, H. Sams, and J. M. Sinnett of MCAIR who, in their supervisory positions, made valuable contributions throughout the program.

SUMMARY

The propulsion system design and its integration with the airframe are major considerations in defining a high performance V/STOL fighter aircraft. The propulsion system must provide thrust in excess of aircraft weight for vertical takeoff, operate efficiently during conventional flight, and integrate with an aerodynamically efficient airframe configuration. Variable cycle engines (VCE), incorporating multiple flow paths and/or variable turbine geometry, offer the potential for achieving these objectives with substantially less cost and weight penalties than encountered with fixed cycle engines. The NAPC funded "Variable Cycle Engine Selection Program" (Contract N00140-75-C-0034) was specifically directed toward evaluating VCE concepts for advanced supersonic Navy V/STOL fighters.

In Phase I, a preliminary screening of VCE concepts, provided by Detroit Diesel Allison and General Electric, was conducted using takeoff gross weight (TOGW) sensitivities. The results showed a potential VCE payoff of 8% to 13% in TOGW when compared to fixed cycle engines. A GE modulating bypass turbofan concept was selected for more detailed evaluation in Phases II and III. The GE engine work for this program was conducted under Contract N00140-75-C-2034 and is reported in the GE Final Summary Report.

A key Phase II activity was the modification of an engine/airframe evaluation procedure developed for the Air Force by MCAIR. The Air Force Procedure was developed for conventional takeoff and landing aircraft and was modified in this program to permit evaluation of V/STOL aircraft. This V/STOL Fighter Design Evaluation Procedure permits calculation of the size, cost, mission and performance characteristics of a systematically selected matrix of lift + lift/cruise (L + L/C) V/STOL fighter aircraft designs. Mathematical relationships are defined to relate aircraft TOGW, cost, mission and performance characteristics to engine and airframe design variables. Finally, an optimization procedure is used to select aircraft designs for specified mission and performance requirements. The optimization payoff functions can be TOGW, life cycle cost, or aircraft capability parameters.

The V/STOL Fighter Design Evaluation Procedure permits simultaneous consideration of up to 11 engine/airframe design variables and up to 17 mission and performance requirements. The results permit identification and evaluation of the effects of propulsion system/airframe interactions on system characteristics. In addition, the effects of aircraft mission and performance requirements on aircraft size, cost and operational flexibility can be readily determined.

The Evaluation Procedure was used in Phase II to develop a data base of aircraft characteristics, using GE fixed cycle turbofan engines (FCE-TF), and to optimize an aircraft design to provide a basis for subsequent VCE payoff evaluations.

In Phase III, a data base of aircraft characteristics was developed using GE variable geometry turbine turbojet (VGTTJ) engines. These data were used to assess the effects of aircraft mission and performance requirements on aircraft design for comparison with the FCE-TF aircraft. The VGTTJ aircraft provided reductions of 11% and 9% in TOGW and life cycle cost, respectively, when sized to achieve representative Navy mission and performance requirements. In addition, the data bases have been transmitted to GE and the Naval Air Development Center for use in continuing trade-off studies.

In Phases II and III, aircraft design, performance and cost analyses were also conducted using versions of the modulating bypass turbofan selected in Phase I. This engine can provide airflow to a remotely located augmentor during VTO and thereby potentially eliminate the need for separate lift engines. Consequently, significantly reduced powered lift system development costs were anticipated. Using the Remote Augmentor Lift System/VCE concept, total system life cycle cost was estimated to be 4% below that of a L + L/C FCE-TF aircraft. However, when sized to provide equivalent combat performance, life cycle cost of the RALS/VCE aircraft system was estimated to be 10% below that of the VGTTJ L + L/C aircraft.

L + L/C designs, using the modulating bypass turbofan VCE without the RALS feature, were evaluated and showed a 9% TOGW payoff relative to the FCE-TF aircraft. As a result, the VCE powered L + L/C aircraft life cycle costs were competitive with the FCE-TF aircraft.

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SYMBOLS AND ACRONYMS (Continued)

Symbol	Definition
RDT&E	Research development test and evaluation
RPM	Revolutions per minute
SFC	Engine specific fuel consumption - lb/hr/lb
SLS	Sea level static
SSS	Subsonic surface surveillance
STO	Short takeoff
T_{EXIT}	Nozzle exit temperature - °F
T	Thrust - lb or temperature - deg's
TF	Turbofan
T_{L1}	Thrust of lift engine 1
T_{L2}	Thrust of lift engine 2
TIT	Engine turbine inlet temperature - °R
TOA	Time of arrival
TOGW	Takeoff gross weight - lb
T.S.	Tactical strike
T/W	Thrust to weight ratio
V	Velocity
V_{LO}	Lift off velocity
VCE	Variable cycle engine
VGTTJ	Variable geometry turbine turbojet
VL	Vertical landing
VTO	Vertical takeoff
W	Weight
$\frac{W\sqrt{\Theta}}{\delta}$	Engine corrected airflow - lb/sec
W_f	Engine fuel flow - lb/hr
WL	Water Line
WOD	Wind over deck - knots
W/S, WOS	Aircraft Wing Loading
ΔTAMB	Engine airflow scheduling variable - deg's
% N_2	Percent max compressor speed
2-D	Two dimensional
Θ, δ_L	Lift engine deflection angle

SYMBOLS AND ACRONYMS (Continued)

Symbol	Definition
η	Scale factor
Θ_B	Aircraft pitch angle
β	Boattail angle
$\delta_{L/C}$	Lift/cruise engine deflection angle

Acronyms	Definition
ADEN	Augmented Deflector Exhaust Nozzle
ACCM	MCAIR Advanced Concepts Cost Model
CADE	Computer Aided Design Evaluation Computer Program
CAP	Combat Air Patrol
CTOL	Conventional Takeoff and Landing
PSIP	Propulsion System Installed Performance Computer Program
RALS	Remote Augmentor Lift System
SEARCH	Optimization computer program
STOVL	Short takeoff/vertical landing
SURFIT	Surface fit computer program
V/STOL	Vertical/short takeoff and landing
VABI	Variable Area Bypass Injector

1. INTRODUCTION

The inherent operational flexibility of variable cycle engines may provide significant benefits in supersonic V/STOL fighters. The combination of powered lift and forward flight performance requirements of supersonic V/STOL fighters necessitate extensive compromises in the design and scheduling of fixed cycle engines. These compromises have resulted in high takeoff gross weights and relatively poor payload and range performance in many designs when compared to conventional supersonic fighters. Variable cycle engines can potentially reduce the compromises necessary with fixed cycle engines with attendant improvements in weight and performance.

During the past several years, a variety of VCE concepts have been identified by the engine companies for CTOL aircraft applications. Such engines are highly adaptable to achieving increased thrust, reduced fuel consumption, or reduced noise at desired flight conditions. However, these engines generally exhibit penalties in weight, size, and cost. Consequently, selection of the specific engine design and operational characteristics for advanced aircraft must be based upon systematic definition and evaluation of the impact of these engine characteristics on the total weapon system.

Systematic engine evaluation procedures were developed and demonstrated for the Air Force in the Reference 1 program. These procedures account for the interactions between the propulsion system, airframe and weapon system requirements for CTOL aircraft. They were directly applicable to similar evaluations of V/STOL fighters with modification required to only selected program elements.

Eight V/STOL VCE concepts, defined by Detroit Diesel Allison and General Electric, were postulated to meet the needs of supersonic V/STOL propulsion systems. Both axi-symmetric and 2-D V/STOL nozzle concepts were included. A preliminary screening was conducted to estimate the potential impact of each VCE on V/STOL fighter TOGW and to select the most promising concept for more detailed evaluations. TOGW payoffs of 8% to 13% were obtained when compared to fixed cycle engine V/STOL fighters, References 2 and 3. As a result of this preliminary screening, NAPC selected a General Electric modulating bypass turbofan concept for detailed evaluation in Phases II and III. This concept provides the versatility to be used in either L + L/C or L/C V/STOL fighters. In addition, the General Electric 2-D Augmented Deflector Exhaust Nozzle (ADEN) was selected by NAPC for the Phase II and III evaluations. This nozzle provides the capability to augment in the vectored thrust operating mode.

The following sections of this report present the approach used and results obtained in Phases II and III of the program. The Phase I approach and results were presented in References 2 and 3. A Management Summary Report, Reference 4, summarizes the results of all three program phases.

2. PHASE II AND III APPROACH

Potential payoffs of advanced engine concepts for supersonic V/STOL aircraft must be assessed in terms of such systems characteristics as takeoff gross weight (TOGW), life cycle cost, and operational flexibility. The impact of mission and performance requirements must also be considered in conducting these assessments. Phase I of this program consisted of a preliminary screening of variable cycle engine concepts and selection of the most promising for more detailed evaluations in Phases II and III. The Phase II and III engine evaluation approach, Figure 1, consisted of both parametric engine/airframe evaluations and design integration and performance analysis as discussed below.

A V/STOL Fighter Design Evaluation Procedure, Figure 1, was developed and used to conduct parametric engine/airframe evaluations. A data base was established using advanced fixed cycle turbofan (FCE-TF) and variable geometry turbine turbojet (VGTTJ) engines. This data base was used to select a reference FCE-TF aircraft design and a VGTTJ aircraft design. The VGTTJ represented a special class of variable cycle engines having an intermediate level of complexity between the FCE-TF and the VCE concepts evaluated in Phase I.

Evaluations of a variable cycle engine turbofan, VCE-TF, selected in Phase I, were also conducted. However, due to the preliminary design status of the engine, parametric descriptions of the size, weight, performance and cost characteristics of this engine were not available and the evaluations were conducted using point design integration layout and performance analysis procedures. The VCE-TF can be used in either - L + L/C or L/C aircraft configurations, Figure 2.

The airframes and engines evaluated in this program incorporated technology consistent with a 1985-1990 IOC and were designed to operate at flight speeds up to Mach 2.0. Figure 3 illustrates the important technology features of the airframes and engines considered. The radar, avionics and advanced material technologies were described in References 5 and 6.

A VTOL Deck Launched Intercept mission was used to establish aircraft internal fuel capacity requirements, Figure 4. Lift/cruise engine size was established by representative performance requirements, also shown in Figure 4, selected by MCAIR. The performance capabilities of each converged aircraft were also computed for four predominately subsonic alternate missions, Figure 5, with internal fuel and two quantities of external fuel.

The following sections of this report discuss the results obtained in the parametric FCE-TF and VGTTJ engine/airframe evaluations and the VCE-TF design integration and performance analysis. The V/STOL Fighter Design Evaluation Procedure and

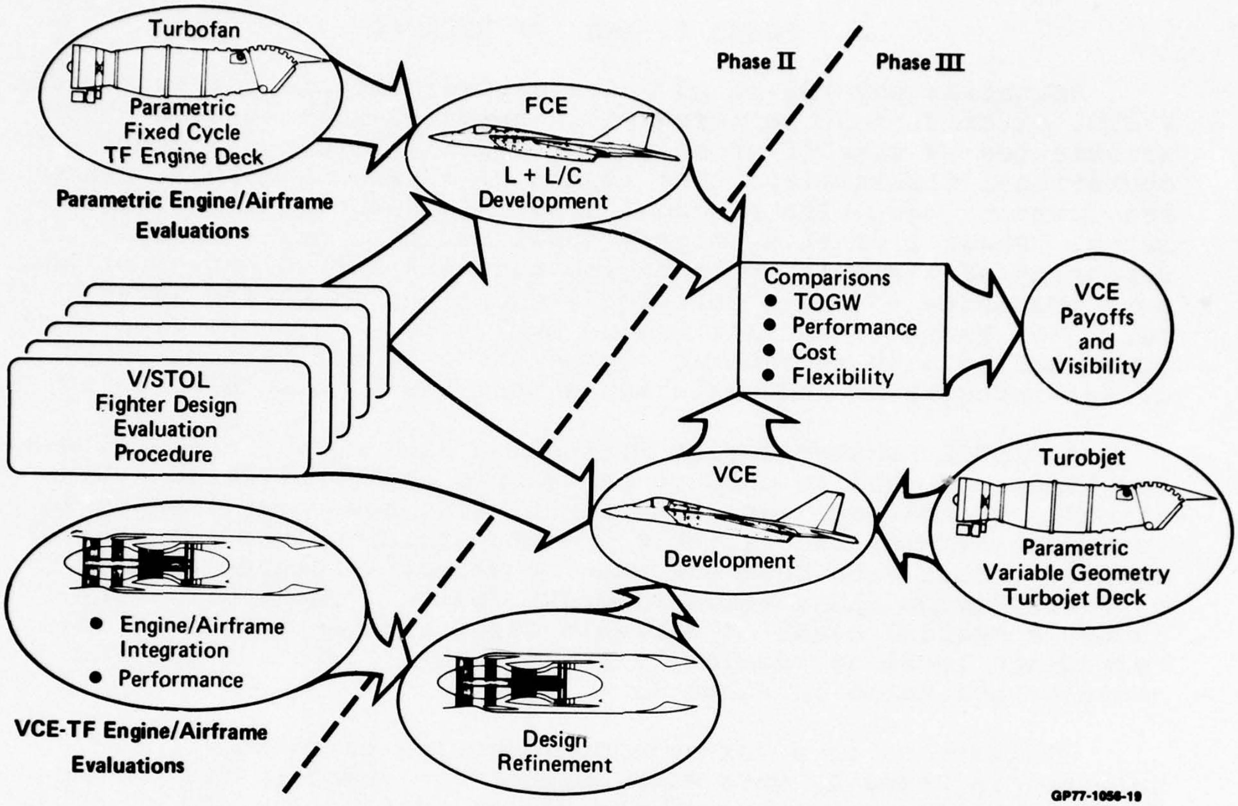


FIGURE 1
PHASE II AND III APPROACH

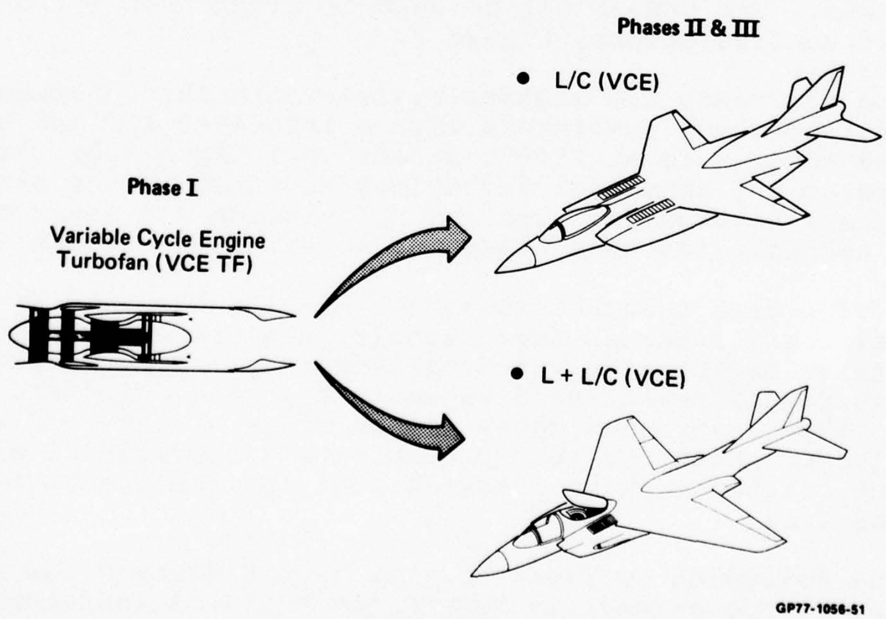
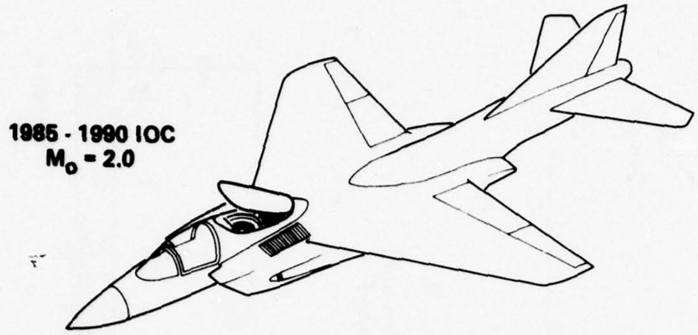


FIGURE 2
VCE-TF DESIGN EVALUATIONS



- Advanced Technology L/C Engines with 2-D Aden Nozzles
- Advanced Technology Lift Engines (T/W = 18:1)
- Auxiliary Inlets for V/STOL Operation
- 30 mm Gun and 500 Rounds of Ammo
- Air/Air and Air/Ground Weapons
- 15% Structural Weight Savings by Using Advanced Materials
- 24 in. Radar Dish
- 925 lb Avionics Package
- Advanced Wing Design
- Decamber Flap

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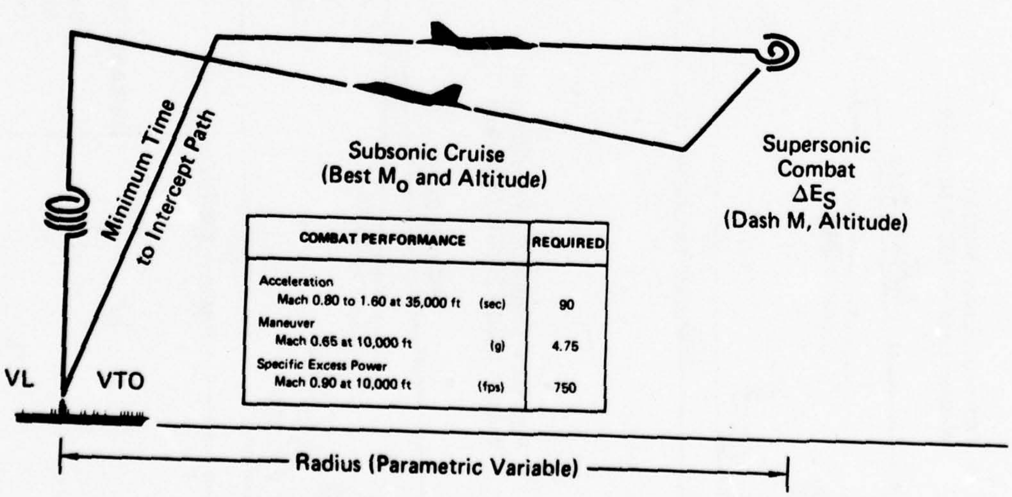
FIGURE 3
PHASE II AND III AIRCRAFT DESIGN FEATURES



COMBAT PERFORMANCE		REQUIRED
Acceleration Mach 0.80 to 1.60 at 35,000 ft	(sec)	90
Maneuver Mach 0.65 at 10,000 ft	(g)	4.75
Specific Excess Power Mach 0.90 at 10,000 ft	(fps)	750

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FIGURE 4
PARAMETRIC INTERCEPT DESIGN MISSION
Sizes Internal Fuel
Weapon Load = 2200 Lb (Retained)

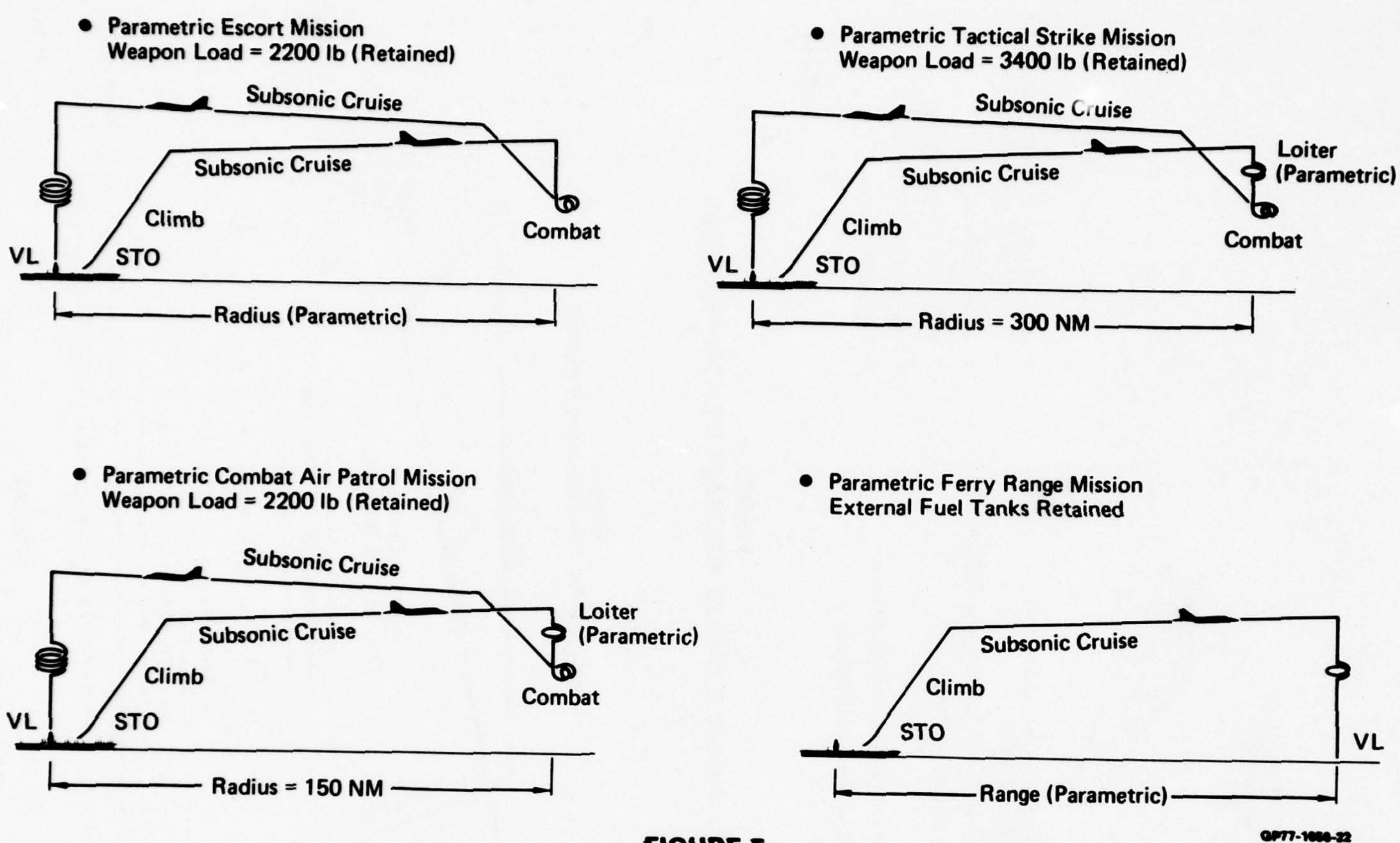


FIGURE 5
PARAMETRIC ALTERNATE MISSIONS (STOVL)

Fuel Load
- Internal
- Internal + (2) 300 Gallon Tanks
- Internal + (2) 600 Gallon Tanks

the baseline L + L/C aircraft used to conduct the parametric engine/airframe evaluations are described in Sections 3.0 and 4.0, respectively. The parametric engine/airframe evaluation results obtained with the FCE-TF and VGTTJ engines are described in Sections 5.0 and 6.0. Section 7.0 describes the VCE-TF evaluations. VCE payoff assessments are discussed in Section 8.0 and conclusions are provided in Section 9.0.

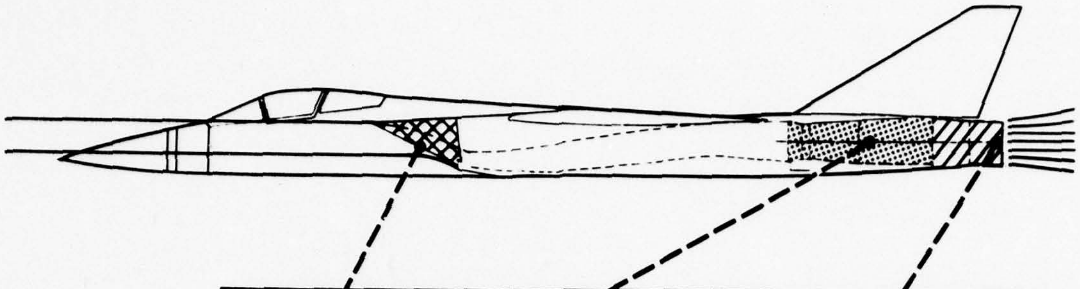
3. V/STOL FIGHTER DESIGN EVALUATION PROCEDURE

Comparisons of aircraft TOGW, performance, cost and operational flexibility provide a valid basis for engine and airframe design selections and trade-offs. However, such comparisons must be made using a systematic analysis procedure because of complex interactions between engine and airframe design variables and aircraft size, performance, cost and mission characteristics.

A prerequisite for a viable procedure is that it properly accounts for propulsion system/airframe interactions in the determination of aircraft size and performance. As shown in Figure 6, such interactions can be identified in terms of throttle-dependent and size-dependent force increments. The throttle-dependent interactions are represented by increments in inlet and nozzle/aft-end drag. These drag increments, which are caused by variations in flow characteristics or geometry, are the result of changes in engine power setting. The lift and drag of the aircraft can also be affected by the relative size of the propulsion system and airframe. Force increments resulting from changes in relative propulsion system size are defined such that they are independent of engine throttle setting.

Aircraft mission and performance requirements also interact with the propulsion system size and thrust and the aircraft design as shown in Figure 7. The development of efficient engine/airframe designs must identify and properly account for such interactions. For example, in a L + L/C fighter aircraft design, the L/C engine size is usually established by one or more specific excess power (P_s) requirements at given Mach numbers, altitudes and power settings. The net propulsive force (F_{NP}), and therefore the engine thrust required to achieve the specified performance (P_s), is a function of aircraft weight (W), lift to drag ratio (L/D), and flight velocity (V), Figure 7. Design variables affect F_{NP} and L/D and these interact to define the engine size required to achieve a specified performance requirement. Similarly, aircraft fuel volume requirements are related to L/D and engine fuel consumption (SFC) by means of an exponential range factor (R_f). Thus, design variables also affect the physical size of the airframe required to achieve a specified mission radius.

MCAIR developed a Fighter Engine/Airframe Evaluation procedure directed at obtaining a valid basis for engine/airframe design selection and aircraft/requirement trade-offs for future CTOL fighter aircraft programs in Reference 1. That procedure was modified to provide the capability to evaluate V/STOL fighter designs, Figure 8. The modifications consisted of developing a V/STOL fighter aircraft sizing, performance and cost analysis program. The V/STOL Fighter Design Evaluation procedure is described in the following paragraphs.



	Inlet Geometry and Airflow	Engine Geometry	Nozzle Geometry and Exhaust Flow
• Throttle Dependent	$\Delta CD_I = f(W_A)$	N/A	$\Delta CD_N = f\left(\frac{AEX}{AEX_{max}}, \frac{PEX}{P_\infty}\right)$
• Size Dependent	$\Delta CD_I = f(A_{CAPT})$	$\Delta CD = f(L_{eng}, D_{eng})$	$\Delta CD_N = f\left(\frac{AEX_{max}}{A_{max_{fuselage}}}\right)$

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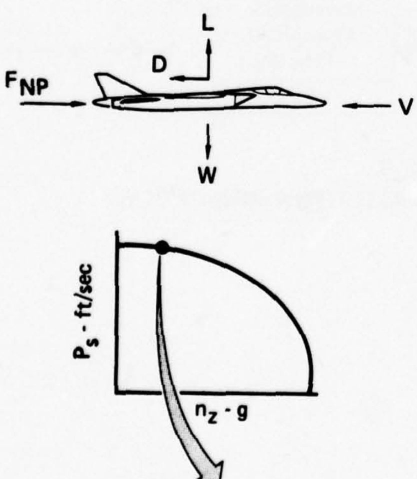
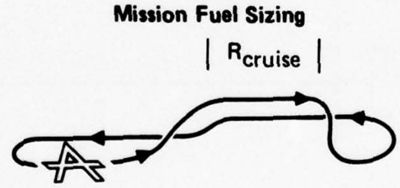
FIGURE 6
PROPULSION SYSTEM AIRFRAME INTERACTIONS VISIBILITY

Engine Thrust Sizing



$$\frac{F_{NP}}{W} = \frac{D}{L} + \frac{P_{s_{req'd}}}{V}$$

Mission Fuel Sizing



$$\Delta W_{cruise} = W_{\underset{cruise}{end}} \left(e^{R/R_f} - 1\right)$$

$$R_f = \frac{L}{D}\ \frac{V}{SFC}$$

$$W_{fuel} = \sum_{mission} \Delta W_{elements}$$

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FIGURE 7
AIRCRAFT REQUIREMENTS INTERACTIONS

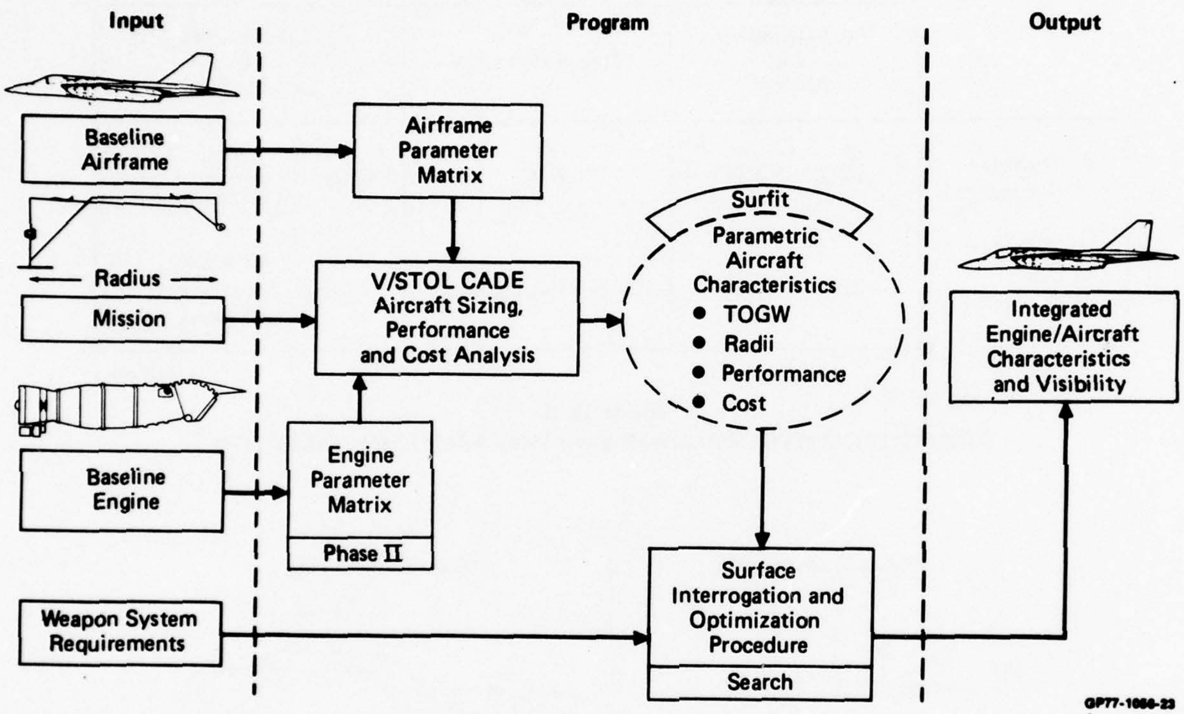

FIGURE 8
V/STOL FIGHTER DESIGN EVALUATION PROCEDURE

3.1 INPUT - Three inputs are required to initiate the use of the evaluation procedure for engine/airframe design selection. In an aircraft development program, the Navy user command makes the initial input by defining role requirements. This input consists of the desired mission and performance capabilities and operational limits. The desired aircraft IOC, maximum Mach number, and other key factors affecting the design are identified. Then, the participating engine and airframe companies must identify design candidates which are compatible with the requirements and the engine airframe component technology consistent with the desired IOC. These selections are judgements, based on the results of previous investigations of similar systems. The engine and airframe companies must also identify the engine and airframe design variables which could significantly affect the aircraft characteristics and the range of values over which each variable should be considered. For example, important airframe design variables could include wing loading, sweep, and aspect ratio; important engine design variables could include fan and overall cycle pressure ratio, bypass ratio, turbine inlet temperature, and engine control schedules and limits.

Consequently, three types of design inputs are required: (1) candidate engine and airframe designs, (2) identification of the important design variables of each candidate, and (3) the values over which the important variables should be evaluated to define an optimum aircraft system.

The impact of varying mission radius and performance requirements on aircraft TOGW and its design and cost characteristics can be determined from the computed aircraft relationships. These requirement inputs can include any combination of mission radii or performance requirements in terms of P_S, N_Z, or acceleration times. A total of 17 requirements can be imposed simultaneously.

3.2 COMPUTATION - Relationships between the engine and airframe design variables and aircraft characteristics must be established to provide a meaningful basis for design selection. These relationships could be obtained by computing the size and performance of aircraft designs representing all combinations of the important engine and airframe design variables. However, the time and cost of such an approach would be impractical. A computational procedure has been developed which provides the relationships required for engine and airframe design selection based on the influence of engine, airframe and mission design variables on aircraft system characteristics. The following paragraphs briefly discuss each of the key computation elements of this procedure which are shown in Figure 8.

3.2.1 Aircraft Matrix Selection - A large number of engine and airframe design variables may be important in determining the aircraft size required to achieve mission and performance requirements. As the number of design variables is increased, the number of possible variable combinations (aircraft designs) also increases rapidly. If, for example, 11 design variables were considered and all variable combinations were analyzed, more than four million aircraft design computations would be required. A mathematical procedure called "Latin Square" was employed to systematically select a manageable matrix of aircraft designs for analysis, Figure 9. The Latin Square procedure defines a minimum number of aircraft designs, N^2, which must be evaluated to obtain meaningful relationships between the computed aircraft characteristics and the design variables. However, in order to improve the accuracy of the V/STOL Fighter Design Evaluations procedure, we doubled the number of aircraft designs defined by the Latin Square procedure by using $2N^2$-N design variable value combinations. These 231 designs encompassed the entire range of all the important engine and airframe design variables.

3.2.2 Aircraft Design and Performance Analysis - Aircraft sizing, performance and cost analyses are accomplished using a computer aided design evaluation procedure called V/STOL CADE, Figure 10. The initial step in this procedure is to define the geometry, propulsion system, aerodynamic, and weight characteristics of the input aircraft design and the scaling characteristics of each major aircraft component. CADE is used to scale the weight and geometry of the input aircraft components to determine physical characteristics. Mission fuel, engine thrust, and configuration size are determined by simultaneously sizing the aircraft to achieve the required design mission radius, VTO and mission thrust levels, and static weight balance. The converged aircraft performance analyses include computation of alternate mission radii and performance at preselected flight conditions and engine power settings including STO capability. In addition, the MCAIR Advanced Concepts Cost Model (ACCM) is used to compute the Life Cycle Cost of the converged aircraft design in terms of RDT&E, Production and Operations and Support (O&S) costs. Life cycle costs are computed for three production quantities, 300, 600 and 900 aircraft. Airframe and subsystem LCC and engine O&S costs are estimated using data correlations based on past MCAIR and Navy experience. Engine RDT&E and Production costs are estimated using a modification of the Rand Time of Arrival (TOA) Model, Reference 7. The Rand model, developed from regressions of historical data on 26 military engines, was modified in this program, using GE data, to reflect advanced technology components

A detailed discussion of the development of the V/STOL CADE aircraft sizing, performance and cost analysis procedure is included as Appendix A.

3.2.3 Correlation of Aircraft Characteristics - A mathematical curve fit procedure (SURFIT) is used to define the relationships between the computed aircraft characteristics obtained from CADE, and the design variables. Each aircraft characteristic parameter defined in CADE is represented by a quadratic equation composed of the design variables as shown in Figure 11.

Aircraft Design Variables

	Range of Variation
Airframe Design	
Combat Wing Loading	70-100 lb/ft^2
Wing Aspect Ratio	2.5-4.0
Wing Sweep	35^o-55^o
Engine Design	
Fan Pressure Ratio	3.2-4.0
Compressor Pressure Ratio	4.8-7.8
Engine Airflow Scheduling (ΔTAMB)	0^o-60^oF
Engine Sizing	
L/C VTO Thrust (% max A/B)	55-80%
Combat Specific Energy (P_s)	100-300 ft/sec
Internal Fuel Sizing	
Intercept Radius	100-200 nm
Intercept Mach No.	1.4-2.0
Intercept Altitude	36,000-50,000 ft

Total Aircraft Designs $(4)^{11} \cong 4.2 \times 10^6$

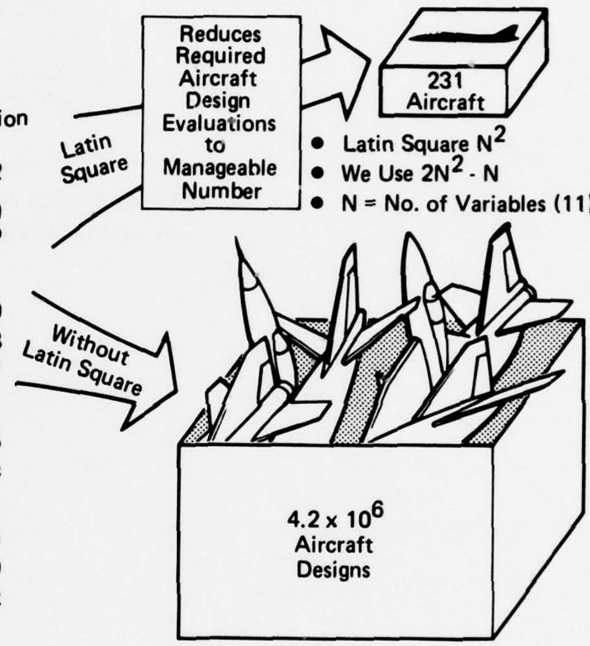

FIGURE 9
SELECTION OF AIRCRAFT DESIGN MATRIX (LATIN SQUARE)

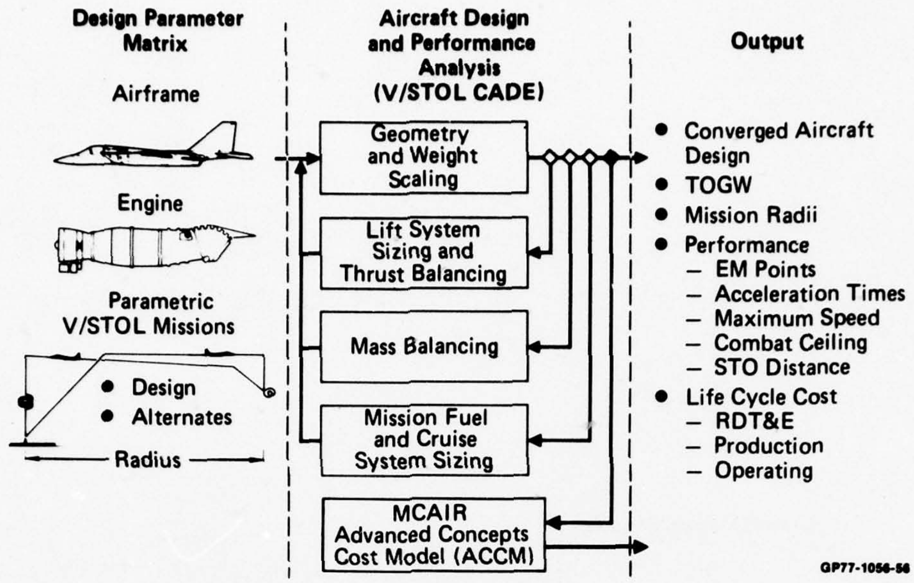

FIGURE 10
DETERMINATION OF PARAMETRIC AIRCRAFT DESIGN CHARACTERISTICS (CADE)

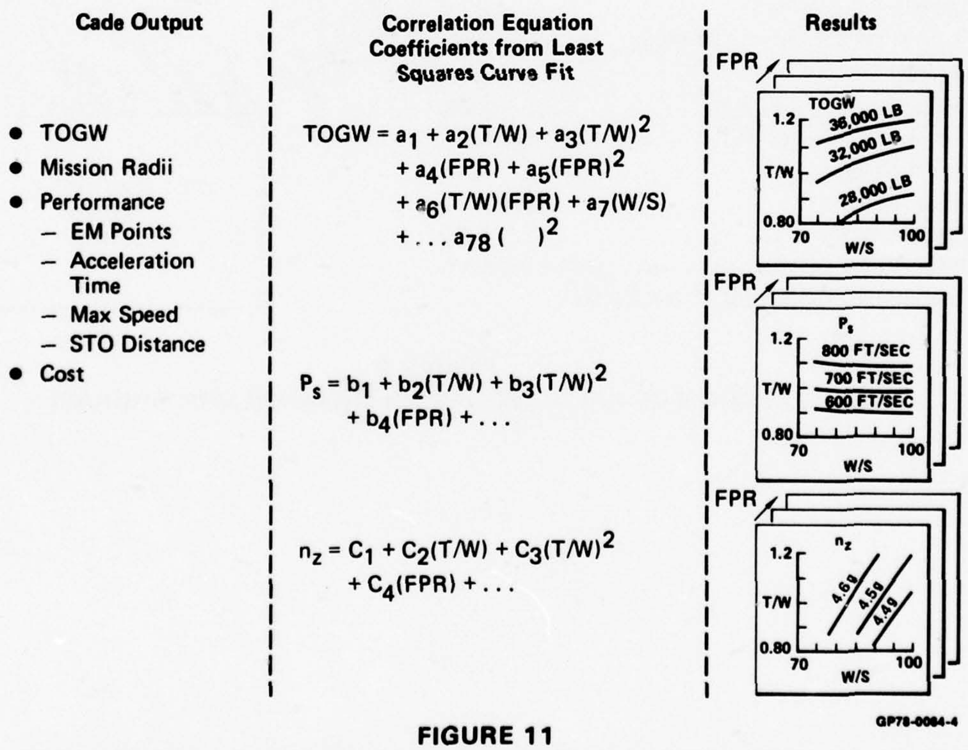

FIGURE 11
DEVELOPMENT OF MATHEMATICAL DESCRIPTION OF A COMPLETE CLASS OF FIGHTER AIRCRAFT (SURFIT)

The result, for 11 design variables, is an equation which represents an 11 dimensional mathematical surface with 78 possible coefficients. A least square curve fit of the computed aircraft characteristics is used to determine coefficient values for each term in equation. Experience has shown that the aircraft characteristics, such as TOGW, are frequently represented by as few as 30 to 35 terms in the equations, with the remaining coefficients equal to zero. The correlation equations provide the relationships required for meaningful engine/airframe design selections. As shown in Figure 11, the equations can be used to define relationships between aircraft characteristics, such as TOGW, P_s, and N_z, and the important design variables, such as T/W and W/S. Although only two design variables are shown in the example, such relationships can be obtained for any combination of the design variables considered. Consequently, the correlation equations provide the capability to compute aircraft weight, mission radii, performance and cost characteristics for any aircraft design encompassed by the Latin Square matrix.

Over 400 CADE output parameters can be correlated using the SURFIT procedure. These include:

1. Take-off gross weight
2. Mission radii and performance parameter
3. Life cycle cost parameters
4. Engine and airframe physical characteristics
5. Mission visibility - at critical mission segments -
   - flight conditions
   - fuel used
   - engine operating characteristics
   - installation losses

The mission radii, performance and cost relationships provide a quantitative basis for cost effectiveness trade-offs. The mission segment relationships provide visibility into propulsion system/airframe interactions to a degree which has not previously been possible.

3.2.4 <u>Aircraft Optimization</u> - The minimum TOGW aircraft design capable of achieving specified mission radius and performance requirements is identified by means of an optimization procedure called SEARCH. This procedure utilizes the correlation equations to describe the variations of aircraft weight and performance parameters as functions of the design variables.

It was shown in Figure 11 that the equations can be used to define variations in TOGW, P_s and N_z as three design variables are changed. The optimization procedure is illustrated by superimposing those relationships, Figure 12. The interactions between the design variables, TOGW, and the two performance parameters are clearly defined. For performance requirements corresponding to P_s = 700 ft/sec and N_z = 4.5 g's, the minimum achievable TOGW and corresponding design variables can be quickly determined. In this example, only two design variables were permitted to change. Repeating this procedure for an additional design variable, such as fan pressure ratio, identifies the

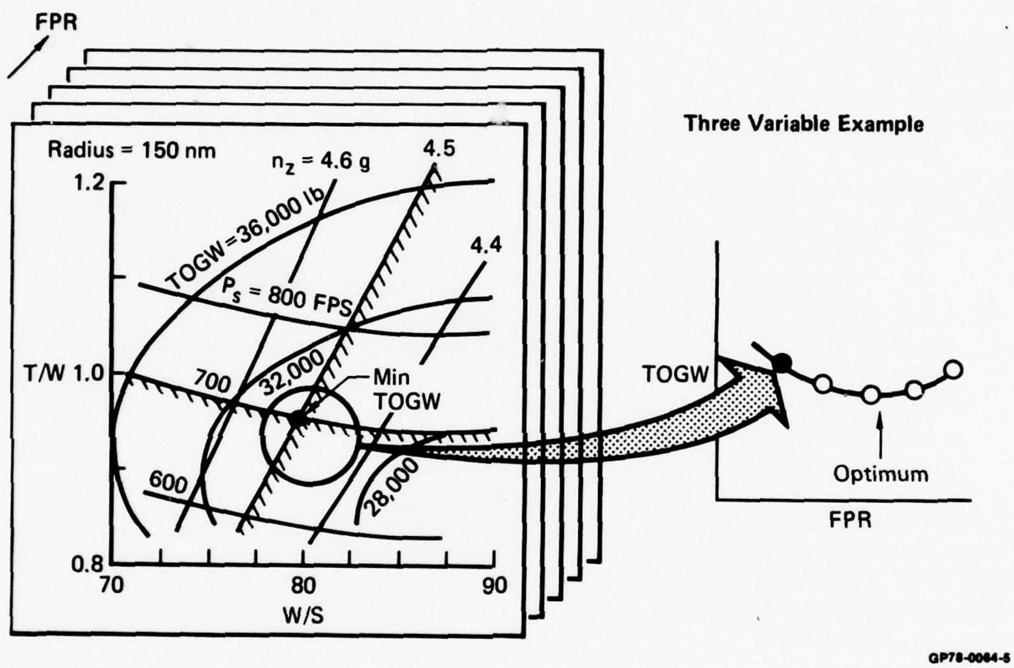

FIGURE 12
TOGW OPTIMIZATION AS A FUNCTION OF DESIGN VARIABLES AND PERFORMANCE REQUIREMENTS

minimum TOGW aircraft for three variables. This optimization procedure considers up to 11 design variables simultaneously.

The SEARCH computer program program is capable of performing optimizations using any of the surface fit parameters as the payoff function, with 11 design variables and up to 17 specified mission radius and performance requirements. Development of this optimization technique was based on Box's "Complex Method", Reference 8. Using this procedure, it is possible to rapidly and inexpensively establish the interactions between mission radius and performance requirements, TOGW, cost, and engine and airframe design variables.

3.3 OUTPUT - The output from the V/STOL Fighter Design Evaluation procedure includes the correlation equations and, for each SEARCH optimization, a description of the geometry, performance and cost characteristics of the selected aircraft. The correlation equations are retained and can be repeatedly used to define and evaluate interactions between the design variables and system requirements. For each aircraft defined using the SEARCH optimization procedure, the design variables are identified, and the engine and airframe geometry can be obtained from the correlation equations. Using those design variables, any mission radius performance or cost parameter for which correlation equations were developed can be determined. Finally, at each segment of the design mission, the fuel used, inlet and nozzle geometry, and installation losses can also be determined.

4. BASELINE L + L/C AIRCRAFT DESIGN

The initial step in utilizing the V/STOL Fighter Design Evaluation Procedure is to define a baseline aircraft for use as the input design. This L + L/C aircraft, shown in Figure 13, was defined using an advanced L/C turbofan engine supplied by General Electric and an advnaced technology lift engine with a thrust-to-weight ratio of 18:1. This aircraft, as drawn in the design process is 55 feet long and has a TOGW of 30,660 lb with an internal fuel load of 9,435 lb. The aircraft is capable of achieving an intercept radius of 96 NM with dash M_o = 1.6 at 40,000 feet.

The V/STOL CADE program aircraft sizing capability was used to scale the baseline aircraft to achieve an intercept radius of 150 NM and selected combat performance requirements. The scaled aircraft results are compared with the baseline aircraft in Figure 14. The scaled aircraft has a TOGW of 33,870 lb and is 58 feet long, Figure 15.

To provide verifications of the V/STOL CADE sizing logic, the computed geometry of the scaled aircraft (CADE output) was utilized to develop a design layout. The baseline and scaled aircraft are compared in Figure 16. No problems were encountered in laying out the aircraft design and very good agreement with the V/STOL CADE results was obtained. For example, the design layout had a maximum fuselage cross-sectional area of 37 ft^2 and a fuselage wetted area of 1006 ft^2. This compared with 35 ft^2 and 980 ft^2, respectively, estimated by V/STOL CADE.

Engine and airframe integration was based on four major design considerations. The considerations are illustrated in Figure 17 and discussed below:

(1) Powered lift system sizing to provide a net lift/ TOGW ratio of 1.05, accounting for lift losses due to non-standard day (90°F) operation, reingestion, ground effects, control margin and primary/auxiliary inlet performance.

(2) Powered lift thrust balancing is accomplished by positioning the lift engines forward of the aircraft c.g. to balance the moment produced by the lift/cruise engines. Lift/cruise engines are sized to meet specified aircraft maneuverability and the lift engines are sized to provide the additional lift required to achieve VTO.

(3) Aerodynamic stability is maintained within limits of 2% to 8% Mean Aerodynamic Chord (M.A.C.) from vertical takeoff to vertical landing, by positioning the wing and distributing the fuel load around the aircraft takeoff c.g.

	GE16/VF17 L/C Turbofan	Lift Engine
BPR	0.95	–
OPR	22.0	11
T.I.T. (^{o}F)	2800	2400
T/W (Inst)	7	18

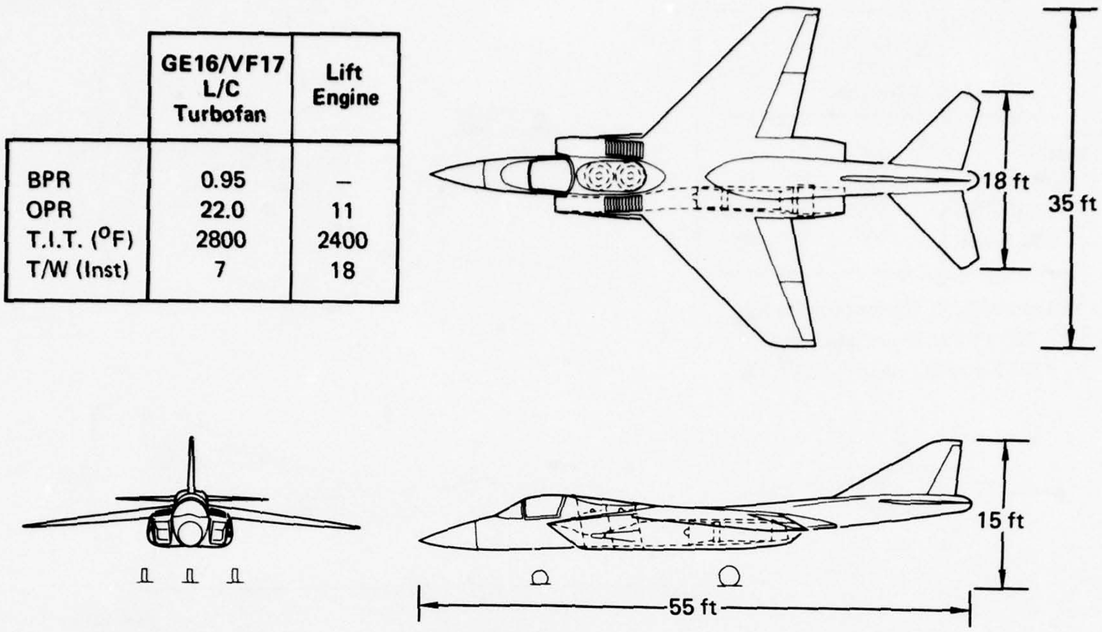

FIGURE 13
BASELINE AIRCRAFT 3-VIEW
Design Layout TOGW = 30,660 lb

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		Requirement	Base Aircraft	Scaled Aircraft
TOGW	(lb)		30,660	33,870
Internal Fuel	(lb)		9,435	11,315
Engine Scale Factor			0.805	0.923
Wing Reference Area	(ft^2)		400	345
Mission Radius	(nm)			
DLI		150	96	150
Fighter Escort (Internal Fuel)			315	414
• (2) 300 gal Tanks		400	661	701
• (2) 600 gal Tanks			926	926
Combat Performance				
Acceleration				
• Mach 0.8 to 1.6 @ 35,000 ft	(sec)	90	115	85
Maneuver				
• Mach 0.65 @ 10,000 ft	(g)	4.75	5.36	4.75
Specific Excess Power				
• Mach 0.90 @ 10,000 ft	(fps)	750	662	752

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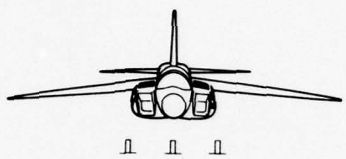
FIGURE 14
L + L/C AIRCRAFT
BASE VERSUS SCALED AIRCRAFT COMPARISON

	GE16/VF17 L/C Turbofan	Lift Engine
BPR	0.95	–
OPR	22.0	11
T.I.T. (^oF)	2800	2400
T/W (Inst)	7	18

150 nm/Mach 1.6 Intercept Radius
P_s = 750 FPS at M_o = 0.90,10,000 ft
n_z = 4.75 g at M_o = 0.65,10,000 ft



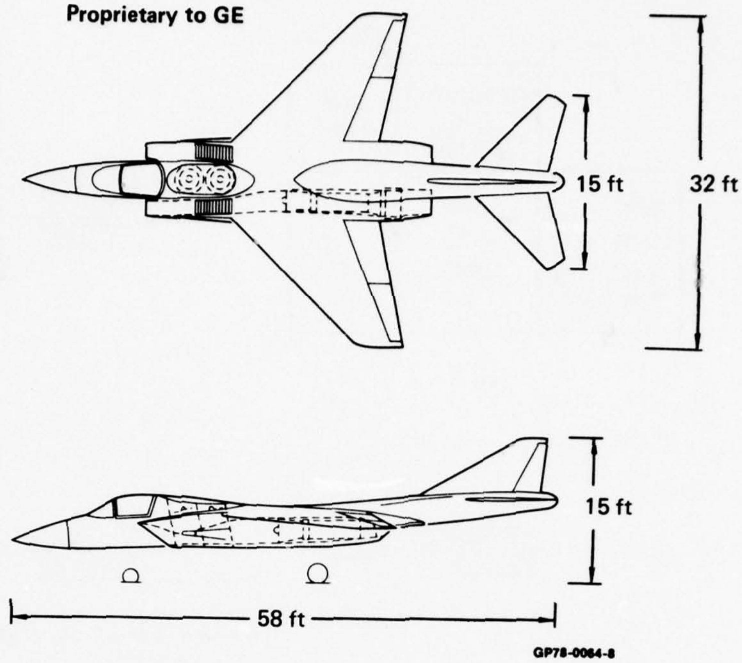


FIGURE 15
AIRCRAFT 3-VIEW
TOGW = 33,870 lb

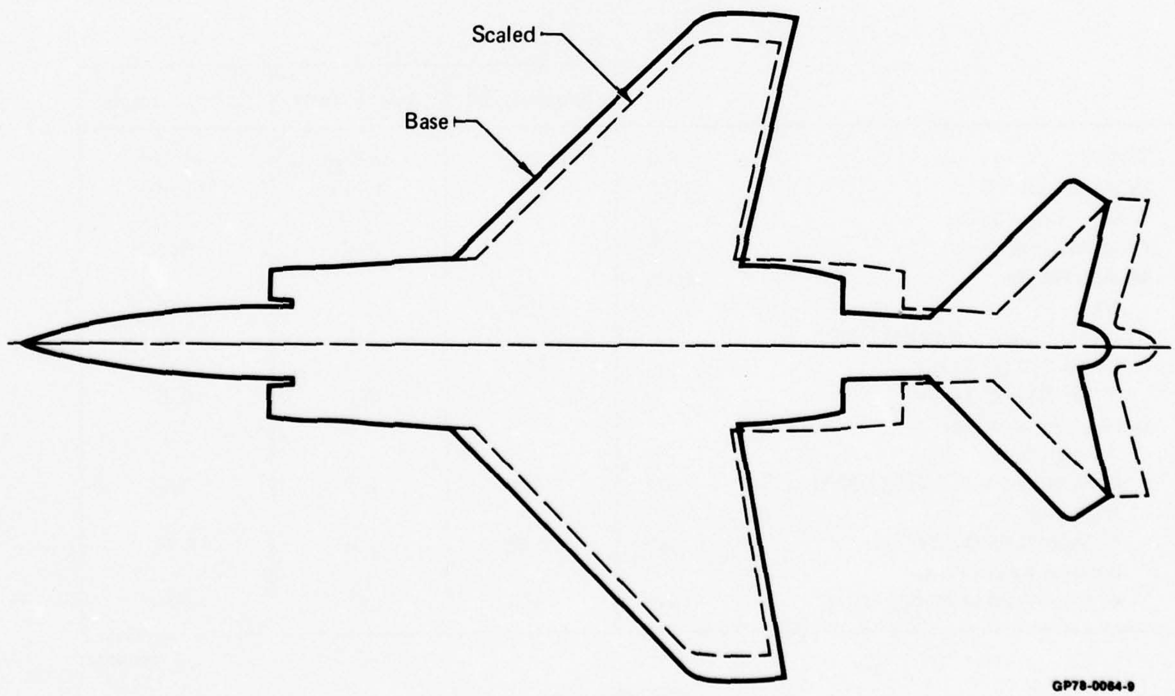
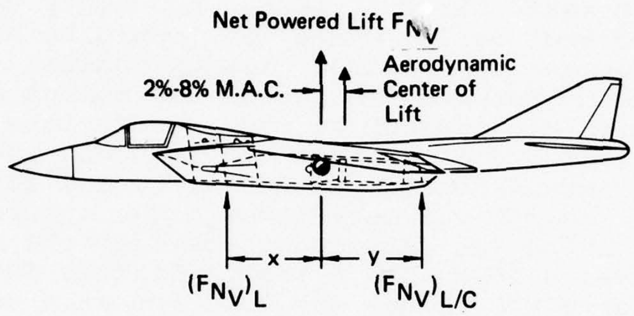


FIGURE 16
BASE AND SCALED L + L/C AIRCRAFT GEOMETRY COMPARISON



(1) F_{N_V}/TOGW = 1.05 (Net)
(2) VTO Thrust Vectors Balanced about Takeoff C.G.
(3) Aerodynamic Stability within Limits (2% to 8% M.A.C.)
(4) Over-the-Side Pilot Visibility

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FIGURE 17
ENGINE/AIRFRAME INTEGRATION DESIGN CONSIDERATIONS

(4) The lift/cruise air induction system was maintained aft of the cockpit to provide over-the-side pilot visibility.

Design of the input aircraft indicated that the level of L/C engine thrust used for VTO could have significant impact on the aircraft geometry and TOGW, Figure 18. It was found that minimum TOGW was obtained when the L/C engines were operating at less than a maximum power. As the power setting of the L/C engine was increased, the DLE thrust was reduced to maintain constant total lift, and the moment arm required to balance the L/C thrust vector increased. This increase in DLE moment arm resulted in increased aircraft length and empty volume between the DLE and the fuel cells, where fuel could be added but was not required to meet the desired mission radius. The L/C engine could not be moved forward, to reduce the moment arm required, due to the design requirement to provide over the side visibility. Conversely, as the L/C VTO thrust was reduced, the DLE thrust increased to maintain constant total lift, and its moment arm decreased. As the DLE was moved toward the aircraft c.g., it displaced fuel which was required to perform the DLI mission. This also increased TOGW. As a result of this TOGW sensitivity, lift/cruise engine VTO thrust was included as a design variable.

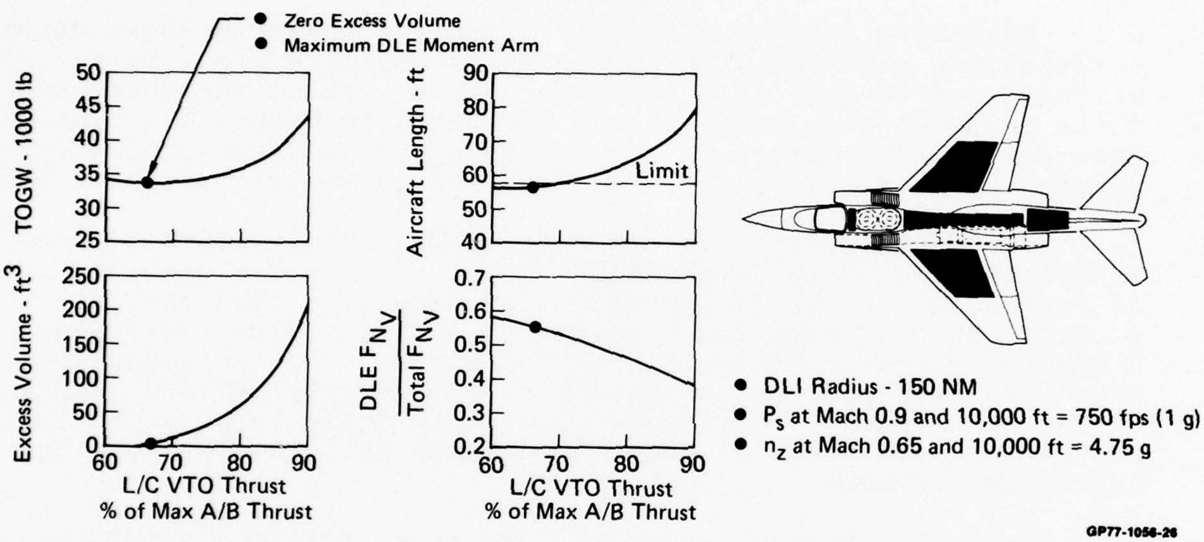

FIGURE 18
IMPACT OF L/C VTO THRUST
Input L + L/C Aircraft

5. L + L/C PARAMETRIC FIXED CYCLE TURBOFAN ENGINE/AIRFRAME EVALUATION

Correlations of parametric aircraft characteristics, developed using the V/STOL Fighter Design Evaluation Procedure, provide a consistent basis for conducting aircraft/requirements interaction trade-offs and engine/airframe design selections. These correlations account for the complex interactions between engine and airframe design variables and aircraft size, performance, cost, and mission characteristics. The following sections describe parametric data development, using advanced technology fixed cycle turbofan engines, examples of aircraft/requirement interaction trade-offs and the selection of an engine/airframe design for specific V/STOL fighter requirements.

5.1 <u>PARAMETRIC DATA DEVELOPMENT</u> - Aircraft characteristic data correlations were developed using three engine design, three airframe design and five sizing variables. These variables and their corresponding value ranges are shown in Figure 19. The data developed consists of propulsion system performance, aircraft characteristics, and, finally, the parametric correlations.

5.1.1 <u>Propulsion System Performance</u> - Utilization of the V/STOL Fighter Design Evaluation Procedure requires generation of installed propulsion system performance data over the complete flight envelope for a matrix of engine design variables. A General Electric parametric V/STOL engine deck, Reference 9, provided the capability to obtain a consistently defined family of engine designs. This deck, along with MCAIR inlet and aft-end performance data, was used to compute installed propulsion system performance.

The engine design variables, sea level static standard day turbine rotor inlet temperature (TIT_{SLS}), fan pressure ratio (FRP), compressor pressure ratio (CPR) and an airflow scheduling variable ($\Delta TAMB_{SLS}$) were used to define engines with design bypass ratio varying from 0.4 to 1.5. The $\Delta TAMB_{SLS}$ variable ranged from zero to 60 degrees to establish the off-design schedule of turbine inlet temperature and thus engine airflow. Maximum fan speed, 105%, was maintained from standard day to the engine inlet temperature defined by standard day plus $\Delta TAMB_{SLS}$ as illustrated in Figure 20. This SLS condition establishes maximum turbine inlet temperature and the cooling airflow required. Typical variations of the engine characteristics with $\Delta TAMB_{SLS}$ are shown in Figure 21. This airflow scheduling variable provided the capability to conduct trades between design bypass ratio, engine performance at altitude, and engine weight.

Parametric data were generated with the engine deck to determine the impact of the design variables on performance and weight. Thermodynamic cycle balance was not achieved with the engine deck for FPR and CPR values above 3.6 and 6.3, respectively, and TIT_{SLS} = 2700°F and $\Delta TAMB$ = 60° as indicated in

Aircraft Design Variables

	Range of Variation
Airframe Design	
Combat Wing Loading	70-100 lb/ft^2
Wing Aspect Ratio	2.5-4.0
Wing Sweep	35^o-55^o
Engine Design	
Fan Pressure Ratio	3.2-4.0
Compressor Pressure Ratio	4.8-7.8
Engine Airflow Scheduling (ΔTAMB)	0^o-60^{o}F
Engine Sizing	
L/C VTO Thrust (% Maximum A/B)	55-80%
Combat Specific Energy (P_s)	100-300 ft/sec
Internal Fuel Sizing	
Intercept Radius	100-200 NM
Intercept Mach Number	1.4-2.0
Intercept Altitude	36,000-50,000 ft

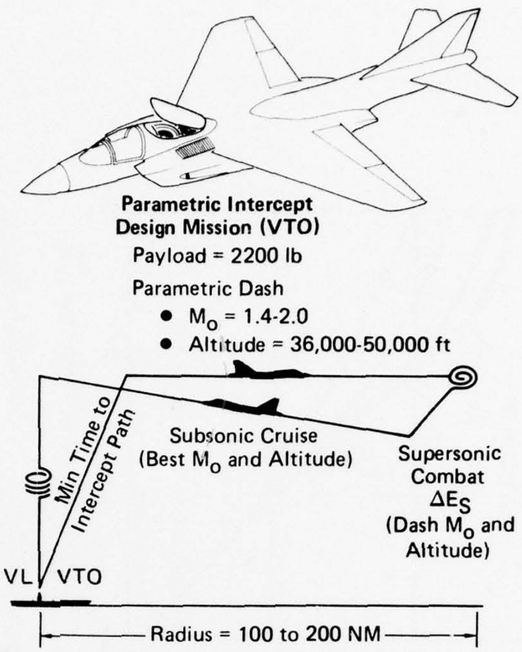

FIGURE 19
DESIGN MATRIX
FCE-/TF Aircraft

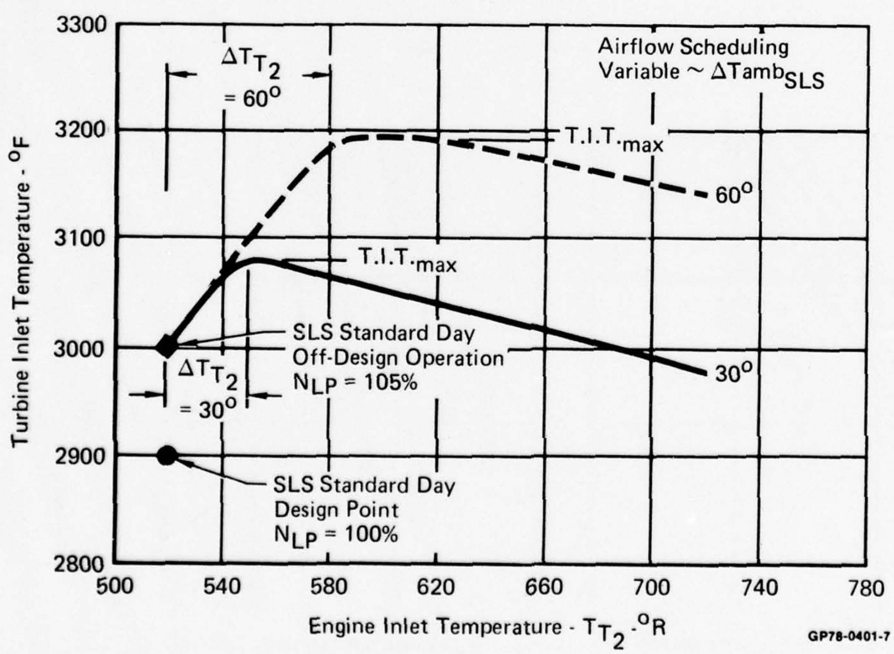

FIGURE 20
GE16/VF18 PARAMETRIC DECK
FCE-TF
Effect of Airflow Scheduling Variable on Turbine Inlet Temperature

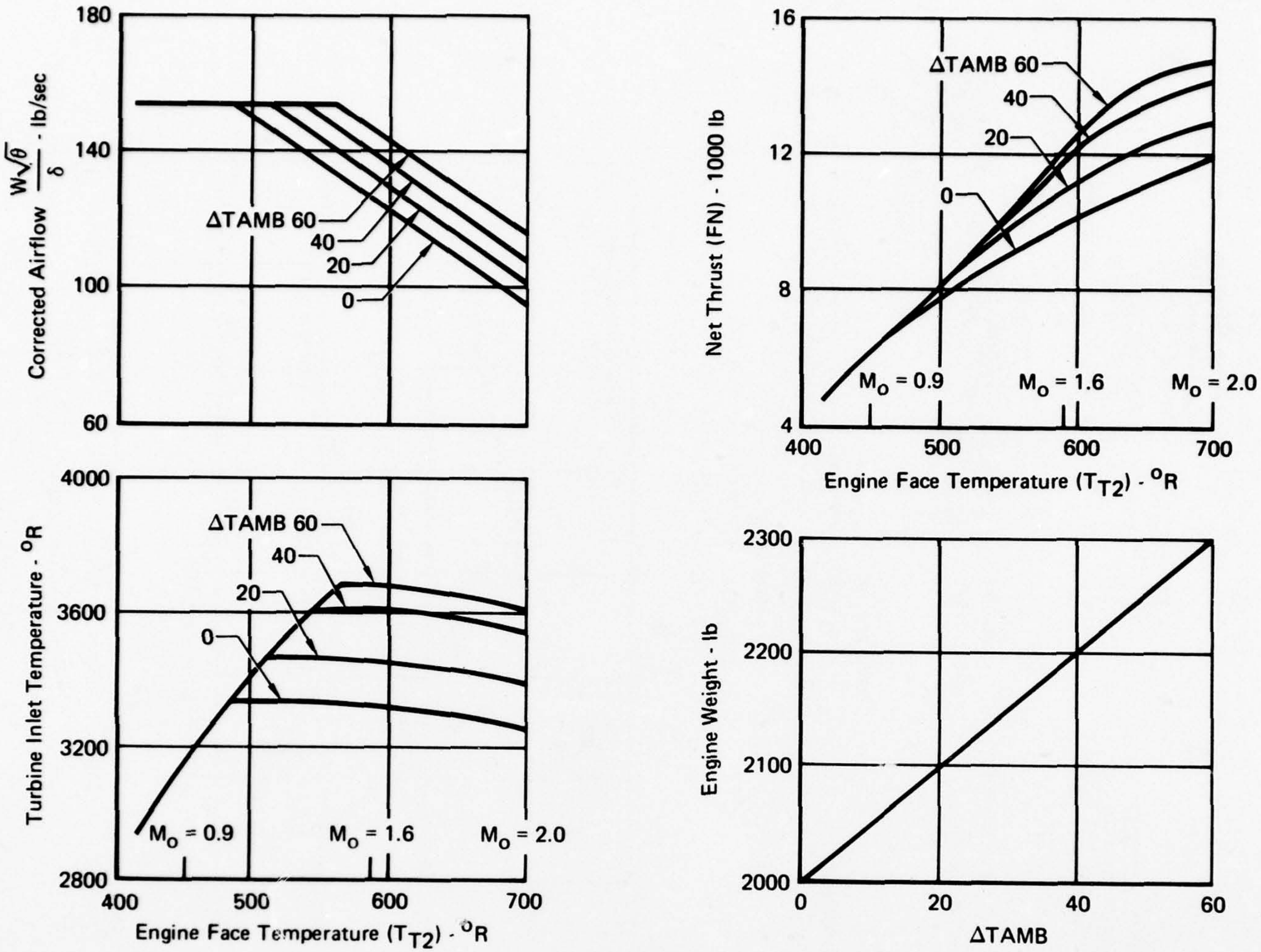

FIGURE 21
GE PARAMETRIC V/STOL ENGINE DECK
FCE-TF
Engine Airflow Scheduling
Altitude = 36,089 ft

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Figure 22. The engine design matrix shown in Figure 23 was selected to provide a family of mixed flow turbofan engines with design bypass ratio ranging from 0.6 to 1.5 and sea level static thrust/weight ratio ranging from 6.5 to 7.2

Installed propulsion system performance data must properly account for the effects of throttle dependent propulsion system drag, inlet total pressure recovery, and compressor bleed and horsepower extractions. A propulsion system thrust/drag accounting system was established to permit evaluations of propulsion system/airframe interactions.

The Propulsion System Installed Performance (PSIP) calculation procedure is schematically illustrated in Figure 24. Baseline aircraft inlet recovery, compressor bleed and horsepower extractions were included in the computation of engine size, weight and installed performance over the complete flight envelope. These data, along with baseline aircraft inlet and aft-end performance, were used in the PSIP procedure to compute installed propulsion system performance. Inlet capture area is sized to meet the airflow demands of the computed engine with a design corrected airflow of 155 lb/sec. Installed propulsion system performance tables along with size, weight and scale factor tables, were then generated for input to V/STOL CADE.

A detailed description of the PSIP procedure and the data generated for input to V/STOL CADE is included as Appendix B to this report.

5.1.2 Aircraft Characterization Data - Aircraft characteristic data were obtained, using V/STOL CADE, for approximately 65% of the 231 aircraft designs evaluated. The failure of 35% of the designs to converge was attributed to (1) the higher bypass ratio engines having excessive fuel requirements to meet the DLI mission radius, and (2) high L/C VTO power settings resulting in excessive lift engine moment arm. The data obtained from each converged design consisted of more than 400 aircraft design, size, weight, performance and cost parameters. A detailed description of the output data is provided in Appendix A.

5.1.3 Data Correlations - Correlations of the computed aircraft characteristics with the 11 engine and airframe design and sizing variables were developed using the SURFIT procedure. These correlations, which are called surface fits, were then evaluated to determine their validity.

Assessments of the surface fit quality were made by comparing CADE and SEARCH results and trends. Results of these assessments are shown in Figure 25 for the engine and airframe variables and in Figure 26 for the mission variables. For these assessments, each variable was changed independtly with the remaining variables held constant. The correlation results were similar to those obtained in previous uses of the procedure.

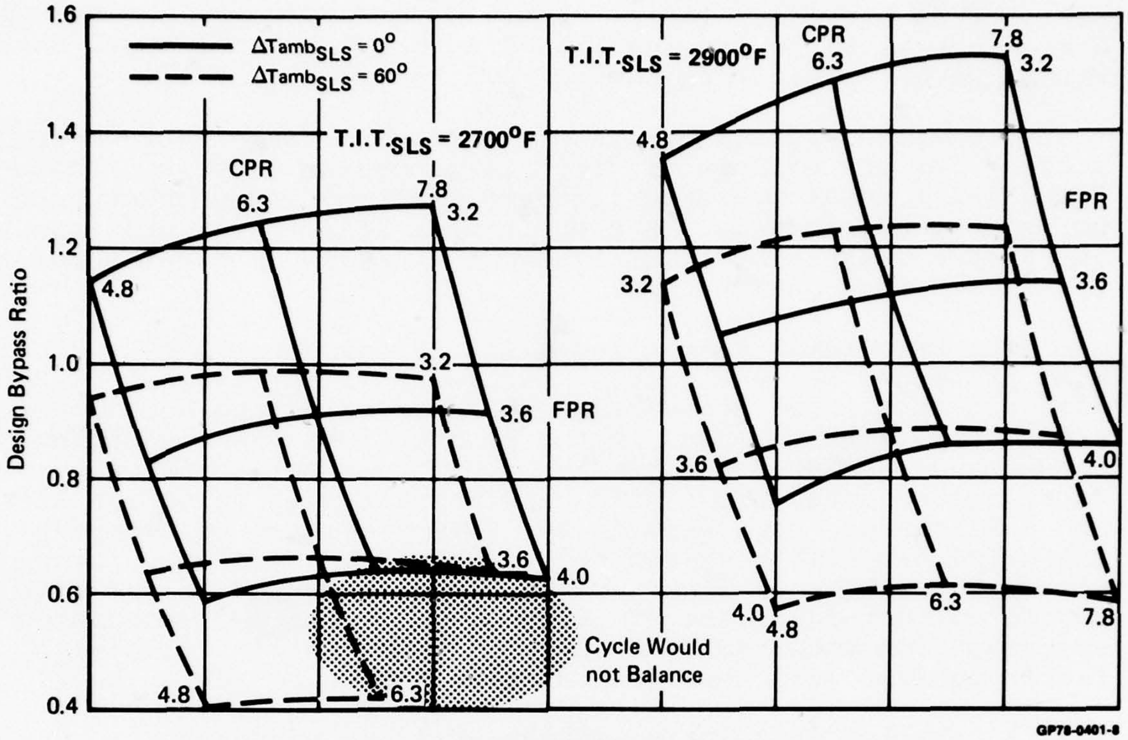

FIGURE 22
GE16/VF18 PARAMETRIC DECK
IMPACT OF DESIGN VARIABLES ON BPR
$(W\sqrt{\theta}/\delta)_{des}$ = 155 Lb/Sec

	Range of Variation
T.I.T.	$T.I.T._{SLS}$ = 2900°F (Fixed) $T.I.T._{max}$ = 2900°F-3190°F
FPR	3.2-4.0
CPR	4.8-7.8
$\Delta TAMB_{SLS}$	0°-60°

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FIGURE 23
PARAMETRIC ENGINE DESIGN MATRIX DEFINED FOR V/STOL FIGHTER DESIGN EVALUATION

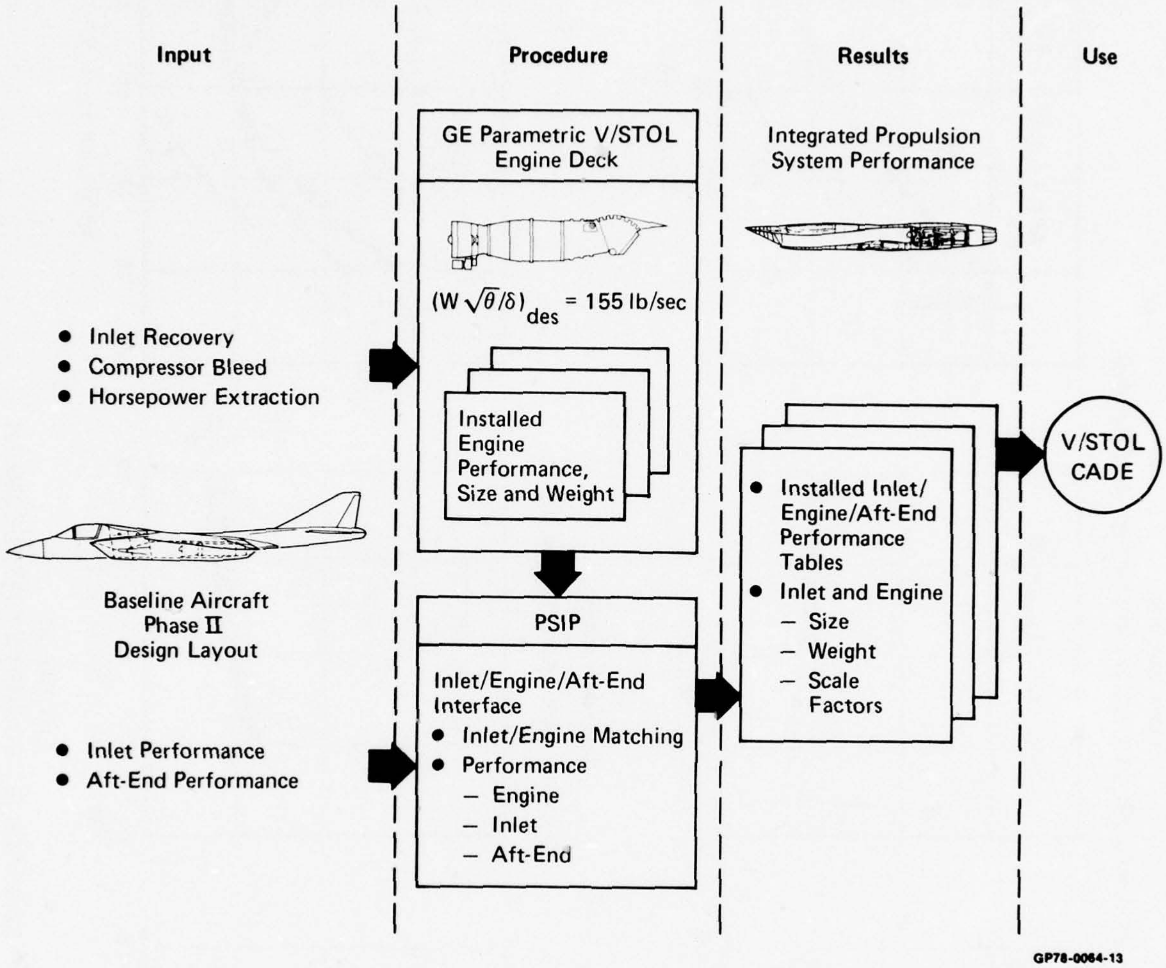

FIGURE 24
GENERATION OF PROPULSION SYSTEM INSTALLED PERFORMANCE

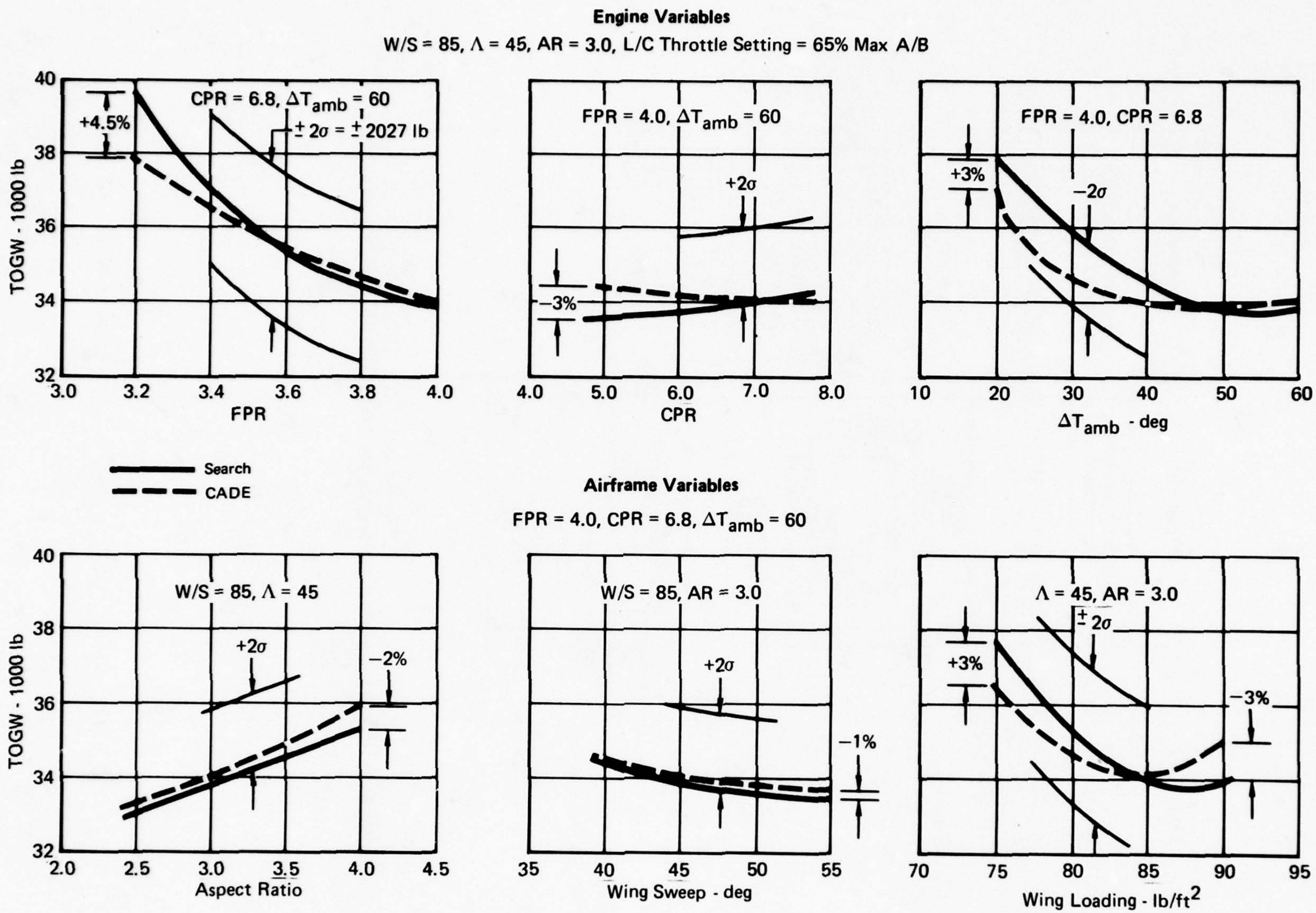

FIGURE 25
SURFACE FIT ACCURACY ASSESSMENT
CADE/SEARCH TREND COMPARISONS

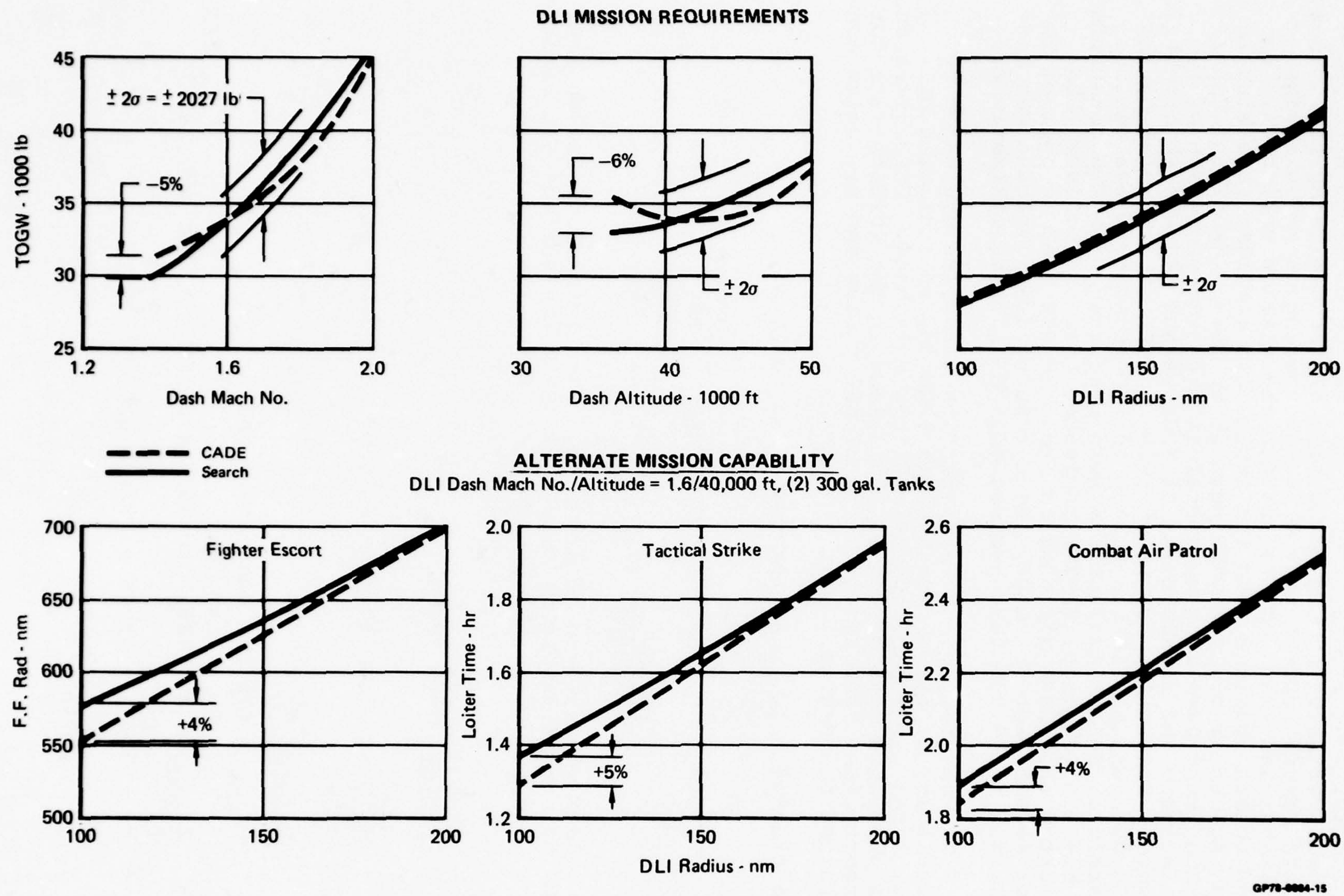

FIGURE 26
SURFACE FIT ACCURACY ASSESSMENT CADE/SEARCH TREND COMPARISONS
W/S = 85 Lb/FT^2, Λ = 45°, AR = 3.0, CPR = 6.8, Δ Tamb = 60°, FPR = 4.0

Typically, TOGW errors of up to ±8% can be obtained with independent variables at the boundaries of the design matrix. These errors ranged rom -3% to + 4.5% for the engine and airframe variables and from -6% to +5% for the mission variables. The TOGW errors obtained with the engine and airframe variables in the regions of minimum TOGW were 2% or less. Excellent CADE/SEARCH trend agreement was obtained with the exception of two variables. The SEARCH trend of TOGW versus CPR was incorrect. However, TOGW had a low sensitivity to CPR as indicated by the CADE data and had little impact on the parametric evaluations. Therefore, SEARCH evaluations were conducted with CPR constrained to 6.6 In addition, SEARCH indicated that the minimum TOGW occurred at a dash altitude of about 36,000 feet as opposed to over 40,000 feet for CADE. As a result, dash altitude was constrained to 40,000 feet for the engine/airframe evaluations.

The accuracy of the surface fits were also evaluated by determining if the differences in TOGW due to increased DLI radius and N_{z_s} capability fell within a 2σ band. This difference was predicted considering 2σ deviations in the surface fits for unconstrained TOGW and the fits of DLI radius and N_{z_s} which constrained the design.

The aircraft $2\sigma_{TOGW}$ was expressed as follows:

$$2\sigma_{TOGW} = 2\{\sigma^2_{TOGW\ (UNCONSTRAINED)} + \{\frac{\partial TOGW}{\partial N_{z_s}} \times N_{z_s}\}^2 + \{\frac{\partial TOGW}{\partial RADIUS} \times \sigma_{RADIUS}\}^2\}^{1/2}$$

CADE was used to generate the sensitivities of the optimum TOGW to variations in N_{z_s} and radius and the surface fit results were used to obtain the deviations. These results were:

$$\frac{\partial TOGW}{\partial RADIUS} = 127 \text{ lb/NM}$$

$$\frac{\partial TOGW}{\partial N_{z_s}} = 5500 \text{ lb/g at } 0.65\ M_o \text{ and } 10{,}000 \text{ ft}$$

$$\sigma_{RADIUS} = 7.26 \text{ NM} \qquad \sigma N_{z_s} = .0125 \text{ g}$$

$$\sigma_{TOGW} = 415 \text{ lbs (unconstrained)}$$

$$2\sigma_{TOGW} = 2\ \{(415)^2 + \{5500 \times .0125\}^2 + \{127 \times 7.26\}^2\}^{1/2}$$

$$= 2\ \{172225 + 4727 + 850121\}^{1/2}$$

$$= 2027 \text{ lbs}$$

Therefore, a predicted $2\sigma_{TOGW}$ of 2027 lb was obtained with the major error being introduced by intercept radius. As would be expected, the majority of the data used in the CADE/SEARCH assessments shown in Figure 25 and 26 fell well within the 2σ (95% probability) band.

5.2 ENGINE/AIRFRAME/REQUIREMENT INTERACTIONS - The aircraft characteristic data correlations obtained in this program afford the unique capability to conduct rapid and inexpensive investigations of aircraft/requirements interactions. The objective of such investigations is to identify the effects of design mission radius and performance requirements on engine and airframe design parameters, aircraft TOGW and cost, and alternate mission performance capabilities. Examples of this capability are presented below.

5.2.1 Single Mission Engine/Airframe/Requirement Interactions - The Deck Launched Intercept (DLI) mission was used to illustrate the potential impact of design mission requirements on system characteristics. Interactions of the DLI mission radius and dash Mach number with aircraft TOGW are shown in Figure 27. For any desired combination of radius and dash Mach number, they can be used to estimate aircraft TOGW and the optimized design parameters. These data were generated by optimizing the aircraft design to produce minimum TOGW at each combination of DLI radius and dash Mach number while meeting specified thrust sizing performance capabilities.

The optimized engine and airframe design variables were unaffected by changing DLI radius and dash Mach number; only the lift engine sizing variable, L/C VTO thrust changed. Since the majority of the fuel was used in the supersonic dash segment of the mission, optimized engine variables produce minimum supersonic dash SFC as indicated by maximum FPR (minimum BPR). Low wing aspect ratio and high wing sweep were selected to minimize supersonic aircraft drag while wing loading was controlled by the N_z = 4.75 g's requirement. The only design variable to be affected significantly by variations in DLI radius and dash Mach number was L/C engine VTO power setting, which varied from 55% to 80% of maximum VTO thrust.

One of the important considerations in the design of a V/STOL fighter is the compatibility of the design with the base(s) from which it must operate. Therefore, the effect of the design requirements on L/C engine nozzle exit temperature was evaluated, Figure 28. As intercept radius and dash Mach number increased, aircraft length increased to provide the necessary internal fuel volume. This increase in length, and hence available DLE moment arm, made it possible to use higher L/C VTO power settings, decrease DLE size, and still maintain a VTO thrust balanced design.

Combat performance requirements can also have a large impact on aircraft TOGW. Therefore, the capability to assess this

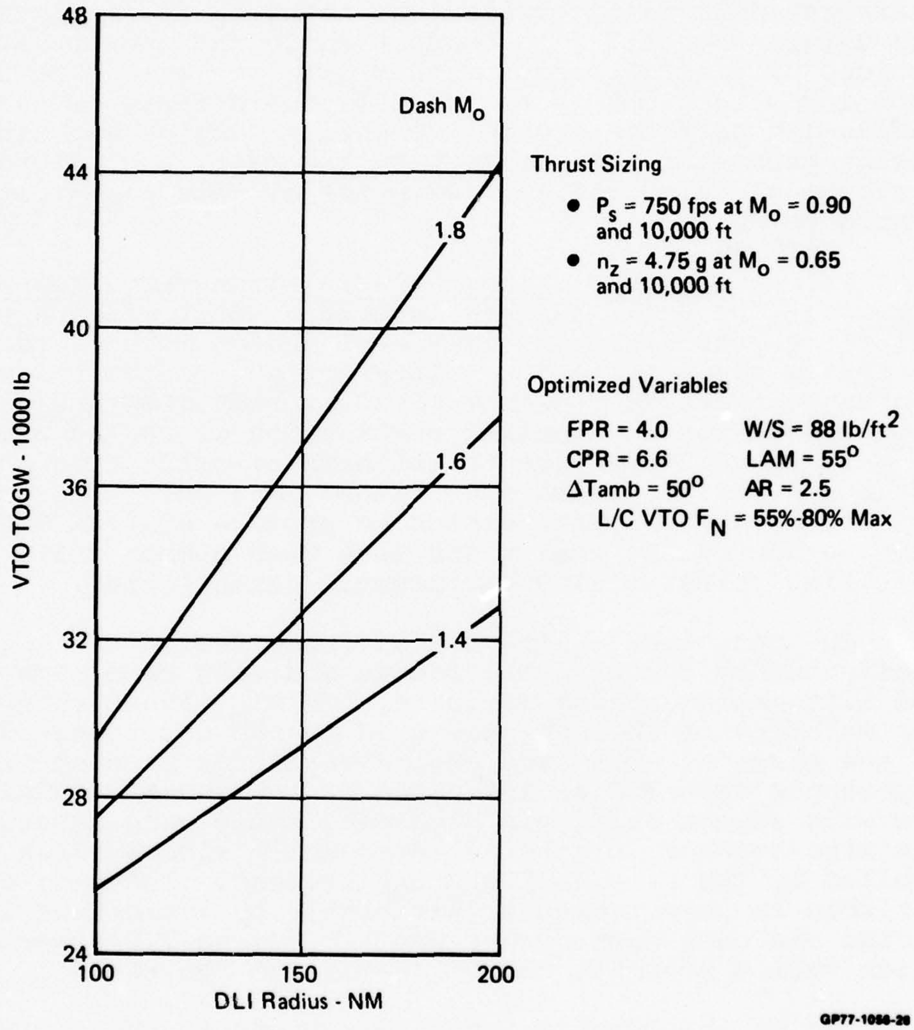

FIGURE 27
ENGINE/AIRFRAME/REQUIREMENT INTERACTION - DLI MISSION
Fixed Cycle Engine Turbofan (FCE-TF)

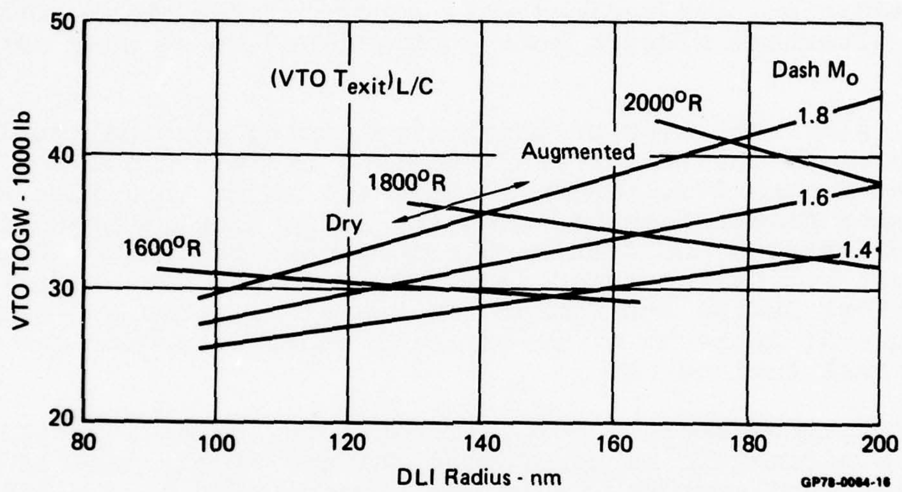

FIGURE 28
ENGINE/AIRFRAME/REQUIREMENT INTERACTIONS
L/C ENGINE NOZZLE EXIT TEMPERATURE
Fixed Cycle Engine Turbofan

impact was also included in the development of the analytical relationships. For example, Figure 29 depicts the effect of required combat P_s on aircraft TOGW. For the P_s capability considered in this study, the aircraft will weigh approximately 32,000 lb when nominal intercept radius and dash Mach number requirements are used. Increasing P_s requirements has a significant impact on TOGW.

5.2.2 Multimission Engine/Airframe/Requirement Interactions - Evaluations were conducted to determine the effect of alternate mission requirements on aircraft TOGW and design. In these evaluations, internal fuel was used to accomplish the DLI mission and external fuel to accomplish the alternate missions. In addition, evaluations were conducted for which both the DLI and alternate mission were accomplished using only internal fuel.

Alternate mission capability, using external fuel, was determined for the aircraft designs optimized for the DLI mission (Figure 27). These results are shown in Figure 30 for the Fighter Escort Mission using two 300 gallon external fuel tanks. As DLI radius and dash Mach number were increased, the fighter escort radius increased from 500 NM to 650 NM. Results for the Tactical Strike and Combat Air Patrol missions are shown in Figure 31 in terms of loiter time capability with two 600 gallon external fuel tanks.

Optimum designs were also defined, using internal fuel only, for a parametric range of both DLI and Fighter Escort Mission radius requirements. This was accomplished by defining specific combinations of DLI and Fighter Escort radii and optimizing the aircraft design, Figure 32, to obtain minimum DLI TOGW while satisfying radii, P_s and N_{z_s} requirements. Thus, these aircraft reflect the design compromises which produce minimum TOGW while achieving the performance requirements of both the supersonic DLI and subsonic Fighter Escort missions.

The multimission requirements produced large variations in the engine and airframe design variables of the FCE-TF aircraft. For example, sizing to a 100 NM DLI radius and a 500 NM Fighter Escort radius, Figure 33, resulted in an optimum design fan pressure ratio of less than 3.6 while the design FPR selected for the DLI mission was at the upper limit of 4.0. Optimum design FPR decreased (increased BPR) to improve subsonic cruise SFC for the Fighter Escort mission. In addition, wing sweep (LAM) and wing loading (W/S) were decreased, Figure 33, to improve subsonic aerodynamic performance. As the Fighter Escort radius was decreased from 500 to 300 NM or the DLI radius requirement was increased from 100 to 200 NM, the Fighter Escort mission impact on the aircraft design decreased. This was a direct result of the fuel required to meet the DLI radius approaching that required to meet the Fighter Escort radius. Compressor pressure ratio and TAMB variations had little impact on TOGW. Wing aspect ratio affected wing weight rather than DLI or Fighter Escort mission fuel usage.

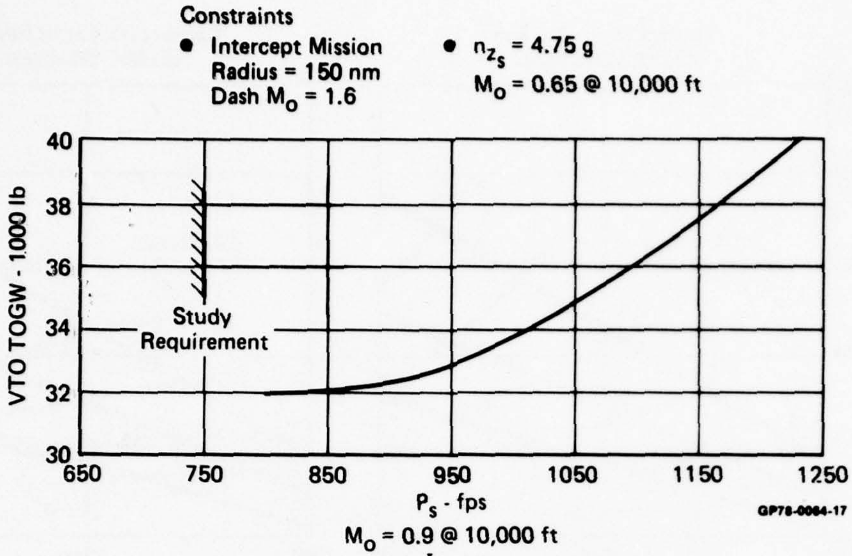

FIGURE 29

ENGINE/AIRFRAME/REQUIREMENT INTERACTIONS - COMBAT PERFORMANCE

Fixed Cycle Engine Turbofan

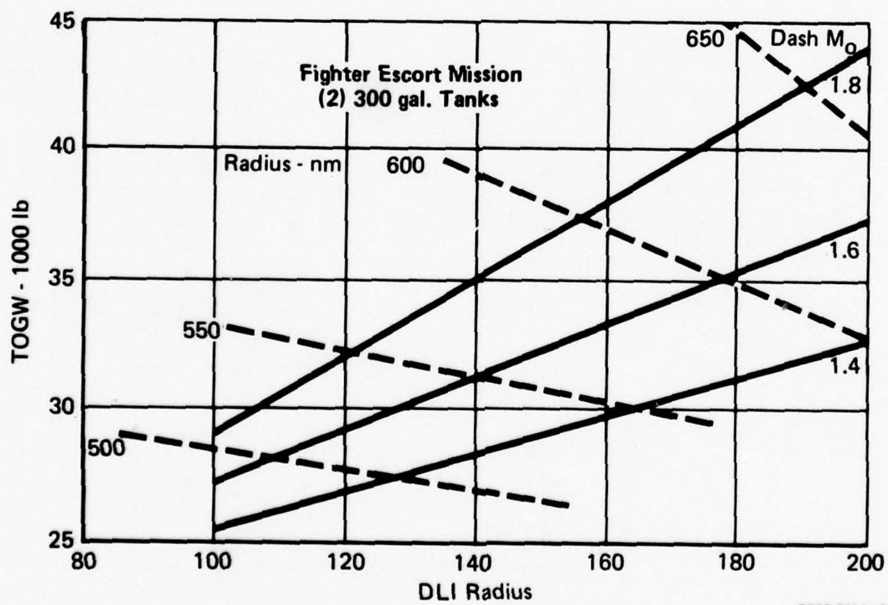

FIGURE 30

ENGINE/AIRFRAME/REQUIREMENT INTERACTIONS - MULTIMISSIONS

External Fuel

L + L/C (FCE-TF)

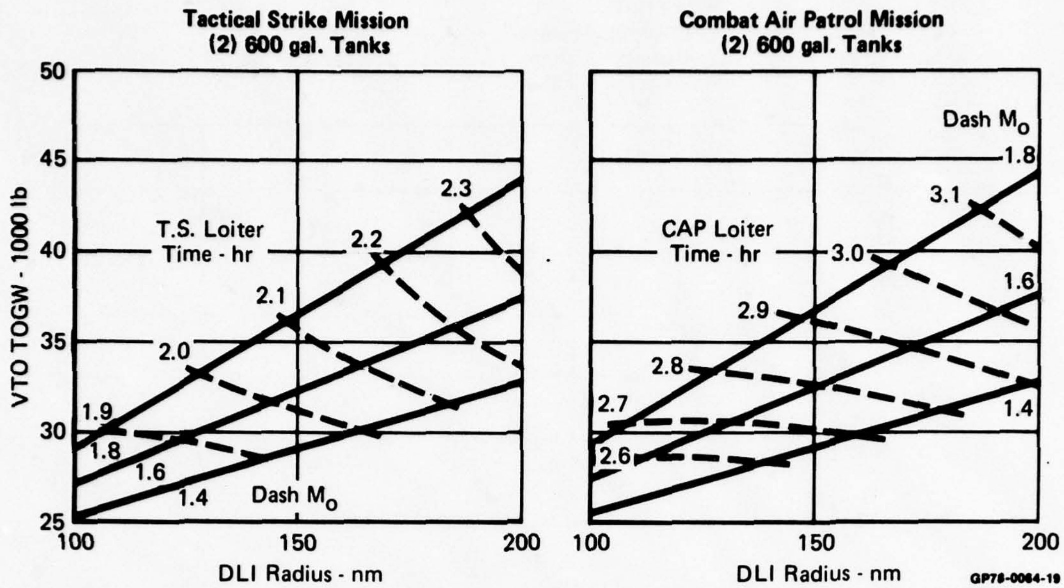

FIGURE 31

ENGINE/AIRFRAME/REQUIREMENT INTERACTIONS - MULTIMISSIONS

External Fuel

L + L/C (FCE-TF)

Sizing Requirements

- P_s at 0.9 M_O/10,000 ft/1 g ≥ 750 ft/sec
- Dash M_O = 1.6/Alt = 40,000 ft
- n_{z_s} at 0.65 M_O/10,000 ft ≥ 4.75 g
- P_s at Dash M_O & Alt ≥ 0 ft/sec
- Internal Fuel Only

Optimized Variables

- FPR = 3.5-4.0
- CPR = 6.6
- ΔTamb = 40-60 (Airflow Scheduling)
- W/S = 72-88
- LAM = 35-55
- AR = 2.5
- $(F_{N_V}/F_{N_{V_{max}}})$ = 0.45-0.80

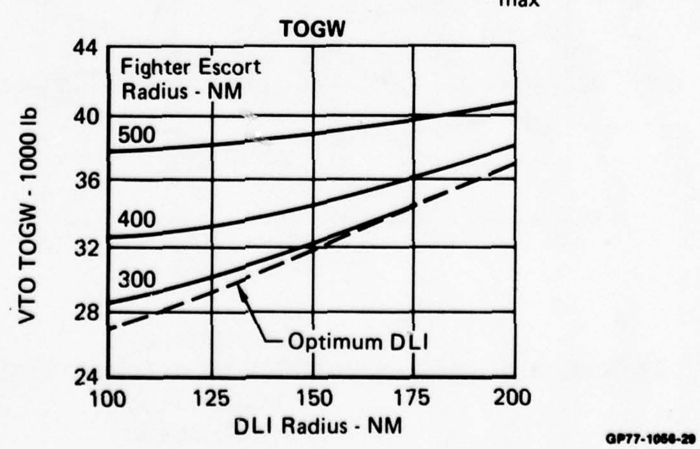

FIGURE 32

ENGINE/AIRFRAME/REQUIREMENT INTERACTIONS - MULTI-MISSION

Fixed Cycle Engine Turbofan

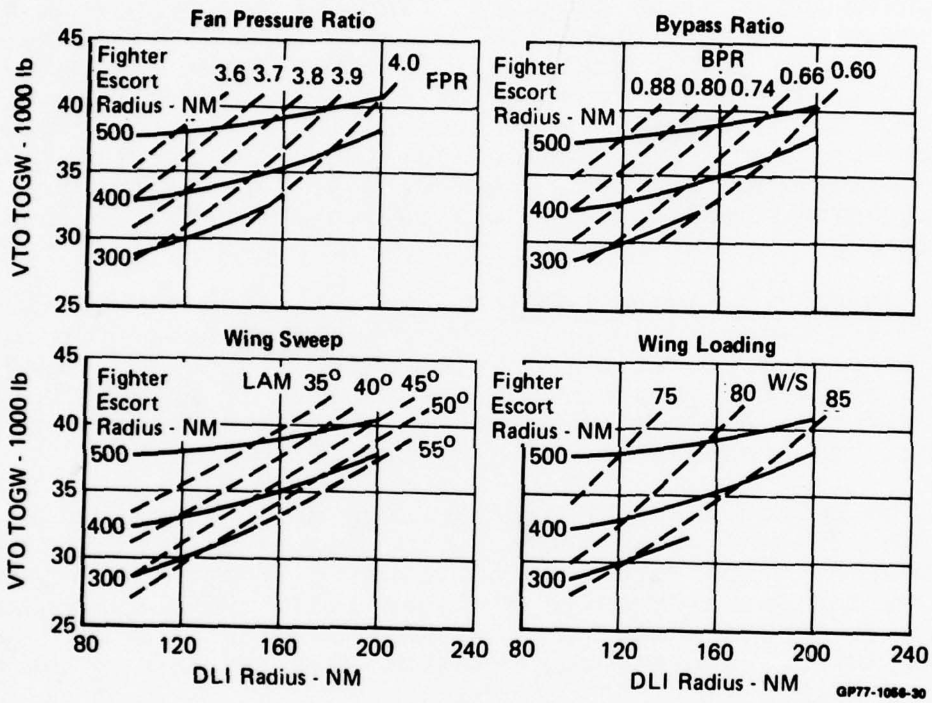

FIGURE 33
MULTI-MISSION INTERACTIONS
Fixed Cycle Engine Turbofan

5.2.3 Life Cycle Cost Evaluations - The V/STOL Fighter Design Evaluation Procedure provided the capability to determine the impact of mission and performance requirements on aircraft life cycle costs. These costs represented the "cradle-to-grave" expenses associated with weapon system ownership. Total LCC for the optimum aircraft designs, defined for variations in DLI radius and dash Mach number, are shown in Figure 34 for 900 production aircraft. Costs for the three principal LCC categories of RDT&E, Production, and Operations and Support are shown in Figure 35. The RDT&E costs include all engineering development and flight test activities. The Production costs include all tooling, manufacturing, assembly, and acceptance tests and component improvement programs. The O&S costs include the cost of personnel, facilities, spares, maintenance, training and fuel during the 15 year operational lifetime of the aircraft. Since the L/C engine design was not affected by variations in radius and dash Mach number, the variations in L/C engine RDT&E and Production costs were those associated with variations in the L/C engine size required. The POL cost variations were due to the increased fuel usage as DLI radius and dash Mach number were increased.

5.3 AIRCRAFT DESIGN SELECTION - An optimized FCE-TF aircraft design was selected to provide a consistent basis for comparison and assessment of variable cycle engine technology payoffs. The SEARCH optimization procedure was used to identify the minimum TOGW aircraft capable of achieving the MCAIR selected V/STOL fighter requirements shown in Figure 36.

The selected FCE-TF aircraft design is described in Figure 37. This figure shows the range of independent design variables considered in the data base development, the values of the design variables selected to minimize TOGW, and the fuel and thrust sizing variables which constrained the aircraft size. According to the SEARCH results, the selected aircraft design has a DLI TOGW of 32,035 lb.

The accuracy of the SEARCH results was analyzed by using the V/STOL CADE program to determine the TOGW for the engine and airframe design variables selected by SEARCH. SEARCH predicted the TOGW within 2%, Figure 38. Furthermore, SEARCH predicted the L/C VTO throttle setting which produced the minimum TOGW. The FCE-TF aircraft design characteristics are included as Figure 39.

The aircraft is capable of meeting or exceeding alternate mission performance requirements using external fuel. The alternate mission performance capabilities of the aircraft are included in Figure 40. The Tactical Strike mission, with a two-hour loiter requirement at 20,000 feet was the most demanding. Approximately 1200 gallons of external fuel is needed to meet this requirement. The ADEN nozzle permits afterburning thrust to be used for STO, thereby, allowing the takeoff distance requirement to be met with large fuel/weapon payloads. For

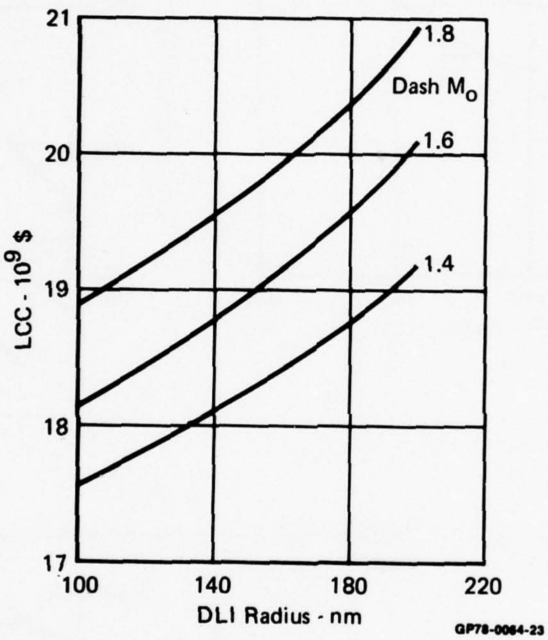

FIGURE 34
PARAMETRIC LIFE CYCLE COST (LCC)
LIFT + LIFT/CRUISE (FCE-TF) AIRCRAFT
900 Aircraft/1976 $/15 Years

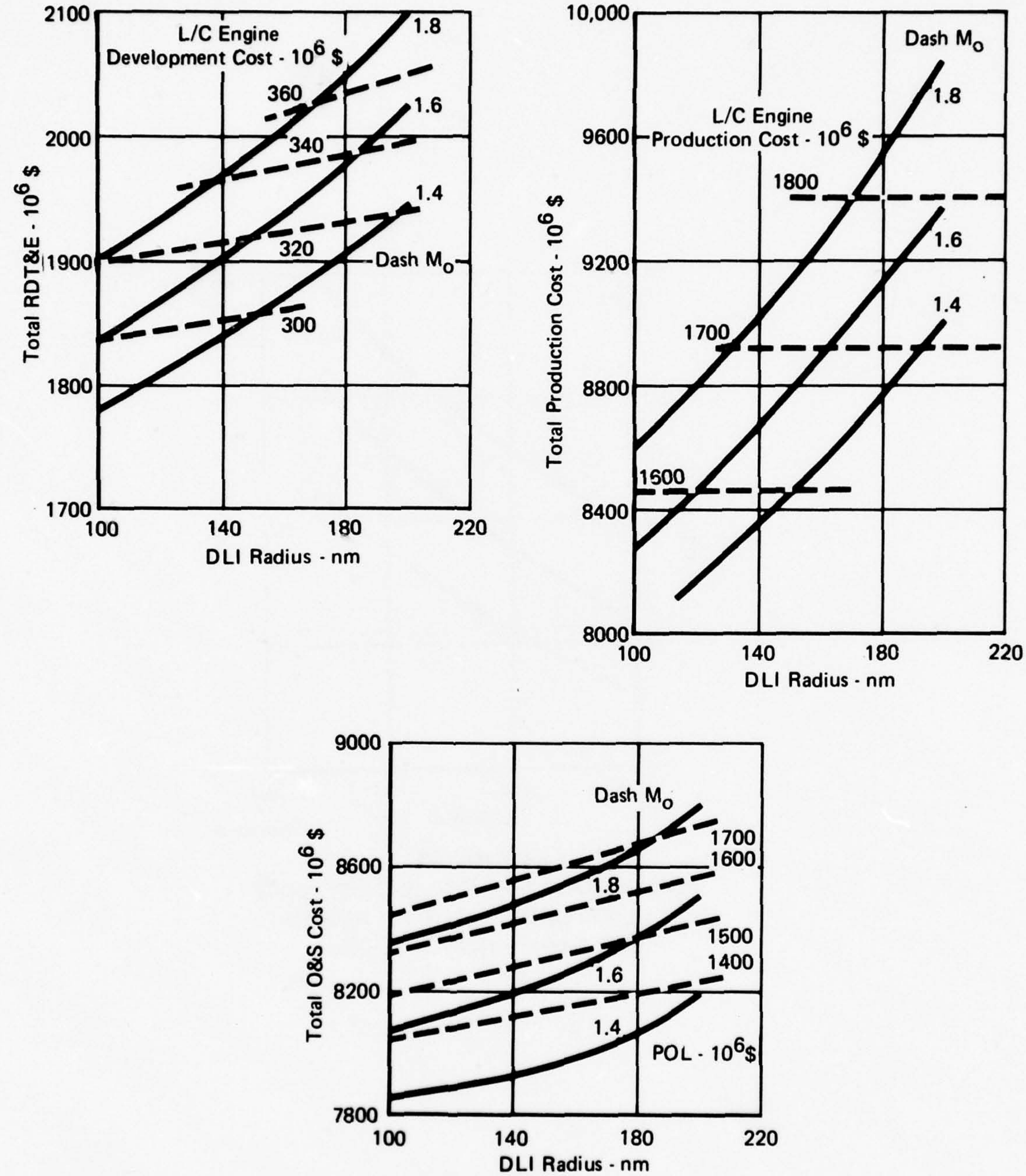

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FIGURE 35
COST BREAKDOWN
LIFT + LIFT/CRUISE (FCE-TF) AIRCRAFT
900 Aircraft/ 1976 $/15 Years

		Required
Mission Performance		
DLI Radius (Int Fuel)	(NM)	150/VTOL
Fighter Escort Radius (Ext Fuel)	(NM)	400/STOVL
Tactical Strike Loiter (Ext Fuel)	(hr)	2.0/STOVL
Combat Air Patrol Loiter (Ext Fuel)	(hr)	2.0/STOVL
Combat Performance		
Acceleration		
Mach 0.8 to 1.6 at 35,000 ft	(sec)	90
Maneuver		
Mach 0.65 at 10,000 ft	(g)	4.75
Specific Excess Power		
Mach 0.90 at 10,000 ft	(fps)	750

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FIGURE 36
MCAIR SELECTED V/STOL FIGHTER REQUIREMENTS

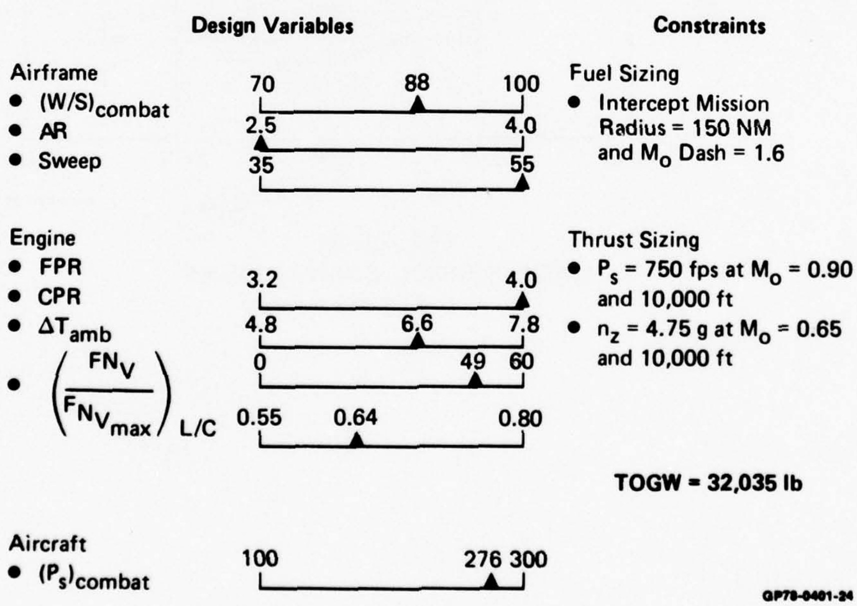


FIGURE 37
L + L/C AIRCRAFT DESIGN SELECTION
GE Fixed Cycle Turbofan L/C Engines

	FPR	CPR	Δ Tamb	AR	Λ	W/S
——— ~ Search	4.0	6.6	49	2.5	55	88
– – – – ~ CADE	4.0	6.6	49	2.5	55	88

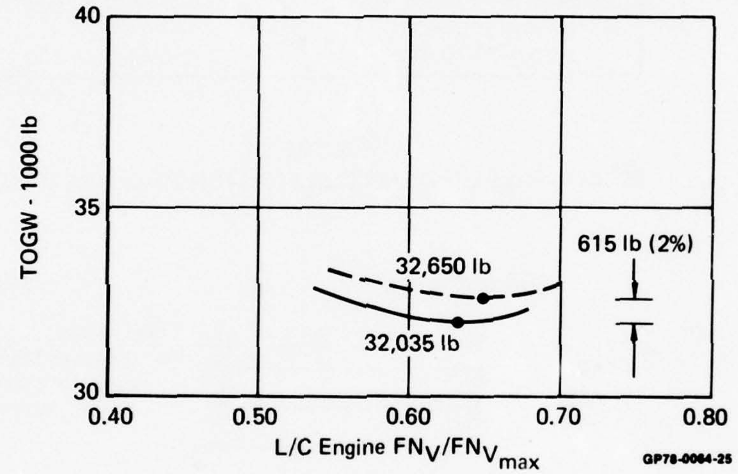


FIGURE 38
CADE/SEARCH COMPARISONS
L + L/C (FCE-TF) Aircraft

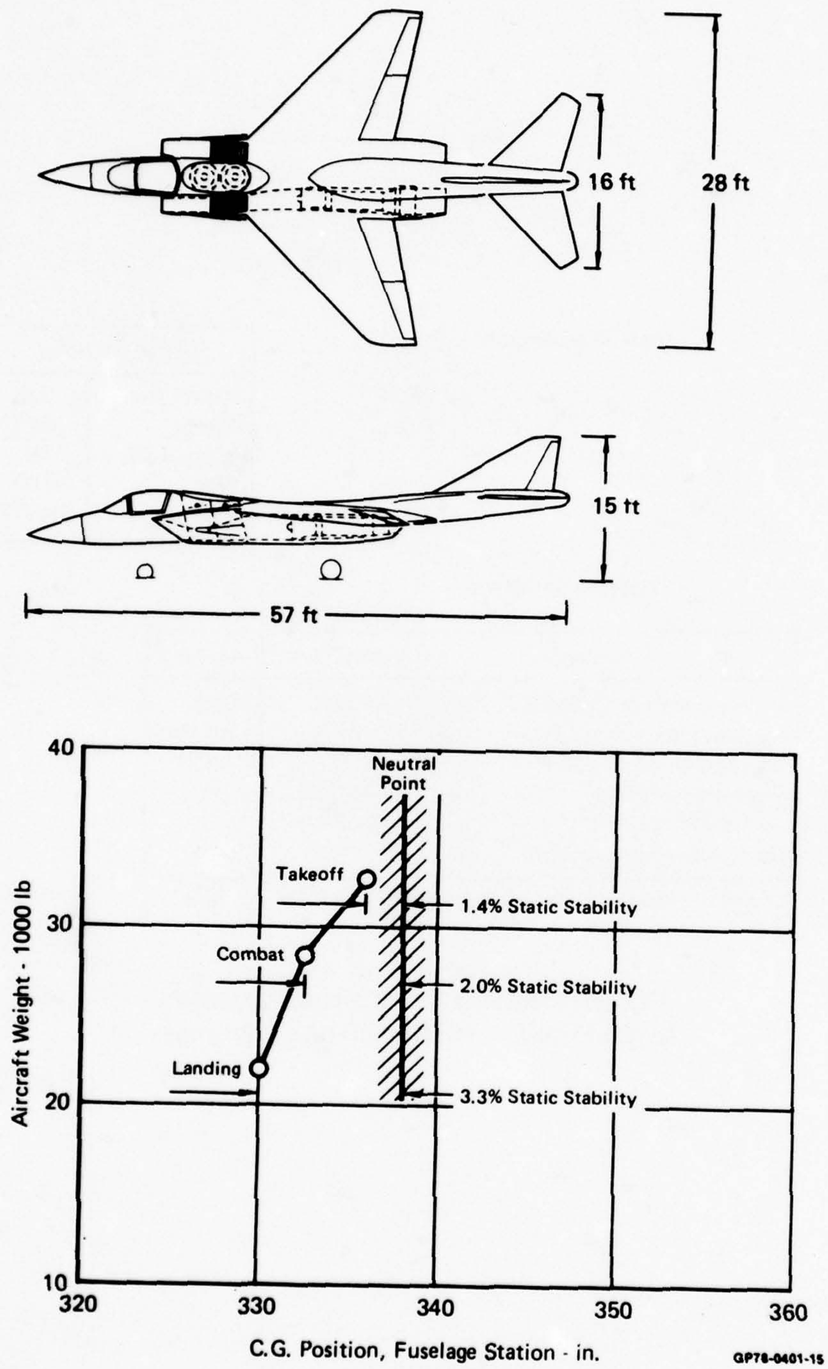
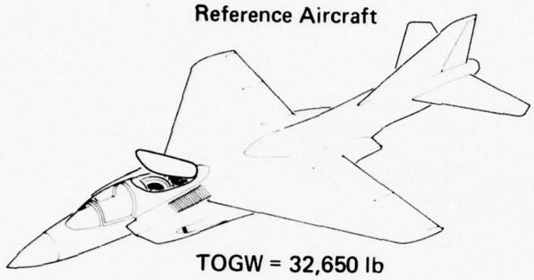


FIGURE 39
FCE-TF AIRCRAFT DESIGN CHARACTERISTICS

Reference Aircraft



TOGW = 32,650 lb

Design Variables	
Aspect Ratio	2.5
Sweep	55^{o}
Wing Loading	88
BPR	0.60
$T.I.T._{max}$	$3180^{o}F$

Performance		Required	Available
P_s, Mach 0.90 @ 10,000 ft	(fps)	750	809
n_{z_s}, Mach 0.65 @ 10,000 ft	(g)	4.75	4.75**
DLI Rad (Int Fuel)	(nm)	150/VTOL	150**
Fighter Escort Rad†	(nm)	400/STOVL	555
Tactical Strike Loiter*	(hr)	2.0/STOVL	2.02
Combat Air Patrol Loiter*	(hr)	2.0/STOVL	2.84

*(2) 600 gal. Tanks **Sizing constraints †(2) 300 gal. tanks

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FIGURE 40
FCE-TF AIRCRAFT DESIGN SUMMARY
GE Fixed Cycle Turbofan Lift/Cruise Engines

example, Figure 41 shows that the FCE-TF aircraft with a VTO TOGW of 32,650 lb can achieve the 400 feet STO requirement at a maximum TOGW in excess of 50,000 lb by using maximum after-burner. The same aircraft weighs 43,000 lb to meet the Tactical Strike requirement with (2) 600 gallon external fuel tanks and could lift off in 200 feet with 10 knots wind-over-deck at intermediate power.

Life cycle cost characteristics of the selected FCE-TF aircraft were estimated using the parametric techniques described in Appendix A. Costs, in terms of the three major LCC categories, are shown in Figure 42 for three production quantities. These costs estimates are based on an operational life of 15 years.

A TOGW sensitivity analysis was also conducted using the selected FCE-TF aircraft. The sensitivity to TOGW to changes in engine size, weight and performance were determined and are included as appendix C to this report.

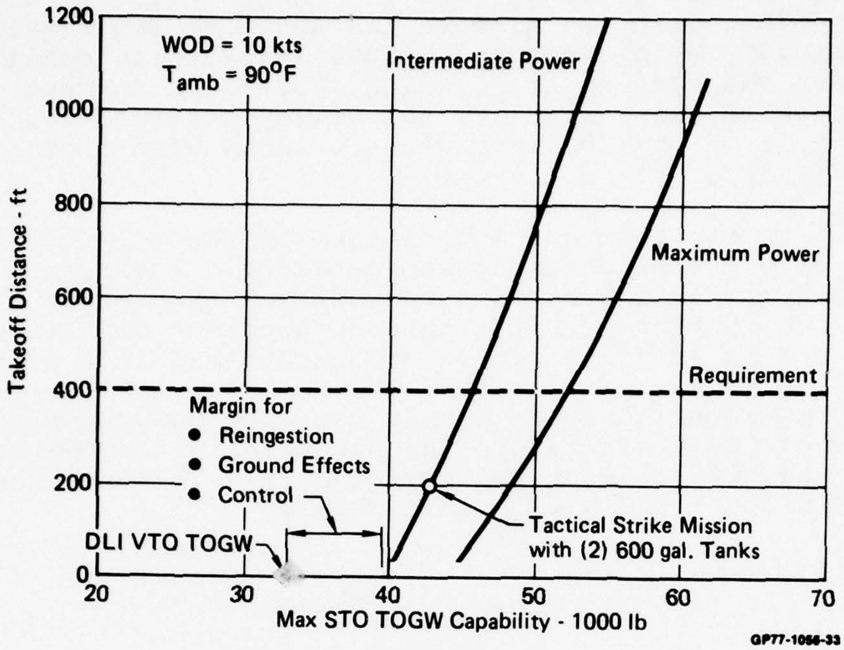

FIGURE 41
STO CAPABILITY USING ADEN NOZZLE
Phase II Reference L + L/C Aircraft

Selected FCE-TF Aircraft

	Millions of 1976 Dollars		
	900 Production Aircraft	600 Production Aircraft	300 Production Aircraft
RDT&E	1,943	1,943	1,943
Production	9,078	6,671	4,044
O&S	8,445	5,721	2,943
Total	19,466	14,335	8,930

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FIGURE 42
FCE-TF AIRCRAFT LIFE CYCLE COST

6. L + L/C PARAMETRIC VARIABLE GEOMETRY TURBINE TURBOJET ENGINE/AIRFRAME EVALUATION

Aircraft characteristic data correlations were developed using variable turbine geometry turbojet engines. The following sections describe the parametric data development, examples of aircraft/requirement interaction trade-offs, selection of a VGTTJ aircraft design, and comparison of the selected design with the FCE-TF aircraft.

6.1 PARAMETRIC DATA DEVELOPMENT - The VGTTJ powered aircraft characteristics were parametrically developed using the engine/airframe design and sizing variables shown in Figure 43. The airframe design and the engine and airframe sizing variables are similar to those used for the FCE-TF aircraft. The engine design variables were changed to reflect the use of turbojets.

A GE parametric VGTTJ computer deck, along with the MCAIR PSIP procedure described in Appendix B, were used to compute installed propulsion system performance. The engines defined by the computer deck, Reference 10, incorporated non-vectoring axisymmetric nozzles. Therefore, weight and thrust vectoring performance adjustments were made to reflect the use of the ADEN nozzle, Figure 44. The impact of ADEN cooling and unvectored performance on aircraft TOGW was estimated to be only about 2%, Figure 45, and these effects were not included in the data development.

The VGTTJ engine design variables consisted of sea level static overall pressure ratio (OPR), turbine inlet temperature (TIT) and an airfrlow scheduling variable (% N_2). The airflow scheduling parameter, defined as compressor rotor overspeed in percent of the design speed (% N_2) was used to establish the off design engine airflow characteristics. Typical variations of the engine characteristics with % N_2 are shown in Figure 46. Parametric data were generated with the engine deck over the complete design range. Sea level static thrust/weight ratio varied from 7.7 to 8.2 over the design range.

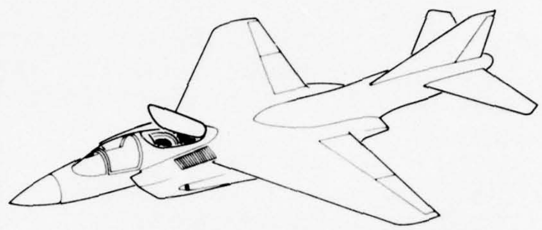
Aircraft characteristics data were obtained for approximately 96% of the 231 variable combinations evaluated. Correlation equations were then developed relating the computed aircraft characteristics to the engine/airframe design and sizing variables.

6.2 ENGINE/AIRFRAME/REQUIREMENT INTERACTIONS - The VGTTJ aircraft characteristic data correlations provide the capability to conduct rapid and inexpensive investigations of aircraft/requirement interactions. These investigations can be used to identify the effects of design mission radius and performance requirements on engine and airframe design parameters, aircraft TOGW and cost, and alternate mission performance capability. Examples similar to those provided for the FCE-TF aircraft are presented below.

6.2.1 Single Mission Engine/Airframe/Requirement Interaction - Typical DLI mission and performance requirement interactions

Aircraft Design Variables

	Range of Variation
Airframe Design	
Combat Wing Loading	70-100 lb/ft^2
Wing Aspect Ratio	2.5-4.0
Wing Sweep	45°-65°
Engine Design	
Turbine Inlet Temperature ($^\circ$F)	2200-2600
Overall Pressure Ratio	10-20
Engine Airflow Scheduling (Percent N_2)	100-110
Engine Sizing	
L/C VTO Thrust (Percent Maximum A/B)	45-75%
Combat Specific Energy (P_s)	150-350 ft/sec
Internal Fuel Sizing	
Intercept Radius	100-200 NM
Intercept Mach Number	1.4-2.0
Intercept Altitude	36,000-50,000 ft



Parametric Intercept Design Mission (VTO)

Payload = 2200 lb

Parametric Dash

- M_o = 1.4-2.0
- Altitude = 36,000-50,000 ft

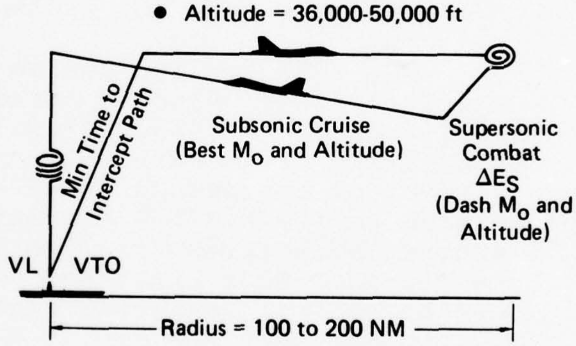


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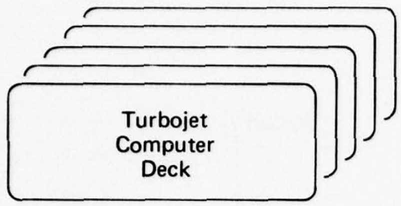
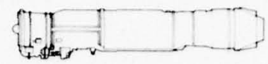
FIGURE 43
AIRCRAFT DESIGN MATRIX
VGTTJ Aircraft

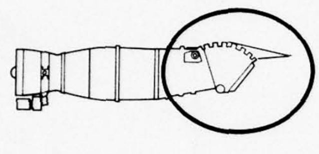
- **Engine Performance Obtained from GE ATS Computer Deck**





- VGT
- OPR = 10-20
- T.I.T. = $2200^{o}F$-$2600^{o}F$
- $\%n_2$ = 100-110
- Axisymmetric Nozzle

- **Aden Nozzle Used to Provide V/STOL Capability**



- Δwt = 385 lb/Engine
- $\left(\frac{FN_{vert}}{FN_{horiz}}\right)_{ADEN} = 0.91$
- No Performance Decrement for ADEN Cooling

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FIGURE 44
VARIABLE GEOMETRY TURBINE TURBOJET EVALUATION
L + L/C V/STOL Fighter

		Req't	VGT Turbojet	
			Without Cooling	**With Cooling**
TOGW	(lb)		28,945	29,680
Internal Fuel	(lb)		8,924	9,264
Engine Scale Factor			0.737	0.791
Wing Reference Area	(ft^2)		288	295
W/S @ TOGW	(lb/ft^2)		101	101
T/W @ TOGW (L/C Engines)			0.880	0.881
$(FN_V/FN_{V_{max}})_{L/C}$			0.55	0.65
Mission Performance				
DLI Radius	(nm)	150	150	150
Combat Performance				
Acceleration				
Mach 0.8 to 1.6 @ 35,000 ft	(sec)	90	79	78
Maneuver				
Mach 0.65 @ 10,000 ft	(g)	4.75	4.75	4.75
Specific Excess Power				
Mach 0.90 @ 10,000 ft	(fps)	750	825	824

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FIGURE 45
EFFECT OF ADEN COOLING ON AIRCRAFT WEIGHT AND PERFORMANCE

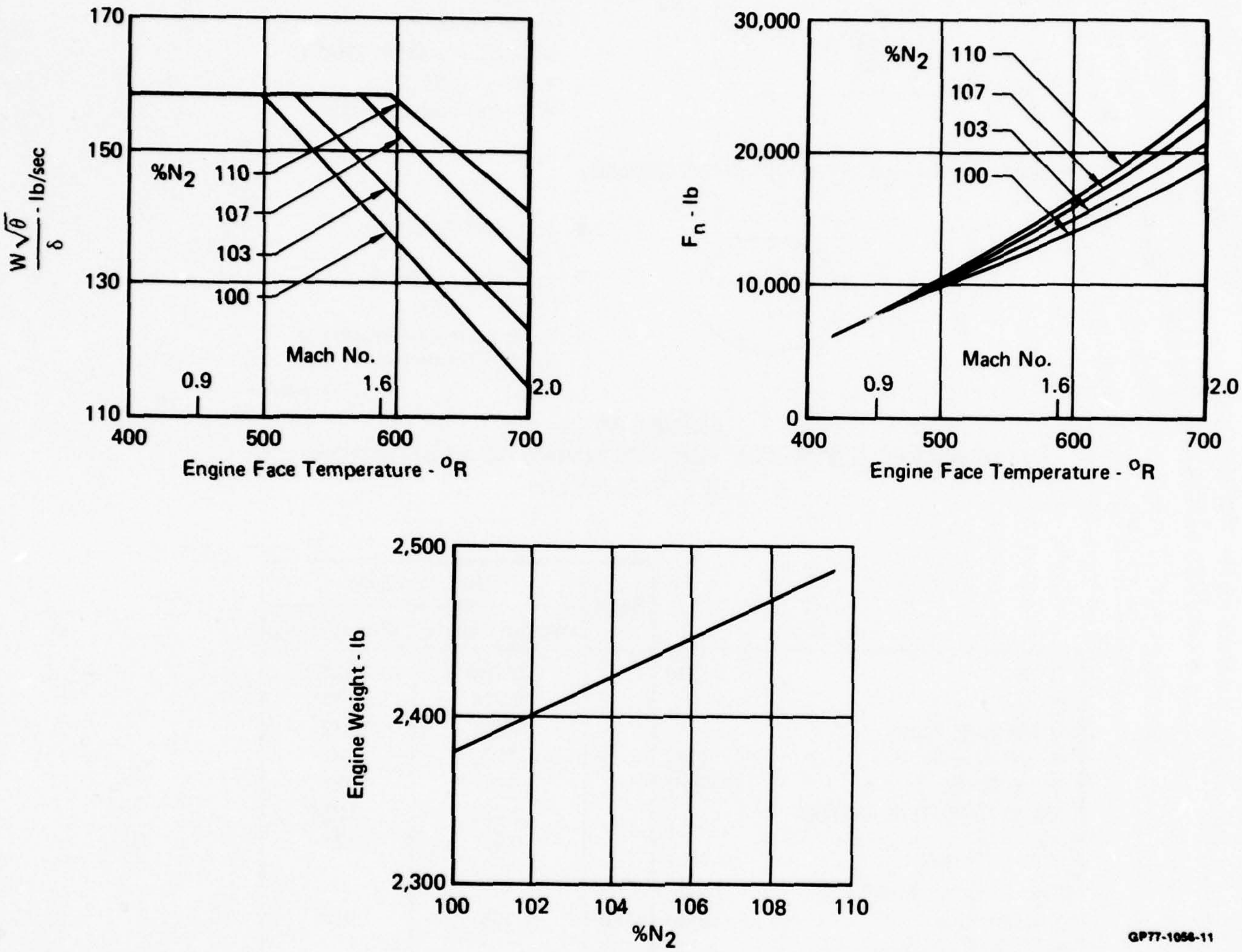

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FIGURE 46
GE PARAMETRIC VGTTJ ENGINE DECK
Engine Airflow Scheduling
Altitude = 36,089 ft

with system characteristics were defined to illustrate this trade-off capability. The impact of DLI mission radius and dash Mach number on aircraft TOGW is shown in Figure 47. Lower TOGW's, relative to the FCE-TF aircraft (Figure 27), were obtained since the majority of the fuel was used in the supersonic dash segment of the mission where turbojets operate most efficiently. The VGTTJ aircraft design variables were not affected by DLI requirements; only L/C VTO thrust significantly changed. The effect of the design mission requirements on L/C engine nozzle exit temperature is illustrated in Figure 48. The VGTTJ exit temperature, at a given radius and dash Mach number, exceeds that of the FCE-TF by approximately 150°F. Increasing subsonic combat performance, P_S, above the study requirement has a significant impact on VGTTJ aircraft TOGW, Figure 49.

6.2.2 Multi-Mission Engine/Airframe/Requirement Interactions - Interactions between DLI and alternate mission capability and DLI TOGW were determined to illustrate potential multi-mission trade-offs. These investigations were conducted using internal fuel plus external fuel and then using internal fuel only.

Alternate mission capabilities, using external fuel, were determined for the optimum aircraft designs defined for variations in DLI mission radius and dash Mach number, Figure 50. Fighter Escort mission radius was determined using two 300 gallon external fuel tanks and Tactical Strike and Combat Air Patrol loiter time were determined using two 600 gallon fuel tanks.

Optimum designs were also defined, using internal fuel only, for a parametric range of both DLI and Fighter Escort mission radius requirements, Figure 51. These multi-mission requirements produced large variations in the airframe design variables of the VGTTJ powered aircraft, but the engine variables were not affected. As indicated in Figure 52, wing sweep and wing loading were decreased to enhance subsonic cruise lift at low values of DLI radius. As DLI radius increased, the fuel required approached that needed to meet the Fighter Escort radius and wing sweep and wing loading increased to reduce supersonic drag. The optimum engine design variables minimized supersonic dash SFC, while the VGTTJ cycle provided good subsonic cruise SFC for the Fighter Escort mission.

6.2.3 Life Cycle Cost Evaluations - The effects of DLI mission requirements on life cycle cost are shown in Figure 53 for 900 production aircraft and a 15 year operational life. Costs for the three principle LCC categories of RDT&E, Production and O&S are included as Figure 54. These cost estimates are substantially below those obtained using FCE-TF engines; reflecting the lower TOGW's achieved using VGTTJ engines.

6.3 AIRCRAFT DESIGN SELECTION - An optimized VGTTJ aircraft was selected for comparison with the FCE-TF aircraft design in terms of TOGW, performance and cost. The selected VGTTJ aircraft is described in Figure 55. This figure shows the design variables

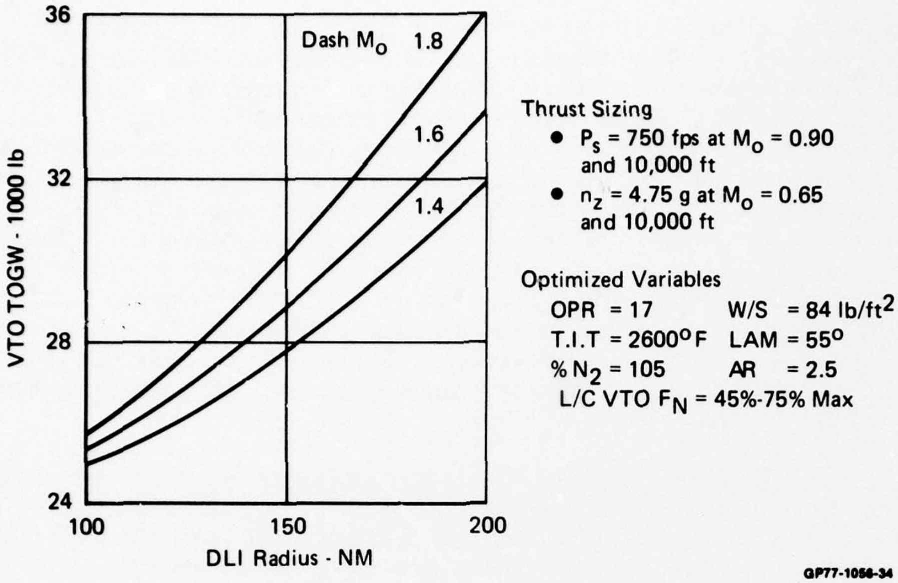

FIGURE 47
ENGINE/AIRFRAME/REQUIREMENT INTERACTIONS - DLI MISSION
Variable Geometry Turbine Turbojet (VGTTJ)

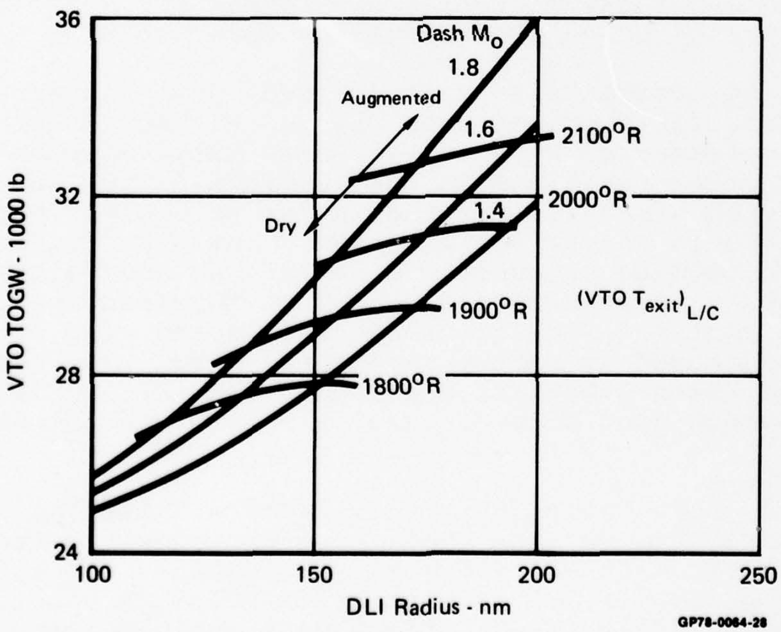

FIGURE 48
ENGINE/AIRFRAME/REQUIREMENT INTERACTIONS
VGTTJ ENGINE
L/C Engine Nozzle Exit Temperature

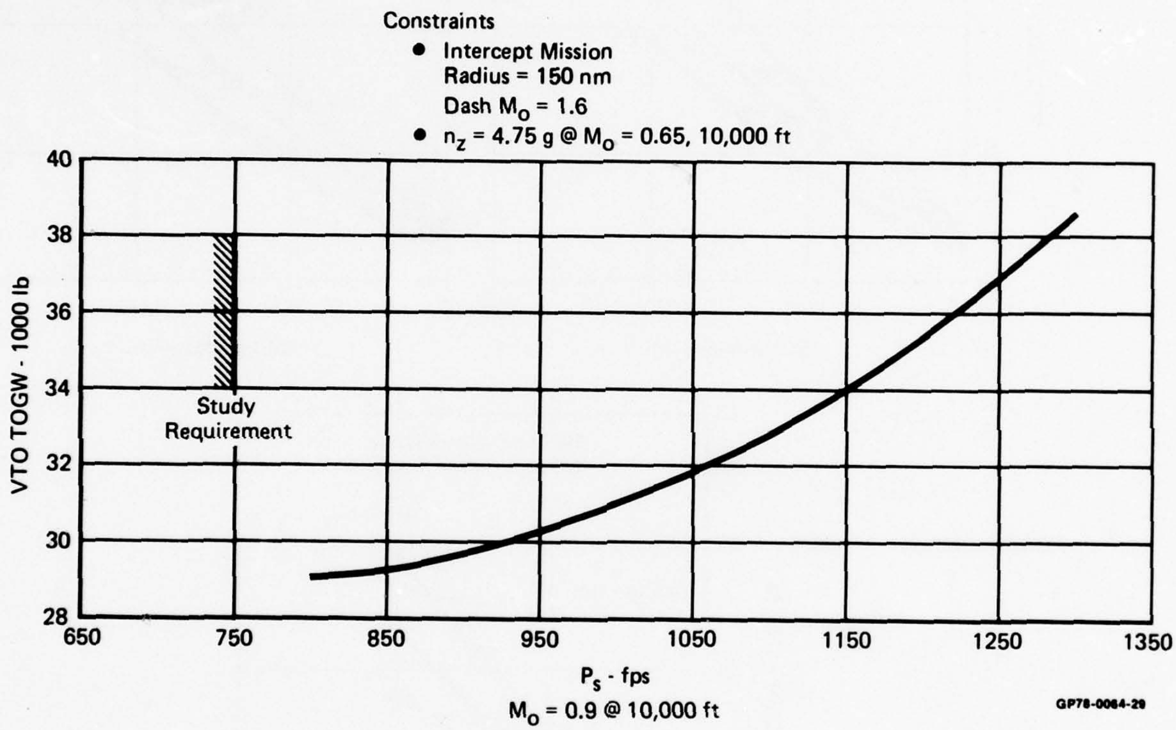

FIGURE 49
ENGINE/AIRFRAME/REQUIREMENT INTERACTIONS
VGTTJ ENGINE
Combat Performance

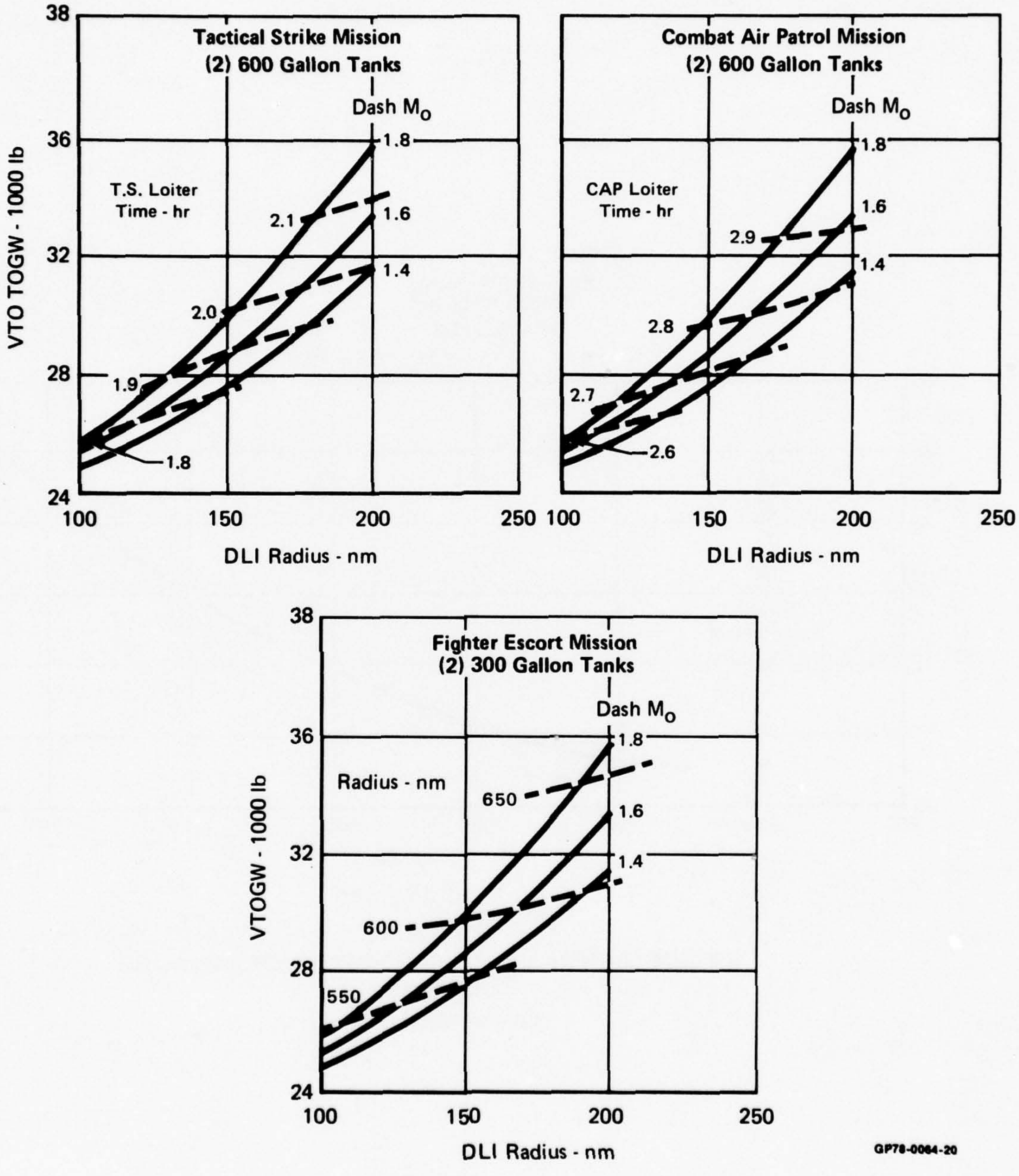

FIGURE 50
ENGINE/AIRFRAME/REQUIREMENT INTERACTIONS - MULTIMISSION
External Fuel L + L/C (VGTTJ)

Sizing Requirements

- P_s at 0.9 M_o/10,000 ft/1 g $\geq$ 750 ft/sec
- Dash M_o = 1.6/Alt = 40,000 ft
- n_{z_s} at 0.65 M_o/10,000 ft $\geq$ 4.75 g
- P_s at Dash M&H $\geq$ 0 ft/sec
- Internal Fuel Only

Optimization Variables

- OPR = 17
- TIT = 3,060
- $\%N_2$ = 105
- $F_{N_V}/F_{N_{V_{max}}}$ = 0.4-0.6
- LAM = 35-55
- WOS = 50-85
- AR = 2.5

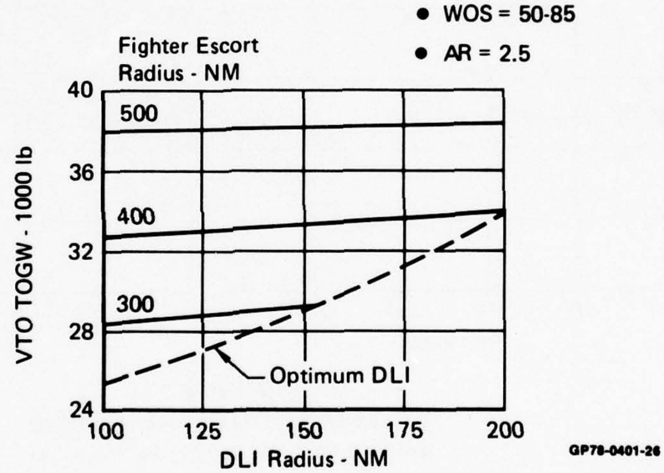

FIGURE 51
ENGINE/AIRFRAME/REQUIREMENT INTERACTIONS - MULTI-MISSION
Variable Geometry Turbine Turbojet - Internal Fuel

Sizing Requirements

- P_s at 0.9 M_o/10,000 ft/1 g ⩾ 750 ft/sec
- Dash M_o = 1.6/Alt = 40,000 ft
- n_{z_s} at 0.65 M_o/10,000 ft ⩾ 4.75 g
- P_s at Dash M&H ⩾ 0 ft/sec
- Internal Fuel Only

Optimization Variables

- OPR = 17
- T.I.T. = 3,060
- % N_2 = 105
- LAM = 35-55
- W/S = 50-85
- AR = 2.5
- $F_{N_V}/F_{N_{V_{max}}}$ = 0.4 - 0.6

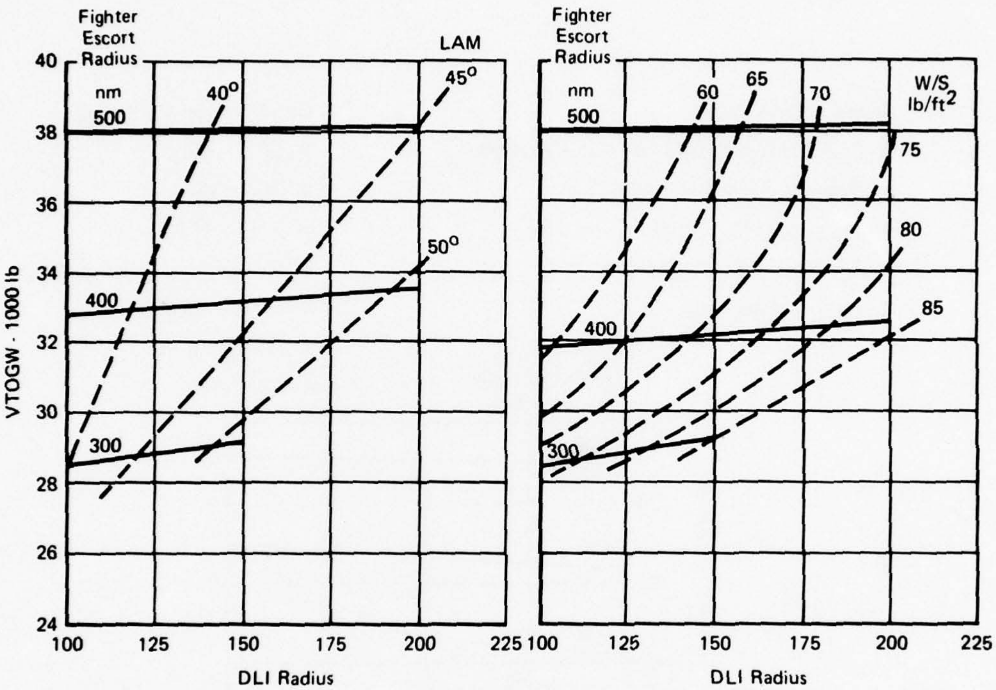

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FIGURE 52
MULTI-MISSION INTERACTIONS
Variable Geometry Turbine Turbojet

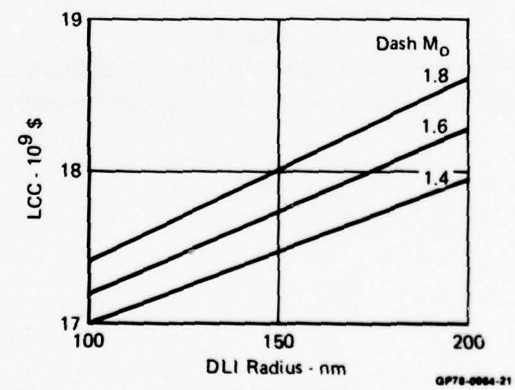

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FIGURE 53
PARAMETRIC LIFE CYCLE COST (LCC)
LIFT + LIFT/CRUISE (VGTTJ) AIRCRAFT
900 Aircraft/1976 $/15 Years

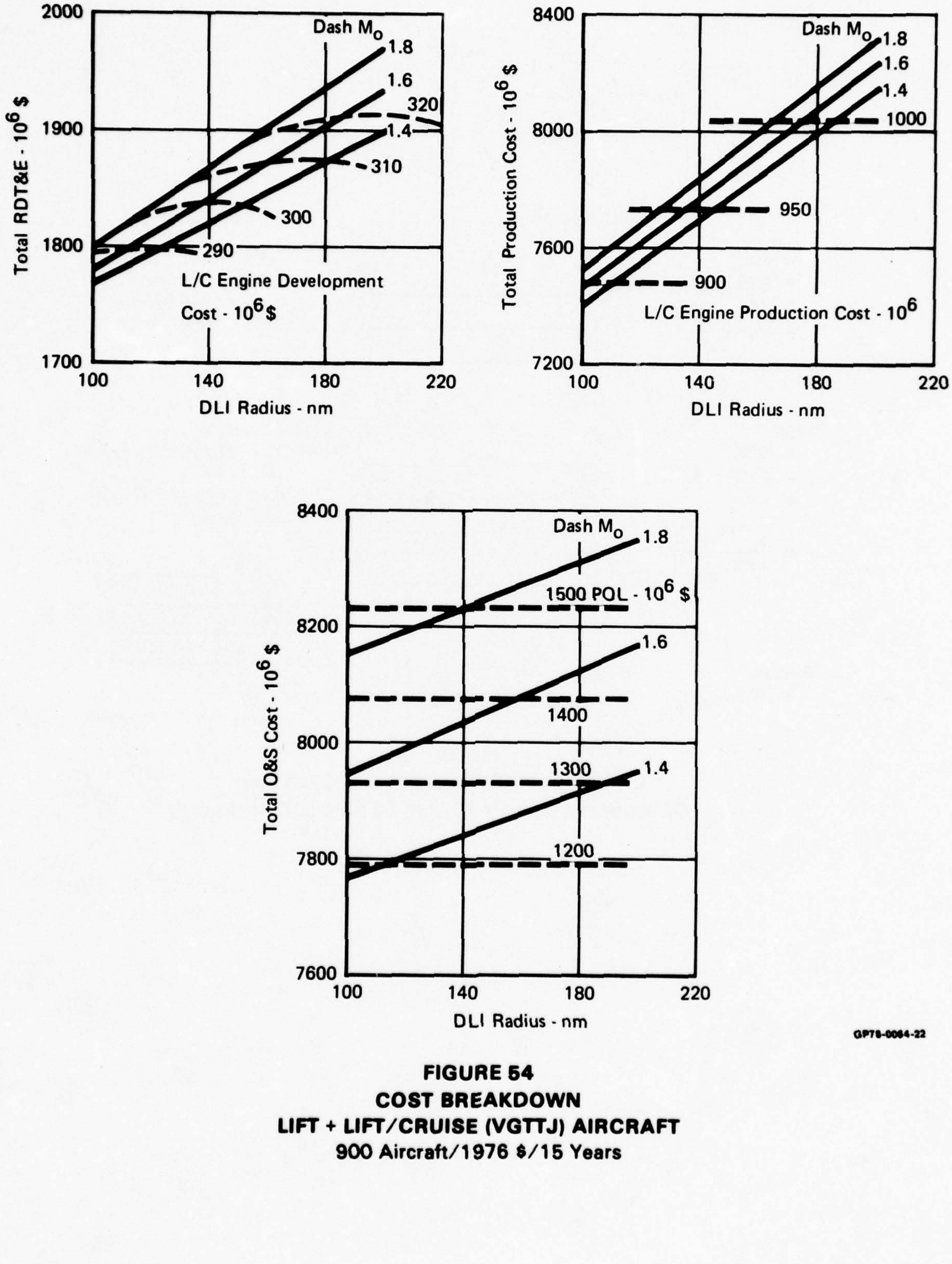
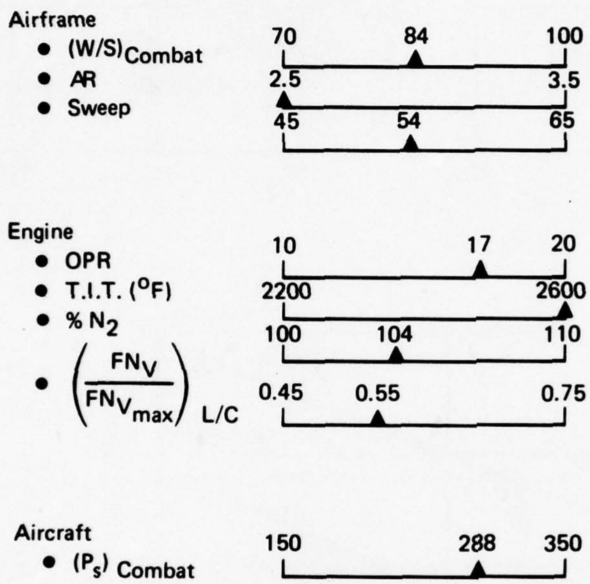


FIGURE 54
COST BREAKDOWN
LIFT + LIFT/CRUISE (VGTTJ) AIRCRAFT
900 Aircraft/1976 $/15 Years

Design Variables | **Constraints**



Fuel Sizing

- Intercept Mission Radius = 150 NM and M_o Dash = 1.6

Thrust Sizing

- P_s = 750 fps at M_o = 0.90 and 10,000 ft
- n_z = 4.75 g at M_o = 0.65 and 10,000 ft

	TOGW - lb
Search	29,100
CADE	29,135

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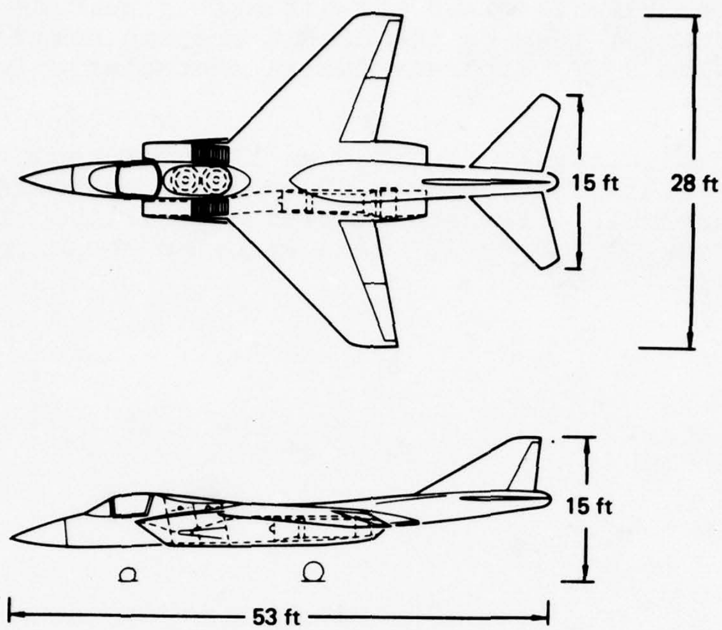
FIGURE 55
L + L/C AIRCRAFT DESIGN SELECTION
GE Variable Geometry Turbine Turbojet L/C Engines

selected to minimize TOGW and the fuel sizing and thrust sizing variables which constrained the aircraft size. As indicated, excellent agreement between the SEARCH results and V/STOL CADE was obtained. The VGTTJ aircraft design characteristics are included as Figure 56.

The VGTTJ aircraft provided an 11% TOGW reduction, relative to the FCE-TF aircraft, Figure 57, and was competitive with the FCE-TF aircraft in alternate mission capability. The LCC estimates for the VGTTJ aircraft were 9% below those for the FCE-TF aircraft, Figure 58.



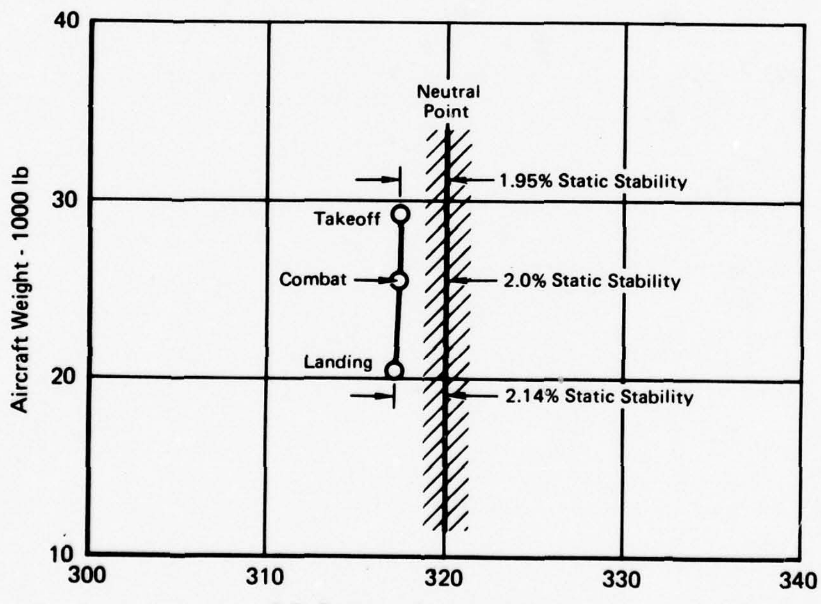
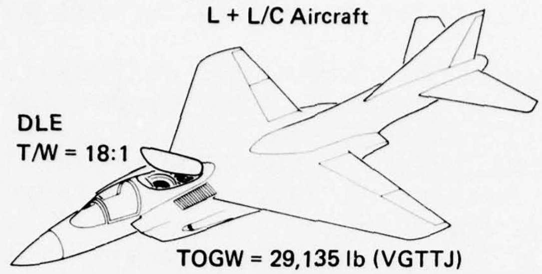


FIGURE 56
VGTTJ AIRCRAFT DESIGN CHARACTERISTICS



Performance		Required	Available (VGTTJ)	Available FCE-TF
P_s, Mach 0.90 at 10,000 ft	(fps)	750	750**	810
n_{z_s}, Mach 0.65 at 10,000 ft	(g)	4.75	4.75**	4.75**
DLI Rad (Int Fuel)	(NM)	150/VTOL	150**	150**
Fighter Escort Rad†	(NM)	400/STOVL	580	555
Tactical Strike Loiter*	(hr)	2.0/STOVL	1.95	2.0
Combat Air Patrol Loiter*	(hr)	2.0/STOVL	2.75	2.8

*(2) 600 gal. tanks **Sizing constraints †(2) 300 gal. tanks

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FIGURE 57
AIRCRAFT DESIGN SUMMARY

Selected FCE-TF Aircraft

	Millions of 1976 Dollars		
	900 Production Aircraft	600 Production Aircraft	300 Production Aircraft
RDT&E	1,943	1,943	1,943
Production	9,078	6,671	4,044
O&S	8,445	5,721	2,943
Total	**19,466**	**14,335**	**8,930**

Selected VGTTJ Aircraft

	Millions of 1976 Dollars		
	900 Production Aircraft	600 Production Aircraft	300 Production Aircraft
RDT&E	1,844	1,844	1,844
Production	7,811	5,766	3,531
O&S	7,987	5,410	2,780
Total	**17,642**	**13,020**	**8,155**

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FIGURE 58
LIFT + LIFT/CRUISE AIRCRAFT LIFE CYCLE COST

7. VARIABLE CYCLE TURBOFAN AIRCRAFT EVALUATIONS

Engine/airframe integration and performance analyses were necessary to evaluate the modulating bypass turbofan VCE concept selected in Phase I. This GE variable cycle turbofan (VCE-TF), Figure 59, is a dual rotor, mixed-flow engine incorporating a variable stator compressor, high temperature rise combustor and a variable area low pressure turbine. In addition, the engine has a forward fan driven by the low pressure turbine rotor, an aft fan driven by the high pressure turbine rotor, and two bypass airflow ducts. The bypass ducts incorporate variable area bypass injectors (VABI's) to provide for mixing the inner and outer bypass flows and for mixing the bypass flow with the core flow. The mixed flow then exits through a single exhaust nozzle. The outer bypass duct is closed and the VCE-TF operates as a conventional mixed flow turbofan during transonic and supersonic flight conditions. At part power subsonic cruise and loiter flight conditions, the inner bypass flow is modulated by a combination of aft fan stator angle closure and opening of the outer bypass duct, thus increasing the engine bypass ratio. A more detailed description of the operation of this engine can be found in the GE final report.

The FCE-TF can be used in conjunction with a lift engine or to provide airflow to a remote augmentor lift system (RALS) during VTO, Figure 59. The RALS/VCE concept has the potential to eliminate the need for separate lift engines and thus, reduce V/STOL propulsion system life cycle cost.

The VCE-TF integration and performance evaluations are discussed in Sections 7.1 and 7.2. The effect of lift engines thrust/weight on L + L/C aircraft TOGW is discussed in Section 7.3.

7.1 <u>L + L/C AIRCRAFT EVALUATIONS</u> - The VCE-TF payoff potential in a L + L/C aircraft was assessed using the airframe design and sizing constraints described in Section 5.3. The results, summarized in Figure 60, were obtained using a wing loading of 88 lb/ft^2, wing aspect ratio of 2.5, and a wing sweep of 55 degrees. The weight and performance characteristics of the FCE-TF and VGTTJ aircraft, also shown in Figure 60 for comparison, indicate competitive TOGW with increased alternate mission performance capability.

7.2 <u>L/C AIRCRAFT INTEGRATION AND PERFORMANCE EVALUATIONS</u> - The payoff potential of the RALS/VCE concept, which produces all of the powered lift necessary for VTOL, was evaluated in a L/C aircraft configuration. In this engine, the front portion of the split-fan is oversized to provide airflow to the remote augmentor lift system (RALS) for VTO. The characteristics of a typical RALS/VCE concept are shown in Figure 61. During VTO, the oversized fan and variable cycle features are used to increase engine airflow and cycle operating pressure ratio. A portion of the RALS airflow is used in a reaction control system (RCS) located in the wing, for roll control. A gimbled nozzle was used for vectoring the RALS thrust. In the conventional flight mode, the VCE is used to match the inlet and engine airflow from $M_O = 0.8$ to $M_O = 2.0$.

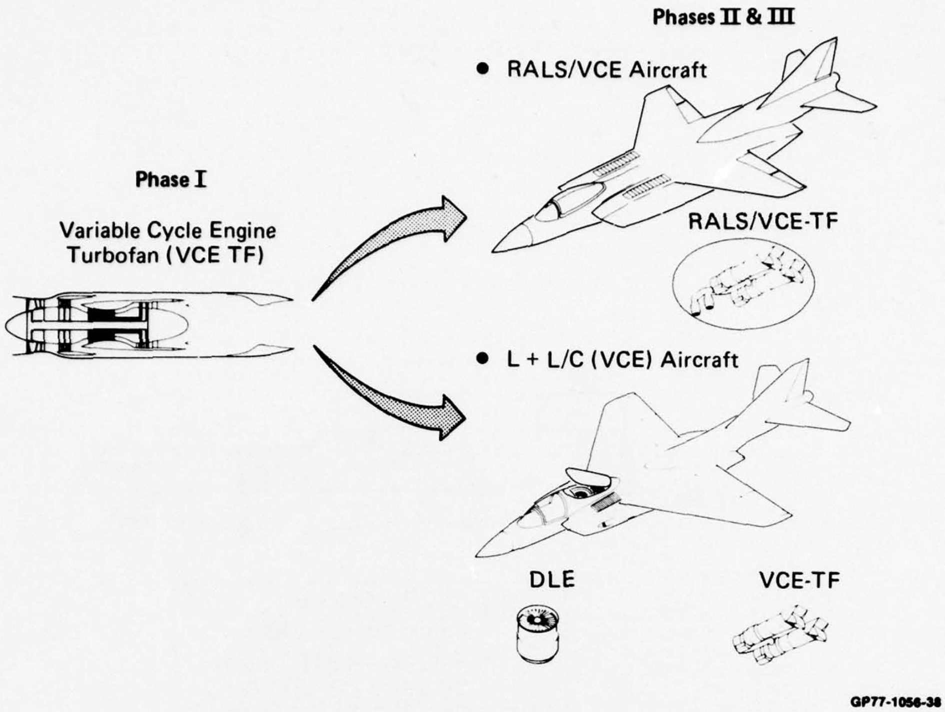

FIGURE 59
VCE-TF AIRCRAFT DESIGN EVALUATIONS

		Requirements	L + L/C Aircraft Designs FCE-TF L/C Engine	VGT-TJ L/C Engine	VCE-TF L/C Engine
• TOGW	(lb)	–	32,650	29,100	29,600
• Internal Fuel	(lb)	–	10,600	9,100	8,960
• Mission Performance					
DLT Radius (Int Fuel)	(NM)	150/VTOL	150**	150**	150**
Fighter Escort Radius†	(NM)	400/STOVL	555	580	598
Tactical Strike Loiter*	(hr)	2.0/STOVL	2.0	1.95	2.2
Combat Air Patrol Loiter*	(hr)	2.0/STOVL	2.8	2.75	3.0
• Combat Performance					
Acceleration					
Mach 0.8 to 1.6 at 35,000 ft	(sec)	90	84	89	78
Maneuver					
Mach 0.65 at 10,000 ft	(g)	4.75	4.75**	4.75**	4.75**
Specific Excess Power					
Mach 0.90 at 10,000 ft	(fps)	750	824	750	832

† (2) 300 gallon tanks
* (2) 600 gallon tanks
** Sizing constraints

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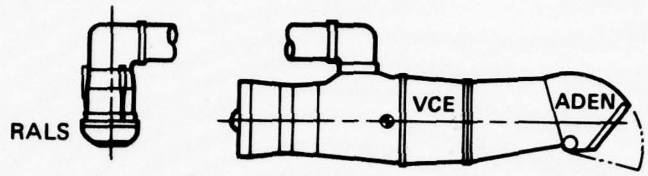
FIGURE 60
WEIGHT AND PERFORMANCE SUMMARY
L + L/C Aircraft



Variable Cycle Features
- Front and Rear VABIs
- Variable Area LP Turbine
- Double Bypass Split Fans

	Cycle Design	
	VTO	Mission
FPR	4.7	3.4
OPR	27.5	20.8
T.I.T.	3200°F	2600°F
Max. Nozzle Exit Temp	3200°F	3350°F
Max Total Engine Flow	200 lb/sec	175 lb/sec
Max RALS Flow	45 lb/sec	–
RCS Flow	16 lb/sec	–

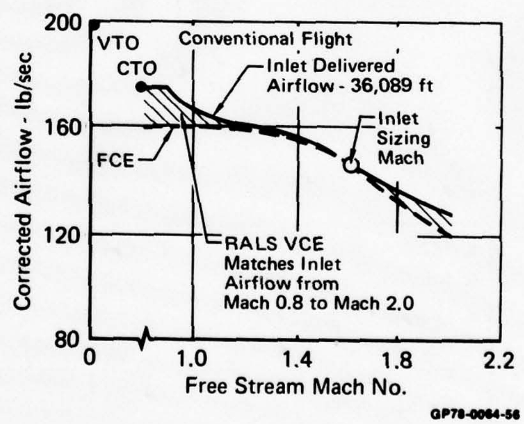


FIGURE 61
GENERAL ELECTRIC RALS VCE CONCEPT
GE16/VF-19 Study A1

The RALS/VCE is sized by VTO requirements as shown in Figure 62. The RALS/VCE is sized to produce a lift/TOGW ratio of 1.2 on a 90°F day, thus providing margin for reingestion, ground effects, and acceleration. Both the RALS and VCE are designed to operate with continuous nozzle exhaust gas temperatures of 2800°F and for short period transients to 3200°F for pitch control.

Aircraft designs using the RALS/VCE concept were found to be highly sensitive to the relative quantity of RALS and ADEN nozzle thrust used for powered lift operation. For example, an acceptable aircraft design could not be obtained using the first RALS/VCE concept (GE16/VF19-A1) provided by GE, Figure 63. For this aircraft design, the RALS supplied 25% of the total powered lift and the ADEN nozzle supplied 75%. This required that the RALS moment arm, relative to the aircraft C.G., be three times longer than the ADEN nozzle moment arm for powered lift thrust balance. The Model 2002 aircraft, Figure 63, was considered unacceptable for three major reasons; first, the aircraft could not be VTO thrust balanced while maintaining reasonable aircraft length. The weight analysis of the aircraft design indicated that the resultant powered lift thrust vector produced by the RALS and ADEN was 16 inches aft of the aircraft TOGW C.G. As a result, the moment produced by the ADEN powered lift thrust was not balanced by the moment produced by the RALS thrust. Secondly, the aerodynamic stability of the aircraft was too high, resulting in excessive trim drag. Finally, the location of the landing gear relative to the ADEN exhaust was unacceptable for VTOL operation.

Considerable airframe and engine design effort was required to obtain a viable RALS/VCE aircraft integration concept, Figure 64. This effort included evaluations of both augmented and non-augmented VCE's and assessments of the unique airflow scheduling capability of the VCE.

7.2.1 <u>RALS/Augmented VCE Evaluations</u> - Four RALS/augmented FCE's were evaluated during Phases II and III. They included ADEN/RALS thrust ratios ranging from 3 to 1.2.

The most attractive aircraft design obtained from the Phase II effort was designated the MCAIR Model 226-2008 and was designed using the GE16/VF19-D1 engine. This engine, which incorporated a modified RALS to minimize aircraft cross sectional area, had an ADEN/RALS thrust ratio equal to 1.8 for VTO. Therefore, the RALS had to be located forward of the aircraft C.G. 1.8 times further than the ADEN nozzle was located aft of the C.G. to provide powered lift thrust balance, Figure 65. In order ot obtain an aft C.G. location and still maintain an efficient aerodynamic configuration, a large quantity of fuel was located in the aft fuselage for VTO as illustrated in Figure 66. During transition from VTO to wing-borne flight, however, it was necessary to transfer fuel from the aft tanks to forward tanks to achieve the required aircraft stability margin. While such procedures are possible in advanced technology systems, they were considered undesirable.

- Size for 90°F Day Operation
- Size to F_{N_V}/TOGW = 1.2 to Provide Margin for
  - Reingestion Effects
  - Ground Effects
  - Acceleration (0.05 F_{N_V}/TOGW)
  - Control
- Use RALS/ADEN Exhaust Gas Temperature of 2800°F
- Provide Capability to Modulate Thrust for Pitch Control
  - RALS/ADEN Exhaust Gas Temperature - 2800°F - 3200°F
- Provide Bypass Airflow for Roll Control
  - 16 lb/sec Per Engine
- Provide Capability to Vector RALS Thrust for Yaw Control
  - RALS Vectoring Nozzle

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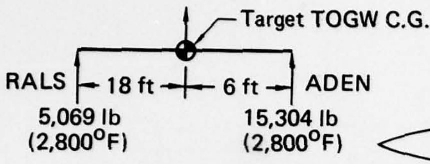
FIGURE 62

RALS/VCE POWERED LIFT SYSTEM SIZING CRITERIA

VTO Thrust Diagram



Unacceptable Design
• Unbalanced VTO Thrust Vector – F_V 16 in. Aft of C.G. • Aircraft Stability to High – 13% at VTO – 22% at VL Should be 2% - 8% • Unacceptable Landing Gear/Aden Relationship

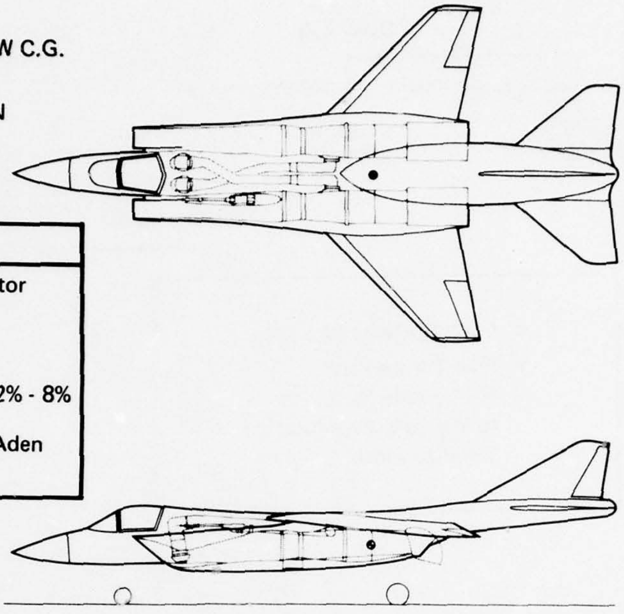


FIGURE 63
INITIAL RALS/VCE AIRCRAFT DESIGN LAYOUT
Model 226-2002 GE16/VF19-A1 RALS/VCE

	RALS Configuration	$F_{N_{ADEN}} / F_{N_{RALS}}$	Aircraft Configurations	Results
Phase II	A1	3.0	• Twin RALS/VCE • Single RALS/VCE • Twin RALS/VCE – RALS Forward and Aft	VTO Thrust Balance Could not be Achieved
	C1	1.25	• Design Sketch Only	RALS Size Prohibitive
	D1	1.8	• Twin RALS/VCE – Modified RALS Design	Balance Questionable (Model 2008)
Phase III	D2	1.2	• Twin RALS/VCE – Modified RALS Design – Compressor Bleed for RCS – T_{exit} = 2800°F	Balanced Configuration - Excess Performance (Model 2012)
	A3 (Dry Power VCE)	1.2	• Twin RALS/VCE – Modified RALS Design – T_{exit} = 2000°F	Excessive Combat Fuel Consumption $\text{Lb Fuel} = \frac{\Delta E_S \times W_F}{P_s}$
	A2 (Mini-Burner)	1.2	• Twin RALS/VCE – Modified RALS Design – T_{exit} = 2000°F	Competitive with 2012 ΔTOGW = +400 lb (Model 2014)

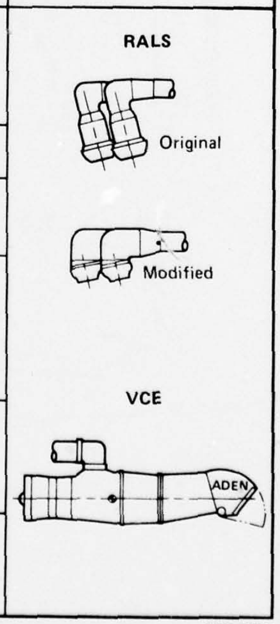


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FIGURE 64
AIRCRAFT DESIGN PROGRESSION

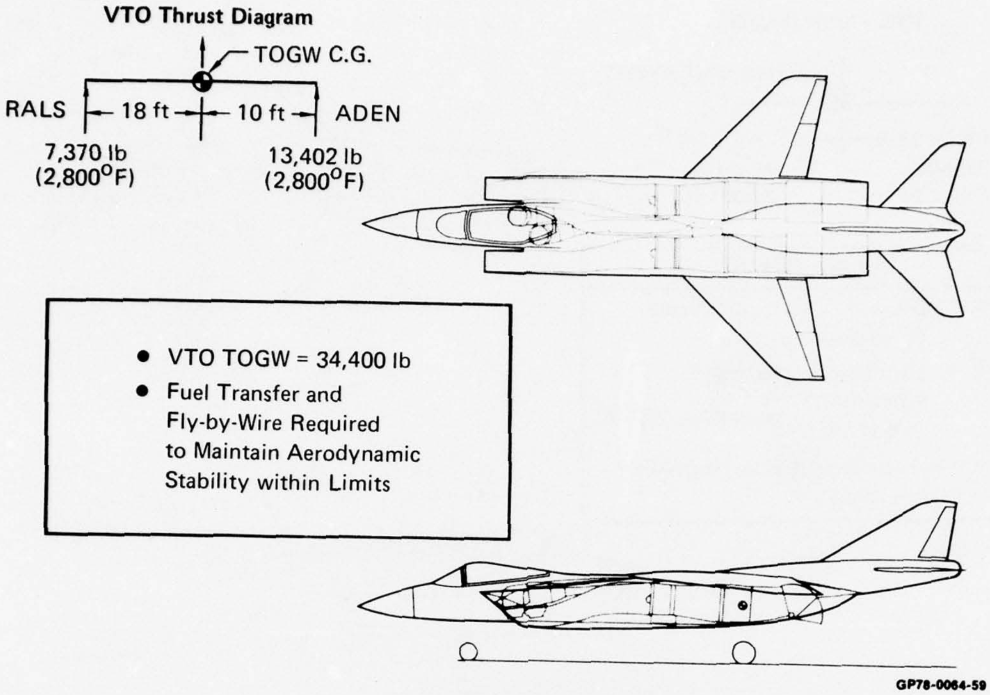

FIGURE 65
MODEL 226-2008 AIRCRAFT DESIGN USING THE GE16/VF19-D1

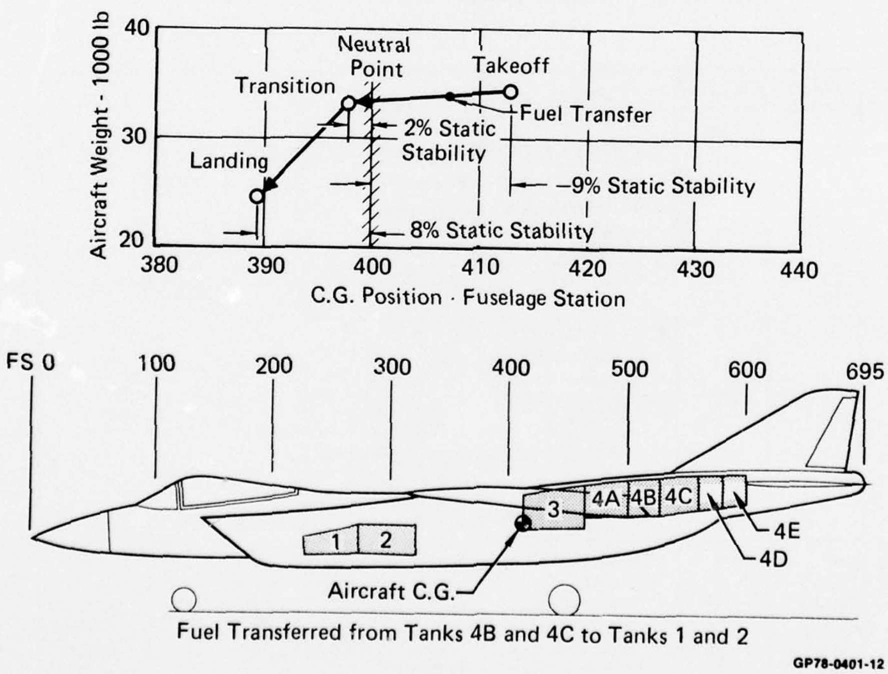

FIGURE 66
MODEL 226-2008
FUEL TRANSFER REQUIRED TO MAINTAIN C.G. TRAVEL WITHIN LIMITS

An analysis was conducted to determine the thrust split required to provide the capability to distribute the fuel around the aircraft C.G., and thus eliminate fuel transfer. A thrust ratio of 1.2 was selected as illustrated in Figure 67. General Electric achieved this ratio in the GE16/VF19-D2 RALS/augmented VCE concept. Compressor interstage bleed air was used for the RCS rather than bypass airflow as on the GE16/VF19-D1 engine. This, then, provided additional bypass airflow for the RALS, thus increased RALS thrust.

A converged aircraft design, Figure 68, was obtained, using the GE16/VF19-D2 engine. The Model 226-2012 aircraft C.G. characteristics are summarized in Figure 69. Positive aircraft stability was obtained after nominal fuel burnoff during VTO, without the use of fuel transfer.

The Model 226-2012 is competitive with the L + L/C aircraft designs in alternate mission capability and superior in combat performance. The weight and performance characteristics of these aircraft are compared in Figure 70. The engine cycle characteristics are compared in Figure 71. The RALS/VCE is sized by the VTO thrust requirements and as a result, exhibits excess thrust at combat conditions. Sizing the RALS/VCE for VTO substantially reduces acceleration time and increases P_s, but also increases TOGW. However, if the L + L/C aircraft were sized to provide an equivalent combat P_s of 1270 feet/second, the resulting TOGW's would exceed 38,000 lb as indicated in Figure 72 for the VGTTJ powered aircraft.

7.2.2 RALS/Non-Augmented VCE Evaluations - Investigations were conducted to assess aircraft sensitivity to the augmentation levels used in both the RALS and VCE. Two options were investigated: (1) removal of the VCE augmentor and (2) operating the VCE non-augmented in VTO and reducing the maximum VTO exhaust gas temperature of both the RALS and VCE from 2800°F to 2000°F.

A converged aircraft design could not be obtained with a RALS/VCE engine for which the VCE afterburner had been eliminated. The non-augmented VCE is comapred with its augmented counterpart in Figure 73. In addition to decreasing engine length and weight the RALS thrust was increased by 26% as the airflow previously used to cool the ADEN nozzle in the augmented design was available for use in the RALS with this concept. However, due to operating the VCE dry, total VTO thrust was reduced by about 15%. Prohibitive combat fuel requirements prevented aircraft design convergence with the GE16/VF19-A3, dry VCE, concept. Supersonic thrust was significantly reduced by operating the FCE non-augmented and, as a result, increased combat fuel requirements prohibitively. Specifically, combat fuel was defined by:

$$\text{Combat Fuel} = \frac{E_h \dot{W}_f}{P_s} \text{ lb} \qquad M = 1.6 \text{ @ } 40\text{K}$$

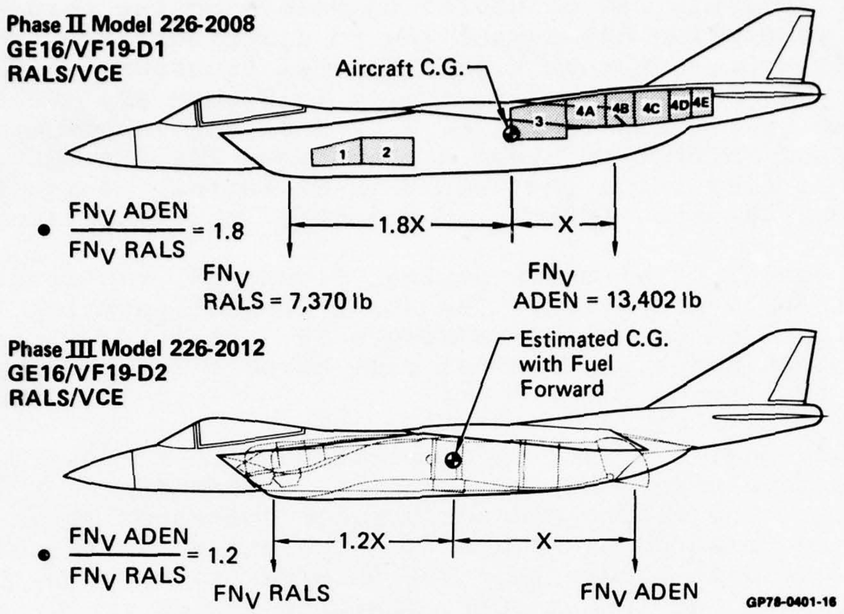

FIGURE 67
AUGMENTED RALS/VCE EVALUATION

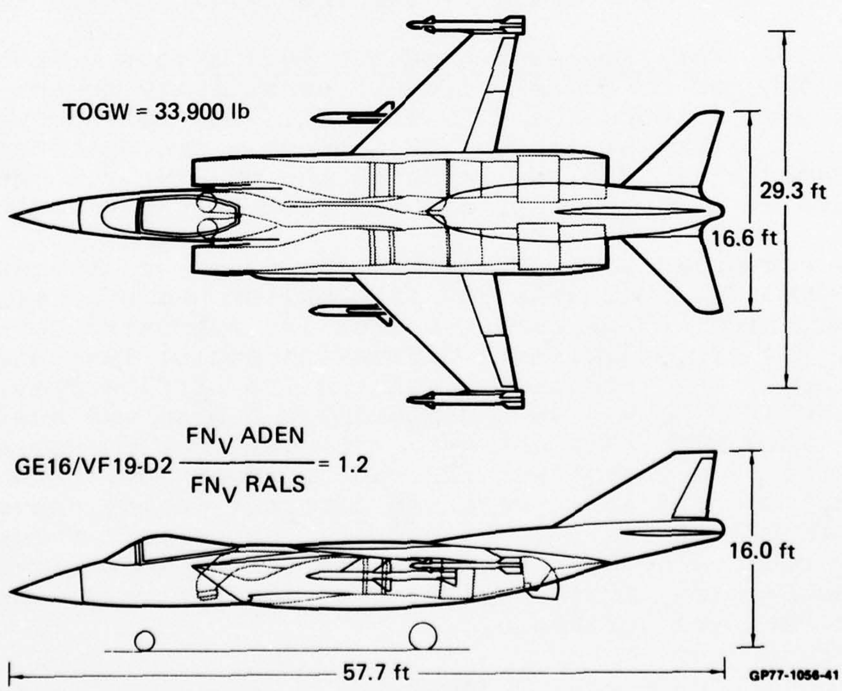

FIGURE 68
MODEL 226-2012
RALS/VCE

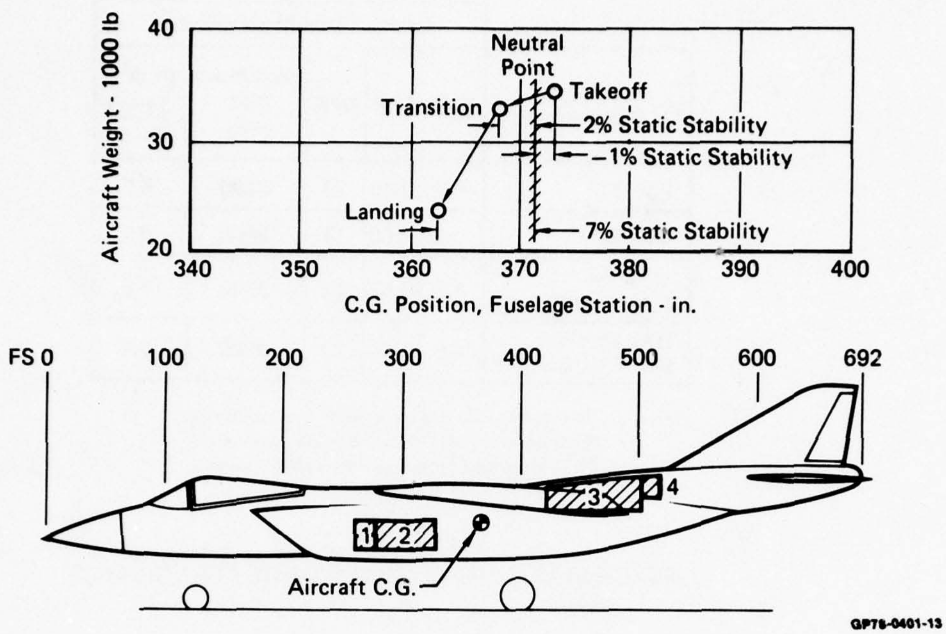

FIGURE 69
MODEL 226-2012
IMPROVED THRUST SPLIT - NO FUEL TRANSFER REQUIRED
RALS/VCE
TOGW = 33,900 Lb

	Requirements	L + L/C Aircraft Designs: FCE-TF L/C Engine	L + L/C Aircraft Designs: VGT-TJ L/C Engine	L + L/C Aircraft Designs: VCE-TF L/C Engines	RALS/VCE Aircraft (Model 2012)
• TOGW (lb)	–	32,650	29,100	29,600	33,900
• Internal Fuel (lb)	–	10,600	9,100	8,960	10,100
• Mission Performance					
DLI Radius (Int Fuel) (NM)	150/VTOL	150**	150**	150**	150**
Fighter Escort Radius† (NM)	400/STOVL	555	580	598	570
Tactical Strike Loiter* (hr)	2.0/STOVL	2.0	1.95	2.2	2.0
Combat Air Patrol Loiter* (hr)	2.0/STOVL	2.8	2.75	3.0	2.7
• Combat Performance					
Acceleration					
Mach 0.8 to 1.6 at 35,000 ft (sec)	90	84	89	78	52
Maneuver					
Mach 0.65 at 10,000 ft (g)	4.75	4.75**	4.75**	4.75**	4.95
Specific Excess Power					
Mach 0.90 at 10,000 ft (fps)	750	824	750	832	1,270

† (2) 300 gallon tanks
* (2) 600 gallon tanks
** Sizing constraints

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FIGURE 70
AIRCRAFT WEIGHT AND PERFORMANCE SUMMARY

L/C Engine Designation	Engine Cycle Characteristics				
	FPR	BPR	OPR	Maximum TIT (^{o}F)	VTO[3] Thrust/Weight
FCE-TF[1]	4.0	0.60	27	3180	6.7
VGTTJ[2]	–	0.00	13	2600	6.7
VCE-TF GE16/VVCE1-A1	4.0	0.50	24	3200	6.6
RALS/VCE GE16/VVCE5-D2	4.0	0.95	28	3200	6.4

Notes: (1) Obtained from GE parametric turbofan deck
(2) Obtained from GE parametric turbojet deck
(3) Based on 90^{o} F day and 97% inlet recovery

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FIGURE 71
LIFT/CRUISE ENGINE CYCLE CHARACTERISTICS

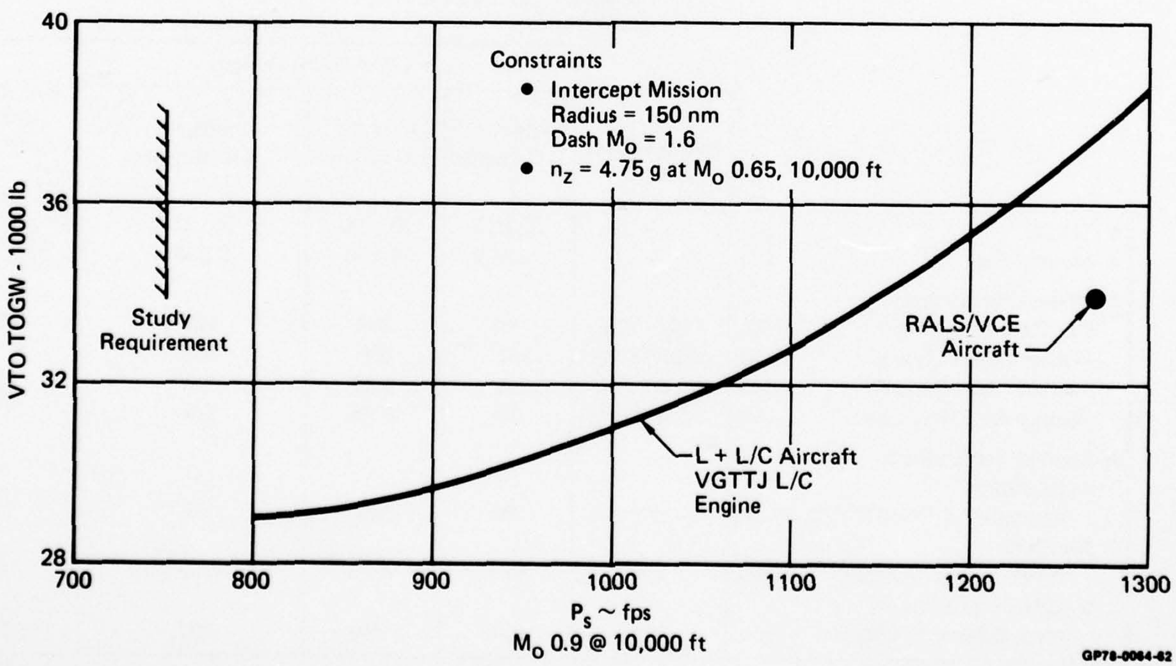

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FIGURE 72
EFFECT OF COMBAT PERFORMANCE CAPABILITY ON AIRCRAFT TOGW

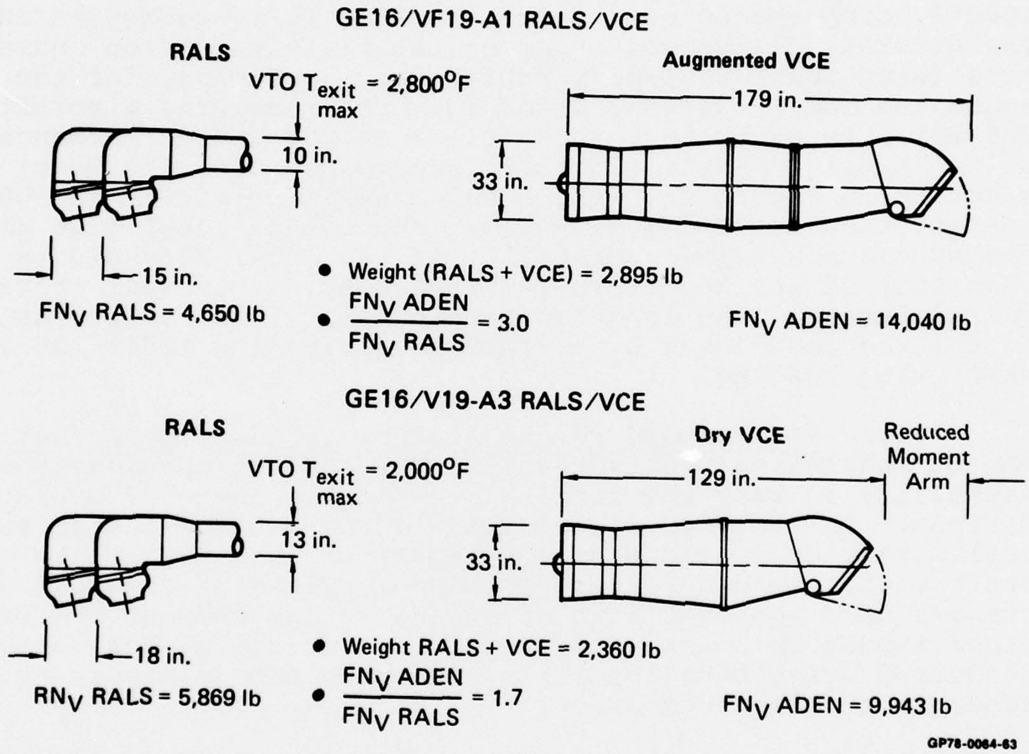

FIGURE 73
EVALUATION OF A NONAUGMENTED RALS/VCE

where: $\dot{E}_h$ = Equivalent combat energy, 32,000 ft
$\dot{W}_f$ = Fuel flow rate at maximum power, lb/sec
P_s = Specific excess power, ft/sec (function of thrust minus aircraft drag)

Decreasing VCE augmentation reduces the P_s at $M_o = 1.6$ at 40,000 feet more rapidly than fuel flow decreases and, thus, significantly increases combat fuel requirements.

A converged aircraft design was obtained with a RALS/VCE engine for which the FCE had limited augmentation capability in the forward flight mode. This limited augmentation FCE, designated the "mini-burner" VCE, used an afterburner temperature rise of 1000°F, compared to over 2000°F for the fully augmented engine. The aircraft design was based on the airframe design characteristics (wing loading, aspect ratio, etc.) optimized for the fully augmented Model 226-2012 aircraft. The resulting aircraft, Model 226-2014, is shown in Figure 74. A weight and performance summary of the Model 226-2014 aircraft is compared with the Model 226-2012 aircraft in Figure 75. The Model 226-2014 aircraft is 800 lb heavier than the Model 226-2012. The combat accel time and specific excess power (P_s) capability of the Model 226-2014 is lower than that of the Model 226-2012; however, it is well above the required levels. The load factor capability can readily be increased to the required level by slightly reducing the Model 226-2014 aircraft wing loading.

7.2.3 <u>VCE Forward Flight Airflow Scheduling Evaluations</u> - The GE modulating bypass turbofan VCE concept provides the unique capability to vary the airflow over a wide range of operating conditions. GE provided engines with three airflow schedules for preliminary evaluations of the impact of this capability on aircraft mission and combat performance. These airflow schedule changes were achieved with no engine design changes and with only minor impact on nozzle size. Airflow scheduling evaluations were conducted using both the fully augmented and "mini-burner" VCE concepts as discussed below.

<u>Fully Augmented VCE Airflow Scheduling Evaluations</u> - The impact of airflow scheduling for the fully augmented VCE was evaluated using the Model 226-2012 aircraft design. The three airflow schedules provided by GE are shown in Figure 76 for a VCE sized by a 34" fan diameter. The nominal schedule represents the airflow used to define the initial RALS/VCE aircraft design. The high airflow schedule was established based on the combat specific excess power requirement at 0.9 M_o at 10,000 feet and the 1.6 M_o, 40,000 feet dash condition. The low flow schedule was estimated to be that airflow necessary to achieve the required combat acceleration time of 90 seconds from 0.8 M_o to 1.6 M_o at 35,000 feet. Aircraft TOGW varied only from 33,800 lb to 34,000 lb for the three schedules.

Aircraft mission and combat performance capabilities were determined for each airflow schedule and are compared in Figure 77.

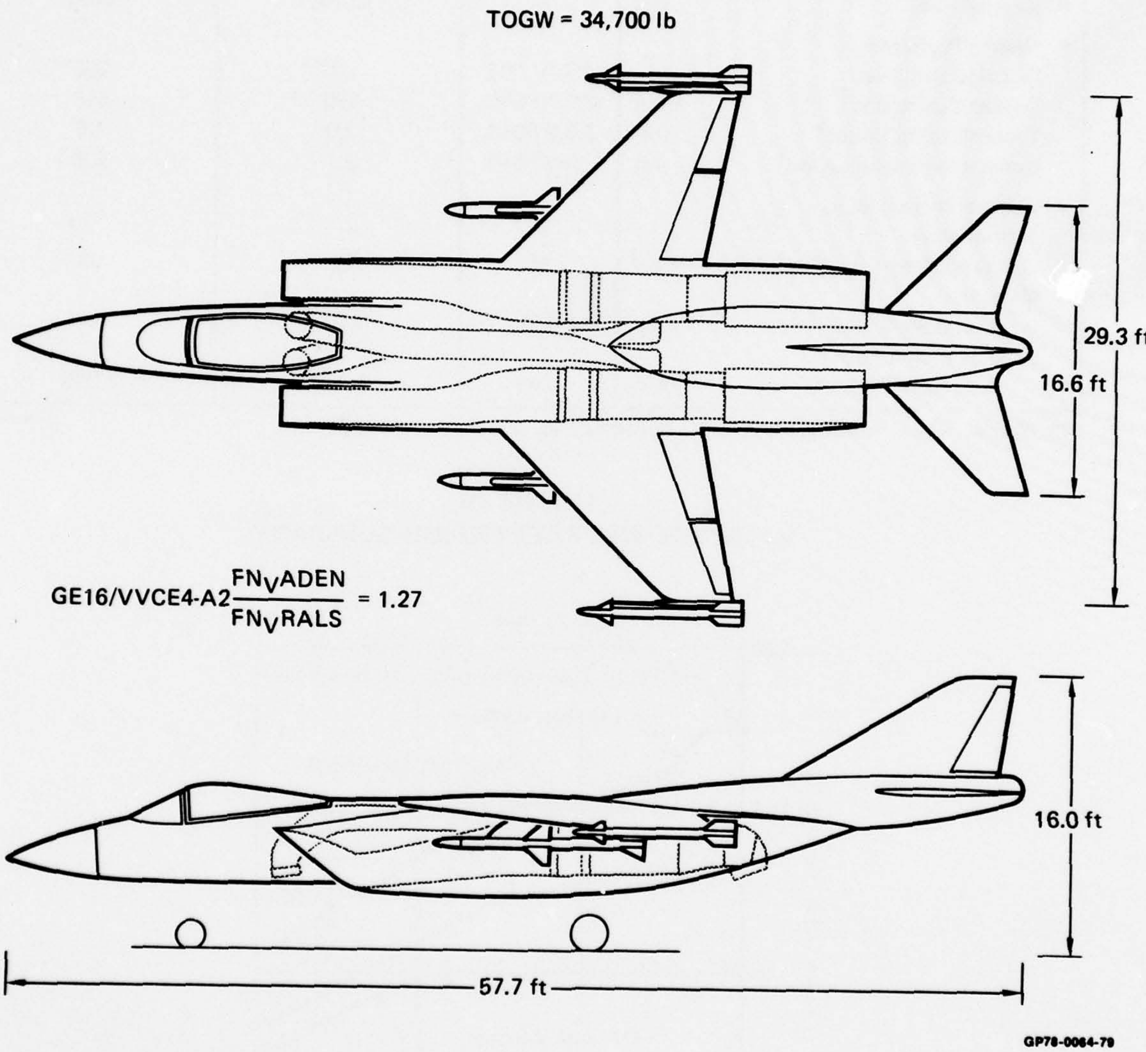

FIGURE 74
MODEL 2014
"MINI-BURNER" RALS/VCE

		Requirements	RALS/VCE Aircraft Model 2012 Fully Augmented VTO T_{exit} = 2800°F	RALS/VCE Aircraft Model 2014 "Mini-Burner" VTO T_{exit} = 2000°F
• TOGW	(lb)	–	33,900	34,700
• Internal Fuel	(lb)	–	10,100	10,000
• Mission Performance				
DLI Rad (Int Fuel)	(nm)	150/VTOL	150**	150**
Fighter Escort Rad†	(nm)	400/STOVL	570	540
Tactical Strike Loiter*	(hr)	2.0/STOVL	2.0	1.8
Combat Air Patrol Loiter*	(hr)	2.0/STOVL	2.7	2.5
• Combat Performance				
Acceleration				
Mach 0.8 to 1.6 @ 35,000 ft	(sec)	90	52	68
Maneuver				
Mach 0.65 @ 10,000 ft	(g)	4.75	4.95	4.7
Specific Excess Power				
Mach 0.90 @ 10,000 ft	(fps)	750	1,270	1,095

*(2) 600 gal. tanks **Sizing constraints †(2) 300 gal. tanks

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FIGURE 75
RALS/VCE AIRCRAFT DESIGN SUMMARY

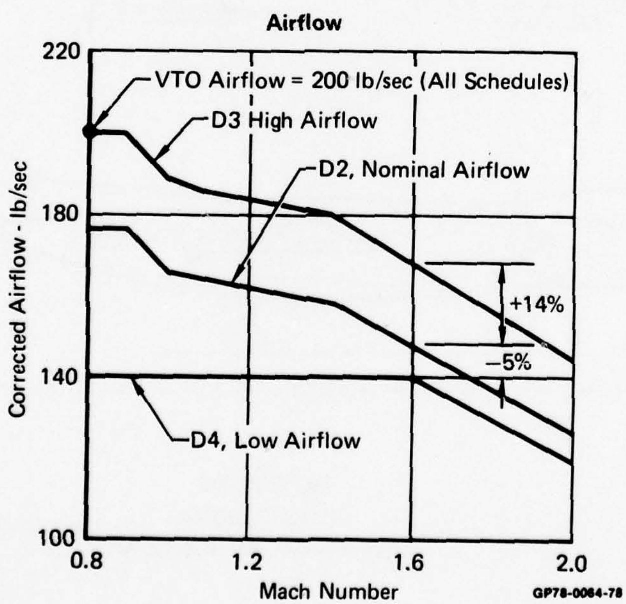

FIGURE 76
AIRFLOW SCHEDULING - FULLY AUGMENTED VCE
Altitude = 36,089 Ft

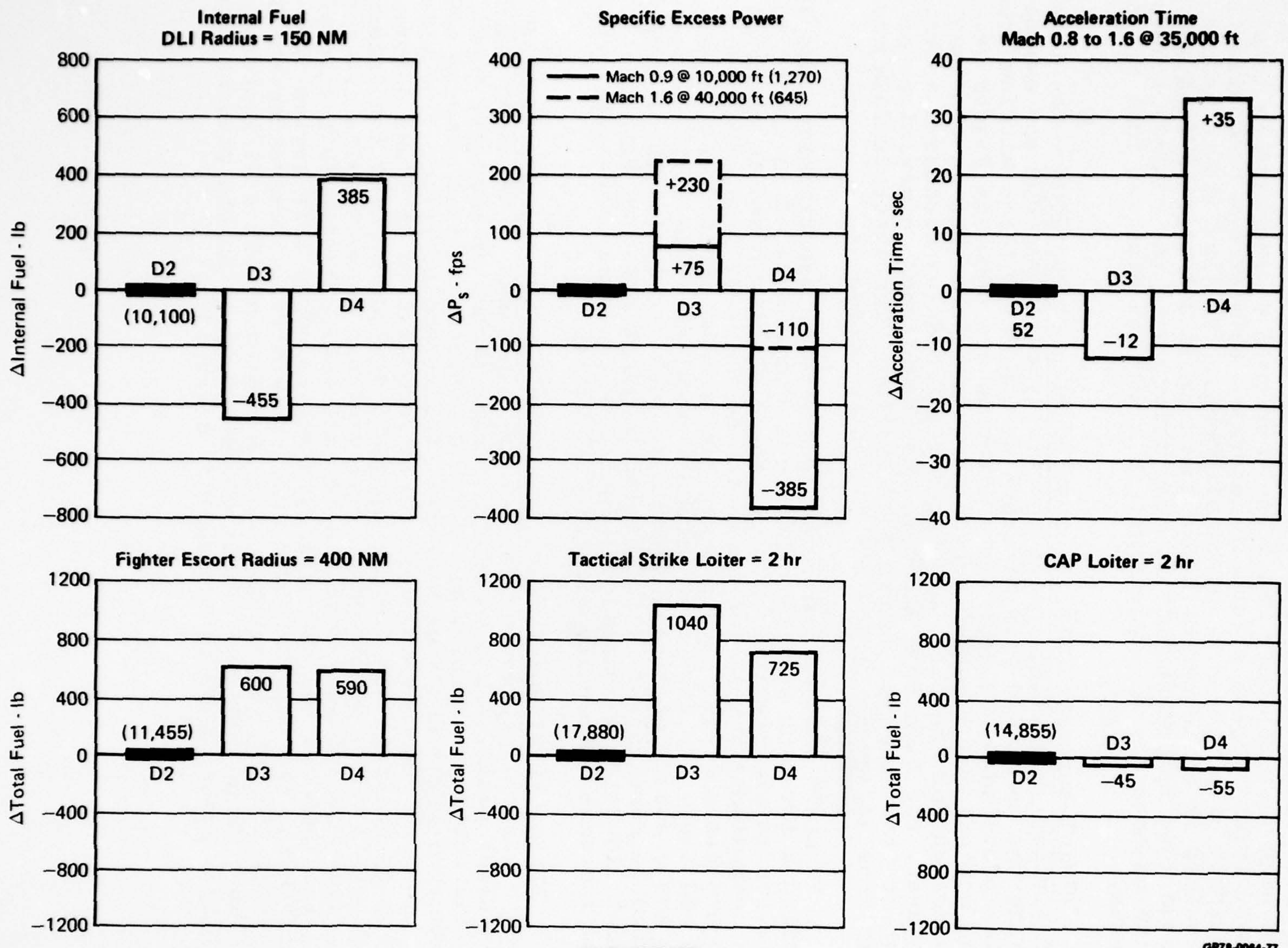

FIGURE 77
AUGMENTED RALS/VCE
Airflow Scheduling Study Summary

The high flow schedule: (1) resulted in approximately a 5% reduction in internal fuel to achieve a 150 NM DLI radius, (2) improved specific excess power, and (3) reduced acceleration time. However, the high flow schedule resulted in up to a 6% increase in total fuel, internal plus external, necessary to meet the predominantly subsonic alternate mission requirements. The low flow schedule resulted in an increase in the quantity of DLI mission fuel and reductions in combat performance, relative to the nominal schedule, with essentailly no improvement in alternate missions fuel requirements.

"Mini-Burner" VCE Airflow Scheduling Evaluations - The impact of airflow scheduling for the partially augmented VCE was evaluated using the Model 226-2014 aircraft design. The three airflow schedules provided by GE for this evaluation are shown in Figure 78. The nominal and low flow schedules were established in the same manner as for the fully augmented VCE schedules discussed above. However, the high flow schedule was established to maximize the thrust available for combat acceleration. The aircraft TOGW varied from 34,400 to 34,700 for the three schedules.

Aircraft mission and combat performance capabilities were determined for each airflow schedule and are compared in Figure 79. Similar to the previous results, the high flow schedule resulted in approximately a 5% reduction in the DLI fuel load, improved supersonic specific excess power and reduced acceleration time. In addition, the high flow schedule resulted in an 8%-10% increase in the quantity of alternate mission fuel required. The low flow schedule results were also similar to those obtained with the Model 226-2012, increased DLI fuel load, reduced combat performance and increased alternate mission fuel loads.

7.3 EFFECT OF DIRECT LIFT ENGINE TECHNOLOGY ON L + L/C AIRCRAFT TOGW - Direct lift engine technology, expressed in terms of thrust-to-weight ratio, can have a significant impact on aircraft TOGW. As indicated previously, the L + L/C analyses in this program were conducted using DLE's with an 18:1 thrust/weight ratio. The effect of reducing DLE thrust/weight ratio from 18:1 to 15:1 was determined by resizing the L + L/C aircraft designs to meet the Intercept mission and performance requirements. These results are shown in Figure 80 and in Appendix C, Figure C-6. The RALS/VCE aircraft is also included for comparison, since reducing lift engine T/W ratio makes the RALS/VCE even more competitive. Decreasing the T/W ratio of the DLE to 15:1 resulted in approximately a 3% increase in design mission TOGW and slight decreases in alternate mission capability. Combat performance was not affected.

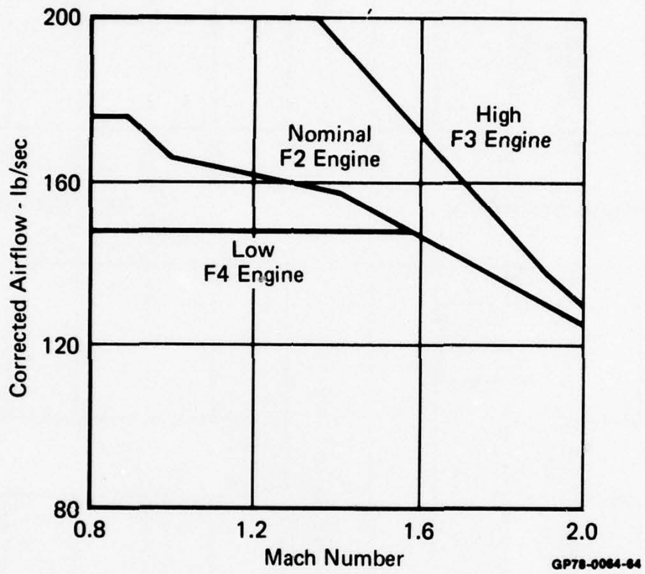

FIGURE 78
RALS/"MINI-BURNER" VCE AIRFLOW SCHEDULES
GE16/VVCE6-F Series Engine
Altitude = 36,089 Ft

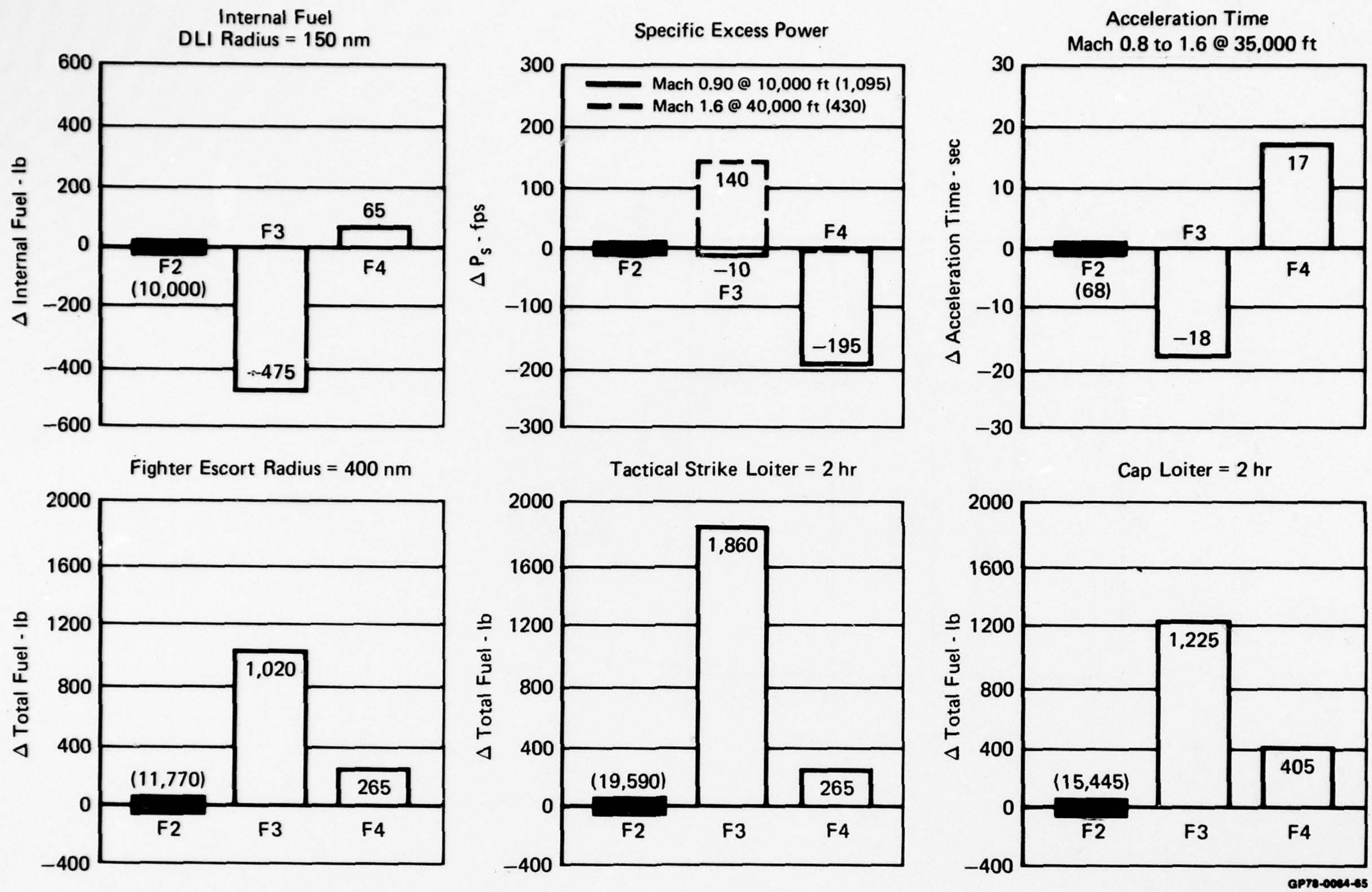

FIGURE 79
RALS/"MINI-BURNER" VCE AIRFLOW SCHEDULING STUDY SUMMARY
Model 226-2014

AD-A053 361 MCDONNELL AIRCRAFT CO ST LOUIS MO F/G 21/5
VARIABLE CYCLE ENGINE EVALUATIONS FOR SUPERSONIC V/STOL FIGHTER--ETC(U)
APR 78 J E CUPSTID, D G GLENNIE N00140-75-C-0034

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		Requirement	L + L/C Aircraft Designs						RALS/VCE Aircraft (Model 2012)
			DLE T/W = 18			DLE T/W = 15			
			FCE-TF	VGTTJ	VCE-TF	FCE-TF	VGTTJ	VCE-TF	
• TOGW	(lb)	–	32,650	29,100	29,600	33,515	29,915	30,400	33,900
• Internal Fuel	(lb)	–	10,600	9,100	8,960	10,835	9,300	9,180	10,100
• Mission Performance									
DLI Rad (Int Fuel)	(nm)	150/VTOL	150**	150**	150**	150**	150**	150**	150**
Fighter Escort Rad†	(nm)	400/STOVL	555	580	598	548	574	590	570
Tactical Strike Loiter*	(hr)	2.0/STOVL	2.0	1.95	2.2	2.0	1.9	2.20	2.0
Combat Air Patrol Loiter*	(hr)	2.0/STOVL	2.8	2.75	3.0	2.8	2.7	2.95	2.7
• Combat Performance									
Acceleration									
Mach 0.8 to 1.6 @ 35,000 ft	(sec)	90	84	89	78	84	88	78	52
Maneuver									
Mach 0.65 @ 10,000 ft	(g)	4.75	4.75**	4.75**	4.75	4.75	4.75**	4.75**	4.95
Specific Excess Power									
Mach 0.90 @ 10,000 ft	(fps)	750	824	750**	832	825	750	832	1,270

†(2) 300 gallon tanks
*(2) 600 gallon tanks
**Sizing constraints

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FIGURE 80
EFFECT OF LIFT ENGINE THRUST/WEIGHT ON AIRCRAFT TOGW

8. VCE PAYOFF ASSESSMENTS

VCE payoffs were assessed in terms of TOGW, life cycle cost, performance and operational flexibility. General Electric estimated VCE-TF engine costs higher than those for FCE-TF and VGTTJ engines of comparable size. For example, the RDT&E and production costs of a VCE-TF were estimated to be 18% and 11% higher, respectively, than a FCE-TF engine sized to the same sea level static thrust. Therefore, for the FCE-TF to be cost effective, these higher engine related costs must be offset by reduced airframe and fuel costs, or, the VCE-TF must provide increased performance and/or operational flexibility. The FCE payoff assessments were conducted using the results obtained from the fixed cycle turbofan, variable geometry turbine turbojet and variable cycle turbofan engine/airframe evaluations. The VCE payoffs were assessed relative to the L + L/C aircraft powered by advanced technology fixed cycle turbofan (FCE-TF) lift/cruise engines and advanced technology lift engines. The TOGW of this FCE-TF aircraft was 32,650 lb when sized to a 150 NM DLI mission radius and representative combat performance requirements, and its LCC was estimated to be in excess of 19 billion dollars.

8.1 <u>AIRCRAFT TAKE-OFF GROSS WEIGHT</u> - Substantial TOGW payoffs were obtained using either VGTTJ or VCE-TF engines in L + L/C aircraft, Figure 81, but the RALS/VCE aircraft was approximately 4% heavier than the FCE-TF aircraft.

The L + L/C aircraft TOGW payoffs were the result of reduced fuel, propulsion system and airframe weight. For example, the variable geometry turbine turbojet produced a TOGW saving of more than 3500 lb when compared to a fixed cycle turbofan-powered aircraft sized to perform the same DLI mission. As shown in Figure 82, about 1500 lb of that TOGW reduction was attributed to reduced fuel requirement with the remainder propulsion system and structural weight reductions. A detailed breakdown of the specific engine operating characteristics which produced these weight savings is shown in Figure 83.

The VGTTJ produces lower SFC at the DLI dash and combat conditions than does the FCE-TF. The maximum power combat SFC difference results in a TOGW saving of 560 lb. At the dash condition, the throttle setting is established where propulsive force is equal to aircraft drag. Consequently, at the dash throttle setting the uninstalled SFC of the VGTTJ is about 0.2 lower than that of the FCE-TF and a 1370 lb TOGW increment is obtained.

The variable geometry features of the VGTTJ are primarily used to minimize subsonic cruise SFC. As shown in Figure 83, the FCE-TF exhibits significantly lower SFC at intermediate power than the VGTTJ. As power is reduced, however, the variable turbine stator flow area is increased in direct proportion to the decreasing turbine inlet temperature. This procedure keeps the engine operating at the intermediate power pressure ratio and airflow and, with the reduced TIT, SFC decreases with throttle setting. When the maximum

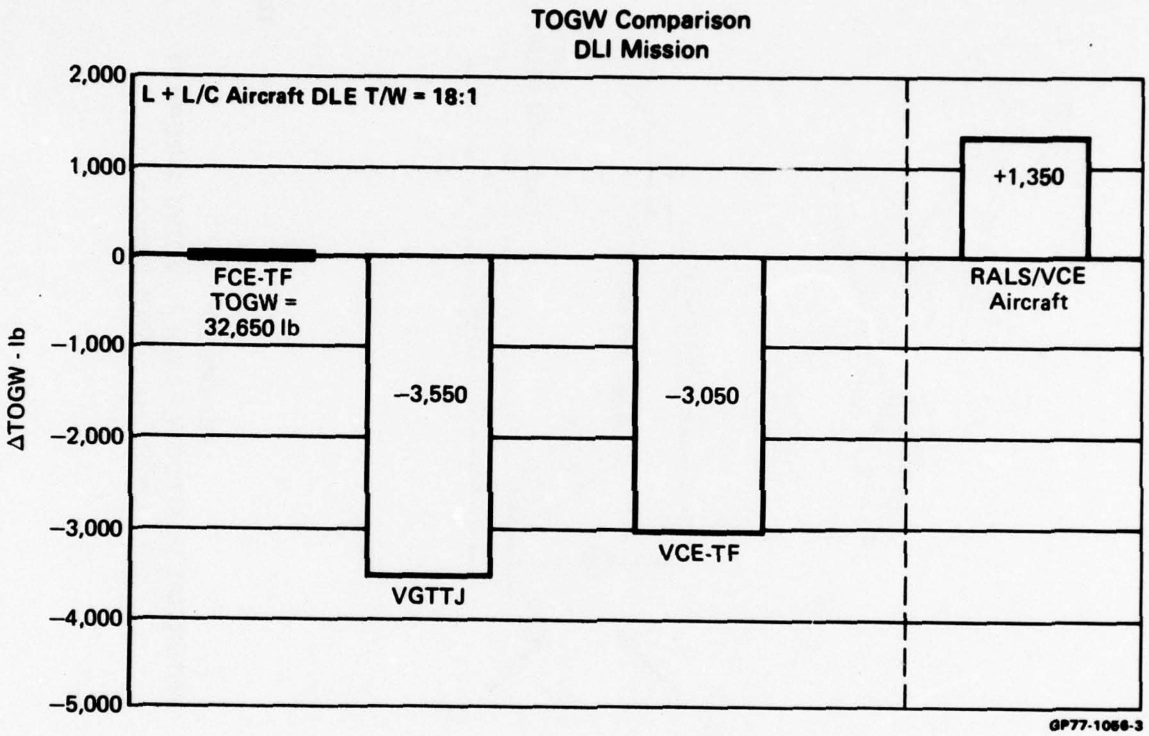


FIGURE 81
VCE PAYOFF ASSESSMENT - TOGW

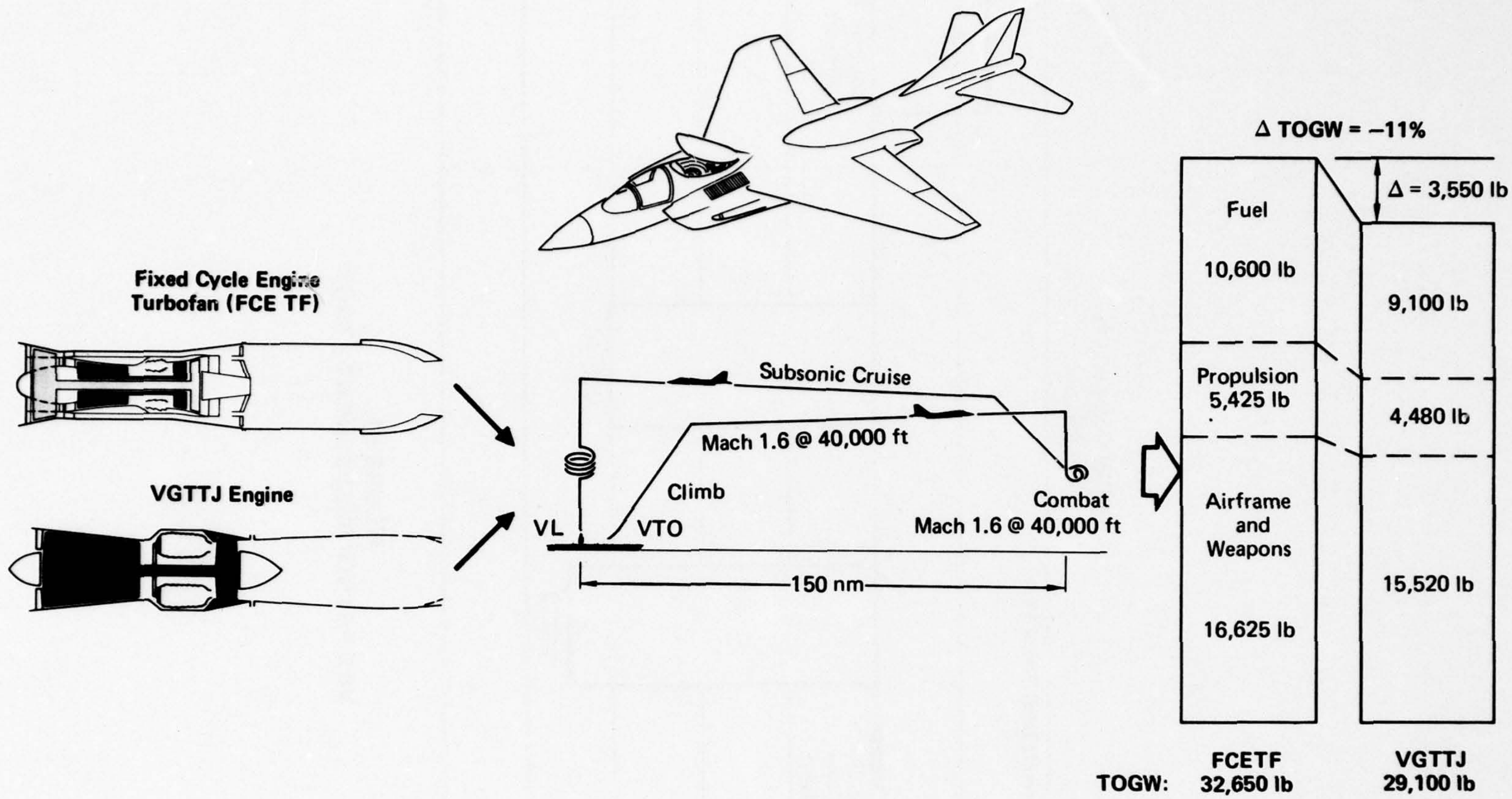


FIGURE 82
POTENTIAL VCE TOGW PAYOFF - VGTTJ AIRCRAFT
Lift + Lift/Cruise V/STOL Fighters

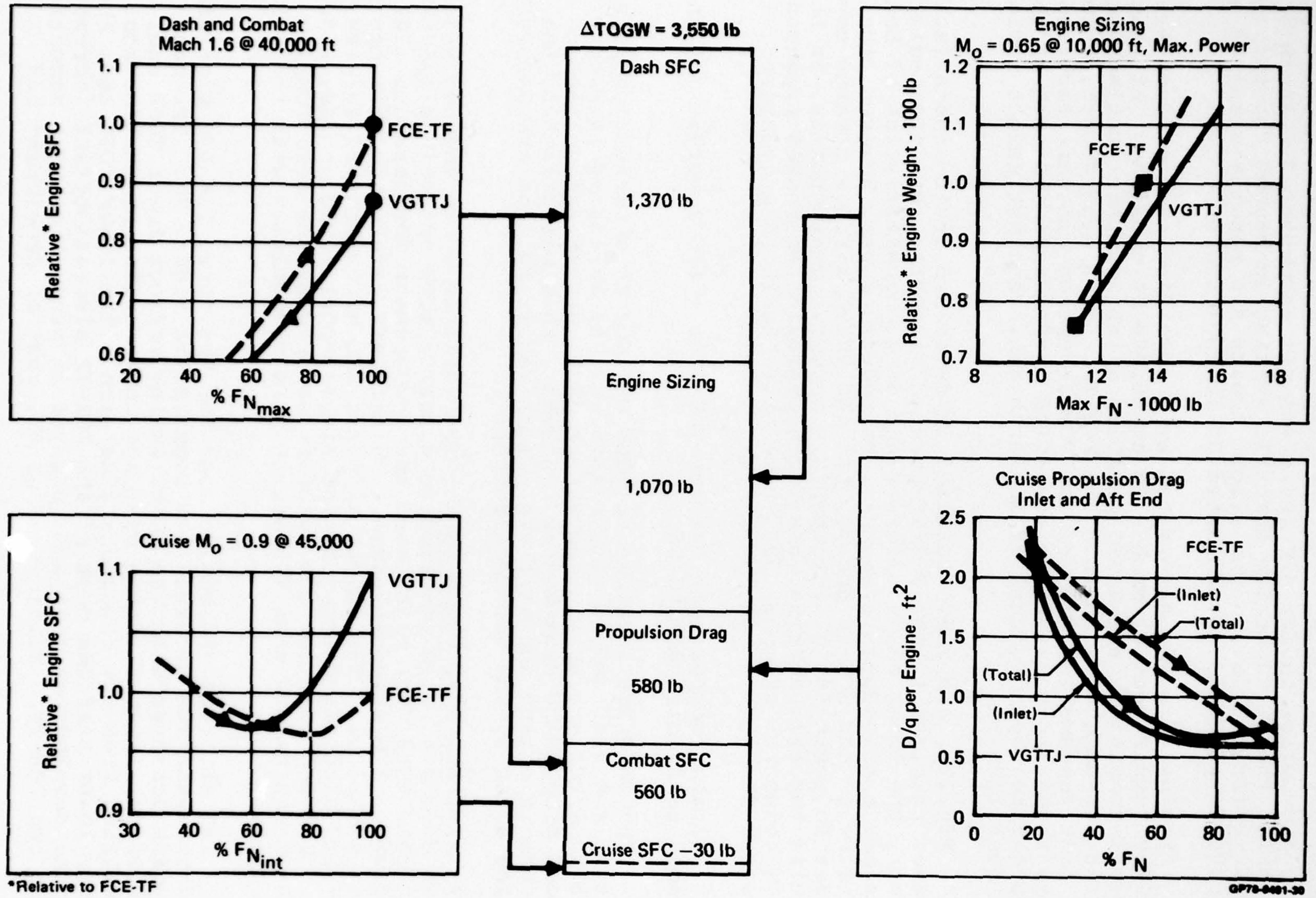


FIGURE 83
VCE PAYOFF CONTRIBUTORS - VGTTJ AIRCRAFT

turbine stator area limit is reached (about 65% of intermediate thrust for this engine) the rotor speed decays with throttle setting and corresponding SFC increases are encountered. In this example, the VGTTJ cruise throttle setting is beyond the turbine area variation limit. The slight cruise SFC penalty obtained with the VGTTJ produced an estimated 30 lb TOGW increase.

Engine size was determined by a specified energy maneuverability requirement at Mach 0.65 at 10,000 ft altitude. At that flight condition, the VGTTJ exhibits slightly higher maximum power thrust-to-weight ratio than the FCE-TF. More significant, however, is that the smaller size of the VGTTJ-powered aircraft required less thrust to achieve the specified performance and each of the two engines were reduced in scale to achieve a net weight saving of over 1000 lb.

Finally, the VGTTJ resulted in decreased cruise installation losses relative to the FCE-TF-powered aircraft. At intermediate power, the inlet and nozzle/aft-end drag characteristics of both systems are essentially equal. At reduced power, however, the airflow of the FCE-TF decays, but the VGTTJ airflow remains constant to about 65% of intermediate thrust. Consequently, at the cruise throttle setting, the VGTTJ installation losses produced a TOGW reduction of about 580 lb relative to those encountered with the FCE-TF.

Similar comparisons for the VCE-TF L + L/C aircraft are included as Figures 84 and 85.

The RALS/VCE increase in TOGW was due to increased propulsion system and airframe weight, Figure 86. As indicated in Figure 87, the RALS/VCE engine reduced SFC at dash, combat and cruise and reduced propulsion system drag. However, this was offset by the increase in engine and airframe weight resulting from the RALS/VCE being sized by the VTO requirement.

8.2 <u>AIRCRAFT LIFE CYCLE COST</u> - The variable cycle engines which have been evaluated resulted in aircraft TOGW reductions and one concept, RALS/VCE, eliminated the requirement for separate lift engines. The attendent impact on aircraft life cycle cost has also been estimated. The lowest aircraft LCC were obtained for the L + L/C aircraft powered by the single-spool VGTTJ engine, Figure 88. The LCC cost for the aircraft powered by the more complex VCE-TF engine and RALS/VCE engine were competitive with the FCE-TF aircraft.

The airframe and engine cost for the three L + L/C aircraft and the RALS/VCE aircraft are compared in Figure 89. The cost payoffs achieved with the VGTTJ engine reflect lower TOGW and, therefore, lower airframe cost and lower engine production cost resulting from the reduced engine size. The lower TOGW and, therefore, lower airframe cost of the FCE-TF aircraft offset increased engine development cost and resulted in production cost competitive with the FCE-TF. Elimination of the cost of developing and

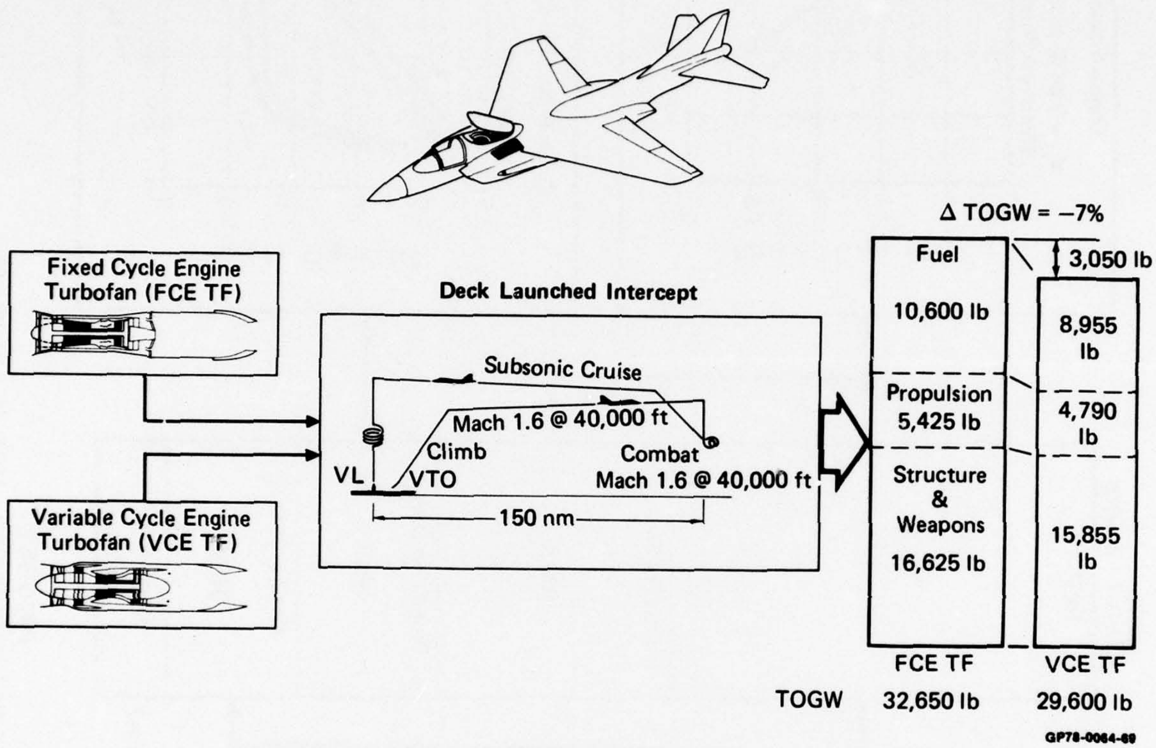


FIGURE 84

POTENTIAL VCE TOGW PAYOFF - VCE-TF AIRCRAFT

Lift + Lift/Cruise V/STOL Fighters

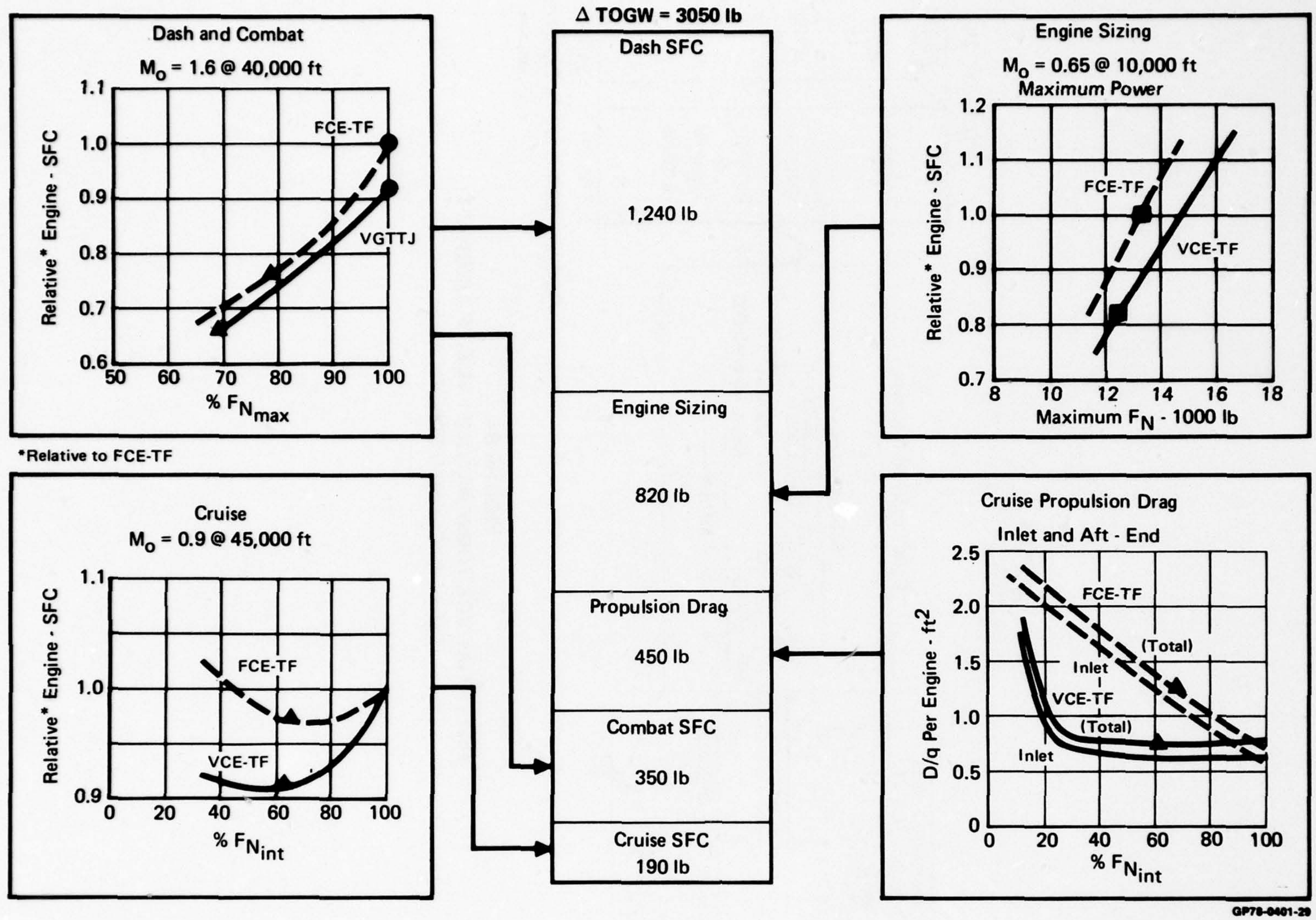


FIGURE 85
VCE PAYOFF CONTRIBUTORS - VCE-TF AIRCRAFT

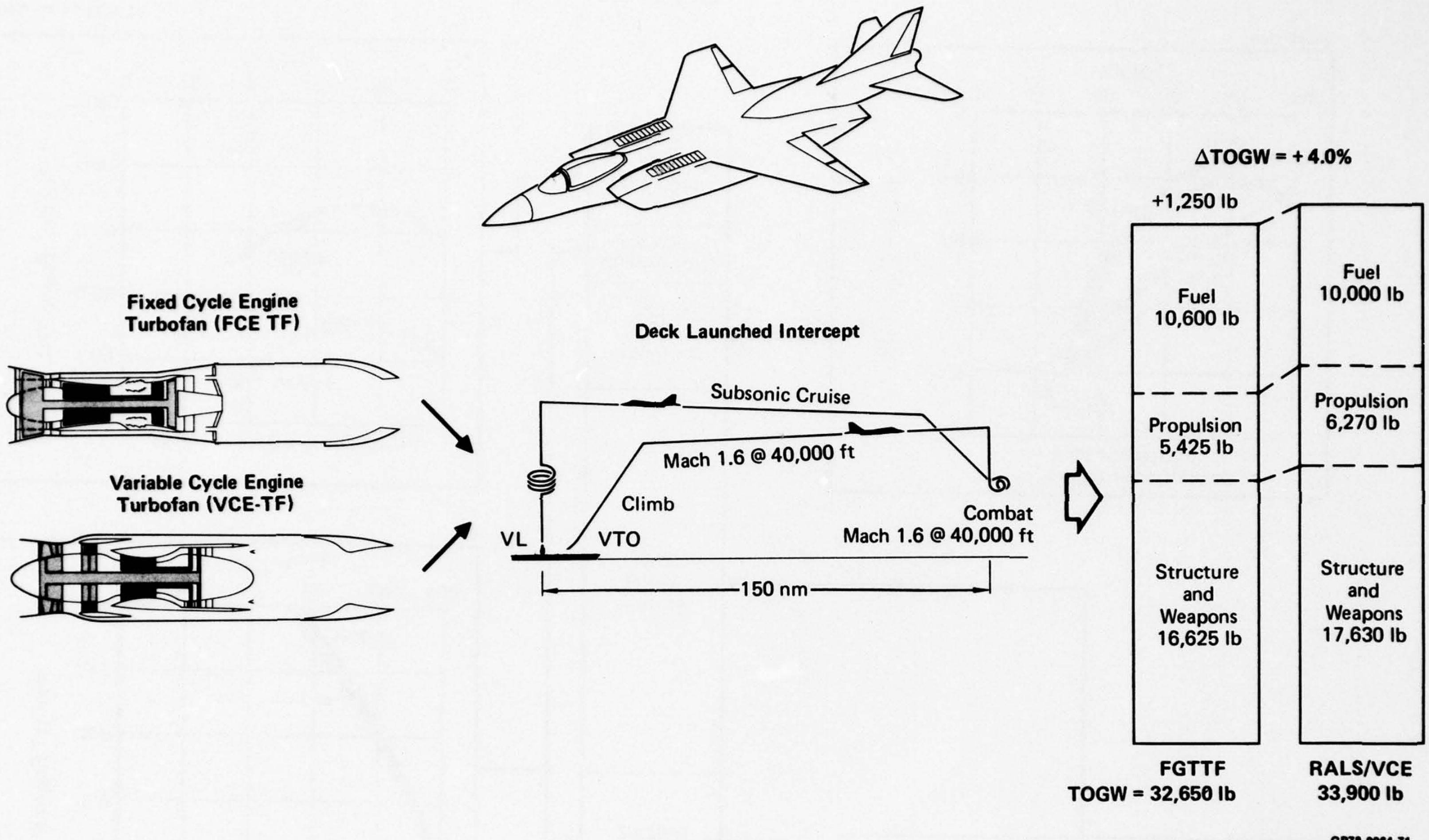
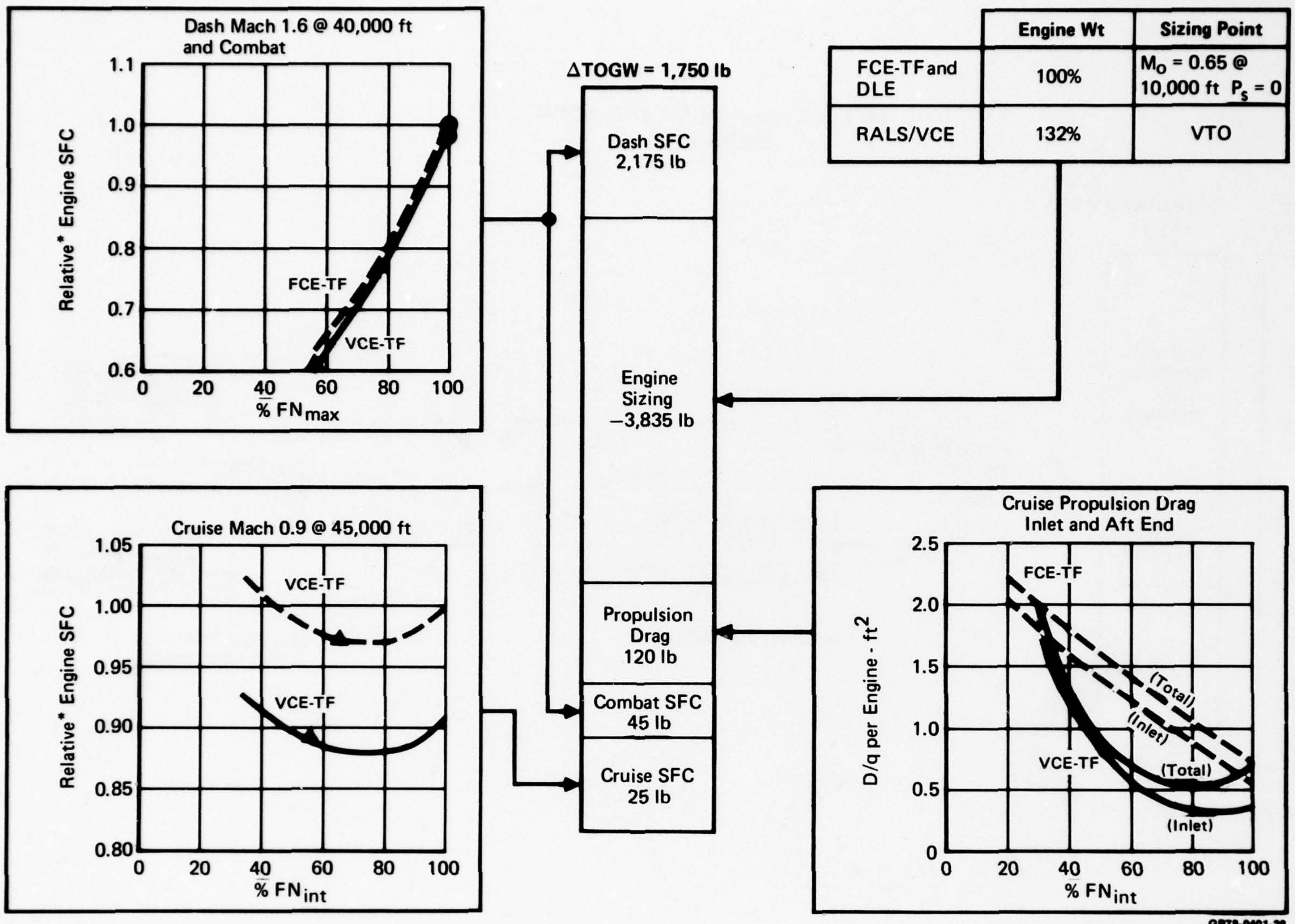


FIGURE 86
RALS/VCE TOGW ASSESSMENT



	Engine Wt	Sizing Point
FCE-TF and DLE	100%	$M_O = 0.65$ @ 10,000 ft $P_s = 0$
RALS/VCE	132%	VTO

*Relative to FCE-TF

FIGURE 87
RALS/VCE TOGW CONTRIBUTORS

Life Cycle Cost Comparison

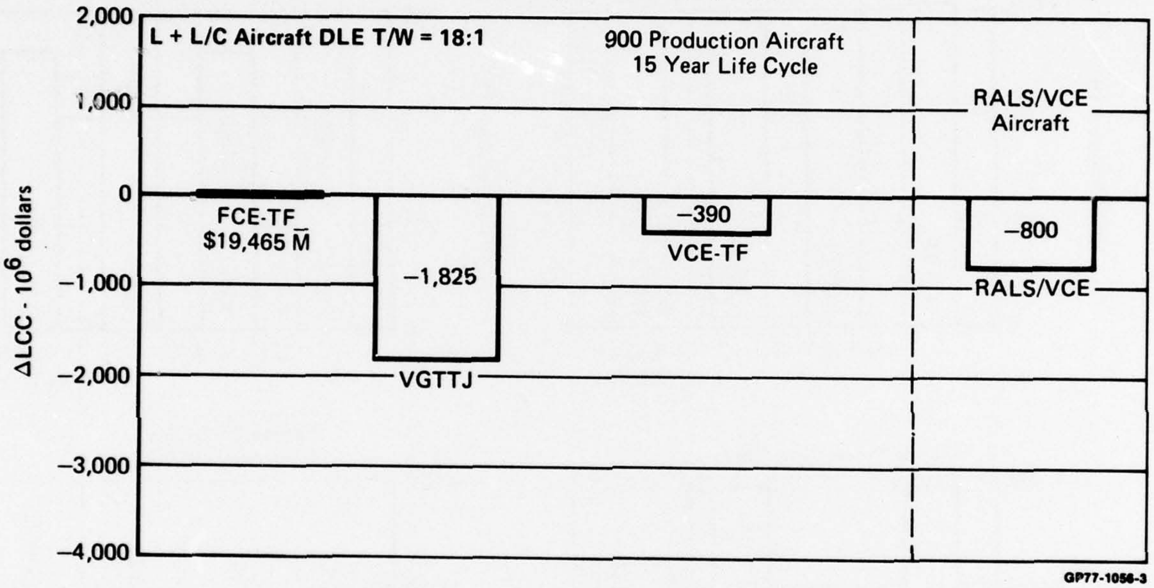


FIGURE 88
VCE PAYOFF ASSESSMENT - LCC

	L + L/C Aircraft			RALS/VCE Aircraft
	FCE-TF	VGTTJ	VCE-TF	
LCC (1976 Dollars)	19.466×10^9	17.642×10^9	19.077×10^9	18.668×10^9
TOGW (lb)	32,650	29,100	29,600	33,900
F_{n-LS} L/C (lbf)	16,465	13,880	14,783	23,975

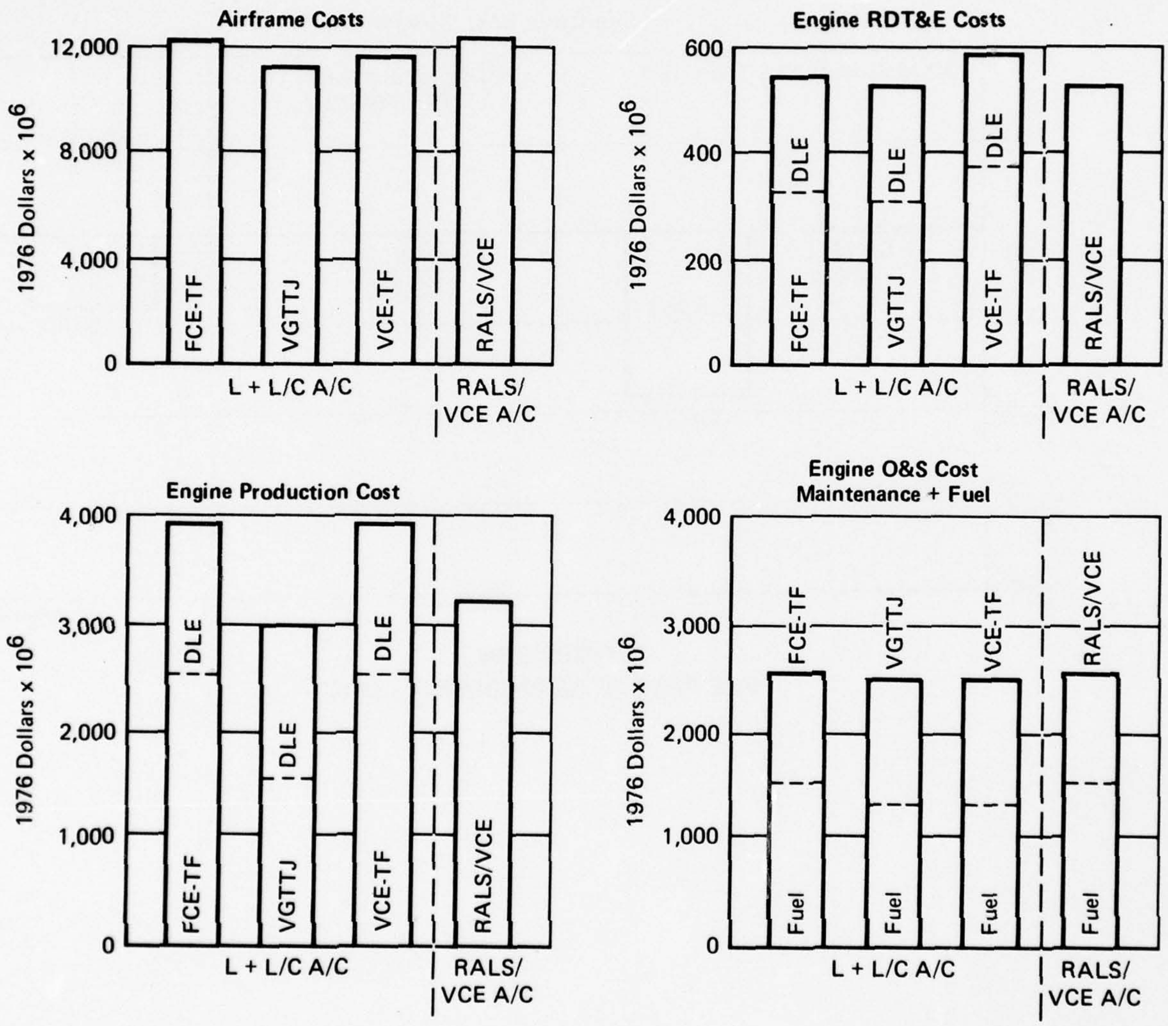


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FIGURE 89
COST COMPARISONS - 900 AIRCRAFT

producing separate lift engines, 1.67 billion dollars, made the RALS/VCE cost competitive with the FCE-TF aircraft.

8.3 AIRCRAFT COMBAT PERFORMANCE - Assessments of the combat performance capability of the several aircraft designs were made to determine VCE impact. Each V/STOL fighter achieved at least the required levels of combat performance. However, the RALS/VCE engines were sized by VTO requirements and, as a result, exceeded the required combat performance level as indicated in Figure 90. Although the RALS/VCE was 4% heavier than the reference aircraft, this aircraft had 40-50% more combat P_S and acceleration capability than that used as representative for advanced systems for this example. If higher combat performance levels than those used in this study are required, the RALS/VCE aircraft will become more competitive. For example, the VGTTJ aircraft was scaled to provide a combat P_S level, 1270 ft/sec, equivalent to that of the RALS/VCE aircraft. The estimated LCC for the scaled turbojet aircraft exceeded the RALS/VCE life cycle cost by 10% or approximately two billion dollars, Figure 91.

8.4 AIRCRAFT OPERATIONAL FLEXIBILITY - The operational flexibility achieved through the use of variable cycle engine features was assessed using the fuel required to achieve the Tactical Strike Mission two hour loiter time as a figure-of-merit. As shown in Figure 92, 5% and 14% fuel savings, relative to the FCE-TF, were obtained with the VFTTJ and VCE-TF engines, respectively. Less than a 1% fuel savings was obtained with the RALS/VCE aircraft design.

The operational mission flexibility achievable with variable cycle features in a L + L/C aircraft is further illustrated in Figure 93. For the DLI mission, the lowest TOGW was achieved using a fixed cycle turbojet. However, including the Tactical Strike Mission resulted in the fixed cycle turbojet going from the lowest to the highest TOGW. Adding variable cycle features to the turbojet reduced the Tactical Strike Mission TOGW but resulted in a slight penalty in DLI TOGW. Adding variable cycle features to the turbofan provided a DLI TOGW competitive with the turbojet and produced the minimum TOGW required to achieve the Tactical Strike Mission.

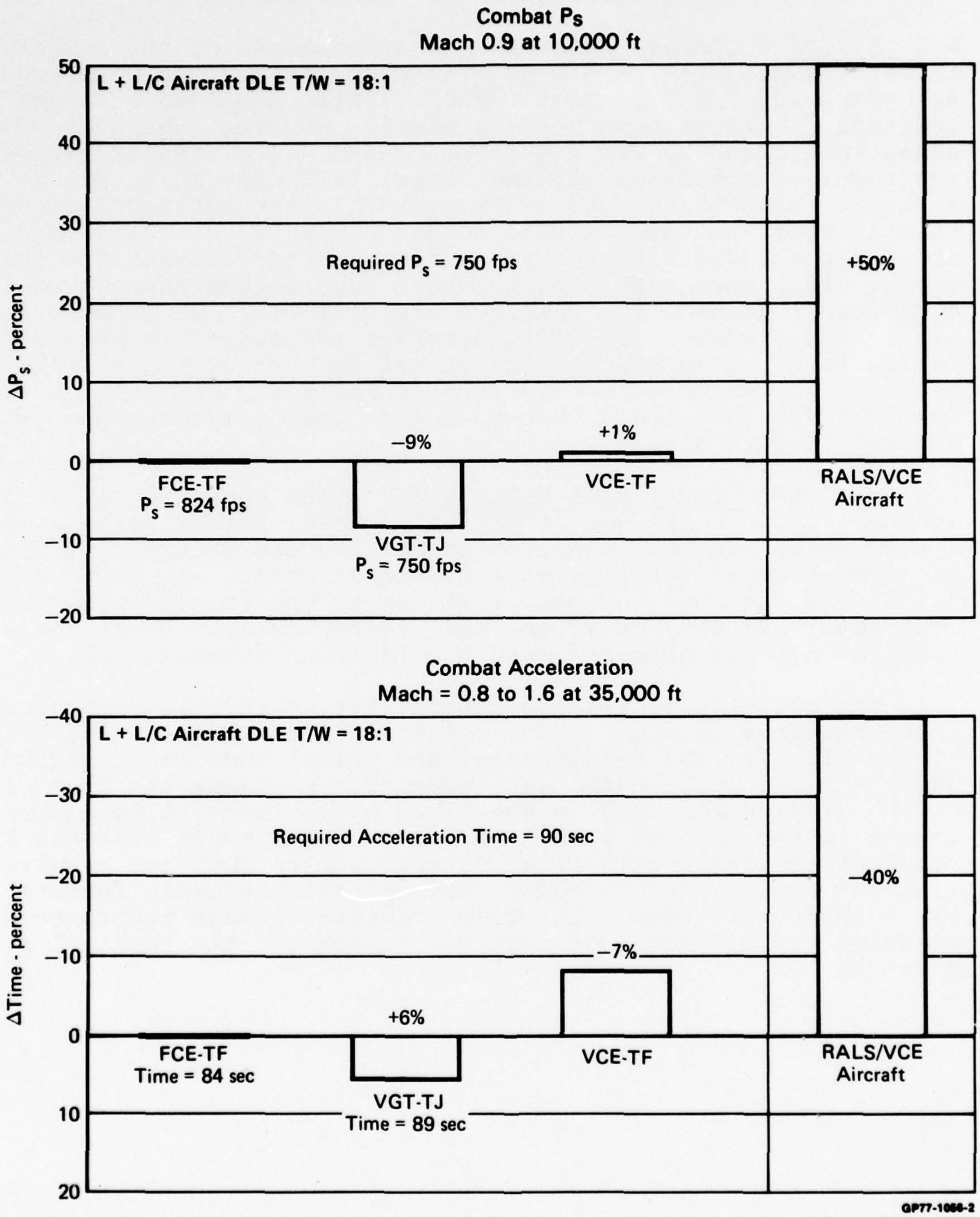

FIGURE 90
VCE PAYOFF ASSESSMENT - COMBAT PERFORMANCE

Combat P_s = 1270 ft/sec at Mach 0.9 @ 10,000 ft

	Millions of 1976 Dollars	
	L + L/C (VGTTJ) Aircraft	RALS/VCE Aircraft
RDT&E	2,137	1,921
Production	9,259	8,402
O&S	9,212	8,345
Total	20,608	18,668

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FIGURE 91
LIFE CYCLE COST FOR EQUIVALENT PERFORMANCE
900 Production Aircraft

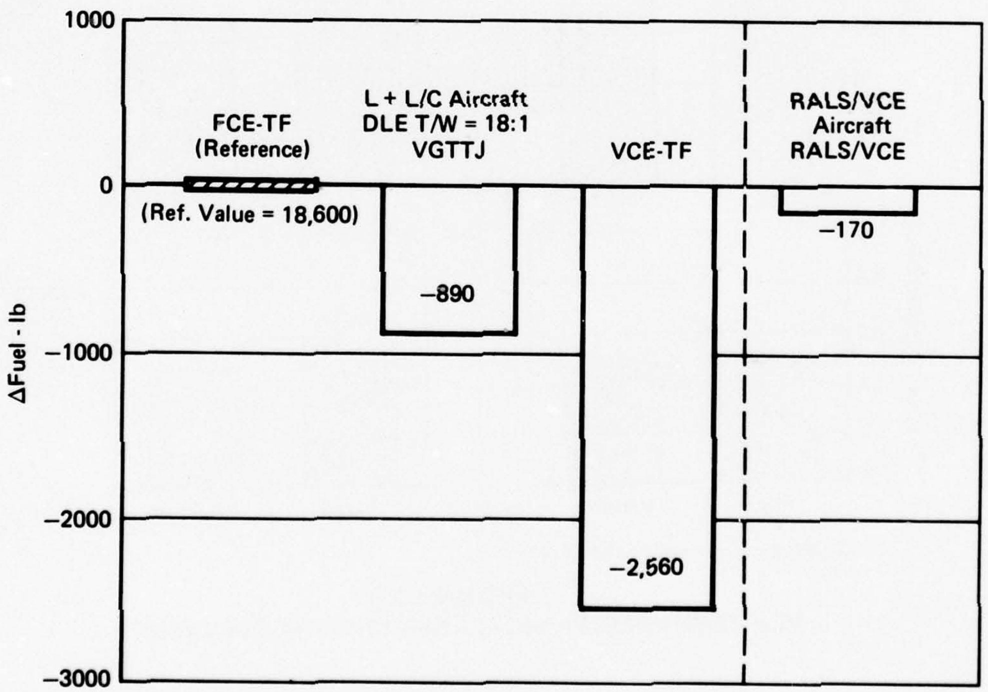

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FIGURE 92
VCE PAYOFF EVALUATION - OPERATIONAL FLEXIBILITY
Two Hour Loiter Tactical Strike Mission - External Fuel as Required

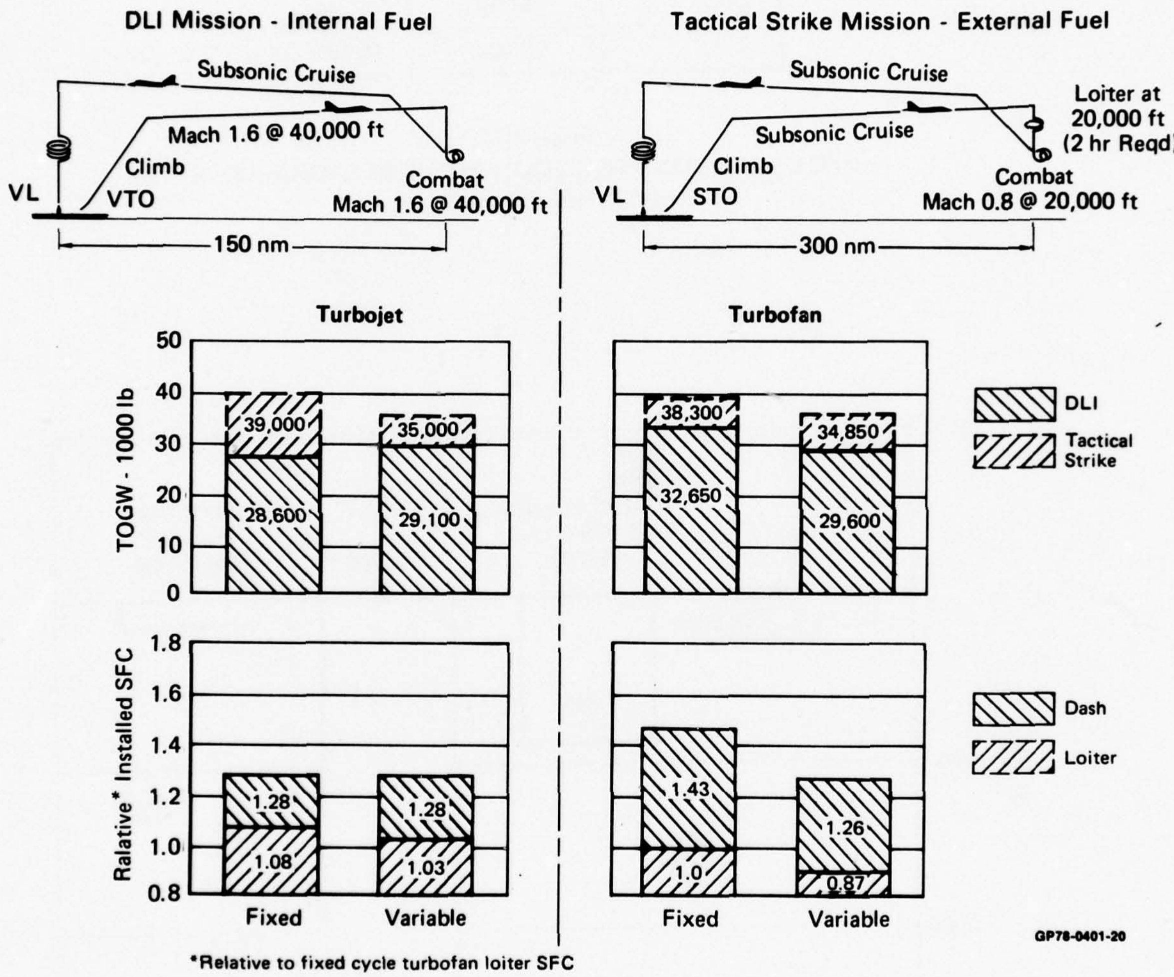

FIGURE 93
VCE TECHNOLOGY INCREASES MISSION FLEXIBILITY

9. CONCLUSIONS AND RECOMMENDATIONS

Variable cycle engines have been evaluated using advanced V/STOL fighter designs to assess their payoffs in terms of total weapon system characteristics. Results indicate that they offer potential benefits in supersonic V/STOL fighters. The major conclusions are discussed below.

A parametric V/STOL Fighter Design Evaluation Procedure was developed and demonstrated which will be a valuable tool in future V/STOL fighter engine/airframe selections. The procedure accounts for the interactions between requirements and aircraft size, performance and cost. This procedure was used to define a L + L/C fighter data base for conducting design selection and aircraft cost effectiveness trade-offs using fixed cycle turbofan and variable geometry turbine turbojet (VGTTJ) engines. A VGTTJ aircraft design was defined which had substantial payoffs relative to a fixed cycle turbofan aircraft. These payoffs included a 11% reduction in Intercept mission TOGW, a 9% reduction in life cycle cost and improved operational flexibility.

A L + L/C V/STOL fighter design was also evaluated using a GE variable cycle turbofan engine (VCE-TF). This engine produced a 9% reduction in Intercept mission TOGW relative to a FCE-TF aircraft. The VCE-TF aircraft was competitive with the FCE-TF aircraft in life cycle cost and improved operational flexibility.

A RALS/VCE lift/cruise aircraft was designed which proved to be an attractive, cost effective concept when compared to the L + L/C designs. Although 4% heavier than the FCE-TF aircraft, the RALS/VCE aircraft life cycle cost was competitive and the RALS/VCE aircraft improved operational flexibility. In addition, the RALS/VCE aircraft provided 50% more combat performance than the L + L/C aircraft designs. Therefore, if a combat capability greater than that used in this study is required, the RALS/VCE will become even more cost effective. For example, the LCC of a VGTTJ aircraft, sized to provide equivalent combat P_s capability, exceeded the RALS/VCE LCC by 10%.

Detailed supersonic V/STOL fighter weapon system studies are required to include RDT&E in areas which were outside the scope of this program. These studies should be both analytical and experimental in nature with engine and airframe companies participating. Airframe company RDT&E studies should include: base compatibility evaluations, ground effects and suckdown loss assessments, hot gas ingestion investigations, powered lift control evaluations and primary/auxiliary air induction system development and testing. In addition, engine components critical to development of the modulation bypass VCE-TF concept, including the RALS, should be included in engine company technology demonstrator programs.

One of the significant advantages of the RALS/VCE concept is the capability to vary the forward flight VCE airflow and thrust over a wide range. A systematic parametric evaluation of this unique capability should be accomplished to determine its impact on inlet, nozzle and VCE control designs and its impact on total weapon system performance.

Consideration should be given to continuing development of the ADEN nozzle. The capability to augment in the vectored thrust mode increases the allowable STOL payload.

At the present time, the Rand TOA model is the only generally available procedure for parametrically predicting engine RDT&E and production cost. New procedures are required which reflect the advanced technology impact of variable cycle engines on life cycle costs.

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8. Box, M.T., "New Method of Constrained Optimization and Comparison with Other Methods," Computer Journal, Volume 8, No. 1, pp. 45-52, dated April 1965.

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APPENDIX A

V/STOL FIGHTER COMPUTER AIDED DESIGN EVALUATION (CADE) PROGRAM

A computer aided procedure, for conducting parametric V/STOL fighter aircraft design evaluations, has been developed by modifying a procedure defined for conventional take-off and landing aircraft. This V/STOL procedure, herein referred to as V/STOL CADE, was developed using both contract and MCAIR funds and provides the capability to compute L + L/C aircraft size, weight, performance and cost characteristics for user specified engine/airframe design parameters and mission profiles as shown in Figure A-1. V/STOL CADE performs six major functions: (1) aircraft geometry and weight scaling, (2) powered lift system sizing and thrust balancing, (3) aircraft mass balancing, (4) cruise engine sizing, (5) fuel sizing, and (6) cost analyses. Output from the V/STOL CADE program includes the geometric and weight characteristics of the aircraft when sized to meet specific requirements, design and alternate mission performance, and aircraft combat performance capability.

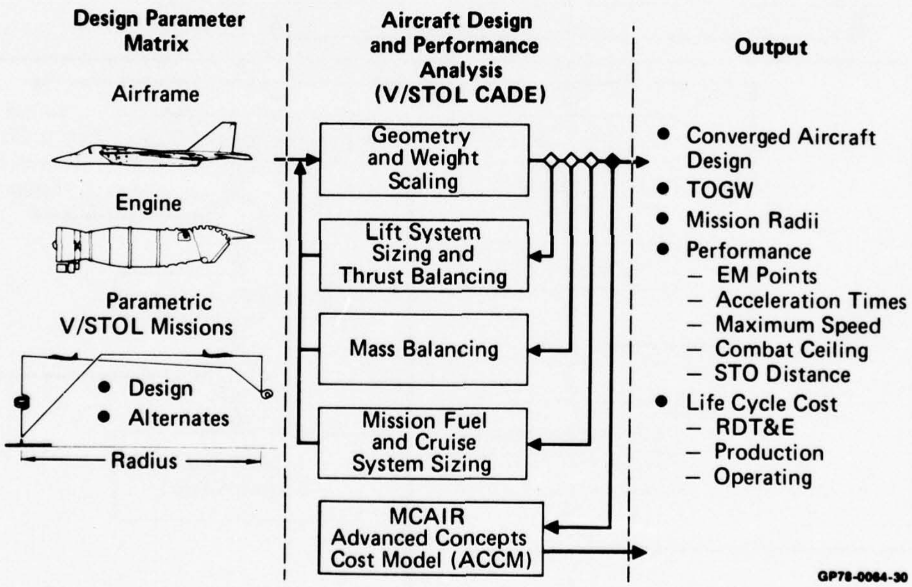

FIGURE A-1
DETERMINATION OF PARAMETRIC AIRCRAFT DESIGN CHARACTERISTICS

The modifications made to the CTOL CADE program to provide the capability to evaluate V/STOL fighter designs are described in the following sections. Aircraft sizing and performance procedure modifications are discussed in Section A.1. The modifications made to the cost model are discussed in Section A.2. Finally, the output data from the V/STOL CADE program is defined in Section A.3.

A.1 Aircraft Sizing and Performance Procedure Modifications

Modification of the CTOL CADE program to provide the capability to conduct V/STOL aircraft sizing and performance analyses required changing existing modules and adding new ones. Modules such as the input module, aerodynamic synthesis module, and cruise engine sizing module, required only minimal change. Other modules, such as the geometric, weight, and center of gravity (c.g.) scaling modules, required extensive change. Two new modules, unique to V/STOL aircraft, had to be added. These were the powered lift system sizing and thrust balance module and a short takeoff (STO) distance calculation module. A simplified flow diagram of the V/STOL CADE program is shown in Figure A-2. The major modifications are discussed below.

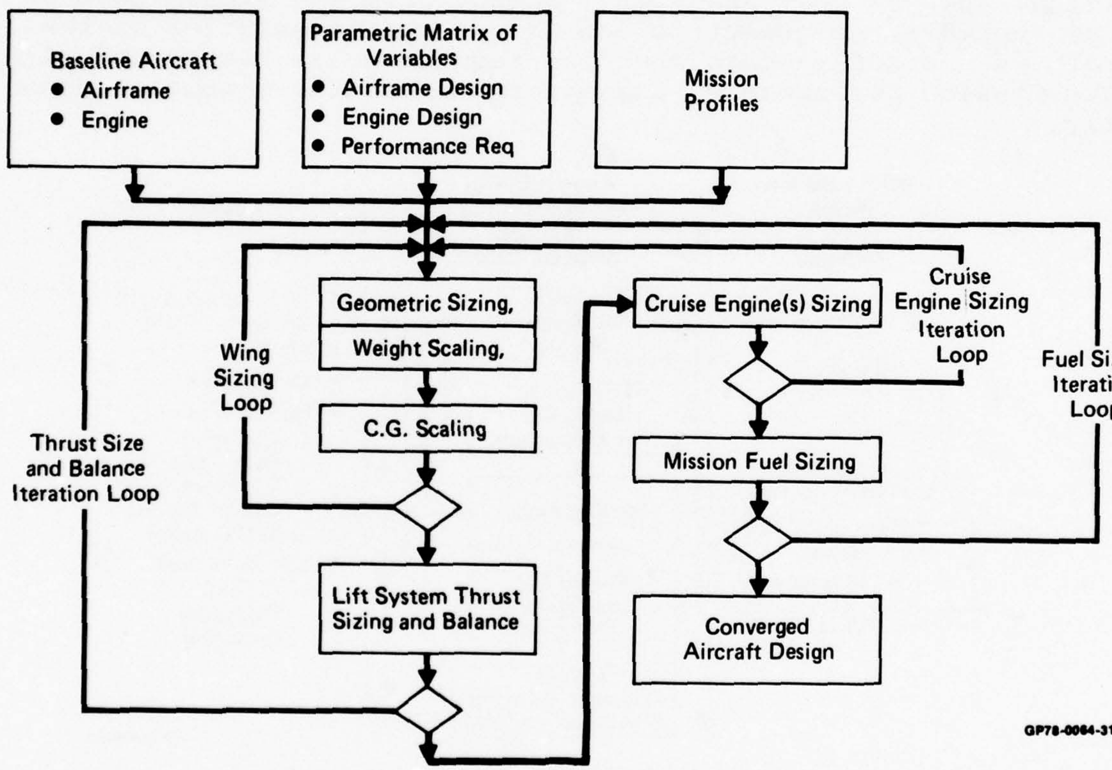

FIGURE A-2
CADE V/STOL COMPUTER PROGRAM LOGIC DIAGRAM

Geometric Size and Weight Scaling - The geometric size and weight scaling modules were rewritten to accommodate L + L/C V/STOL aircraft. Figure A-3 summarizes the important geometric size and weight scaling module capabilities and limitations. The program logic will handle either axisymmetric or two-dimensional V/STOL lift/cruise (L/C) nozzle designs. The aircraft may have one or more direct lift engines (DLE), located in tandem, forward of the c.g., in conjunction with one or two L/C engines, positioned with their thrust vectors aft of the c.g. As shown in Figure A-4, the aircraft has four scaleable fuselage segments, plus fixed forward and aft fuselage segments. The scaleable segments consist of a fuel bay located forward of the lift engines, the lift engine segment, a variable center segment, and the L/C engine segment. The aircraft wing and tail surfaces are fully scaleable, as in the CTOL CADE program. The baseline horizontal tail and vertical tail volume coefficients are preserved. A minimum gap between the horizontal tail and the wing trailing edge is specified through input.

- **Capabilities:**
  - Axisymmetric or 2D V/STOL L/C Nozzle Designs
  - One or More DLE Located in Tandem, Fwd of C.G.
  - One or Two L/C Engines, Lift Thrust Aft of C.G.
  - Four Scalable Fuselage Segments
  - Ten Fuel Tanks
  - 38 Mass Balancing Subsections
- **Limitations:**
  - L + L/C Powered Lift Concept
  - Fuselage-Integrated Nacelles
  - Conventional Control Surfaces
  - Fixed Planform Wings

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FIGURE A-3
GEOMETRY AND WEIGHT SCALING

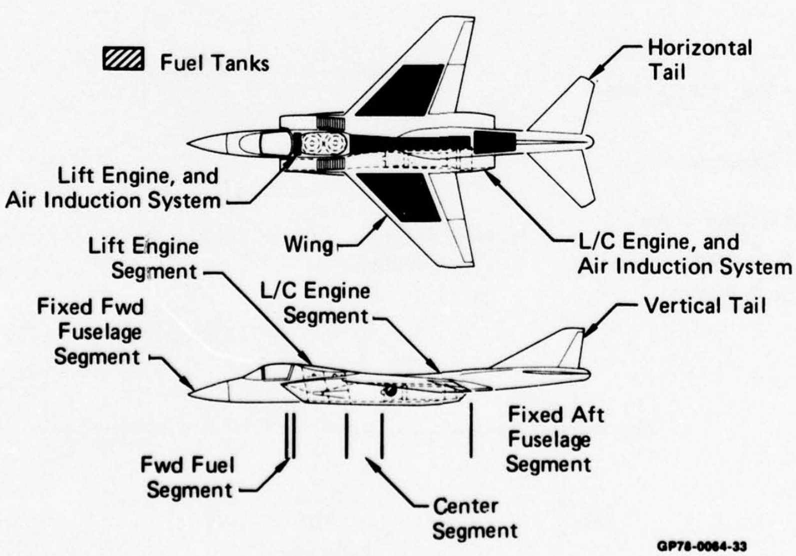

FIGURE A-4
AIRCRAFT SEGMENTED FOR DETAILED GEOMETRY SCALING

There are ten fuel tanks; two wing tanks, the fuel tank forward of the DLE's, four center section tanks, two banks in the L/C section, and an aft fuselage tank. The wing tanks scale with wing area and are assumed full to start. The aft fuselage tank is fixed in quantity. The forward and one of the center fuselage tanks are scaleable as a function of fuel quantity and distribution. The program will size the fuel load to the fuel required to meet the design mission.

An example of the geometric sizing logic is shown in Figure A-5, for the forward fuselage segment. For this example, the forward fuselage segment contains two direct lift engines canted with respect to the vertical by the angle θ. When the lift engine thrust is scaled, lift engine length, L_E, and diameter, D_E, are scaled proportionally. The baseline fuselage height through the engine bay, H_{B_O}, is then incremented by the change in the vertical component of the additional engine length. The fuselage width is correspondingly changed by maintaining the fuselage height to width ratio. The perimeter of the fuselage is scaled as a conic using the new height and width. Length is also added to the fuselage proportional to the lift engine(s) diameter change. The resulting volumetric change is then computed using the scaled length width, and height. Similar scaling logic is used to define the forward fuel segment geometry, with the volume available for fuel calculated as a function of the total volume change.

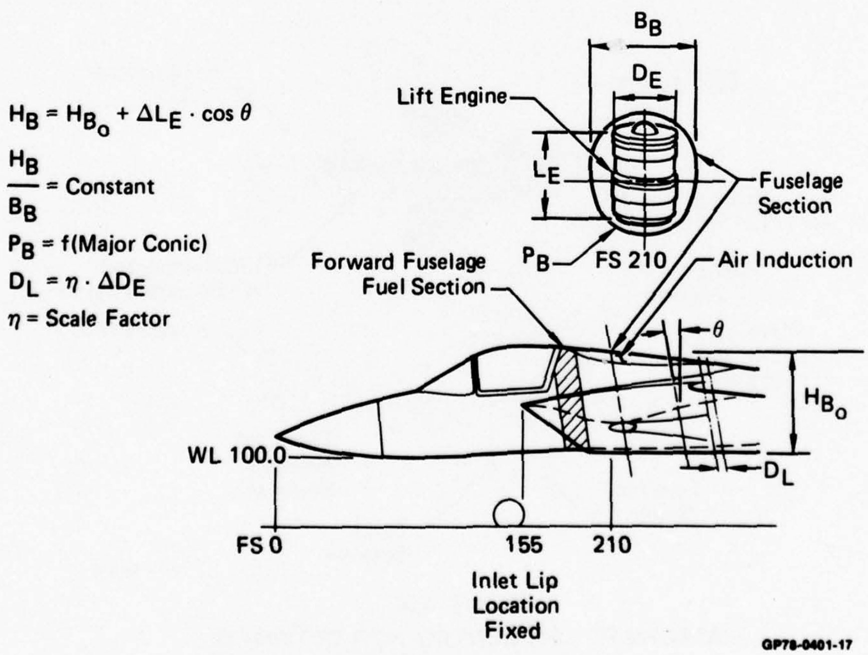

FIGURE A-5
TYPICAL GEOMETRIC CONSIDERATIONS

Thirty-eight subsections are used to define the weight and c.g. of the aircraft. Figure A-6 shows the various weight groups and their subsections. Each component is scaled using weight scaling procedures consistent with current conceptual design practice. This technique is similar to that used in the CTOL CADE program with the addition of V/STOL-related components. The c.g. is computed by taking the summation of the weight component moments, about the aircraft nose, and dividing the total by a weight component summation. A combat c.g. is similarly calculated, using the fuel distribution at combat weight, and is used as a reference when shifting the wing to maintain a required static stability margin.

- Fuselage Group (14)
  - Fixed
  - Shell Material
  - Bending Material
  - Wing Reaction Material
  - Fuel Prov
  - L/C Engine Prov
  - L/C Air Induction Prov
  - Vertical Tail Prov
  - Horizontal Tail Prov
  - Landing Gear Prov
  - L/C Engine Cavity Prov
  - DLE Prov
  - DLE Air Induction Prov
  - DLE Cavity Prov
- Landing Gear Group (4) Nose/main Landing Gear
  - Structure
  - Wheels and Tires
  - Brakes
  - Controls
- Propulsion Group (5)
  - L/C Engines
  - DLE
  - Controls
  - L/C Engine Section
  - DLE Section
- Air Induction Group (2)
  - Ramps
  - Ducts
- Wing
- Horizontal Tail
- Vertical Tail
- Fuel Systems
- Surface Controls
- Reaction Controls
- Hydraulics
- Fixed Empty Weight
- Usable Fuel
  - Fuselage
  - Wing
- Trapped Fuel
- Weapons
- Fixed Useful Load

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FIGURE A-6
DETAILED COMPONENT WEIGHT BREAKDOWN USED TO SCALE AIRCRAFT WEIGHT AND CENTER OF GRAVITY

V/STOL CADE, at present, is limited to lift plus lift/cruise powered lift concepts with fuselage-integrated nacelles. The current aerodynamic synthesis methods further limit the design to conventional aerodynamic control surfaces (single or twin verticals) and fixed planform wings. The program has the capability of being easily modified, however, to accommodate other configuration concepts and synthesis methodologies.

Powered Lift System Sizing and Balance - A new module was added to the CADE program to provide the capability to determine the powered lift system size and thrust vector locations required for thrust moments balance. Figure A-7 summarizes the required capabilities of this module and the options available to the user. In this new module the L/C engine is sized, as with the standard CADE program, by conventional flight performance requirements. To provide vertical takeoff (VTO) capability, the DLE must be sized to provide the additional thrust required above that available from the vectored L/C engine(s). V/STOL CADE provides this capability plus the additional feature of varying the VTO throttle setting of the L/C engine from reduced power to maximum A/B thrust. The throttle setting has a direct effect on the size of the DLE's required and the location of the thrust vectors for moment balancing.

Requirements:

- L/C Engine Sized by Flight Performance Requirements
  - VTO Throttle Setting Varied from Reduced Power to Maximum Afterburner
- DLE's Sized to Provide Lift/TOGW = 1.05 After Accounting for
  - Reingestion, Fountain and Suckdown Effects
  - Control Margin During VTO
  - Thrust Vectoring Losses and Nonstandard Day
- L/C and DLE Thrust Moments Balanced about C.G. at TOGW

Options:

- Options Available to Size to Any Lift/TOGW Requirement and Ambient Temperature Condition
- Option to Specify DLE or L/C Engine Size

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FIGURE A-7
POWERED LIFT SYSTEM SIZING AND BALANCE

The DLE's are sized to provide a specified total power lift thrust (DLE + L/C) to TOGW ratio. In addition, the continuous bleed lift engines provide thrust for roll control during VTO. The powered lift system sizing accounts for influences of reingestion, fountain effects and suckdown effects. Figure A-8 illustrates typical ground effect and reingestion corrections. These relationships are explicitly defined through input to the program as a function of the ratio of the height of the nozzle above the ground to jet nozzle diameter. Thrust vectoring losses and nonstandard day environments are also accounted for in the determination of lift engine size.

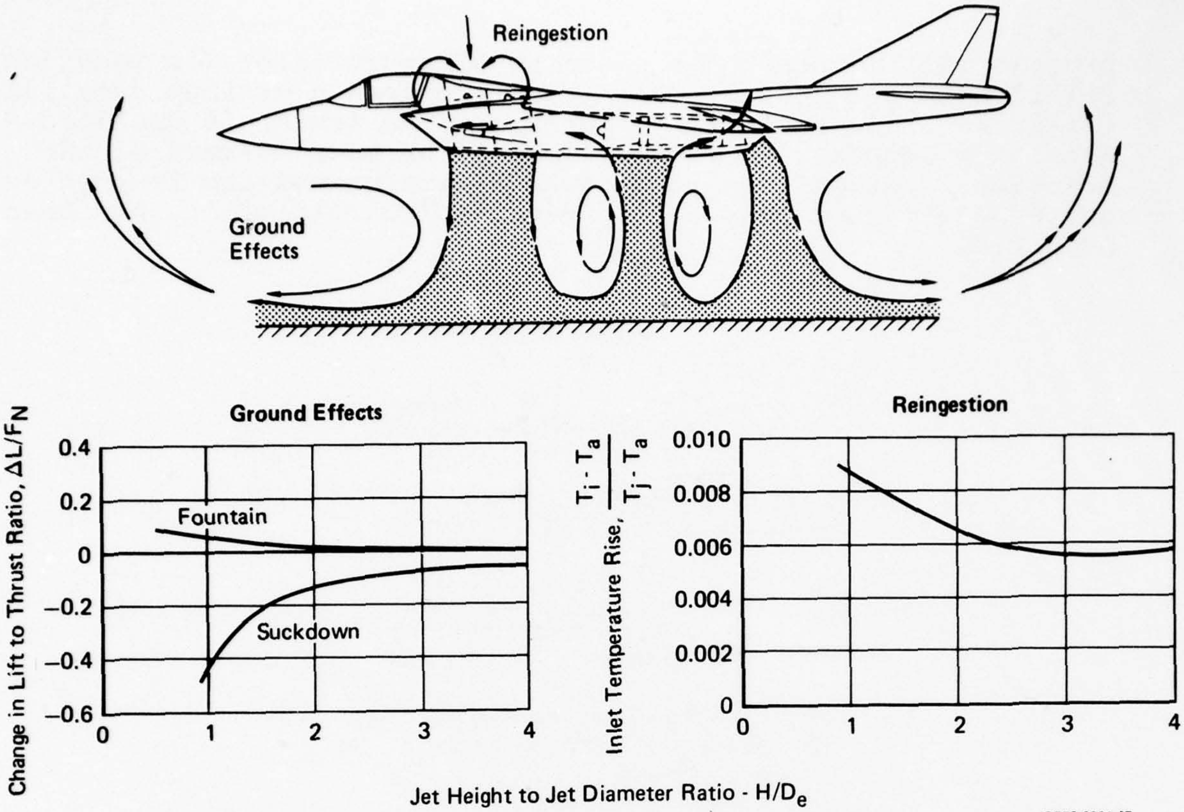
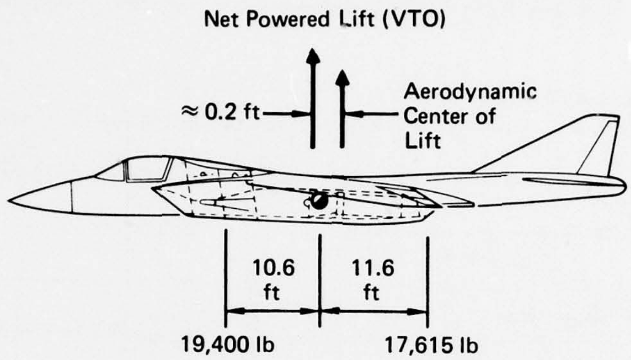


FIGURE A-8
LIFT SYSTEM SIZING ACCOUNTS FOR REINGESTION AND GROUND EFFECTS

Additional logic is contained in the powered lift system sizing and balancing module for locating the DLE's relative to the L/C engines to provide a thrust moment balance about the c.g. Figure A-9 shows the thrust moment arm relationships. for a typical V/STOL CADE onverged aircraft design, which provide thrust balance at takeoff gross weight (TOGW). This figure also points out several other important design considerations that were prominent in the formulation of the CADE logic. As mentioned previously, the wing is located by mass balancing the scaled aircraft to provide a specified static stability margin at combat weight and c.g. The c.g. for TOGW is determined for the VTO thrust balance calculation and may provide more or less static stability than explicitly specified for combat. The most forward and aft c.g. locations are determined by the program and output as general information. The maximum aircraft length is also calculated by the program and is output since this dimension is critical for Navy aircraft. No attempt is made within the the program to constrain aircraft length. Aircraft length, however, is sensitive to L/C VTO throttle setting which can be varied as discussed above. The inlet lip location is important from an over-the-side pilot visibility standpoint. The V/STOL CADE program will maintain the baseline aircraft inlet lip location relative to the nose of the aircraft unless a minimum duct length criteria, included in the program scaling logic, is violated. When this happens, the inlet lip will be move forward of the baseline location. In this case, a warning message is printed, advising the user that over-the-side pilot visibility has been impaired.



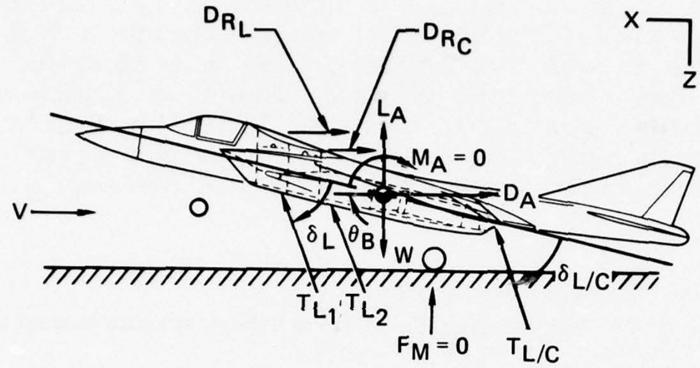
(1) VTO Thrust Vectors Balanced About Takeoff C.G.
(2) Aerodynamic Stability within Limits
(3) Aircraft Length
(4) Over-the-side Pilot Visibility

GP78-0064-38

FIGURE A-9
PROPULSION INTEGRATION DESIGN CONSIDERATIONS

Short Takeoff Calculation - Short takeoff (STO) evaluation methodology for V/STOL aircraft was developed for inclusion in V/STOL CADE. A STO distance calculation was required in order to evaluate the alternate mission capability of V/STOL aircraft. The following paragraphs outline this procedure.

The STO calculation is composed of two parts: (1) the lift-off speed determination and (2) the takeoff distance required to accelerate to the lift-off speed, including a transition from ground roll attitude and nozzle deflection angles to those used at lift-off. Figure A-10 shows the forces acting on the aircraft at lift-off. The program computes the speed at which a force and moment balance on the aircraft is achieved (for zero force on the main gear), vertical acceleration is zero, and the horizontal acceleration is at least the minimum required (.065 g's). It is assumed that the aerodynamic moment, M_A, of the aircraft can be balanced by the stabilator. A similar force diagram is used for the ground roll portion of the calculation. In this case, the aircraft is assumed to be in a level attitude $\theta_B = 0$, and aerodynamic moments are assumed to be balanced. The aircraft ground roll acceleration (a/g) is calculated at zero ground speed and at the rotation speed, where the rotation speed is specified as the lift-off speed less 10 knots. The variation of a/g with ground roll distance is illustrated by Figure A-11. The ground roll distance is calculated for the two segments shown by the use of the mean-value theorem, and the total distance is the sum of the two segment distances.



Assume:

$\Sigma F_x = (A/G)\, W = 0.065\, W$

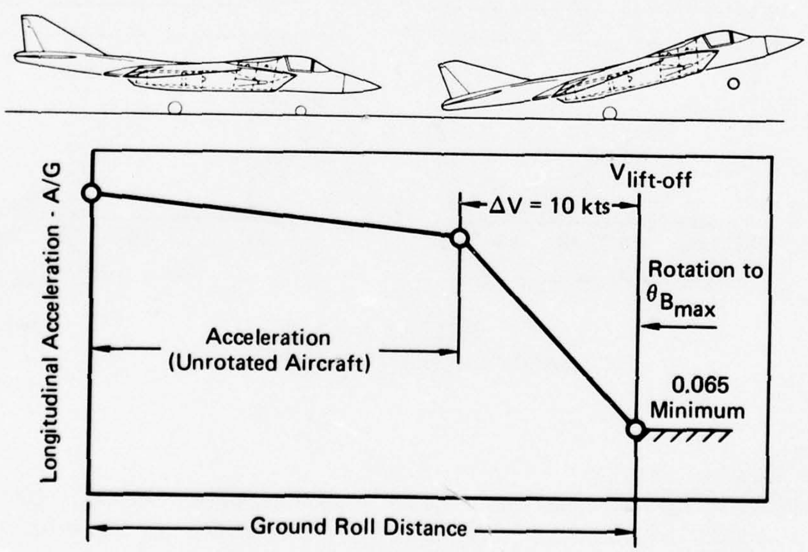
$\Sigma F_z = 0$

$\Sigma M_{C.G.} = 0$

Solve Simultaneously for Lift-Off Velocity

GP78-0064-39

FIGURE A-10
SHORT TAKEOFF CALCULATION FORCE DIAGRAM FOR LIFT-OFF



GP78-0064-40

FIGURE A-11
SHORT TAKEOFF CALCULATION

Figure A-12 illustrates the procedure used by the program to obtain a solution. It selects a L/C engine deflection angle at lift-off and solves for the lift engine deflection angle, lift engine thrust required, lift-off speed, and STO distance. This procedure is repeated for a number of L/C engine deflection angles until either (1) the lift engine thrust required equals the lift engine thrust available or (2) the minimum STO distance is obtained. For the example shown in Figure A-12, the lift engine thrust available was the limiting factor. A minimum distance could be found by allowing the calculation to continue and assuming unlimited lift engine thrust available.

- Assume L/C Engine Vector Angles
- Solve for L.E. Vector Angle, L.E. Thrust and Velocity at Which Moment and Force Equations are Satisfied
- Calculate Ground Roll Distance to Lift-Off Velocity
- Determine L/C Engine Vector Angle at Which:
  - L.E. Thrust Required = Thrust Available, or
  - Takeoff Distance is a Minimum
- Repeat for Each Alternate Mission External Tank Configuration

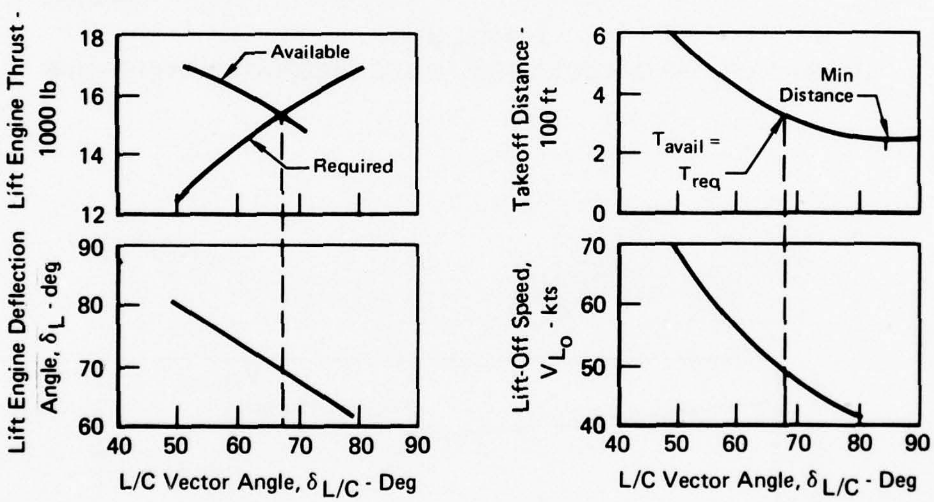


FIGURE A-12
CADE V/STOL STO METHOD

GP78-0064-41

A.2 <u>Life Cycle Cost</u>

The MCAIR Advanced Concepts Cost Model (ACCM) provides the basis in V/STOL CADE for computing aircraft life cycle cost. The engine cost logic of the ACCM was modified, using GE data, to account for advanced engine components and to include direct lift engine. The following paragraphs briefly discuss these procedures which affect engine Development, Production and Operations and Support (O&S) costs.

Engine Development Costs - In V/STOL CADE, fighter LCC includes the development cost to Model Qualification Test (MQT) for both the L/C engine and the direct lift engine.

The Rand Time of Arrival (TOA) cost procedure, Reference 8, is used in the ACCM to compute engine cost. TOA is defined as the estimated calendar time of arrival of the engine technology. As indicated in Figure A-13 the difference between TOA and MQT dates can have a significant impact on development cost. A negative value of TOA calendar date minus MQT calendar date indicates that the technology will be available to develop the engine before the planned MQT date. This should reduce development risk and cost. If the opposite occurs and the estimated TOA date is later than the planned MQT date, an accelerated technology development is required and increased risk and cost will occur. The Rand procedure computes TOA as a function of turbine inlet temperature (TIT), overall pressure ratio (OPR), maximum dynamic pressure (q), engine weight, sea level static intermediate power SFC and sea level static max power thrust. Past studies have shown that the TOA computation does not properly reflect emerging technology trends. For example, only three of the engines used in the Rand correlations had "cooled" turbine technology. Furthermore, the TOA equation was based on CTOL engines and therefore does not include the V/STOL nozzle development requirements associated with a L/C engine. Consequently, the Rand engine development cost analysis procedure was adjusted using cost data supplied by GE for an advanced technology fixed cycle L/C engine as shown in Figure A-13.

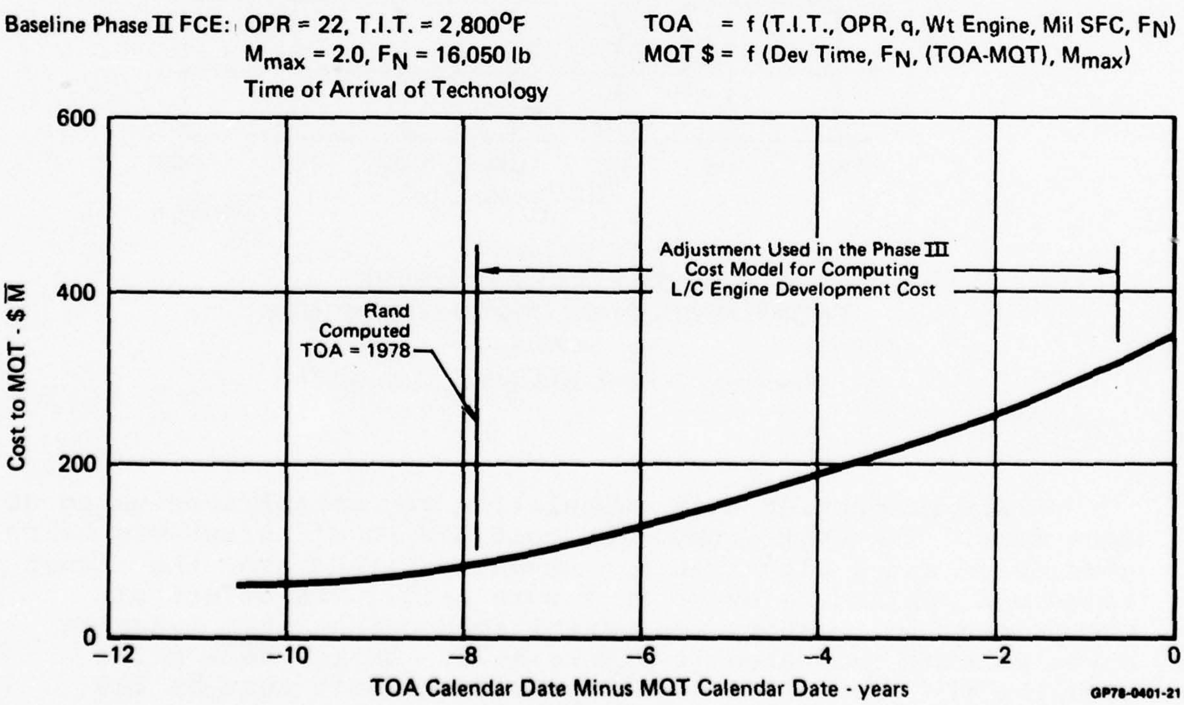


FIGURE A-13
RAND TOA COST PROCEDURE
ENGINE DEVELOPMENT COST METHODOLOGY
1976 $

The Rand TOA cost procedure cannot be used to compute advanced technology direct lift engine MQT cost. Therefore a GE estimate was used.

Engine Production Costs - The V/STOL CADE cost model also uses the Rand TOA cost procedure to compute L/C engine production cost. DLE production costs are based on GE data. Component Improvement Cost (CIP), incurred during the production phase, are included for both the L/C engines and DLE's.

The effect of TOA on production engine cost is shown in Figure A-14. This relationship was also adjusted using production engine cost data supplied by GE for an advanced technology fixed cycle turbofan L/C engine. A TOA adjustment of 1.4 years was required to match the data provided.

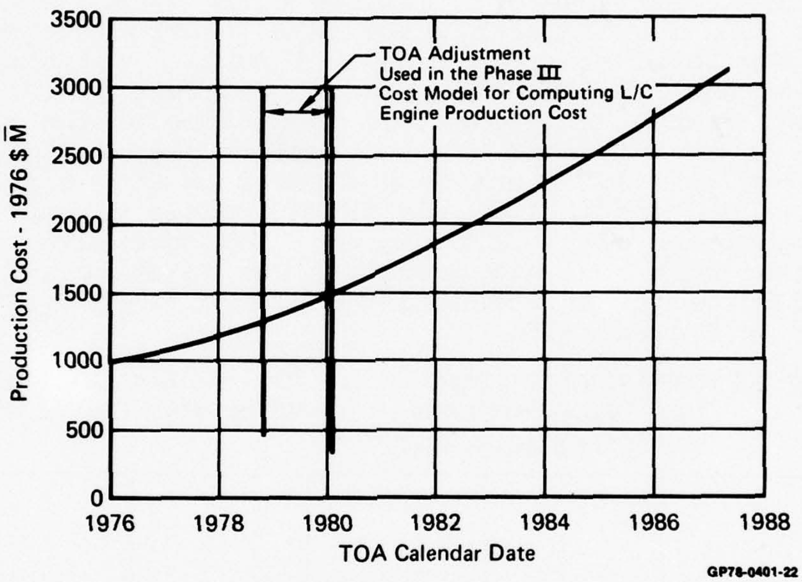


FIGURE A-14
RAND TOA COST PROCEDURE
ENGINE PRODUCTION COST METHODOLOGY
1976 $
Production $ = f(FN, TOA, Mmax, (TOA-MQT)

A DLE production cost correlation was established using GE cost data. The unit production cost per lb of thrust was being considered and a slight thrust advantage trend over the thrust range was applied as shown in Figure A-15. The effect of DLE production quantity was established using a 90% learning curve as also indicated in Figure A-15. Using these data, doubling the production quantity, reduces unit cost by 10%.

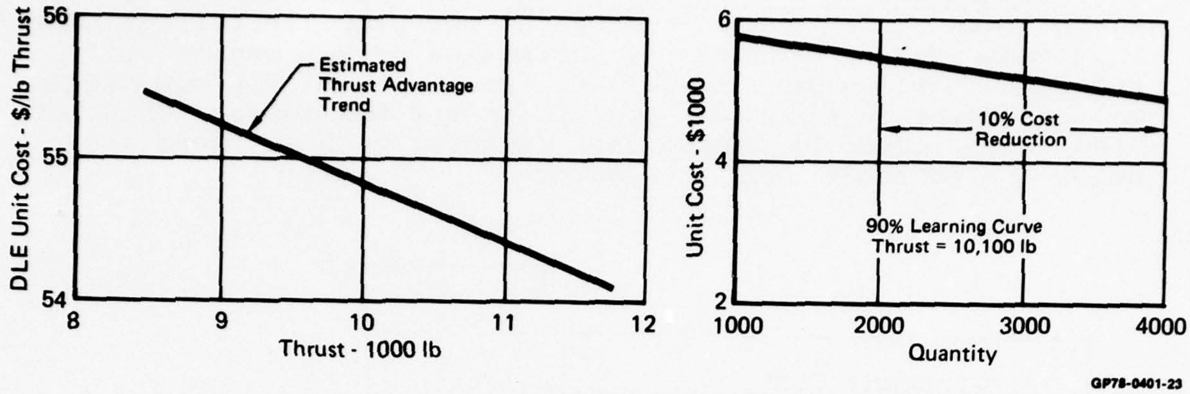


FIGURE A-15
DIRECT LIFT ENGINE (DLE) PRODUCTION COST
1976 $

The engine production cost model was also modified to include a CIP cost increment equal to 114% of development costs. A comparison between MCAIR and GE estimated production engine costs was made. MCAIR estimates, using the procedures described above, were within 3% of the costs estimated by GE for both the DLE and L/C engines.

Operations and Support Cost - The MCAIR O&S cost estimating procedure is used to estimate both total system and the engine contribution to O&S costs. This is accomplished by modifying the O&S input data as shown below:

	O&S Input Data	
	With Engines	Without Engines
Engine Overhall $/Flying Hour	150	0
Maintenance Personnel per Squadron	16	13
Ground Officers per Squadron	5	4
Maintenance Man Hours/Flying Hour	22	19
Shop Support Personnel/Squadron	8	7
Replenishment Spares Cost/Flying Hour	280	200

<u>VCE Impact on L/C Engine Costs</u> - As indicated above, the engine cost estimating procedures do not properly reflect emerging technologies. Therefore, estimation of VCE engine costs required modifications to reflect the impact of VCE components on L/C engine development, production and O&S costs. This has been accomplished by adding cost factors, such as those shown below for variable turbine geometry.

	VGT Cost Factor
Development Cost	+ 2.1%
Production Cost	+ 6.0%
O&S Cost	+ 4.9%

A.3 <u>V/STOL CADE Output Data</u>

Over four hundred aircraft size, weight, performance and cost parameters are provided in a 10 by 47 data array for each converged aircraft design. A sample array is included at the end of this appendix along with the definition of the parameters included in the data array.

ENG.ID.= 67 FPR=4.000 CPR= 6.600 DTAMBD=49.00 AT41 DATE 77/07/29. SECONDS = 86.691

STANDARD OUTPUT FILE WRITTEN FOR CASE 1

1	2	3	4	5	6	7	8	9	10
1.0000	10582.7631	4.0000	6.6000	49.0000	88.0000	55.0000	2.5000	.8846	.6500
11	12	13	14	15	16	17	18	19	20
1.6000	46000.0000	.2500	.0600	.3000	.0100	.7700	142.9584	10725.7215	32646.4960
21	22	23	24	25	26	27	28	29	30
22063.7329	28413.3908	713.9574	5423.1662	692.1501	293.1584	9.0343	14.3037	38.0287	56.9756
31	32	33	34	35	36	37	38	39	40
.0089	1436.8828	1.6996	3.1966	15.1135	4131.8145	1.4842	2.7480	3.8130	1071.5613
41	42	43	44	45	46	47	48	49	50
18603.0982	17874.7499	1727.6454	2162.0000	1.8215	2.4082	99.7225	98.5265	417.4707	213.5528
51	52	53	54	55	56	57	58	59	60
-2706.6182	-1776.7087	2307.8640	8.6921	9.8711	6.8321	27.9906	33646.4960	.0000	-.0000
61	62	63	64	65	66	67	68	69	70
45.0000	3.0000	6.4388	10.0000	0.0000	90.0000	37.3514	38456.4960	.0000	-.0000
71	72	73	74	75	76	77	78	79	80
45.0000	3.0000	6.1100	10.0000	0.0000	90.0000	42.6291	42836.4960	.0000	-.0000
81	82	83	84	85	86	87	88	89	90
45.0000	3.0000	9.3624	10.0000	0.0000	90.0000	42.6283	-1133.9129	.0409	.0479
91	92	93	94	95	96	97	98	99	100
15388.5000	8334.5000	.5503	.9577	.5452	-.7554	241.1949	.0661	.0263	14743.3000
101	102	103	104	105	106	107	108	109	110
5434.3000	.9532	.4284	.2513	-.0906	824.5460	.1023	.0225	21387.0000	4901.0000
111	112	113	114	115	116	117	118	119	120
.7268	.1924	-.0038	0.0000	569.5167	.1907	.0214	16946.3000	2971.3000	.4956
121	122	123	124	125	126	127	128	129	130
-.2640	.0007	0.0000	273.2599	.2971	.0306	8123.8000	1739.8000	.7424	.1924
131	132	133	134	135	136	137	138	139	140
-.0048	0.0000	323.4517	.0606	.0484	24943.9376	9656.9376	.5197	.7620	.0246
141	142	143	144	145	146	147	148	149	150
-.2014	347.5854	.1203	.0557	15353.7806	4811.7806	.6901	1.0312	.0570	-.3223
151	152	153	154	155	156	157	158	159	160
318.4164	.1220	.0559	12510.8148	2763.6150	1.0986	.4119	.1087	-.6121	4.7497
161	162	163	164	165	166	167	168	169	170
.9089	.1782	16946.3000	2971.3000	.7098	-.2640	.0307	0.0000	2.4630	.7385
171	172	173	174	175	176	177	178	179	180
.1230	8123.8000	1739.8000	1.0486	.1924	-.0046	0.0000	72.5279	74.8230	84.3427
181	182	183	184	185	186	187	188	189	190
115.1818	46639.9181	55576.8562	0.0000	0.0000	694.0056	334.1858	2486.6104	2796.2421	1134.1003
191	192	193	194	195	196	197	198	199	200
9.1434	803.0833	594.5778	1000.9317	529.1362	150.0000	0.0000	27532.7609	40000.0000	1.6000
201	202	203	204	205	206	207	208	209	210
1.1693	12649.9444	21176.8960	121.1649	5.5085	268.9390	1.0966	.4116	.1087	-.6121
211	212	213	214	215	216	217	218	219	220
28413.3908	40000.0000	1.6000	2.0000	18515.3459	40324.6960	0.0000	5.5085	268.9390	1.0986
221	222	223	224	225	226	227	228	229	230
.4118	.1087	-.6121	24591.1917	44763.5986	.9500	.7159	2548.1663	3015.4616	137.4765

V/STOL CADE OUTPUT DATA ARRAY

(Example)

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231 2.6507	232 246.1781	233 2.0449	234 .0769	235 .2937	236 0.0000	237 301.4872	238 0.0000	239 553.5511	240 0.0000
241 32781.7714	242 38701.1966	243 .9000	244 .7221	245 3430.8625	246 3970.3132	247 514.1466	248 2.6623	249 248.1666	250 2.6039
251 .0769	252 .2933	253 0.0000	254 28413.3908	255 10000.0000	256 .9000	257 2.0000	258 26057.0965	259 61341.9267	260 0.0000
261 2.2728	262 259.6139	263 1.7837	264 .0769	265 -.0066	266 0.0000	267 26009.9831	268 43566.9780	269 .9000	270 .7156
271 2685.4002	272 3169.4902	273 524.3132	274 2.6499	275 246.1533	276 2.0454	277 .0769	278 .2937	279 0.0000	280 0.0000
281 0.0000	282 0.0000	283 0.0000	284 300.0000	285 1.2822	286 34960.1261	287 37687.3257	288 .9000	289 .7785	290 4001.5397
291 4489.7932	292 256.0727	293 2.7992	294 258.1248	295 1.8012	296 .0769	297 .2962	298 0.0000	299 31054.3464	300 20000.0000
301 .5399	302 .4153	303 3168.8118	304 3715.3684	305 0.0000	306 1.3120	307 190.8088	308 2.2225	309 -.1795	310 .1554
311 0.0000	312 29613.3908	313 20000.0000	314 .8000	315 1.0000	316 11569.4842	317 12781.0115	318 0.0000	319 2.9462	320 293.1584
321 .9365	322 -.0055	323 .1976	324 0.0000	325 26523.9296	326 43533.1993	327 .9300	328 .7640	329 2553.8586	330 3398.5918
331 269.0596	332 2.7665	333 254.6750	334 1.8713	335 .0769	336 .2915	337 0.0000	338 300.0000	339 2.0181	340 0.0000
341 0.0000	342 150.0000	343 1.9076	344 34643.5125	345 37756.0816	346 .9000	347 .7424	348 3733.0546	349 4261.7464	350 110.5785
351 2.7110	352 251.8941	353 1.9280	354 .0769	355 .2921	356 0.0000	357 30460.4925	358 35000.0000	359 .7415	360 .6164
361 3070.7869	362 3359.3498	363 0.0000	364 2.0629	365 229.7229	366 1.9331	367 -.0466	368 .1644	369 0.3000	370 2843.3956
371 35000.0000	372 1.5000	373 2.0000	374 21266.8718	375 46094.2260	376 0.0000	377 4.9677	378 276.4510	379 .9777	380 .3896
381 .1247	382 -.7627	383 24816.7849	384 44567.0774	385 .9000	386 .7156	387 2570.2273	388 3040.2380	389 142.7715	390 2.6499
391 246.1536	392 2.0454	393 .0769	394 .2937	395 0.0000	396 150.0000	397 2.7061	398 1874.5949	399 0.3000	400 0.0000
401 1942.6031	402 3793.5424	403 2943.5427	404 9.1847	405 140.3663	406 323.0006	407 219.0000	408 20.3536	409 308.7482	410 97.3579
411 49.7296	412 25.0909	413 14.1292	414 646.9221	415 798.2854	416 357.3634	417 607.2871	418 188.4564	419 515.1711	420 382.7121
421 1942.6031	422 6421.4439	423 5721.4403	424 8.0997	425 140.3663	426 323.0006	427 219.0000	428 20.3536	429 308.7482	430 97.3579
431 49.7296	432 25.0909	433 14.1292	434 1070.5094	435 1294.3701	436 653.0706	437 1107.5332	438 327.6087	439 1030.3421	440 765.4242
441 1942.6031	442 8827.7403	443 8445.9733	444 7.5395	445 140.3663	446 323.0008	447 219.0000	448 20.3536	449 308.7482	450 97.3579
451 49.7296	452 25.0909	453 14.1292	454 1450.2566	455 1836.7443	456 926.7241	457 1570.2608	458 450.9791	459 1545.5132	460 1148.1363
461 0.0000	462 0.0000	463 0.0000	464 0.0000	465 0.0000	466 0.0000	467 0.0000	468 0.0000	469 0.0000	470 0.0000

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V/STOL CADE OUTPUT DATA ARRAY (Continued)

(Example)

OUTPUT DATA ARRAY PARAMETER DEFINITIONS

LOCATION	DEFINITION OF CONTENTS
1	Case Number
2	Internal Fuel Weight
3	Fan Pressure Ratio
4	Compressor Pressure Ratio
5	Airflow Scheduling Parameter - (Δ Tamb) SLS
6	Combat Wing Loading
7	Wing Leading Edge Sweep Angle
8	Wing Aspect Ratio
9	Takeoff Thrust to Weight Ratio
10	Lift/Cruise Engine Throttle Setting for VTO
11	Dash Mach No. for Deck Launched Intercept Mission
12	Dash Altitude for Deck Launched Intercept Mission
13	Wing Taper Ratio
14	Wing Thickness to Chord Ratio
15	Wing Conical Camber
16	Wing Mean Line Camber
17	Wing L.E. Radius to Chord Ratio Coefficient
18	Excess Volume Indicator
19	Internal Fuel Capacity
20	Design Takeoff Gross Weight (VTO)
21	Zero Fuel Weight
22	Combat Gross Weight (60% Internal Fuel)
23	Fuel System Weight
24	Propulsion System Weight
25	Air Induction System Weight
26	Lift/Cruise Engines Airflow, SLS
27	Lift/Cruise Engines Capture Area
28	Lift/Cruise Engines Nozzle Exit Area (Max.)
29	Fuselage Maximum Cross-Sectional Area
30	Fuselage Length
31	Fuselage Fineness Ratio
32	Wetted Area Total Aircraft
33	Lift/Cruise Engine Scale Factor Times No. of Engines
34	Lift/Cruise Engine Diameter
35	Lift/Cruise Engine Length
36	Lift/Cruise Engine Weight
37	Lift Engine Scale Factor Times No. of Engines
38	Lift Engine Diameter
39	Lift Engine Length
40	Lift Engine Weight
41	Lift Engines VTO Thrust
42	Lift/Cruise Engines VTO Thrust
43	Lift/Cruise Engines VTO Exhaust Temperature
44	Lift Engines VTO Exhaust Temperature
45	Lift/Cruise Engines VTO H/D Ratio
46	Lift Engines VTO H/D Ratio
47	Lift/Cruise Engines Inlet Temperature
48	Lift Engines Inlet Temperature
49	Lift/Cruise Engines Fountain
50	Lift Engines Fountain

LOCATION	DEFINITION OF CONTENTS
51	Lift/Cruise Engines Suckdown
52	Lift Engines Suckdown
53	Lift Engines Bleed Thrust
54	Lift/Cruise Engines Moment Arm
55	Forward Lift Engine Moment Arm
56	Aft Lift Engine Moment Arm
57	Center of Gravity Location at Takeoff
58	STO Gross Weight 1 (No Ext. Fuel) Tactical Strike Mission
59	Ground Roll to Rotation Initiation
60	Velocity at Rotation Initiation
61	Lift Engine Vector Angle for Ground Roll
62	Lift/Cruise Engine Vector Angle for Ground Roll
63	STO Distance (MLG Lift-off)
64	Velocity at MLG Lift-off
65	Wing Angle of Attack at MLG Lift-off
66	Lift Engine Vector Angle at MLG Lift-off
67	Lift/Cruise Engine Vector Angle at MLG Lift-off
68	STO Gross Weight 2 (600 Gal. Ext. Fuel) T.S. Mission
69	
70	Locations 69-77 same as 59-67
71	
72	
73	
74	
75	
76	
77	
78	STO Gross Weight 3 (1200 Gal. Ext. Fuel) T.S. Mission
79	
80	Locations 79-87 same as 59-67
81	
82	
83	
84	
85	
86	
87	
88	Specific Excess Power at 1 "G" EM #1
89	Lift Coefficient
90	Drag Coefficient
91	Gross Thrust
92	Ram Drag
93	Delta Inlet Axial Force/Dynamic Pressure
94	Delta Inlet Axial Force Ref. Cond./Dynamic Pressure
95	Delta Nozzle Axial Force/Dynamic Pressure
96	Delta Nozzle Axial Force Ref. Cond./Dynamic Pressure
97	Specific Excess Power at 1 "G" EM #2
98	
99	
100	

LOCATION	DEFINITION OF CONTENTS
101	
102	
103	
104	
105	
106	Specific Excess Power at 1 "G" EM #3
107	
108	
109	
110	
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115	Specific Excess Power at 1 "G" EM #4
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124	Specific Excess Power at 1 "G" EM #5
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133	Specific Excess Power at 1 "G" EM #6
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142	Specific Excess Power at 1 "G" EM #7
143	
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LOCATION	DEFINITION OF CONTENTS
151	Specific Excess Power at 1 "G" EM #8
152	
153	
154	
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156	
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158	
159	
160	Maximum Sustained Load Factor EM #1
161	
162	
163	
164	
165	
166	
167	
168	
169	Maximum Sustained Load Factor EM #2
170	
171	
172	
173	
174	
175	
176	
177	
178	Acceleration Time From M=.8-1.6 at 25000 Ft.
179	30000 Ft.
180	35000 Ft.
181	Acceleration Time From M=.8-1.6 at 40000 Ft.
182	Intermediate Power Combat Ceiling
183	Maximum Power Combat Ceiling
184	(Not Used)
185	(Not Used)
186	Fuel Used for Warm-up DLI
187	Fuel Used for Takeoff DLI
188	Fuel Used for Climb Out DLI
189	Fuel Used for Dash Out DLI
190	Fuel Used for Combat DLI
191	Fuel Used for Climb back DLI
192	Fuel Used for Cruise Back DLI
193	Fuel Used for Loiter DLI
194	Fuel Used for Landing DLI
195	Reserve Fuel, DLI
196	Radius for DLI
197	Combat Loiter Time, DLI
198	Average Gross Weight Dash Out, DLI
199	Altitude
200	Mach No.

LOCATION	DEFINITION OF CONTENTS
201	Throttle Setting
202	Net Propulsive Force
203	Fuel Flow
204	Distance
205	Nozzle Exit Pressure Ratio
206	Corrected Airflow
207	Delta Inlet Axial Force/Dynamic Pressure
208	Delta Inlet Axial Force Ref. Cond./Dynamic Pressure
209	Delta Nozzle Axial Force/Dynamic Pressure
210	Delta Nozzle Axial Force Ref. Cond./Dynamic Pressure
211	Combat Gross Weight, DLI
212	
213	Locations 212-223 same as 199-210
214	
215	
216	
217	
218	
219	
220	
221	
222	
223	
224	Average Gross Weight Cruise Back, DLI
225	
226	Locations 225-236 same as 199-210
227	
228	
229	
230	
231	
232	
233	
234	
235	
236	
237	Fighter Escort Radius With No Ext. Fuel
238	Fighter Escort Loiter Time with No Ext. Fuel
239	Fighter Escort Radius with (2) 300 Gal. Tks.
240	Fighter Escort Loiter Time with (2) 300 Gal. Tks.
241	Average Gross Weight, F.E. Cruise Out
242	
243	Locations 242-253 same as 199-210
244	
245	
246	
247	
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250	

LOCATION	DEFINITION OF CONTENTS
251	
252	
253	
254	Combat Gross Weight, F.E. with (2) 300 Gal. Tks.
255	
256	Locations 255-266 same as 199-210
257	
258	
259	
260	
261	
262	
263	
264	
265	
266	
267	Average Gross Weight, F.E. Cruise Back
268	
269	Locations 268-279 same as 199-210
270	
271	
272	
273	
274	
275	
276	
277	
278	
279	
280	Fighter Escort Radius with (2) 600 Gal. Tks.
281	Fighter Escort Loiter Time with (2) 600 Gal. Tks.
282	Tactical Strike Radius with No Ext. Fuel
283	Tactical Strike Loiter Time with No Ext. Fuel
284	Tactical Strike Radius with (2) 300 Gal. Tks.
285	Tactical Strike Loiter Time with (2) 300 Gal. Tks.
286	Average Gross Weight, T.S. Cruise Out
287	
288	Locations 287-298 same as 199-210
289	
290	
291	
292	
293	
294	
295	
296	
297	
298	
299	Average Gross Weight, T.S. Loiter
300	

LOCATION	DEFINITION OF CONTENTS
301	Locations 300-311 same as 199-210
302	
303	
304	
305	
306	
307	
308	
309	
310	
311	
312	Combat Gross Weight, T.S. with (2) 300 Gal. Tks.
313	
314	Locations 313-324 same as 199-210
315	
316	
317	
318	
319	
320	
321	
322	
323	
324	
325	Average Gross Weight, T.S. Cruise Back
326	
327	
328	
329	
330	
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335	
336	
337	
338	Tactical Strike Radius with (2) 600 Gal. Tks.
339	Tactical Strike Loiter Time with (2) 600 Gal. Tks.
340	Combat Air Patrol Radius with No Ext. Fuel
341	Combat Air Patrol Loiter Time with No Ext. Fuel
342	Combat Air Patrol Radius with (2) 300 Gal. Tks.
343	Combat Air Patrol Loiter Time with (2) 300 Gal. Tks.
344	Average Gross Weight, C.A.P. Cruise Out
345	
346	Locations 345-356 same as 199-210
347	
348	
349	
350	

LOCATION	DEFINITION OF CONTENTS
351	
352	
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357	Average Gross Weight C.A.P. Loiter
358	
359	Locations 358-369 same as 199-210
360	
361	
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363	
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365	
366	
367	
368	
369	
370	Combat Gross Weight C.A.P. with (2) 300 Gal. Tks.
371	
372	Locations 371-382 same as 199-210
373	
374	
375	
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377	
378	
379	
380	
381	
382	
383	Average Gross Weight C.A.P. Cruise Back
384	
385	Locations 384-395 same as 199-210
386	
387	
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391	
392	
393	
394	
395	
396	Combat Air Patrol Radius with (2) 600 Gal. Tks.
397	Combat Air Patrol Loiter Time with (2) 600 Gal. Tks.
398	Ferry Range with (2) 600 Gal. Tks.
399	(Not Used)
400	

LOCATION	DEFINITION OF CONTENTS
401	RDT&E Cost for 300 Aircraft
402	Production Cost for 300 Aircraft
403	O&S Cost for 300 Aircraft
404	Unit Flyaway Cost
405	Airframe Design & Development Cost
406	Lift/Cruise Engine Development Cost
407	Lift Engine Development Cost
408	Subsystems Development Cost
409	Flight Test Aircraft Cost
410	Flight Test Airframe Cost
411	Flight Test Lift/Cruise Engine Cost
412	Flight Test Lift Engine Cost
413	Flight Test Subsystems Cost
414	Airframe Production Cost
415	Lift/Cruise Engine Production Cost
416	Lift Engine Production Cost
417	Avionics Production Cost
418	Subsystems Production Cost
419	Petroleum, Oil & Lubricants Cost
420	Engines O&S Cost
421	Locations 421-440 Same as 401-420 for 600 Aircraft
422	
423	
424	
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426	
427	
428	
429	
430	
431	
432	
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434	
435	
436	
437	
438	
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441	Locations 441-460 same as 401-420 for 900 Aircraft
442	
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LOCATION	DEFINITION OF CONTENTS
453	
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461	Locations 461-470 Not Used
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APPENDIX B
PROPULSION SYSTEM INSTALLED PERFORMANCE PROGRAM (PSIP)

MCAIR has developed an automated procedure which utilizes engine company performance decks and MCAIR inlet and nozzle/aft-end designs and parasitic extraction requirements to compute installed propulsion system performance. Installed performance data must properly account for the effects of throttle dependent propulsion system drags, inlet total pressure recovery, and compressor bleed and horsepower extractions. The MCAIR Propulsion System Installed Performance (PSIP) program incorporates a thrust/drag accounting system which clearly identifies the propulsion system/airframe interactions. Data generated using PSIP is input to the CADE program for use in conducting aircraft sizing and performance analyses.

The PSIP program, Figure B-1, utilizes a GE parametric engine deck and inlet and aft-end designs from the CADE input aircraft design layout. Aircraft inlet recovery, compressor bleed and horsepower extractions are input to the GE parametric deck. The GE deck is then used to compute engine size, weight and installed performance over the complete flight envelop. This data, along with aircraft inlet and aft-end performance, is used in the PSIP procedure to compute installed propulsion system performance. PSIP is used to calculate the inlet capture area required to meet the airflow demands of a unity scale engine. The aircraft inlet and aft-end drags are then scaled to reflect the changes in inlet and engine nozzle size and operation of the unity scale engine relative to the input aircraft inlet and engine nozzle. Installed propulsion system performance tables along with size, weight and scale factor tables are then generated for input to V/STOL CADE.

The propulsion system performance data is based on the thrust/data accounting system described in Figure B-2. The propulsion system inlet and nozzle/aft-end forces are segregated into those which are dependent on geometry and throttle position. The geometry dependent forces are aircraft drag increments caused by changing the size of the propulsion system relative to the airframe. These increments are defined with the inlet and nozzle operating at the reference conditions. The throttle dependent forces are defined to account for operation of the inlet and nozzle at conditions other than the reference conditions. These throttle dependent forces are included in the definition of installed propulsion system performance.

The inlet geometry dependent force increments are defined at the critical mass flow ratio while the throttle dependent increments are defined at the operating mass flow ratio. This force breakdown is illustrated in Figure B-3. The geometry dependent forces include; (1) all additive and cowl forces associated with inlet bleed, environmental control and leakage which are inlet size dependent. The throttle dependent force

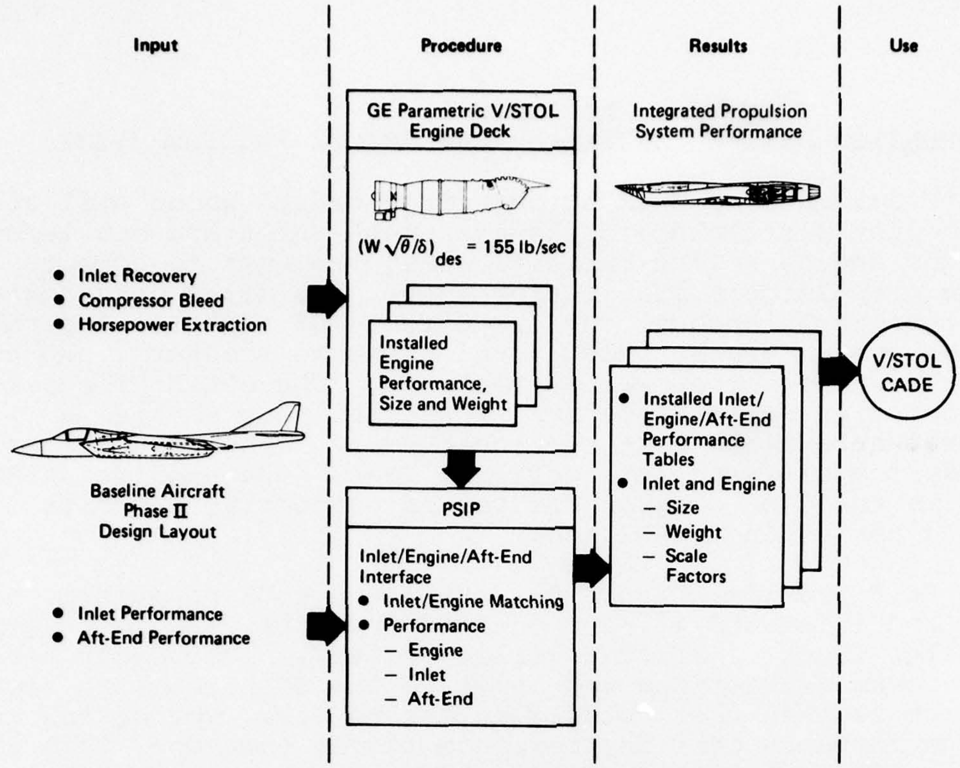
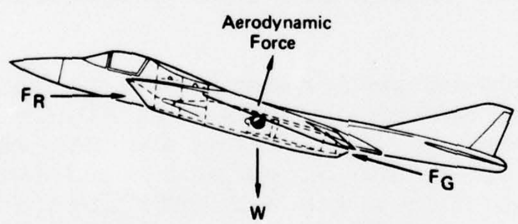


FIGURE B-1
GENERATION OF PROPULSION SYSTEM INSTALLED PERFORMANCE



OPERATING REFERENCE CONDITIONS

Inlet	**Nozzle/Aft-End**
• Mass Flow Ratio - Critical	• $P_{ext} = P_{ambient}$
	• Max. Nozzle Exit Area

Propulsion System Increments

- Geometry Dependent - Defined by Propulsion System Size Changes at Operating Reference Conditions
- Throttle Dependent - Defined by Departure from Operating Reference Conditions

FIGURE B-2
PROPULSION SYSTEM INSTALLED PERFORMANCE (PSIP)
CTOL THRUST/DRAG ACCOUNTING SYSTEM

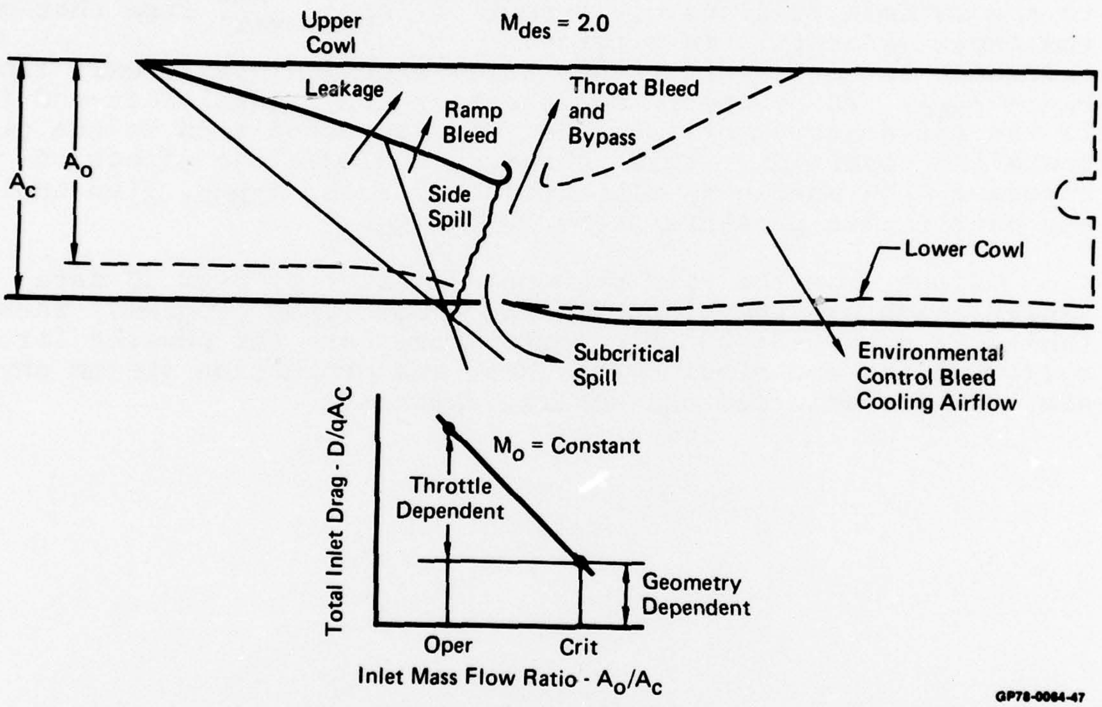


FIGURE B-3
PROPULSION SYSTEM INLET FORCES

includes all forces resulting from; (1) bypass, engine cooling airflow, and engine allowance airflows for scheduling tolerances and (2) the change in additive and cowl, bleed, ECS and leakage forces from the references to the operating conditions.

The nozzle/aft-end geometry dependent force increments account for deviations from the input aircraft relationship of maximum nozzle area to maximum fuselage cross-section area while the throttle dependent increments account for changes in A_9 flap position and static pressure ratio. This force breakdown is illustrated in Figure B-4. The geometry dependent force is the incremental change in external nozzle/aft-end force resulting from changing the maximum nozzle exit area, $A9_{max}$, in relation to the maximum fuselage cross-section, $A_{Fus.\ MAX}$, from that of the input aircraft. This force increment is determined with a fully expanded nozzle exit flow, $P_{ex} = P_{amb}$. The throttle dependent external nozzle/aft-end force is the force increment from the reference condition to the given operating condition. This increment includes the effect of changing ADEN nozzle A_o flap projected area, A_{PROJ}, flap angle, β, and exit static pressure ratio, P_{ex}/P_{amb}.

Output from the PSIP procedure consist of over 30 data tables which are then input to the V/STOL CADE program. These tables, Figure B-5, contain performance data for powered lift system sizing and mission analysis, and propulsion system physical characteristics and scaling exponents.

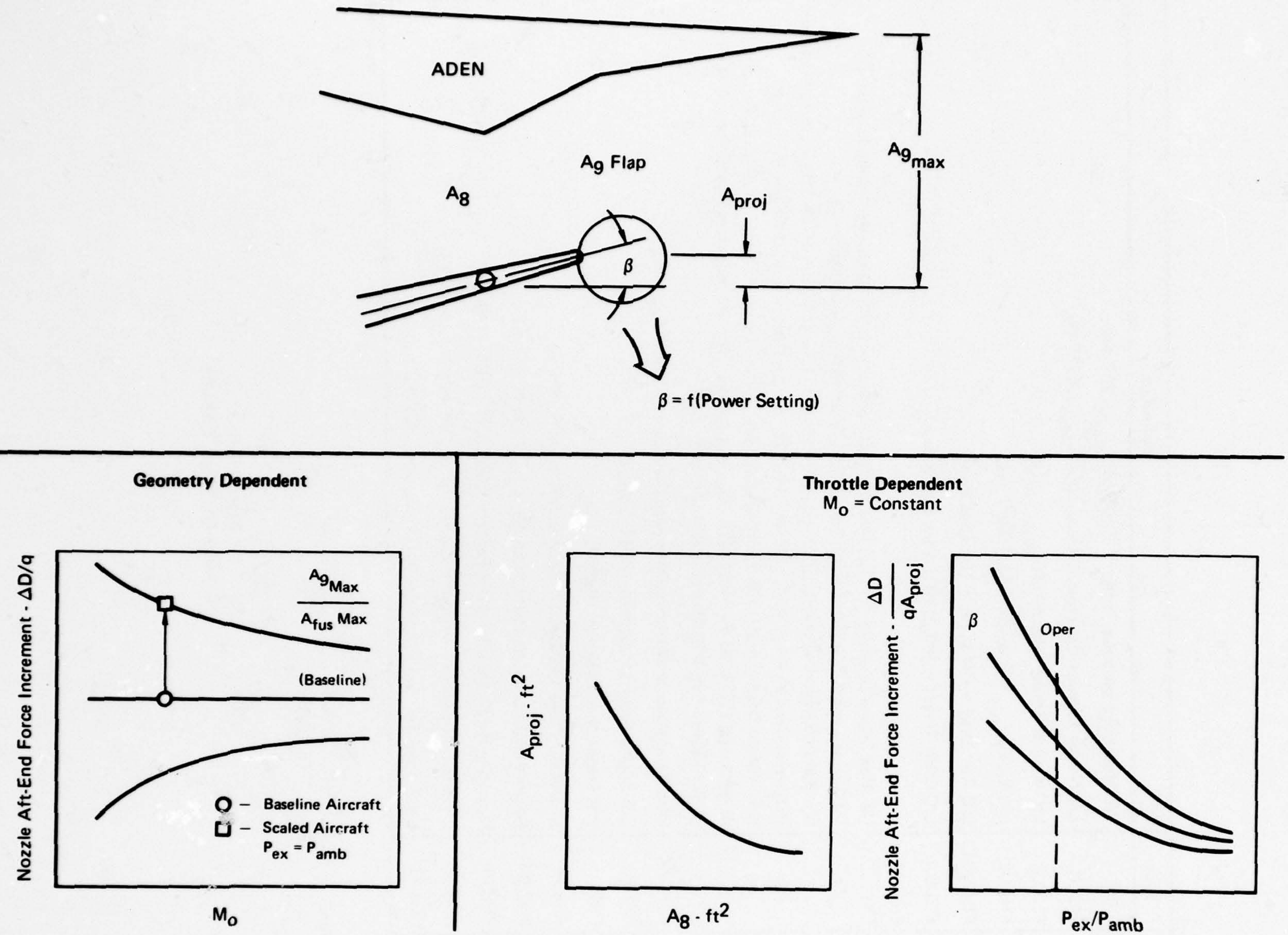


FIGURE B-4
PROPULSION SYSTEM NOZZLE/AFT-END FORCES

Table	Definition
TJLC	L/C Nozzle Exhaust Gas Temp ~ ^{o}R, $f(F_n/F_{n_{max}})$, 90°F Day
WGLC	L/C Nozzle Exhaust Gas Flow ~ lb/sec, $f(F_n/F_{n_{max}})$, 90°F Day
FNTLC	L/C Vertical Thrust ~ lb, $f(F_n/F_{n_{max}}, T_{amb})$
FNRLC	L/C $F_n/F_{n_{horiz}}$ ~ f(Vector Angle), 90°F Day
FRAMLC	L/C Ram Drag ~ $f(M_o)$, 90°F Day, Max Power
FGLCO	L/C Gross Thrust ~ $f(M_o)$, 90°F Day, Max Power
Propulsion List	(1) Max Engine Diameter ~ ft, (2) Max Nozzle Diameter ~ ft, (3) Diameter Scaling Exponent, (4) Engine Length ~ ft, (5) Length Scaling Exponent, (6) Engine Weight ~ lb, (7) Weight Scaling Exponent, (8) Distance from Engine Face to C.G. ~ ft, (9) C.G., Scaling Exponent, (10) Inlet Capture Area ~ ft^2, (11) Not used (12) Length Duct ~ ft, (13) Weight Ramp ~ lb, (14) Weight Duct ~ lb, (15) Standard Day SLS Max Power Thrust ~ lb, (16) L/C VTO Vector Angle ~ deg, (17) VTO F_n ~ lb (90°F Day, Max Power), (18) Distance from Engine Face to VTO Thrust Vector ~ ft, (19) Max Nozzle Area ~ ft^2
IAXORC	Inlet Axial Force at Operating Reference Condition - $FORC/qA_c$, $F(M_o)$
FGEM	L/C Engine Gross Thrust ~ lb, f(EM Pt. No., α)
FREM	L/C Engine Ram Drag ~ lb, f(EM Pt. No., α)
FIAEM	Inlet Axial Force Increment ~ $\Delta IAF/q$, ft^2, f(EM Pt. No., α)
FNZEM	Nozzle Axial Force Increment ~ $\Delta NAF/q$, ft^2, f(EM Pt. No., α)
FIAOR	Operating Reference Inlet Axial Force ~ $IORC/q$, ft^2, f(EM Pt. No., α)
WAECO	L/C Engine Corrected Airflow ~ $W\sqrt{\theta}/\delta$, lb/sec, f(EM Pt. No., α)
PEXPO	L/C Nozzle Exit Static Pressure Ratio ~ P_{ex}/P_a, f(EM Pt. No., α)

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Note: $Z = \dfrac{F_{n_{max}} - F_n}{F_{n_{max}} - F_{n_{min}}}$ (Z Transform)

FIGURE B-5
PSIP OUTPUT TABLES

Table	Definition
AEXEM	Nozzle Exit Area ~ A_g, ft^2, f(EM Pt. No., α)
FN4	Min A/B Net Propulsive Force ~ NPF, lb, f(M_o, Alt)
FN2	Max A/B Net Propulsive Force ~ NPF, lb, f(M_o, Alt)
RED2	Mod A/B Corrected Fuel Flow ~ $W_f/\delta\sqrt{\theta}$, lb/hr, f(M_o, Alt, Z)
RED4	Mod A/B Inlet Axial Force Increment ~ ΔIAF/q, ft^2, f(M_o, Alt, Z)
RED6	Mod A/B Nozzle Exit Area ~ A_g, ft^2, f(M_o, Alt, Z)
RED8	Mod A/B Nozzle Exit Pressure Ratio ~ P_{ex}/P_a, f(M_o, Alt, Z)
RED10	Mod A/B Engine Corrected Airflow ~ $W\sqrt{\theta}/\delta$, lb/sec, f(M_o, Alt, Z)
RED12	Mod A/B Nozzle Axial Force Increment ~ ΔNAF/q, ft^2, f(M_o, Alt, Z)
FN3	Min Power Net Propulsive Force ~ NPF, lb, f(M_o, Alt)
FN1	Int Power Net Propulsive Force ~ NPF, lb, f(M_o, Alt)
RED1	Reduced Power Corrected Fuel Flow ~ $WF/\delta\sqrt{\theta}$, lb/hr, f(M_o, Alt, Z)
RED3	Reduced Power Inlet Axial Force Increment ~ ΔIAF/q ~ ft^2, f(M_o, Alt, Z)
RED5	Reduced Power Nozzle Exit Area ~ A_g, ft^2, f(M_o, Alt, Z)
RED7	Reduced Power Nozzle Exit Pressure Ratio ~ P_{ex}/P_a, f(M_o, Alt, Z)
RED9	Reduced Power Engine Corrected Airflow ~ $W\sqrt{\theta}/\delta$, f(M_o, Alt, Z)
RED11	Reduced Power Nozzle Axial Force Increment ~ ΔNAF/q, ft^2, f(M_o, Alt, Z)

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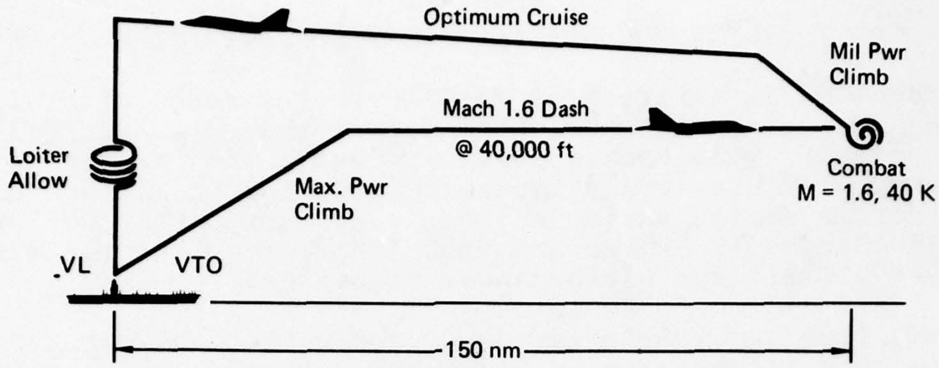
Note: $$Z = \frac{F_{n_{max}} - F_n}{F_{n_{max}} - F_{n_{min}}}$$ (Z Transform)

FIGURE B-5 (Continued)
PSIP OUTPUT TABLES

APPENDIX C
REFERENCE AIRCRAFT TOGW SENSITIVITIES

The TOGW sensitivity of the FCE-TF reference aircraft, to changes in engine size, weight and performance characteristics, were defined. These sensitivities provide the capability to conduct preliminary evaluations to determine the effect of engine and airframe design variables on L + L/C aircraft TOGW. They reflect changes in engine and fuel sizing required to maintain constant DLI mission performance, Figure C-1.

The TOGW sensitivities, developed using the V/STOL CADE program, are illustrated in Figures C-2 through C-6. Figure C-2 summarizes the sensitivity of TOGW to the engine physical characteristics. The engine weight, length, and diameter were perturbed independently ±5% from the reference aircraft engine values. Figures C-3 and C-4 show the effect of changes in fuel flow and engine throttle dependent drags, at the critical mission segments, on TOGW. Reference aircraft fuel flow and drag have been incremented over the percent range shown for the dash, combat and cruise DLI mission segments, independently. The effect of variations in the takeoff thrust to weight ratio (conventional flight) on TOGW is provided in Figure C-5. The effect of changes in lift engine thrust to weight on TOGW is shown in Figure C-6. To obtain this data, the lift engine weight was incremented, at a constant value of thrust.



Performance Requirements:

P_s at Mach 0.90 @ 10,000 ft = 750 fps

n_{z_S} at Mach 0.65 @ 10,000 ft = 4.75 g

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FIGURE C-1
DLI MISSION REQUIREMENTS FOR SENSITIVITY ANALYSIS

Characteristics	$\frac{\Delta \text{ TOGW}}{\Delta \text{ Value}}$	Reference Value
W_e	3.58 lb/lb	2014 lb/Eng
L_e	−109 lb/ft	15.05 ft
D_e	2012 lb/ft	3.21 ft

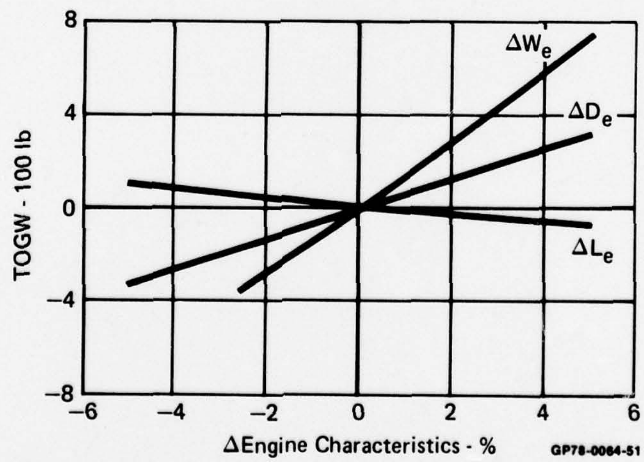

FIGURE C-2
SENSITIVITY OF TOGW TO
ENGINE PHYSICAL CHARACTERISTICS

Mission Segment	$\frac{\Delta\ TOGW}{\Delta\ W_F}$	Reference Value
Dash	0.495 lb/lb/hr	21,441 lb/hr (Total)
Combat	0.121 lb/lb/hr	39,040 lb/hr (Total)
Cruise	1.011 lb/lb/hr	2,949 lb/hr (Total)

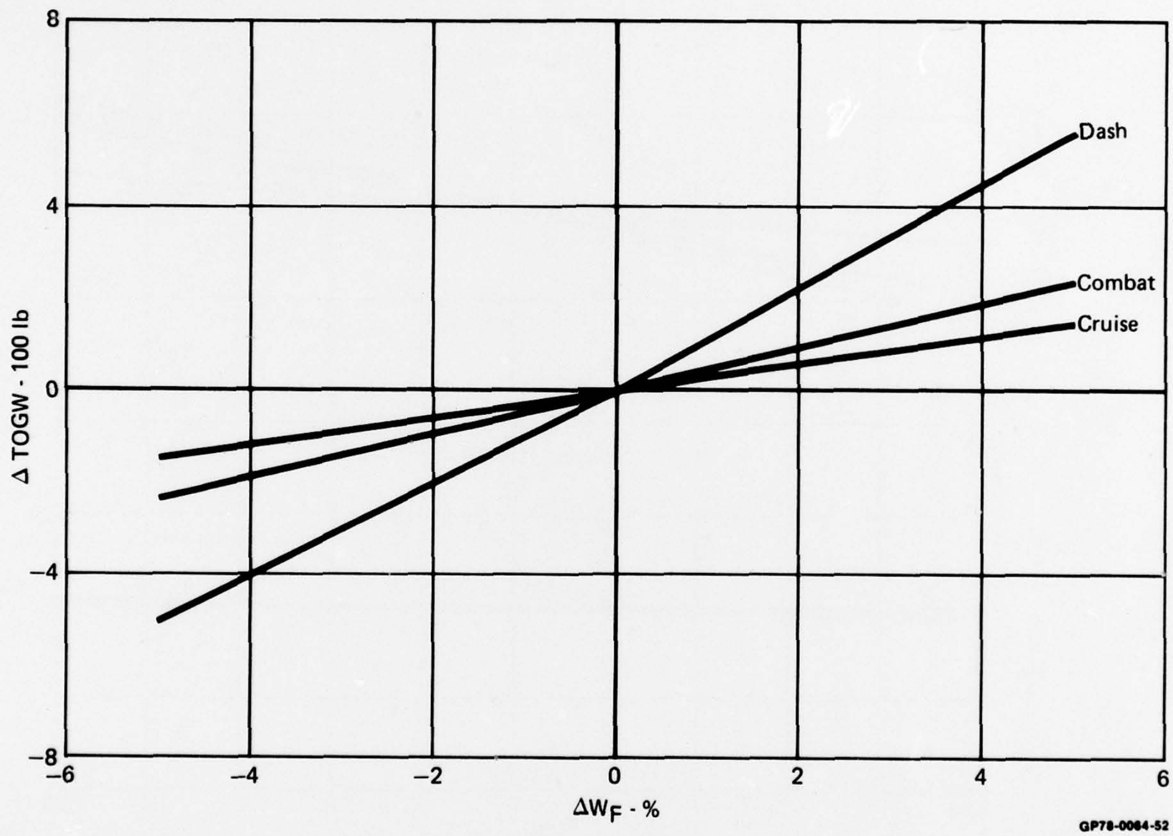

FIGURE C-3
SENSITIVITY OF TOGW TO
FUEL FLOW AT CRITICAL DLI MISSION SEGMENTS

Mission Segment	$\frac{\Delta \text{ TOGW}}{\Delta \text{ Drag}}$	Reference Value	
		IAF	NAF
Dash	867 lb/ft^2	1.086 ft^2	0.109 ft^2
Combat	638 lb/ft^2	1.086 ft^2	0.109 ft^2
Cruise	151 lb/ft^2	1.939 ft^2	0.289 ft^2

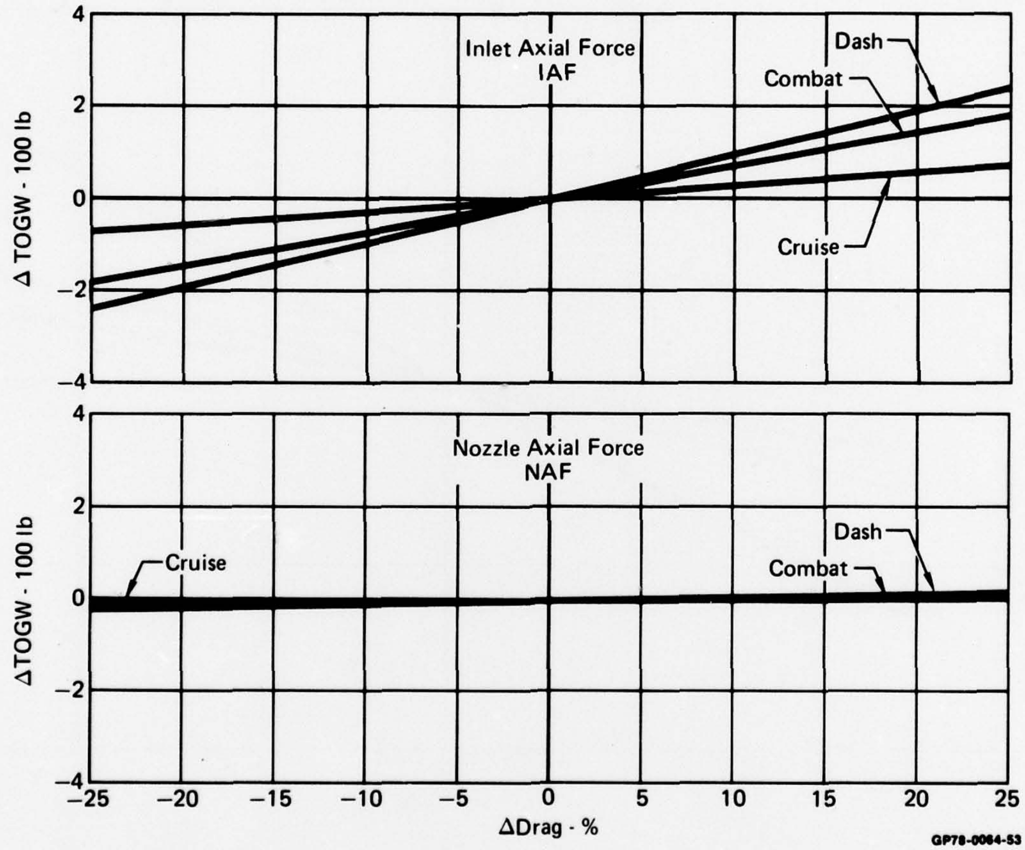

FIGURE C-4
SENSITIVITY OF TOGW TO
DRAG AT CRITICAL DLI MISSION SEGMENTS

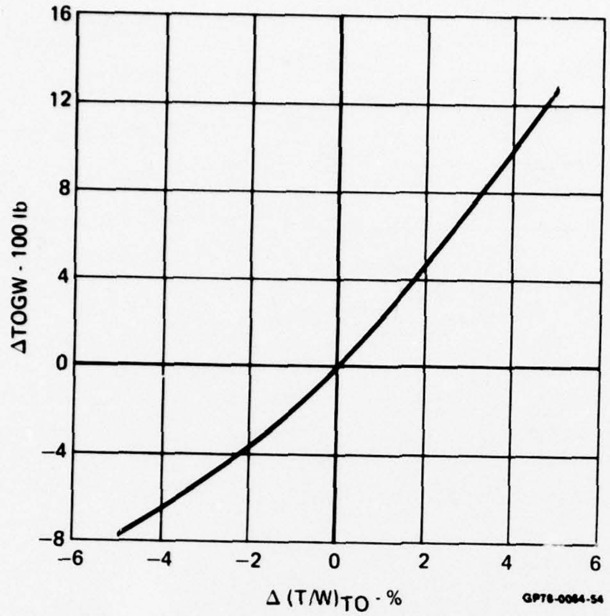

FIGURE C-5
SENSITIVITY OF TOGW TO TAKEOFF THRUST/WEIGHT RATIO
Reference Value of T/W = 0.8819

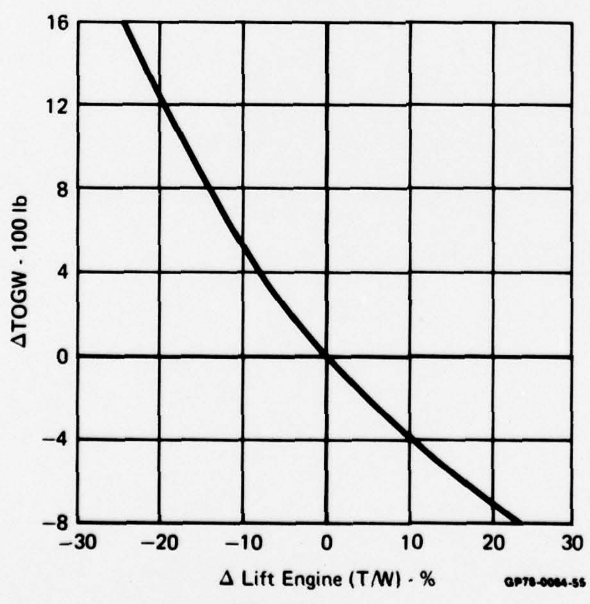

FIGURE C-6
SENSITIVITY OF TOGW TO
LIFT ENGINE THRUST/WEIGHT RATIO
Reference Value = 18