(NASA-CR-144882) YF-17/ADEN SYSTEM STUDY Final Report (Northrop Corp.) 160 p HC A08/MF A01 CSCL 01C

N79-27126

Unclas
G3/05 29348

NASA Contractor Report 144882

# YF-17/ADEN System Study

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W. H. Wooten

July 1979

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Dryden Flight Research Center
Edwards, California 93523

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# YF-17/ADEN System Study

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Scientific and Technical
Information Office

1979

FOREWORD

This report was produced by Northrop Aerosciences Research under NASA Contract No. NAS4-2499 to Dryden Flight Research Center with the guidance of NASA Technical Monitor Mr. F. Olinger. Volume 1, contained herein, represents a consolidation of considerable effort in a number of diverse disciplines. The authors would particularly like to acknowledge the contributions of Northrop personnel S. Radinsky, J.H. Wells, and R. Kubow of Structures Advanced Design, W.E. Nelson of Controls Research, and E. Skulick and D. Johnson of Pricing.

Recognition is also due W.H. Wooten of General Electric Co, Cincinnati, Ohio for the extensive analysis and information provided with regard to YJ101 engine modification and program cost estimates.

## SUMMARY

The purpose of this study was to demonstrate the feasibility of incorporating the G. E. ADEN 2-D vectoring nozzle design on the YF-17 fighter in order to provide a manned flight demonstrator of 2-D nozzle technology. In support of this objective, the study examines the system design modifications required, assesses the expected performance and IR/RCS vulnerability of the modified aircraft, and provides estimates of the overall program cost. Results indicate the program is feasible and can be accomplished at reasonable cost and low risk.

The YF-17 YJ101 engines and aft structure would be modified to integrate ADEN nozzles with a thrust vectoring flap deflection range of 10° up to 20° down. This modification would increase the aircraft weight 600kg (1325 lbs), or about 5% fully fueled. An additional modification to add canards just below the canopy requires removal of the forward fuel cell, which offsets the increased weight of the ADEN installation. As a result, no net weight penalty is incurred for the canard-configured YF-17/ADEN; however, fuel capacity is diminished. A thrust reverser concept was also defined as a desirable added capability.

Modifications to the pitch control system were defined to provide the capability for direct lift, aircraft pointing, negative static margin, and enhanced deceleration. The integrity of the modified system was verified for all modes of operation on the Northrop flight simulator. Results are included in the study.

Analysis showed unvectored thrust-minus-drag improvements to be minimal, with YF-17 baseline performance penalized for increased weight of the ADEN installation and trim drag of the canard. Vectored thrust performance, however, showed some potential benefits in direct lift, aircraft pointing, handling at low dynamic pressure, and takeoff/landing ground roll, indicating that vectored thrust operation probably offers the most fruitful area for flight research. Inclusion of the reverser would offer significant additional dividends in combat maneuvering and landing performance.

Full scale development, testing, and aircraft modification can be accomplished in 27 months, culminating in a 12 month flight test program at NASA Dryden. Cost of the program is estimated to be 15.9 million dollars for the canard-configured version and 13.2 million dollars for the version without canard. It is recommended that the program be pursued to develop experience in the implementation of 2-D nozzle technology, and for the opportunity to evaluate that technology on a full scale manned fighter aircraft. The canard-configured version is recommended as the configuration to be implemented as it offers the greatest potential technical yield.

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# ABBREVIATIONS, ACRONYMS AND SYMBOLS

| | |
|---|---|
| ADEN | AUGMENTED DEFLECTOR EXHAUST NOZZLE |
| $A_8$ | NOZZLE THROAT AREA |
| $C_D$ | DRAG COEFFICIENT, $D/qS_W$ |
| $C_L$ | LIFT COEFFICIENT, $L/qS_W$ |
| $C_{T-D}$ | MEASURED THRUST MINUS DRAG COEFFICIENT, $T-D/qS_W$ |
| CAS | COMMAND AUGMENTATION SYSTEM |
| CVC | CANARD/VEER CONTROL |
| c.g. | CENTER OF GRAVITY |
| D | DRAG FORCE |
| ECS | ENVIRONMENTAL CONTROL SYSTEM |
| $F_G-D_{aft}$ | MEASURED GROSS THRUST MINUS METRIC AFTERBODY DRAG |
| $F_{G_I}$ | IDEAL GROSS THRUST |
| fps | FEET PER SECOND |
| FS | FUSELAGE STATION |
| g | GRAVITATIONAL ACCELERATION CONSTANT |
| IR | INFRARED |
| LEX | LEADING EDGE EXTENSION |
| MAC | MEAN AERODYNAMIC CHORD |

# INTRODUCTION

The intent of this study is to demonstrate the feasibility of developing an inexpensive near-term flight demonstrator for 2-D vectoring nozzle technology through modification of a YF-17 to incorporate General Electric (G. E. ) ADEN nozzles. Presented herein are the design modifications required to integrate the ADEN with the YF-17 airframe, estimates of the potential system performance, and the program plan and cost for follow-on model testing, full-scale design development, fabrication and flight test support.

The application of 2-D nozzle technology to fighter design has been a subject of intense interest in recent years, as it appears to offer a number of potential advantages: increased survivability through reduced IR and RCS signatures, thrust-minus-drag improvement due to more favorable nozzle/airframe integration, and the expanded aircraft maneuvering capability offered by thrust vectoring and reversing. These benefits have been predicted as a result of numerous model test efforts and analytical studies; however, full-scale flight verification of these predictions has yet to be accomplished, and presents itself as a logical next step in the development of 2-D nozzle technology.

The YF-17/ADEN integration, shown conceptually in Figure 1, offers a timely and comparatively inexpensive means of demonstrating 2-D nozzle feasibility in that it utilizes a currently available high performance fighter that can be modified with relative ease to accept the ADEN, an existing and proven 2-D nozzle in a notably advanced state of development. Both Northrop and G. E. have invested considerable effort in 2-D nozzle development programs that have yielded results directly applicable to the definition of the modifications required to accomplish the integration of the ADEN with the YF-17. Under contracts to the Navy reaching back to 1972, GE has developed the ADEN concept to the point where a full scale version of the nozzle has been built, and, in 1976, tested in combination with the YF-17 YJ101 powerplant (Reference 1). As a result, the viability of the engine/nozzle combination has been established and valuable information developed on ADEN internal performance, cooling requirements, and actuation loads.

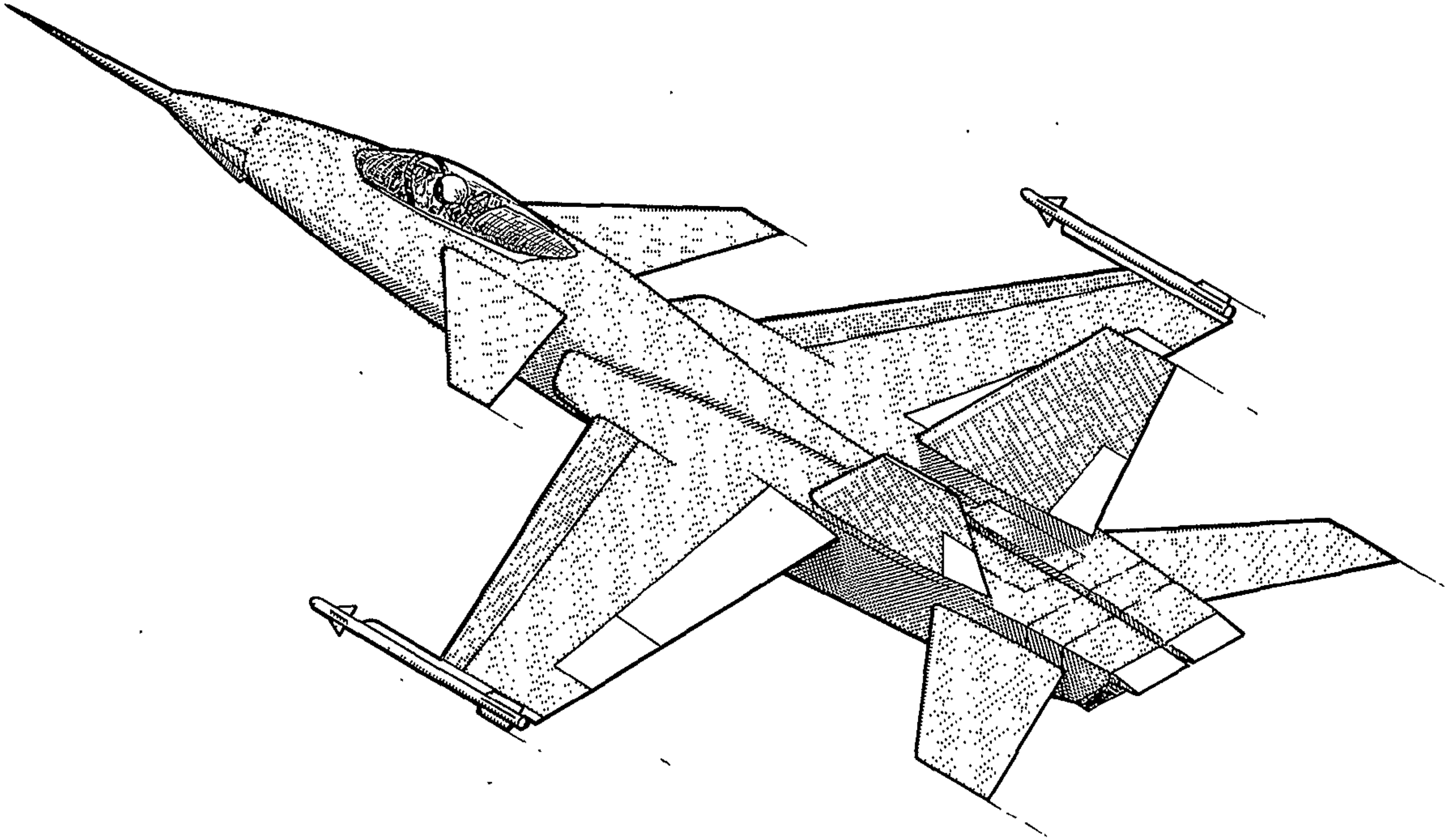


FIGURE 1. YF-17/ADEN 2-D NOZZLE TECHNOLOGY DEMONSTRATOR CONCEPT

During the above-mentioned testing, data was also taken to determine the infrared (IR) emission levels of the ADEN during operation of the YJ101. These data were expanded by further testing during 1978 at Navy facilities in Lakehurst, N.J. (Reference 2). G.E. has also defined ADEN radar cross section (RCS) characteristics through testing of a 1/4-scale ADEN model (Reference 3). A data base has thus been developed for the prediction of the YF-17/ADEN survivability characteristics against current and future threat missiles. It is presented in Volume II of this report (classified Secret) entitled "YF-17/ADEN IR/RCS Characteristics."

Northrop interest in the application of 2-D nozzle technology to the YF-17 led to investigations of the canard concept as a means of trimming the pitching moment produced when the exhaust jet is vectored. In 1977, Northrop model-tested a number of possible approaches to canard location and mounting which resulted in selection of the final "shoulder" location (Reference 4). This configuration was aerodynamically refined, and canard planform and sizing information developed in further model testing at NASA Langley in 1977 (Reference 5).

In later stages of the YF-17/ADEN concept development, the opportunity arose to test the ADEN on a 0.10 scale model of the F-18 (for which the YF-17 is the prototype) as part of an investigation of non-axisymmetric nozzle concepts under joint NASA/NAVY/Northrop/GE/Boeing contract NASA 4-2499. After Northrop/GE discussion on how to most favorably blend the ADEN external contours with the F-18 afterbody, the resulting integration was then tested at NASA Langley. With the jet exhaust simulated by high pressure internal air supply, the scaled F-18/ADEN integration was investigated over a range of representative flight conditions at both unvectored and vectored nozzle settings. The results of this test provided the basis for the flight performance and analysis section of this report. Documentation of the test is provided in Reference 6.

A firm foundation has thus been laid for the definition of a full scale YF-17/ADEN 2-D technology research vehicle. This report represents Northrop/G.E. efforts to provide that definition in sufficient depth to allow a confident assessment of the cost for the proposed modification plan. The study was performed in five tasks:

Task 1: Configuration Design

Task 2: Control System Design

Task 3: IR/RCS Suppression Analysis

Task 4: Flight Demonstration Technology Assessment

Task 5: Program Plan and Cost Estimate for Design, Fabrication, and Flight Test

The report is organized along similar lines except that the classified results of Task 3 are presented separately in the aforementioned Volume II to allow ease of handling of Volume I. Consequently, the results of Task 4 are presented in Section 3 of this volume, and the results of Task 5 in Section 4.

# 1. CONFIGURATION DESIGN MODIFICATIONS

## 1.1 Concept Development

This section provides a general review of major factors influencing the development of the final YF-17/ADEN concept, including applicable previous testing on ADEN and on YF-17 modification for non-axisymmetric nozzles and canards, design decisions aimed at producing an optimum combination of ADEN with the YF-17, and definition of various flight performance guidelines to allow effective demonstration of 2-D nozzle capability. Design modifications are discussed more fully in following sections. Figure 2 provides a three-view drawing of the final proposed modification.

Program Goals. The YF-17/ADEN full-scale modification and flight test program has been designed to accomplish the following:

- Demonstration of the feasibility of design, fabrication, and operation of a full-scale non-axisymmetric-nozzle-equipped high performance fighter.
- Verification of the integrity of the system during flight operation.
- Definition of the effects of the non-axisymmetric integration on unvectored cruise aircraft performance.
- Identification of the steady state performance and aircraft maneuvering capability available in the vectored thrust mode throughout the attainable YF-17/ADEN flight envelope.
- Establishment of the in-flight IR/RCS characteristics of the YF-17/ADEN.
- Application of thrust vectoring to develop short takeoff and landing capability.
- Investigation of the maneuvering and STOL potential of a thrust reverser (optional).

Flight Maneuver Modes. Four control modes were selected to demonstrate maneuvering capability on the YF-17 with canards available to trim vectored thrust-induced pitching moments. The first "normal" mode covers all vehicle operation with active canard but without vectored thrust. The second "lift" mode balances lift forces on the canard, horizontal tail, and vertical component of vectored thrust, such that the pitching moments from these forces cancel each other but result in combined positive lift. The third "pointing" mode uses pitching moments from the same

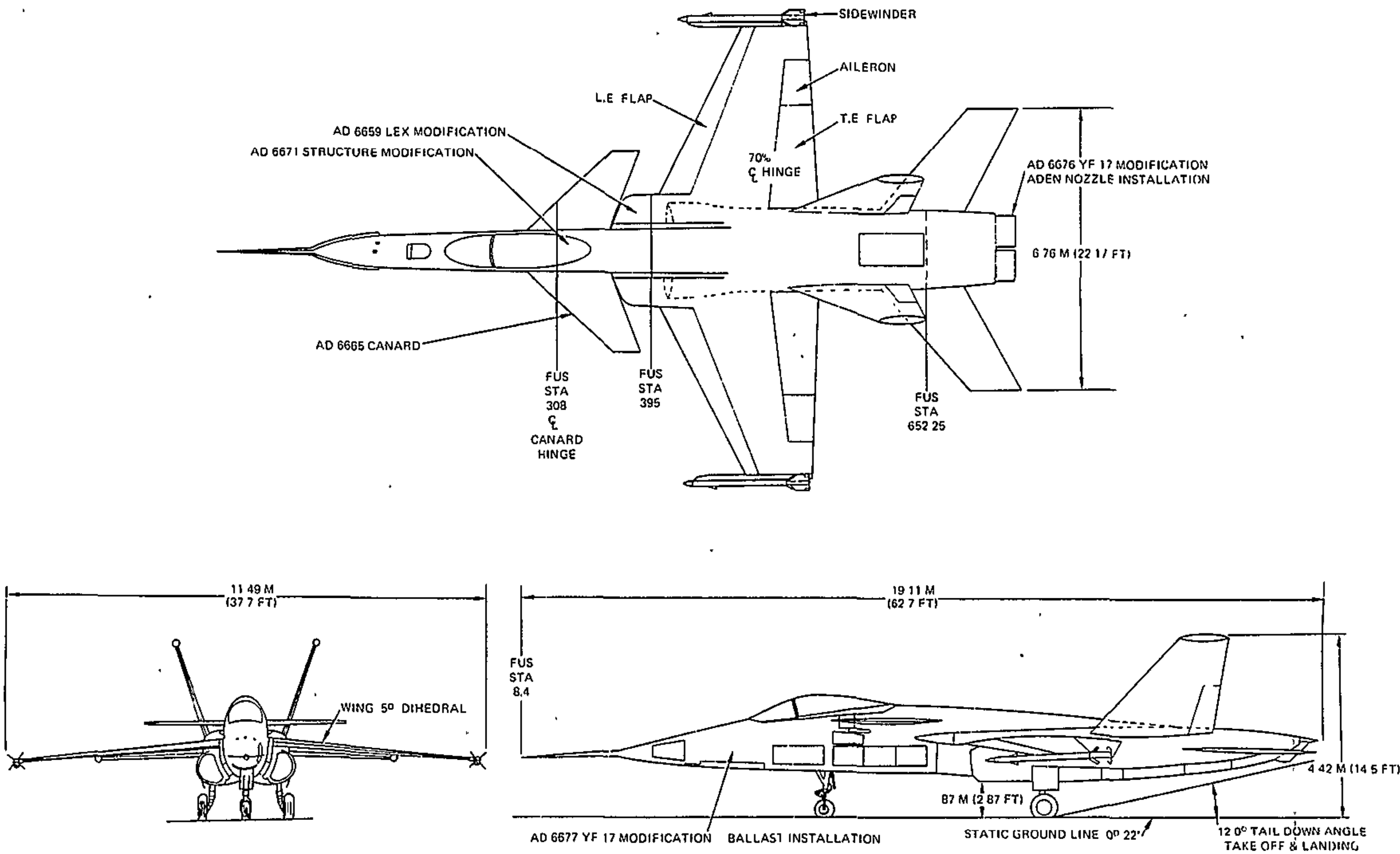



**FIGURE 2. 3-VIEW OF YF-17/ADEN WITH CANARDS**

three sources to rotate the aircraft to a different trimmed state about its center-of-gravity while cancelling excess lift developed in the process. The fourth "decel" mode will use negative horizontal tail deflection to cancel the vertical deflected thrust component, producing a deceleration force from the combined effects of horizontal tail drag and diminished thrust along the x-axis due to vectoring. If the canard is not present, the lift mode will not be available and versatility in the normal and pointing modes will be diminished.

Thrust Vectoring Capability. Vectoring capabilities of the YF-17/ADEN will be demonstrated by mechanically deflecting the ADEN upper flap, or VEER (Variable Exhaust Expansion Ramp) — 10° (upward) and +20° (downward). The -10° upward limit is dictated by anticipated onset of separation of the deflected exhaust on the VEER. The +20° downward limit represents the approximate value at which nozzle performance begins to fall off rapidly with thrust vector angle. The full 30° range will be available for both dry and afterburning power settings.

The full-scale YJ101/ADEN demonstrated at Peebles utilized a rotating hood capable of deflecting thrust up to 110° from the 0° deflection axis in order to provide vertical takeoff and landing (VTOL) capability. As the YF-17 is not designed to utilize vectored thrust for VTOL, this feature will be eliminated on the YF-17/ADEN; significant simplifications to the ADEN cooling and actuation systems, as well as to the aft fuselage external fairings, are possible as a result.

Design Constraints.

- Engine/Airframe Loads: The engine case will be designed to withstand loads of +10 and -3 g. This provides margin over the YF-17 design maximum g loads of +7.33 and -3 g.
- Nozzle Actuation Rates: The VEER actuation rate selected is 20°/sec, the same rate used for the A8 control flap, and the rate which proved to be successful on the YJ101 round nozzle. The 20°/sec speed matches favorably with the 15°/sec YF-17 flap actuation rate.
- YF-17 Fuselage Modification Limits: In order to preserve the YF-17 horizontal tail actuation system and to minimize the area modified on the aft aircraft structure, design changes are restricted to the area rearward of FS 652.25.

Engine Mount System. The engine mounting system is an important engine/airframe interface which provides the means of transmitting engine thrust and maneuver loads from the engine to the airframe structure. With the existing YF-17/YJ101 mounting system, vectored thrust operations would introduce a large bending moment into the engine casing due to the location of the vertical thrust component in relation to the engine mounts. A bending moment of sufficient magnitude could result in ovalization of the thin-walled outer ducts which in turn will adversely affect engine clearances in the turbine and compressor. Therefore, for the YF-17/ADEN, the mounting system is revised to reduce this bending moment by relocating the top rear center-mount to a position further aft.

ADEN Installation in the YF-17. When installed in the YF-17, the ADEN will be oriented such that its original centerline is canted exit-in 2°, and rotated exit-down 6°. The 2° inward cant minimizes base area between the two ADENs, at negligible thrust loss. The 6° downward cant orients the ADEN hardware envelope to provide the best external aft fuselage closure contours. The ADEN thrust axis is readjusted to 0° through rescheduling of the VEER and $A_8$ actuation.

Thrust Reverser Concept. It is felt that the availability of in-flight thrust reversing capability would greatly enhance the opportunity for investigation of maneuvering options with the YF-17/ADEN. With this in mind, G.E. has identified a block-and-turn reverser concept which could be developed and integrated with the YF-17/ADEN. Details of the concept will be discussed in section 1.3.

Canard Development Program. In the event that a decision is made in favor of the canard approach for the YF-17/ADEN, the canard will be "shoulder-mounted" as shown in Figure 1 with a planform of 5.37 meter$^2$ (57.8 sq. ft.) exposed area. The original YF-17 LEX will be removed to eliminate aerodynamic and mechanical interference with the canard and replaced with a wing root fairing. As the original LEX includes an integral ECS intake, its removal requires a new separate ECS scoop intake.

The canard installation shown in Figure 2 represents considerable investigation on the part of Northrop into the feasibility of integrating a canard with the basic YF-17 design as a means of trimming vectored 2-D nozzle thrust. Figure 3 presents a flow chart summarizing a progressive series of tests and requirements that eventually established the most desirable canard approach in terms of location, planform, and exposed area.

As shown, the efforts were initiated in 1976 to investigate possible canard locations on a .08 scale YF-17 model in the Northrop 2.13 x 3.05 M (7 x 10 ft) low speed

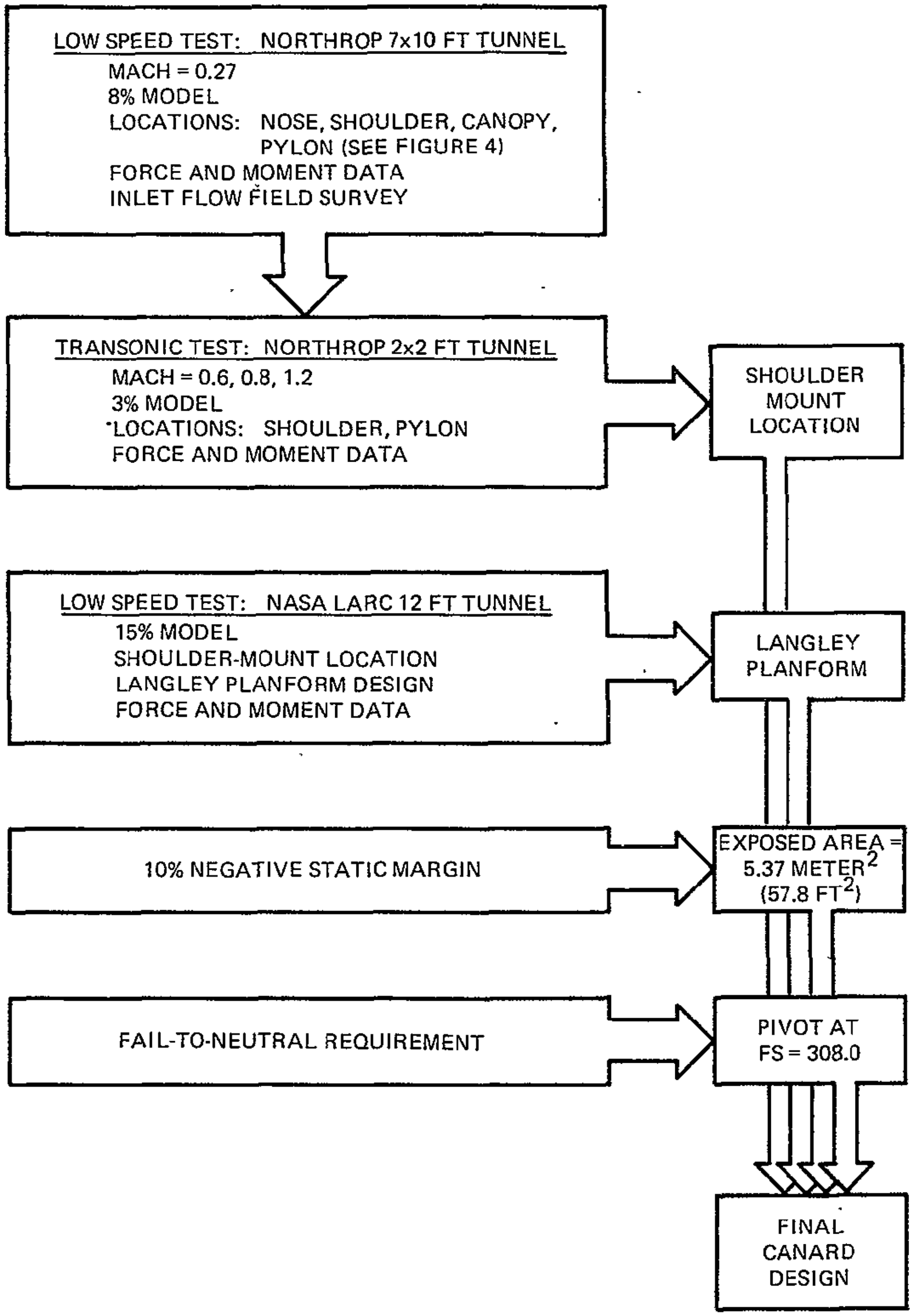



FIGURE 3. YF-17/ADEN CANARD DEVELOPMENT

tunnel (Reference 7) and in this way identify the most promising candidates for further testing at transonic speeds. The model included flow-through inlets with total pressure rakes mounted forward of the inlet to determine canard wake interference effects where applicable. Four locations were considered, with the canard planform areas in each location sized to produce equal pitching moments about the aircraft c.g. Figure 3 furnishes sketches on the locations; Table 1 summarizes the test results for each location.

TABLE 1. CANARD LOCATION TEST RESULTS

| LOCATION | PLANFORM | LOCATION | RESULTS |
|---|---|---|---|
| NOSE MOUNT | DELTA | FORWARD ON NOSE | INLET INTERFERENCE AT MODERATE CANARD DEFLECTIONS. ($\delta_C \geqslant 10^o$) |
| SHOULDER MOUNT | YF-17 WING TYPE | UPPER FUSELAGE BELOW AND NEAR CANOPY | REMOVAL OF LEX COMPENSATED BY CANARD. INLET INTERFERENCE AT HIGH DEFLECTION ANGLES. ($\delta_C > 20^o$) |
| OVER-CANOPY SPLIT MOUNT | YF-17 WING TYPE | LEFT AND RIGHT PYLONS STRADDLING CANOPY | SEVERE LATERAL-DIRECTIONAL STABILITY PROBLEMS. DETERIORATION OF RUDDER EFFECTIVENES. DIFFICULTY OF CONSTRUCTION. |
| PYLON MOUNT | YF-17 WING TYPE | ON PYLON, ABOVE NOSE | SOME LATERAL-DIRECTIONAL STABILITY PROBLEMS. INCREASED LIFT AT HIGH ANGLE OF ATTACK. LOSS OF MOMENT-GENERATING CAPABILITY AT MODERATE ANGLE OF ATTACK. |

Based on the results listed in Table 1, the shoulder mount concept and a modified delta version of the pylon mounted canard were selected for further evaluation in the Northrop 2 x 2 transonic tunnel.

As indicated in Figure 2, the transonic test (Reference 8) evaluated the two selected configurations at $M_N$ = 0.6, 0.8, and 1.2. Both concepts exhibited similar lift characteristics subsonically; at Mach = 1.2 the shoulder-mounted canard produced the greatest lift. Given the added penalty to pilot visibility with the pylon-mounted canard, the decision was made to concentrate further design development on the shoulder mounted concept.

Further refinement of the canard design was rendered possible through related tests by NASA Langley in their low speed tunnel in 1978 (Reference 5), in which the aerodynamic consequences of replacing the YF-17 LEX with a closely-coupled shoulder-mounted canard were investigated on a 15% scale model. Of somewhat different planform

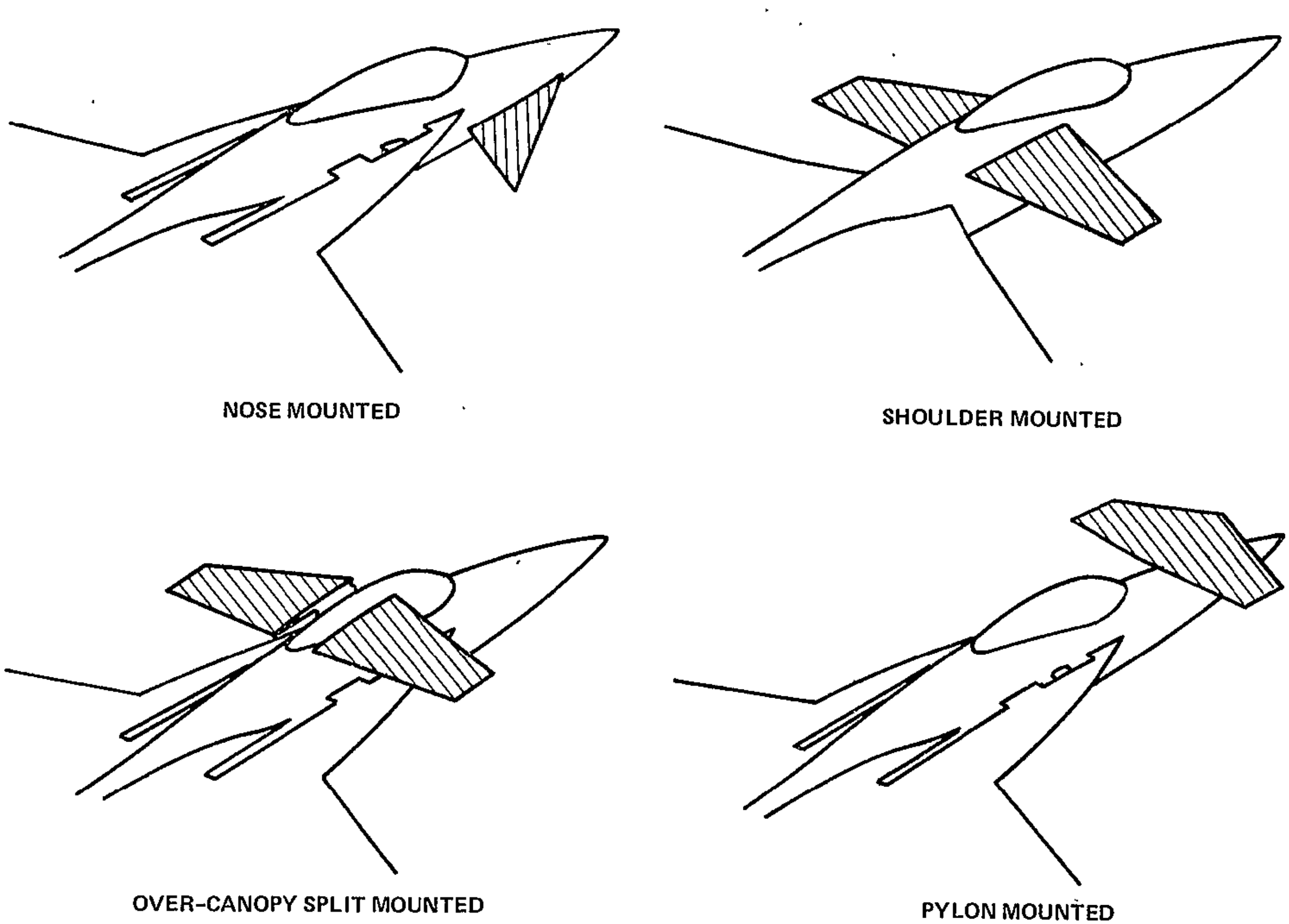



FIGURE 4. POTENTIAL CANARD LOCATIONS

design than the canard chosen by Northrop, the Langley canard was tested at several shoulder locations, with attention directed to flow coupling effects and aircraft stability characteristics. When compared to the Northrop canard, the Langley design exhibited similar overall aerodynamic performance, with a lower actuation hinge moment required. For this reason, it was ultimately selected as the final canard concept for the YF-17/ADEN. The canard pivot point was located at FS 308 to insure that the canard will stabilize in neutral position in the event of a failure in the canard actuation system.

## 1.2 Loads Analysis

The use and control of vectored thrust on the YF-17/ADEN will introduce significant new loading conditions into the aircraft and YJ101 engine structures. Revised load estimates were made to anticipate and design for these conditions in the modification of the engine and the airframe. Following discussions between Northrop and G.E., a flight condition of Mach = 0.9, 10,000 ft., max. power was agreed on as the most representative worst case design loading condition for the engine/airframe.

Engine Loads. Deflection of the ADEN VEER to vector thrust produces a corresponding vertical thrust component which acts in relation to the existing YJ101 mounting system to produce a significantly increased bending moment in the outer engine casing. Figure 5 shows the magnitude of this increased moment for the selected design loading condition and illustrates how, by relocating the rear link mount to a point 57.4 inches aft of its former location, the moment is reduced. Figure 6 compares the bending moment conditions with the original and revised mount system for the worst case of 10g loading combined with 20° of thrust vectoring. With the mount redesign, the maximum bending moment in the outer duct has changed sign and increased from 1500-1950 KgM (130,000 in.-lb to 170,000 in.-lb). Preliminary stress analysis indicates that the existing Ti-6Al-4V honeycomb outer duct has adequate buckling strength to withstand this increase while maintaining proper engine clearances.

The reaction loads at the engine mounts to weight, thrust (unvectored), inertia and gyroscopic loads are compared in Figure 7 for the original and revised mounting systems at unvectored max A/B power for the Mach 0.9, 3050 M (10,000 ft) condition. The resulting loads, derived through analytical estimation methods, were used in the preliminary design of the aircraft engine support and in modification of the fuselage for the new engine mounting arrangement.

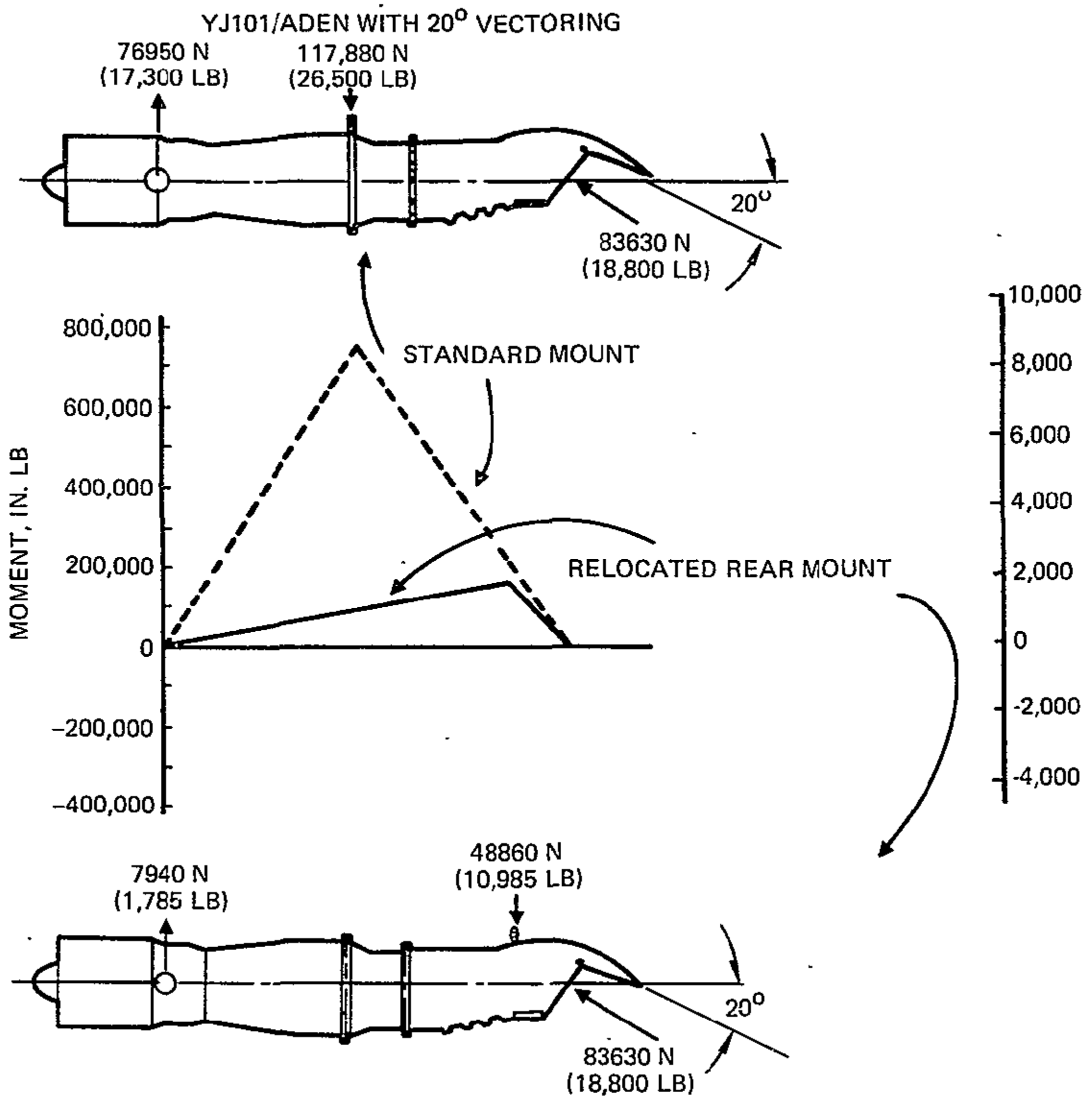



FIGURE 5. ENGINE CASING BENDING MOMENT REDUCTION DUE TO REVISED MOUNT SYSTEM, MAX POWER, MACH = 0.9, 3050 M (10,000 FT.), 20° VECTORING

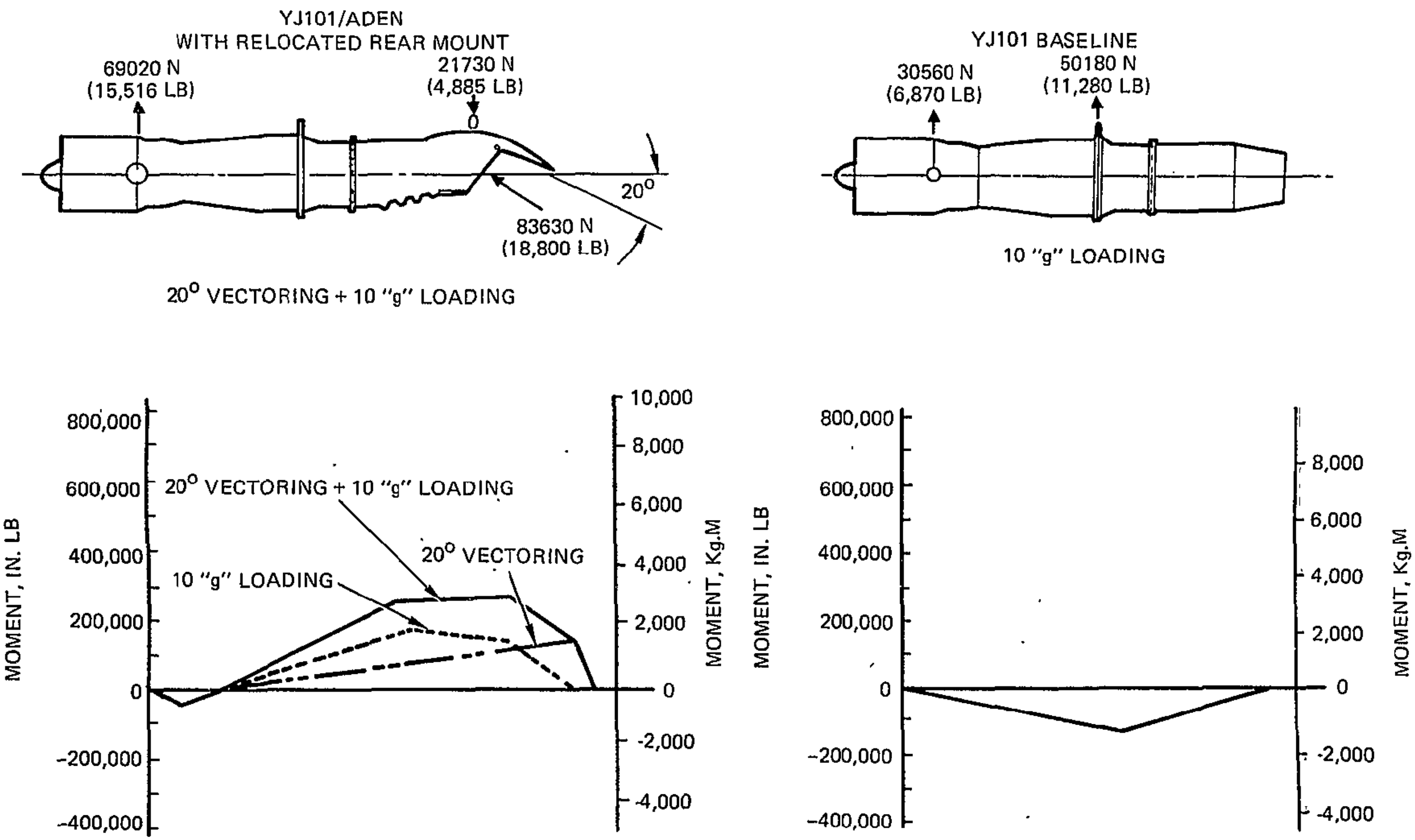
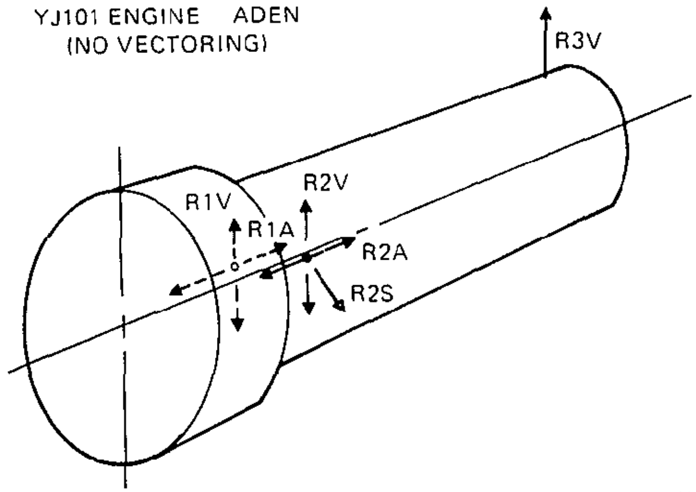



**FIGURE 6. MOMENT DIAGRAMS FOR YJ101/ADEN WITH RELOCATED REAR MOUNT COMPARED TO THE YJ101 10 "g" DESIGN LOADING BASELINE**

PRELIMINARY MOUNT LOADS
YJ101 ENGINE ADEN
(NO VECTORING)

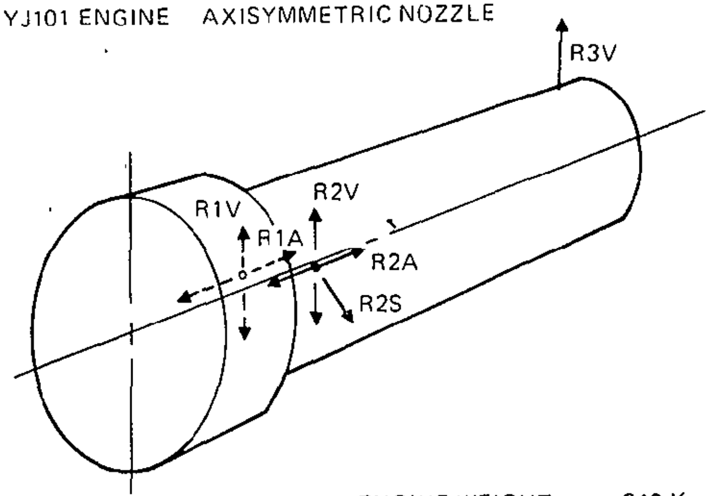



ENGINE WEIGHT 942 Kg
CG LOCATION - STA 234
FRONT MOUNT -- STA 200
REAR MOUNT STA 301

(REACTION FORCES IN N)

| | R1V | R1A | R2V | R2A | R2S | R3V |
|---|---|---|---|---|---|---|
| THRUST | - | 41810 | – | 41810 | – | – |
| IG VERTICAL | ± 3096 | – | ±3029 | · | – | 3109 |
| IG AXIAL | ± 62 | ± 4653 | ± 62 | ± 4581 | – | ± 138 |
| IG S.DE | ± 520 | ±11800 | - | ±11804 | ± 9234 | – |
| 1 RAD SEC (YAW) | ± 1437 | – | ±1437 | | – | 2887 |
| 1 RAD SEC (PITCH) | | ±10955 | -- | ±10951 | – | – |
| 1 RAD SEC$^2$ (YAW) | | ± 832 | – | ± 836 | – | . |
| 1 RAD SEC$^2$ (PITCH) | ± 111 | - | ± 111 | | - | ± 231 |
| 1 RAD.SEC$^2$ (ROLL) | ± 71 | | ± 67 | | | |

PRELIMINARY MOUNT LOADS
YJ101 ENGINE AXISYMMETRIC NOZZLE



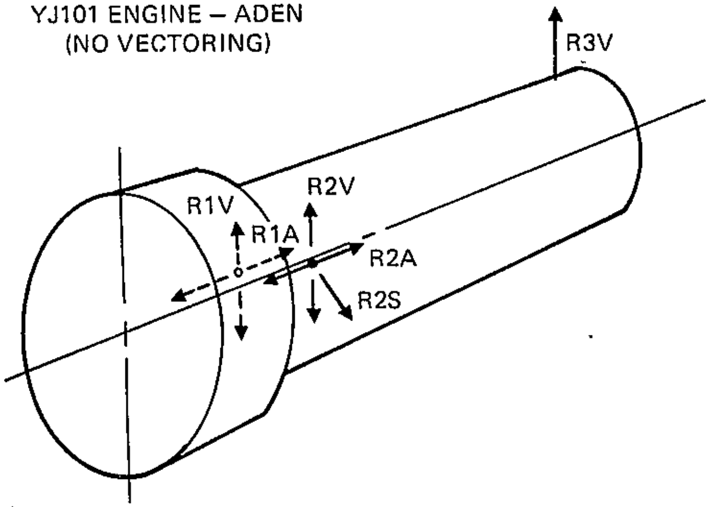

ENGINE WEIGHT 846 Kg
CG LOCATION STA 229
℄ FRONT MOUNT STA 200
℄ REAR MOUNT STA 243 6

(REACTION FORCES IN N)

| | R1V | R1A | R2V | R2A | R2S | R3V |
|---|---|---|---|---|---|---|
| THRUST | – | 41810 | | 41810 | | · |
| IG VERTICAL | ± 1419 | - | ±1357 | | | ± 5516 |
| IG AXIAL | ± 138 | ± 4181 | ± 138 | ± 4114 | | |
| IG SIDE | ± 467 | ± 9038 | ± 463 | ± 9043 | ± 8296 | |
| 1 RAD SEC (YAW) | ± 3336 | - | ±3336 | | | ± 6681 |
| 1 RAD 'SEC (PITCH) | ± 262 | ±10955 | | ±10951 | -- | |
| 1 RAD/SEC$^2$ (YAW) | . - | ± 832 | | ± 836 | - | . |
| 1 RAD 'SEC$^2$ (PITCH) | ± 262 | - - | ±262 | - | - | ± 529 |
| 1 RAD·SEC$^2$ (ROLL) | ± 71 | | ± 67 | | - | |

FIGURE 7a. ESTIMATED REACTION LOADS AT THE ENGINE MOUNTS ACCOUNTING FOR WEIGHT, UNVECTORED THRUST, INERTIA, AND GYROSCOPIC LOADS (N)

PRELIMINARY MOUNT LOADS
YJ101 ENGINE – ADEN
(NO VECTORING)

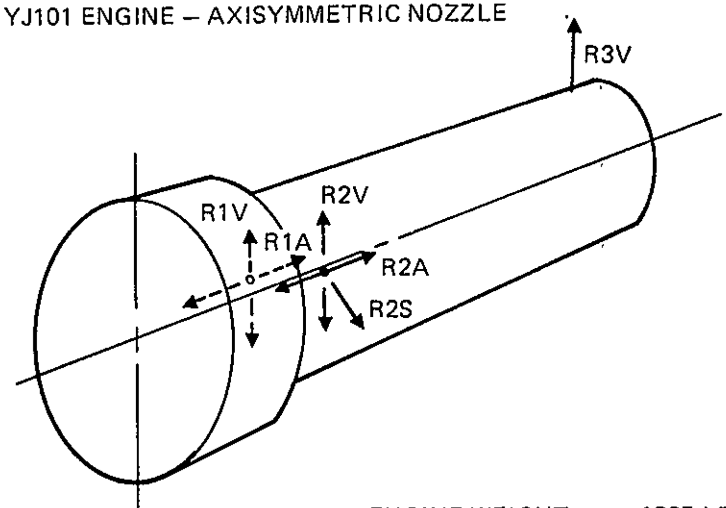



ENGINE WEIGHT – 2076 LB
CG LOCATION – STA 234
FRONT MOUNT – STA 200
REAR MOUNT – STA 301

(REACTION FORCES IN LBS)

| | R1V | R1A | R2V | R2A | R2S | R3V |
|---|---|---|---|---|---|---|
| THRUST | – | 9400 | – | 9400 | – | – |
| IG VERTICAL | ±696 | – | ±681 | – | – | 699 |
| IG AXIAL | ±14 | ±1046 | ±14 | ±1030 | – | ±31 |
| IG SIDE | ±117 | ±2653 | – | ±2654 | ±2076 | – |
| 1 RAD/SEC (YAW) | ±323 | – | ±323 | – | – | 649 |
| 1 RAD/SEC (PITCH) | – | ±2463 | – | ±2462 | – | – |
| 1 RAD/SEC$^2$ (YAW) | – | ±187 | – | ±188 | – | – |
| 1 RAD/SEC$^2$ (PITCH) | ±25 | – | ±25 | – | – | ±52 |
| 1 RAD/SEC$^2$ (ROLL) | ±16 | – | ±15 | – | – | – |

PRELIMINARY MOUNT LOADS
YJ101 ENGINE – AXISYMMETRIC NOZZLE




ENGINE WEIGHT – 1865 LB
CG LOCATION – STA 229
℄ FRONT MOUNT - STA 200
℄ REAR MOUNT – STA 243.6

(REACTION FORCES IN LBS)

| | R1V | R1A | R2V | R2A | R2S | R3V |
|---|---|---|---|---|---|---|
| THRUST | – | 9400 | – | 9400 | – | – |
| IG VERTICAL | ±319 | – | ±305 | – | – | ±1240 |
| IG AXIAL | ±31 | ±940 | ±31 | ±925 | – | – |
| IG SIDE | ±105 | ±2032 | ±104 | ±2033 | ±1865 | – |
| 1 RAD/SEC (YAW) | ±750 | – | ±750 | – | – | ±1502 |
| 1 RAD/SEC (PITCH) | – | ±2463 | – | ±2462 | – | – |
| 1 RAD/SEC$^2$ (YAW) | – | ±187 | – | ±188 | – | – |
| 1 RAD/SEC$^2$ (PITCH) | ±59 | – | ±59 | – | – | ±119 |
| 1 RAD/SEC$^2$ (ROLL) | ±16 | – | ±15 | – | – | – |

FIGURE 7b. ESTIMATED REACTION LOADS AT THE ENGINE MOUNTS ACCOUNTING FOR WEIGHT, UNVECTORED THRUST, INERTIA, AND GYROSCOPIC LOADS (LBS)

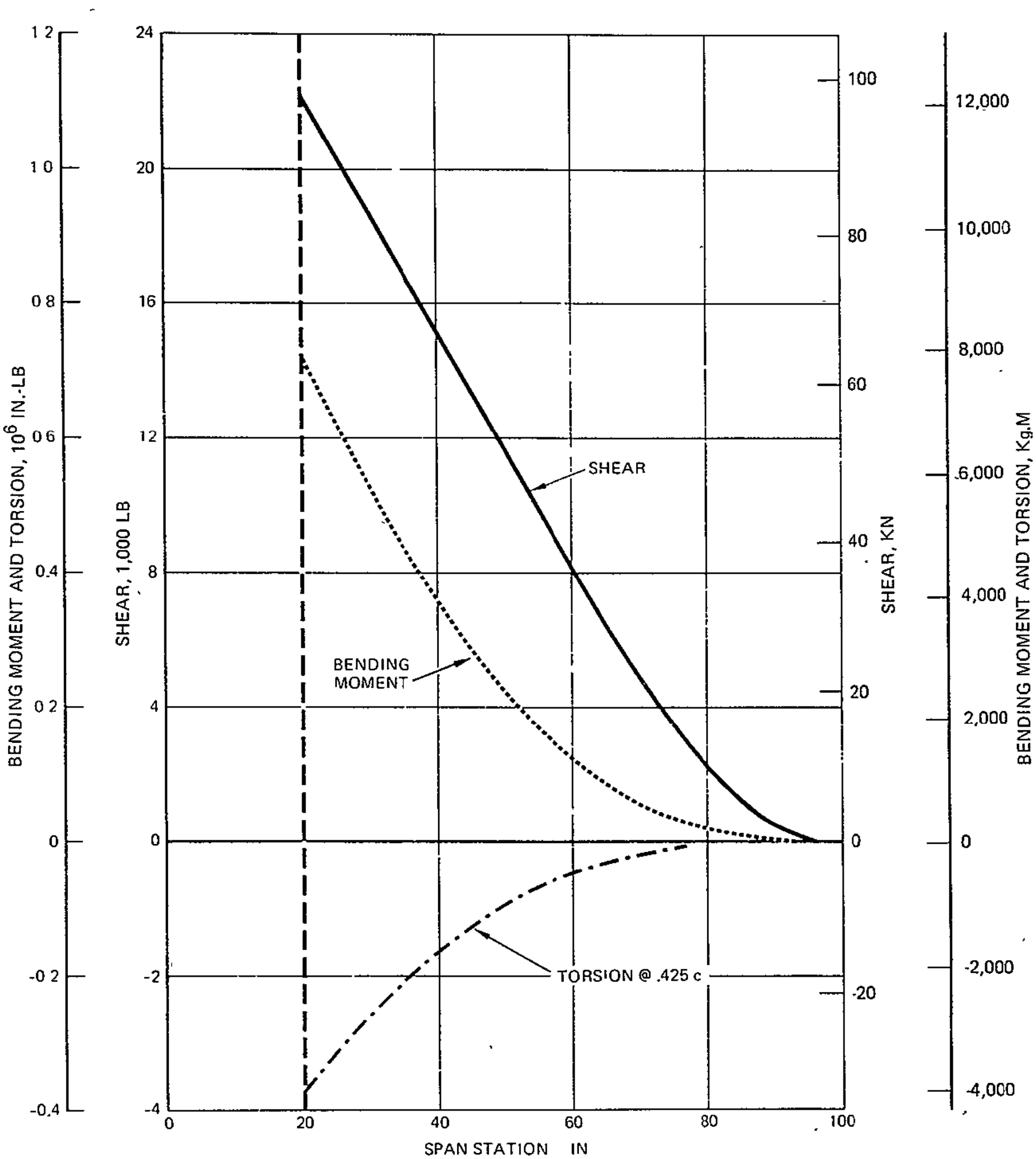



**FIGURE 8. ULTIMATE LOADS FOR CANARD DESIGN, S.L., M = 0.6, $\sigma_c = 15^o$**

Canard Loads. The canard was designed for a loading condition of Mach = 0.6, sea level, at a deflection of 15°. This condition represented the largest deflection in the severest dynamic pressure (q) environment anticipated for the canard. Although higher flight Mach numbers and q's are anticipated at sea level, less canard deflection is required to perform aircraft maneuvers; for Mach = 0.6/15° deflection at higher altitudes, the dynamic pressure loading is less severe. The canard actuation system itself does not present a limit load problem as the canard is designed to drive to a neutral position in the event of a double failure in the system. Figure 8 summarizes the expected canard loads.

Wind Root Fairing. Air loads for design of the wing root fairing which replaces the LEX were developed using data from analysis of the baseline YF-17 with LEX, and modifying the data for application to the wing root fairing. Figure 9 represents the design loading conditions for the fairing.

Airframe Loads. Major loading changes on the YF-17 airframe will derive from transmission of the vectored thrust vertical component through the relocated aft mount to the aft structure, and from aerodynamic loading redistributions caused by removing the LEX and adding the canard.

Based on previously identified critical flight conditions for the baseline YF-17, revised net fuselage loadings were developed for varying load factors at Mach = 0.9 sea level, at Mach = 0.9, 7620M (25,000 ft), and at Mach = 1.1, 6100M (20,000 ft.) At each condition the aircraft was trimmed using a combination of stabilizer deflection, canard deflection, and vectored thrust. Comparison of net bending moments at approximately 10 stations between the ballast location and the ADEN nozzle established that operation of the airplane to load factors of at least 5.0 would be permissible at all conditions analyzed.

Operational Flight Envelope. Based on loads analyses presented above, YF-17 operational limits are estimated for the overall aircraft at various canard deflections. Figure 10 presents the results, showing the overall aircraft 5-g structural envelope as well as canard load limit curves for deflection angles of 7°, 10°, and 15°. The canard load limit curves translate the M = 0.6, sea level, 15° deflection design capacity to comparable loading at different flight conditions for the deflections shown. The loads analyses and envelope presented here should be regarded as preliminary in nature with more extensive analysis, particularly in the high q portion of the envelope, planned for the full-scale development phase.

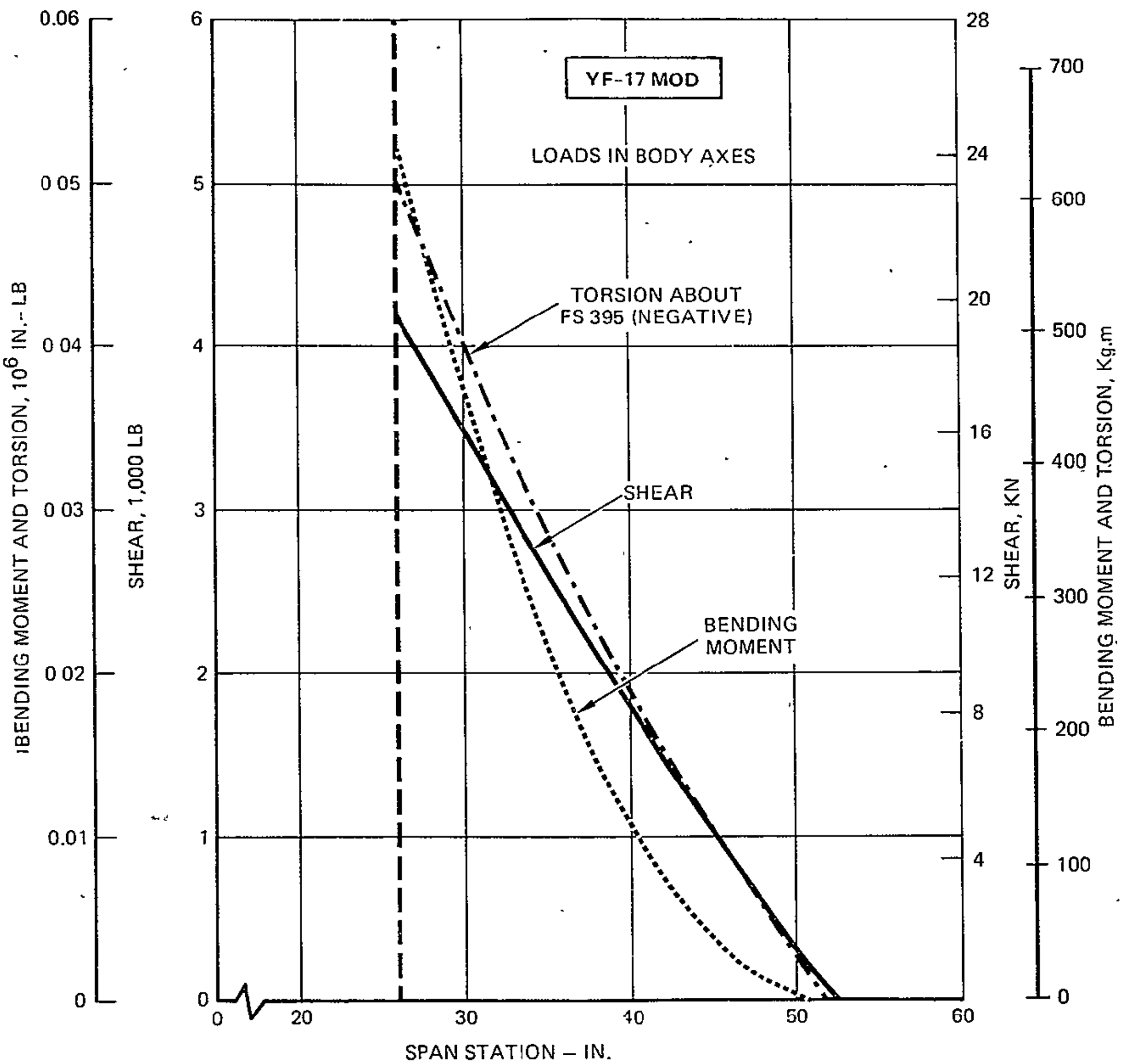



**FIGURE 9. ULTIMATE AIRLOADS DISTRIBUTION ON WING ROOT FAIRING (DWG AD 6659) M = 1.6, $\theta = 3.9^{\circ}$, q = 8788 Kg/m$^2$ (1,800 PSF)**

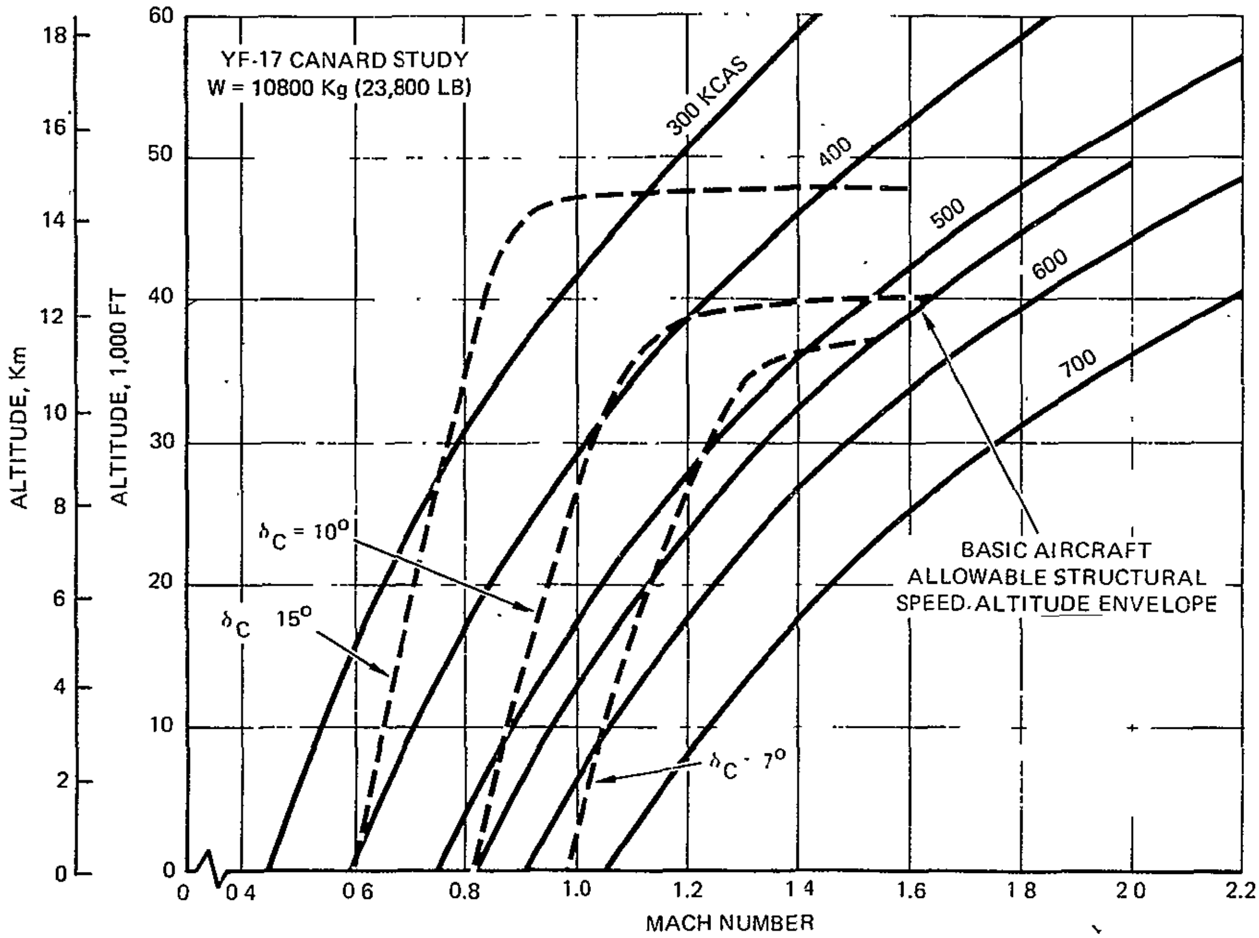



**FIGURE 10. FLIGHT ENVELOPE FOR CANARD DEFLECTION**

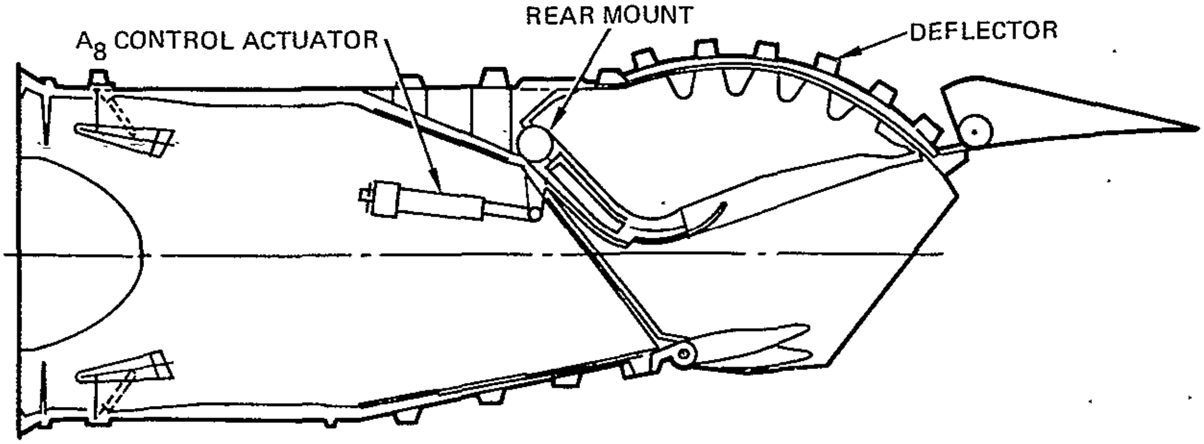
## 1.3 YJ101 Engine Design Modifications

Mounting System. As previously discussed, the aft link mount located on the top vertical centerline of the engine rear mount ring will be moved 145.8 cm. (57.4 inches) aft to a point over the nozzle in order to prevent excess bending movements from acting on the engine casing. The YJ101 main mounts located at the mid-frame of the engine remain unchanged and consist of two self-aligning bearings on either side of the engine at the horizontal centerline that absorb the engine thrust loads, vertical loads and the couple due to side or pitch maneuvers.

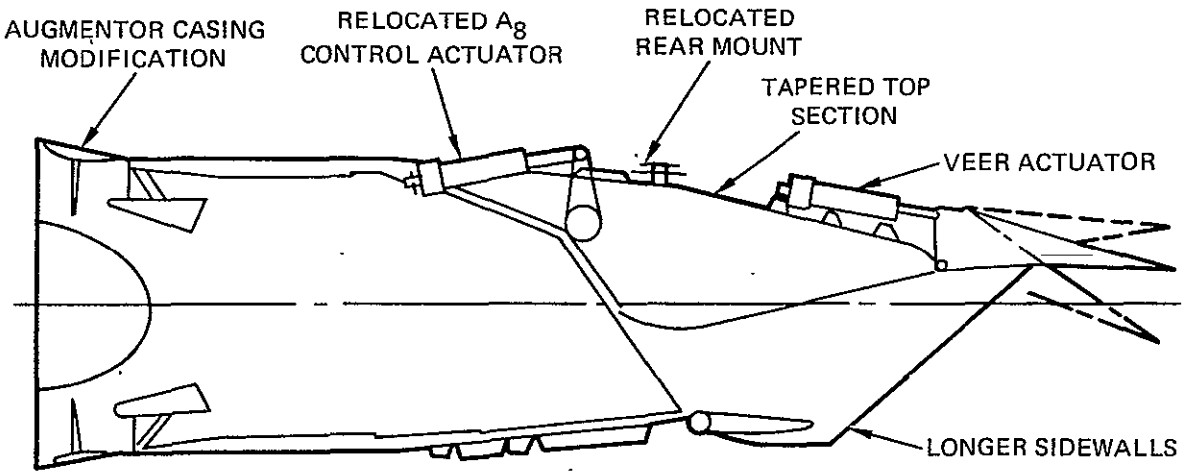
Relocating the rear mount to a point over the nozzle requires minor design changes to the front of the augmentor casing and to the augmentor fuel injectors. The forward section of the augmentor casing will be modified to include a small angle conical section to increase the local buckling stability (Figure 11). Flow characteristics of the baseline YJ101 augmentor will be preserved by adding a sheet metal flow guide in the modified section to duplicate the original bell-shaped geometry. The local increase in casing diameter caused by this modification will require lengthening of the existing augmentor fuel injectors.

ADEN Casing Modifications. With the elimination of the VTOL deflecting hood from the YF-17/ADEN, the opportunity for a number of design improvements in internal/external aerodynamics and VEER cooling becomes available, with attendant weight reduction benefits. Figure 11 shows both the original and redesigned ADEN. As can be seen, removal of the deflector eliminates the need for the raised arc section in the top of the exhaust duct which was required to effectively seal the deflector during VTOL operation. With the elimination of the arc, the nozzle envelope can be significantly reduced by tapering the top section of the duct. This modification in turn allows the VEER actuators to be positioned on the top of the duct near the VEER hinge line without creating local discontinuities or contoured surfaces in the aircraft fairing. It also permits direct ducting of the cooling air from the plenum chamber above the nozzle flaps to the VEER as shown in Figure 12.

On the original ADEN with deflecting hood the length of the casing sidewall was limited in that it had to fair with the deployed deflector. In the hoodless YF-17/ADEN, the casing sidewall design can now be modified to have external boattailing compatible with the fuselage lines and increased length to provide improved flow containment at the VEER during thrust vectoring.




ADEN FOR STATIC GROUND DEMONSTRATOR TEST




ADEN FOR YF-17 FLIGHT TEST

**FIGURE 11. COMPARISON OF ADEN DESIGNS FOR THE DEMONSTRATOR TEST AND THE YF-17 FLIGHT PROGRAM**

<u>VEER Design.</u> On the ADEN Ground Static Demonstrator, the VEER was a boiler plate design simulating aircraft mounted hardware, because it was anticipated to be part of the aircraft wing flap system rather than nozzle hardware. However, in the YF-17 installation, with the nozzles at the aft end of the fuselage, the VEER is more ideally mounted to the nozzle itself. The elimination of the deflector allows the VEER to be hinged directly to the casing as illustrated in Figure 11. Thrust vectoring modulation

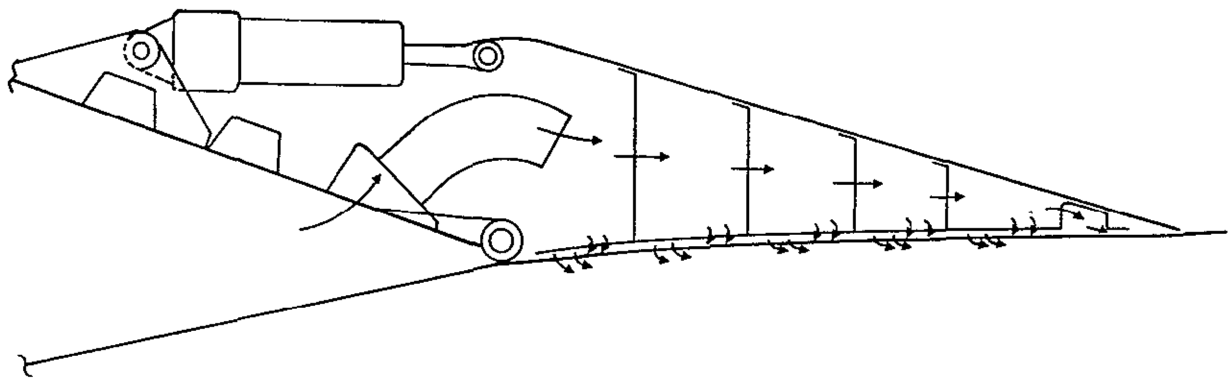


FIGURE 12. VEER COOLING FLOW PATHS

with the VEER from -10° (VEER up) to +20° (VEER down) is provided by three hydraulic actuators mounted on top of the nozzle casing.

The VEER must be designed to withstand the aerodynamic forces produced by both internal and external flows during thrust vectoring. To accomplish this, data on the VEER pressure environment developed during previous ADEN testing and verified in the recent NASA Langley F-18/ADEN wind tunnel investigations were used to identify and design for the worst-case pressure loads on the VEER.

In the initial ADEN Demonstrator tests, cooling air for the VEER was provided from an external source. During later ground test for IR measurement, flexible hoses were used to duct engine fan air around the deflector to the VEER. This arrangement, although not suitable for flight operation, was feasible for the IR ground tests since the deflector remained in the stowed position.

The elimination of the deflector resolved the potential in-flight VEER coolant supply ducting problem for the YF-17/ADEN installation. Instead of flexible hoses, a curved rigid cooling air supply duct connects the air plenum chamber above the nozzle flaps with the VEER (Figure 12). The high pressure coolant air flows from the plenum through the duct into each of the six baffled interconnected chambers of the VEER and impinges on the VEER liner. The spent air then exits through five sets of holes in the liner to film-cool the VEER as shown in Figure 12.

VEER film cooling slots, similar to the cooling slots used in the augmentor liner, are being considered as an alternate means of discharging the spent cooling air in the direction of the exhaust jet, thereby contributing to increased thrust performance.

Both ejection methods will be evaluated before making a final selection of the VEER cooling design.

The total cooling flow requirements for the ADEN during afterburner operation are shown in Figure 13. The cooling flow requirements for the YJ101 with the round nozzle are also shown for comparison. While a lower cooling requirement is shown for the ADEN, it will be seen in the flight performance analysis of Section 3 that cooling the ADEN actually results in an added penalty to the YJ101 performance due to higher pressure losses through the ADEN cooling system and the unavailability of VEER cooling air for added combustion in the afterburner.

It should be noted that the 1.1% $W_8$ cooling flow rate used for VEER cooling at max A/B is sufficient to cool the VEER surface to approximately 700°F during maximum dry operation and thus could be used to demonstrate reduced IR signature at max dry power settings.

Installation in YF-17. As shown in the installation drawing (Figure 13) the ADEN nozzles were angled inward 2° from the engine centerline to reduce the installed base drag between the nozzles. This change, however, resulted in mechanical interference between the inner $A_8$ hydraulic actuators. A brief study was made to determine the

| ADEN/YJ101 COOLING FLOW COMPARISON | | |
|---|---|---|
| | % $W_8$ ADEN | % $W_8$ YJ101 |
| SCREECH | 2.16 | 4.2 |
| LINER | 4.28 | 7.3 |
| FLAPS | 4.84 | 3.5 |
| VEER | 1.10 | – |
| TOTAL | 12.38 | 15.0 |

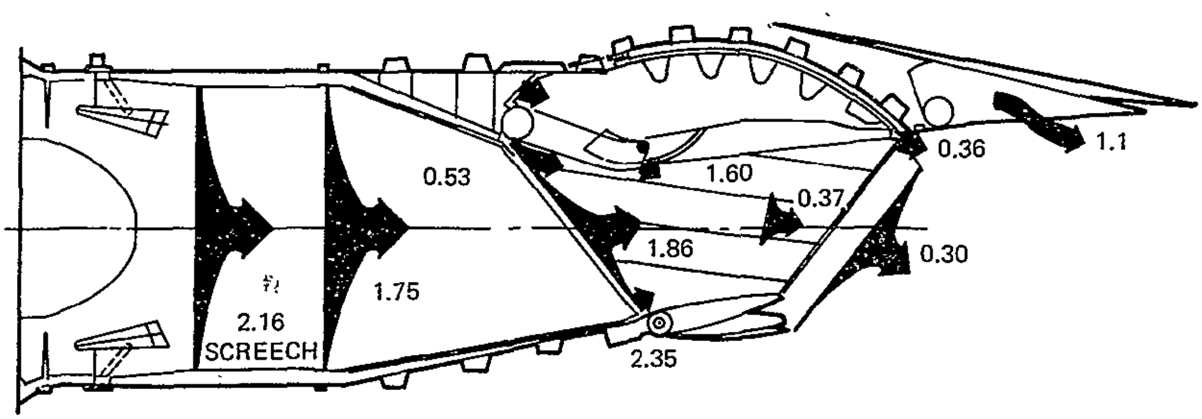



FIGURE 13. ADEN COOLING FLOW IN PERCENT $W_8$ FOR MAXIMUM AFTERBURNING.

feasibility of eliminating the inner actuators and operating the $A_8$ flaps with a single but larger actuator on the outer wall of the nozzle. However, the increased actuator size and the resulting increase in the bearing mount size, spline and torque tube loads made this approach unattractive. A more desirable alternative was to relocate the $A_8$ actuators toward the top of the nozzle in the transition zone where the duct changes from circular to a two-dimensional cross-section. With the actuators in this position the nozzle envelope was reduced by approximately 1.5 inches per engine, an amount sufficient to provide adequate clearance between engines.

All major components of the augmentor/nozzle are common for a right and left hand engine configuration. A changeover from one configuration to the other can be simply made by rotating the augmentor duct 180° to obtain the required 2° inward cant. A left and right hand engine augmentor fuel supply manifold and electrical cables for the ignitor and flame detector will be required for the YF-17 ADEN installation to avoid additional modifications to the basic YJ101 engine.

Thrust Reverser Concept. Preliminary investigations were conducted to identify the most promising thrust reverser concept which could be integrated with the YF-17/ ADEN while satisfying the following guidelines:

- Capable of use in flight and during landing
- 50% reverse thrust
- Variable reverse thrust
- Low internal performance penalty for forward thrust operation
- No drag penalty when stowed
- Rapid actuation
- Reliable concept
- Light weight
- Compatible with YJ101
- Compatible with ADEN exhaust system and YF-17 airframe structure

The studies identified a block and turn cascade design as being the most promising concept. This design would use clamshell blockers to divert the flow and variable cascade blades to direct it (Figure 15). The blocker and blade positions would be synchronized to provide reverse thrust modulation while maintaining constant total exhaust area in order to protect the engine from sudden changes in exhaust duct pressure. The use of folding cascade blades to close the reverse exhaust ports would result in less compromise to the aircraft structure than an axially sliding cover and additionally, avoid the risk of buffeting at high flight speeds which afflicts hinge mounted external

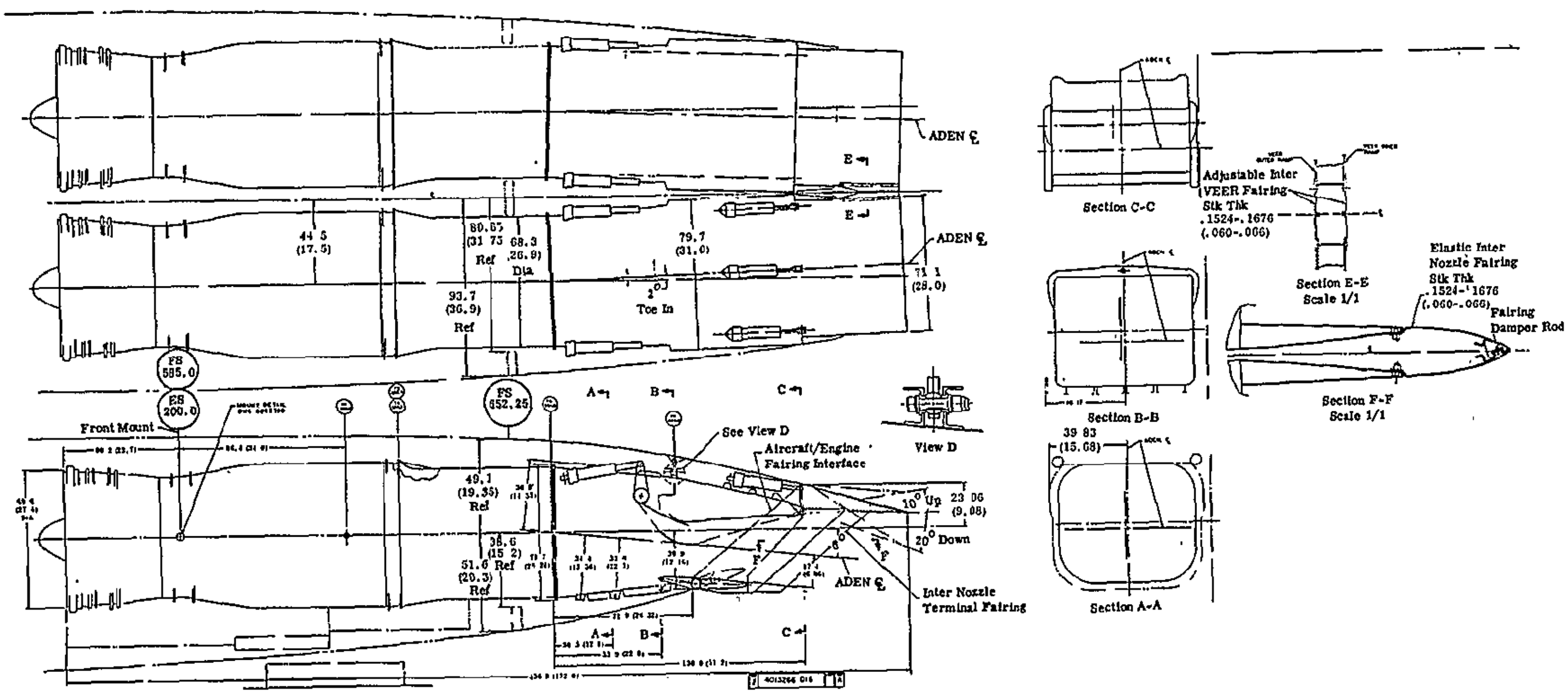



FIGURE 14. INSTALLATION OF THE ADEN IN THE YF-17

doors. Leakage loss in the cruise blocker positions would be minimized by use of a comformable seal. With exhaust equally split between top and bottom of the duct, pitching moments due to thrust imbalance will be avoided. The reverser would be located at the aft end of the round augmenter duct. This position provides the aft-most location for reverser efflux while avoiding for the most part the complex transition section where the duct shape changes from round to rectangular, and severely complicates reverser design and fabrication.

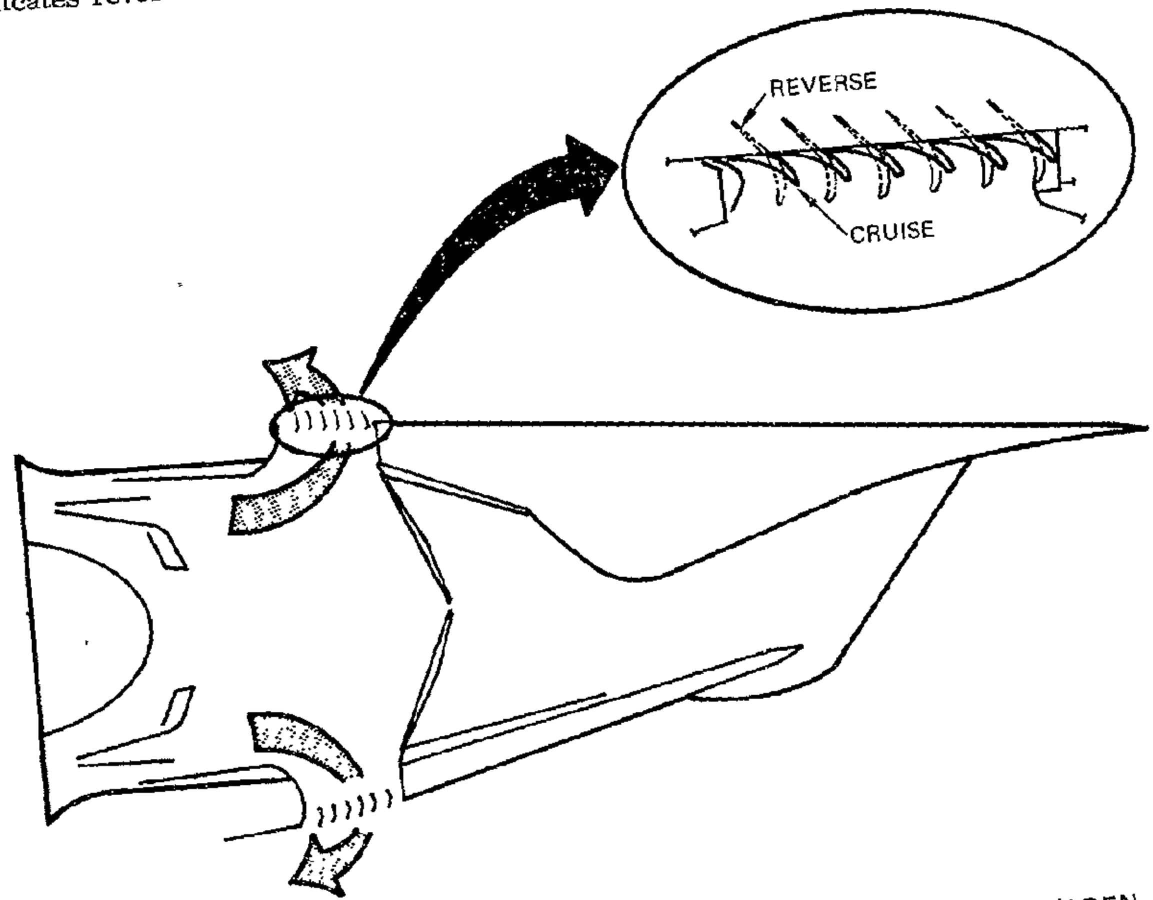



FIGURE 15. RECOMMENDED THRUST REVERSER CONCEPT FOR YF-17/ADEN FLIGHT TEST

## 1.4 Aft Fuselage Modifications

Figures 16, 17, and 18 offer a visual synopsis of the modifications required to accommodate the ADEN nozzle in the YF-17 aft fuselage. A layout of the revised structure is provided in drawing No. 6676, Appendix B. A verbal description is also provided herein.

Revisions to the YF-17 structure were limited to the area aft of FS 652.25 so as not to affect the horizontal tail pivot mechanism. In modifying the YF-17 to the ADEN aft end, all existing structure aft of FS 652.25 will be removed and stored for future restoration to the original dual axisymmetric aft end.

To withstand the additional loads and high temperatures imposed by thrust vectoring, almost all of the non-axisymmetric structural revisions will be made from titanium. Three new machined frames will be located at FS 660.2, FS 667.1, and FS 674.5, and connected to spliced extensions of upper and lower longerons and center keel structure which exists at FS 652.25. At the top centerline of each engine bay a fitting will be cantilevered from the FS 674.5 frame to engage the revised rear engine mount at FS 686. The mount fitting will be anchored back to the FS 652.25 frame by intercostals placed between the new frames and bound by upper and lower sheet straps. Provisions are made in the design of the new frames for extension of the ventral structural engine bay access doors to FS 674.5.

Aft fuselage external line continuity from FS 674.5 to the point where ADEN exit geometry becomes the external line close-out is provided by removable side and upper nonstructural fairing panel assemblies, and a lower trailing edge piece, for each engine/nozzle. Each upper panel assembly attaches to FS 674.5 and to a nozzle mounted upper trailing edge member, utilizing floating nutplates and oversize holes to prevent loading from deflections of the engines relative to the YF-17 airframe. The lower trailing edge piece attaches to the FS 674.5 frame; the side panel assemblies connect to the upper panel assembly and lower trailing edge, as well as FS 674.5. Louvers are included in the upper panels to allow venting of the engine bay purge airflow.

Non-axisymmetric contours will be carried forward from FS 652.25 by adding small upper and lower frames to the 652.25 frame to build up the gutter areas, and blending forward to approximately FS 620 with foam plastic and fiberglass skin.

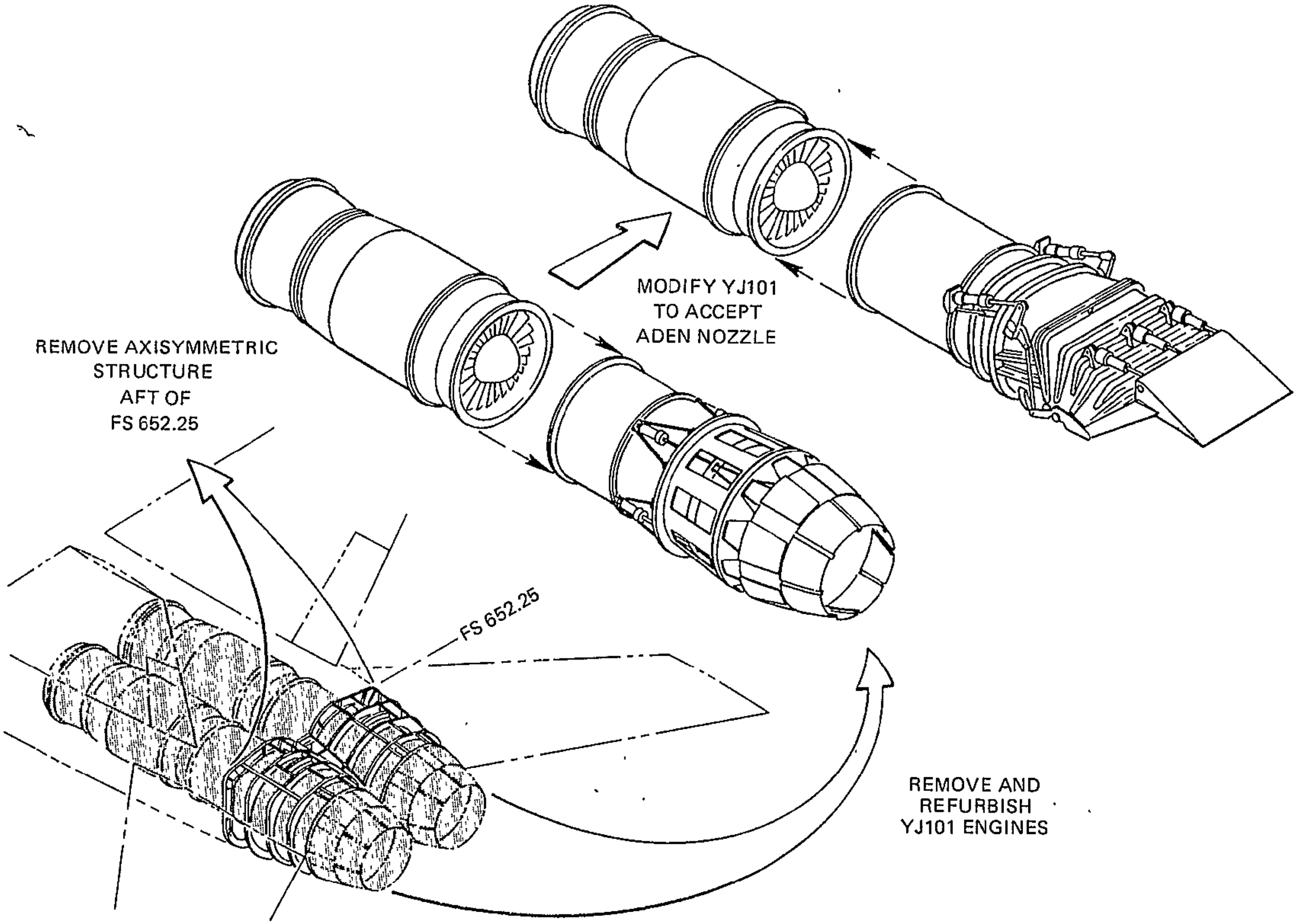



FIGURE 16. INITIAL MODIFICATIONS FOR ADEN

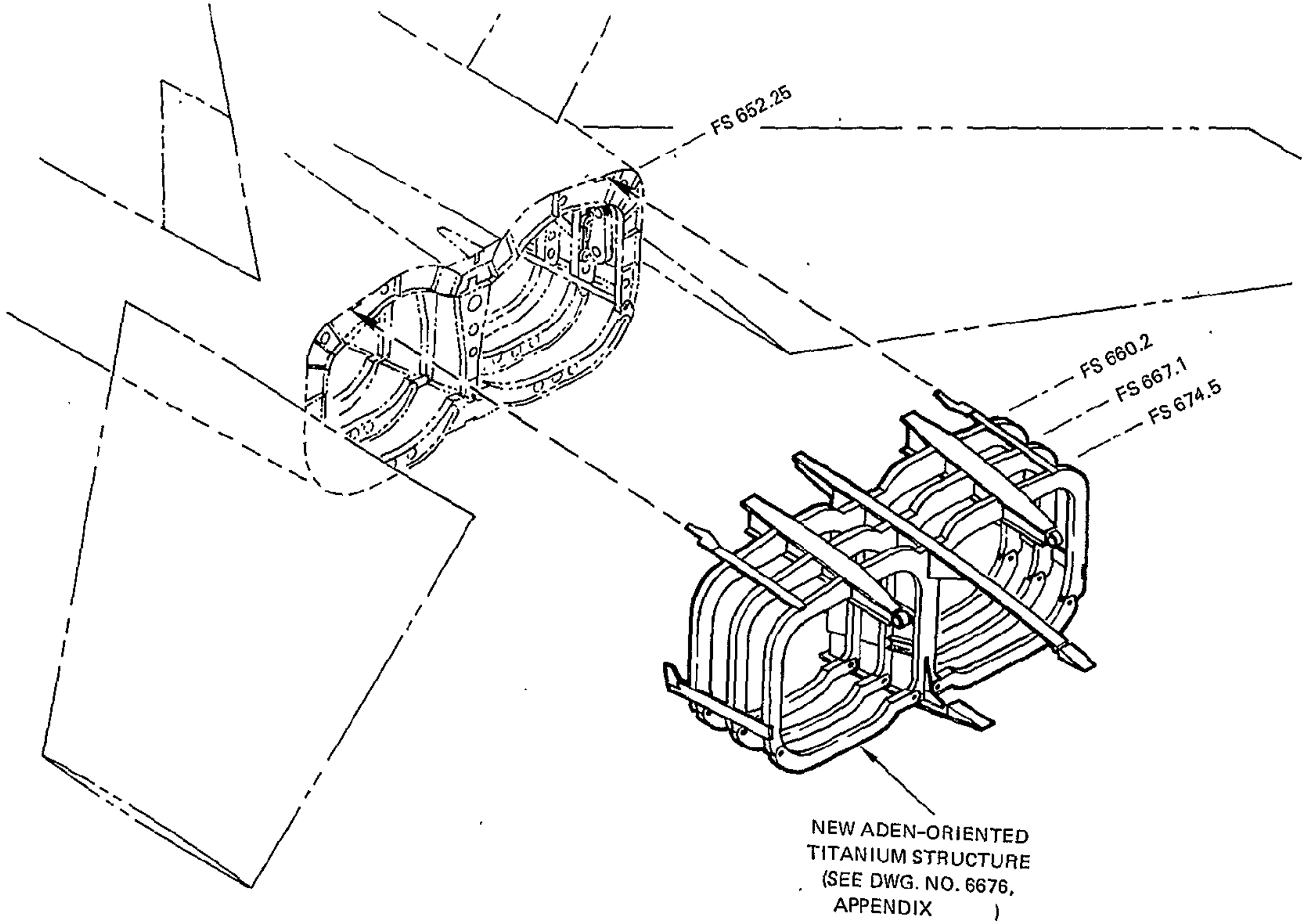



FIGURE 17. YF-17/ADEN AFT STRUCTURE DESIGN

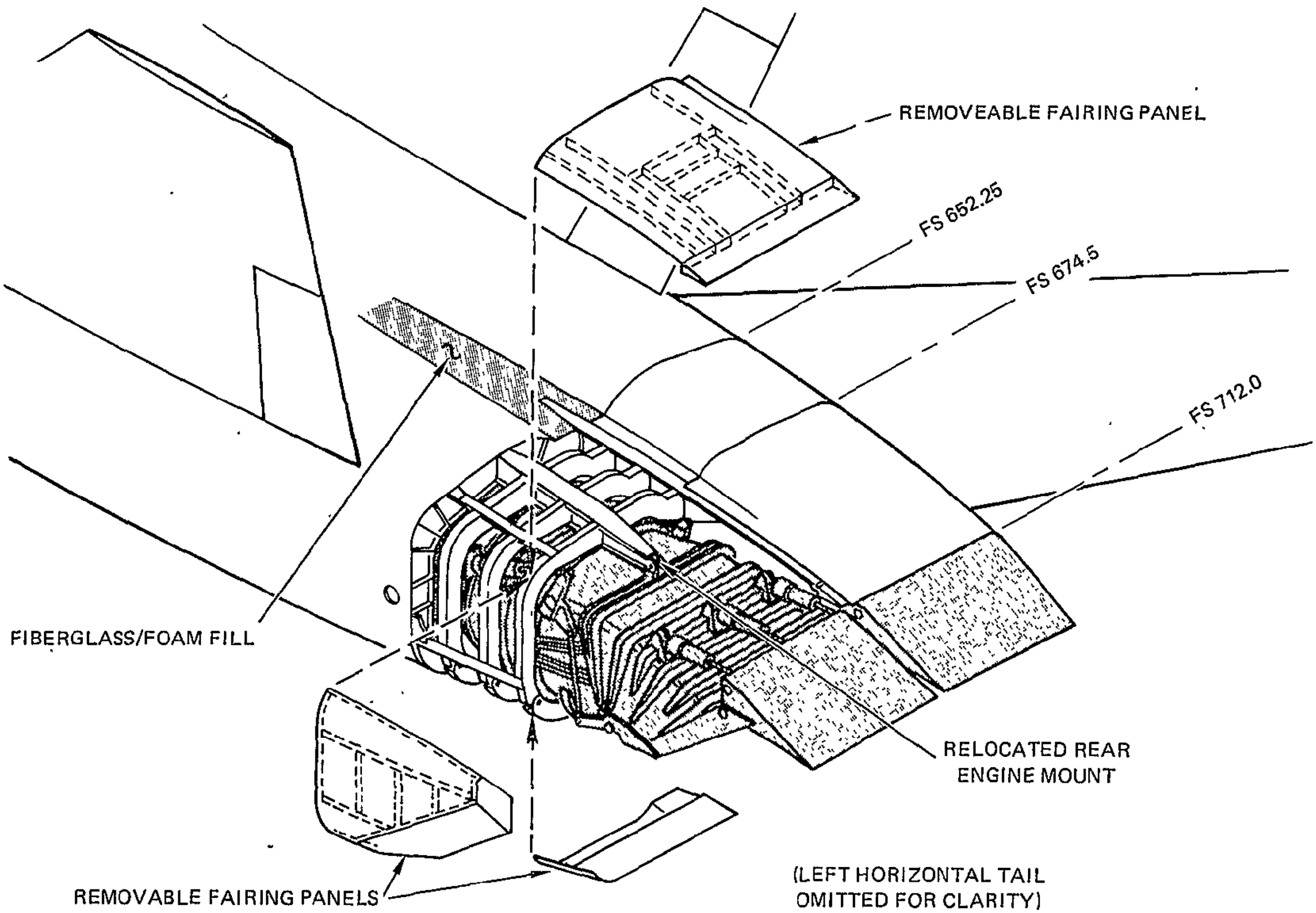



FIGURE 18. INSTALLATION OF ADEN IN YF-17

## 1.5 Forward Fuselage/Canard Modifications

The changes to the baseline YF-17 that will be required to incorporate canards are summarized in Figure 19.

In preparation for rework of the YF-17 forward fuselage for installation of the canards and actuation system, the following items of structure and equipment will be removed from the airplane; leading edge extensions from FS 395 forward; gun and ammunition drum package from the gun bay (FS 143 to 218); fuel tank located between FS 310 and 370; and flight test equipment located between FS 302.75 and FS 310 above the ECS inlets. All items, with the exception of the flight test equipment, will be stored for future restoration of the airplane to its original configuration. The flight test equipment will be transferred to the vacated gun bay of the forward fuselage. In order to compensate for the effect on airplane c.g. of the removal of the gun and ammunition drum as well as changes in the aft end, it will be necessary to include a 2000 lb. ballast package in the gun bay. Removal of the fuel tank will necessitate capping of the fuel and vent pipes connecting to that tank.

Structure aft of the pilot's seat bulkhead will be modifed to accommodate the canard surfaces. A torque tube, interconnecting left and right hand canard surfaces, will be located at FS 314, 71.1 cm (28 inches) above the horizontal reference plane and pass through holes cut in the aircraft skin. The holes will be surrounded by external aluminum doublers attached by rivets to exiting fastener locations, including a field pattern of rivets. Machined aluminum bearing support fittings and canard actuator support fittings will be installed on FS 310 bulkhead. The FS 317 frame will be relieved to allow actuator control arm movement, and reinforced by adding formed aluminum sheet doublers to maintain required strength. Machine aluminum fittings to anchor the actuation system will be attached at the FS 325 frame as shown in Figure 19. Dwgs 6671 and 6699, Appendix B, detail the structural changes and canard actuation system controls.

The canard panels, symmetrical about the chord plane, will be single spar, full depth honeycomb, bonded assemblies, similar in design to the F-5 horizontal stabilizer. A single piece machined steel detail forms the interconnecting torque tube, root rib splice, and inboard spar segment. The L.H. and R.H. torque tubes will be taper pin spliced at the airplane centerline upon installation. A machined aluminum spar segment, mechanically attached to the steel spar segment, extends outboard to a formed aluminum sheet tip rib. Formed aluminum sheet ribs mechanically attached

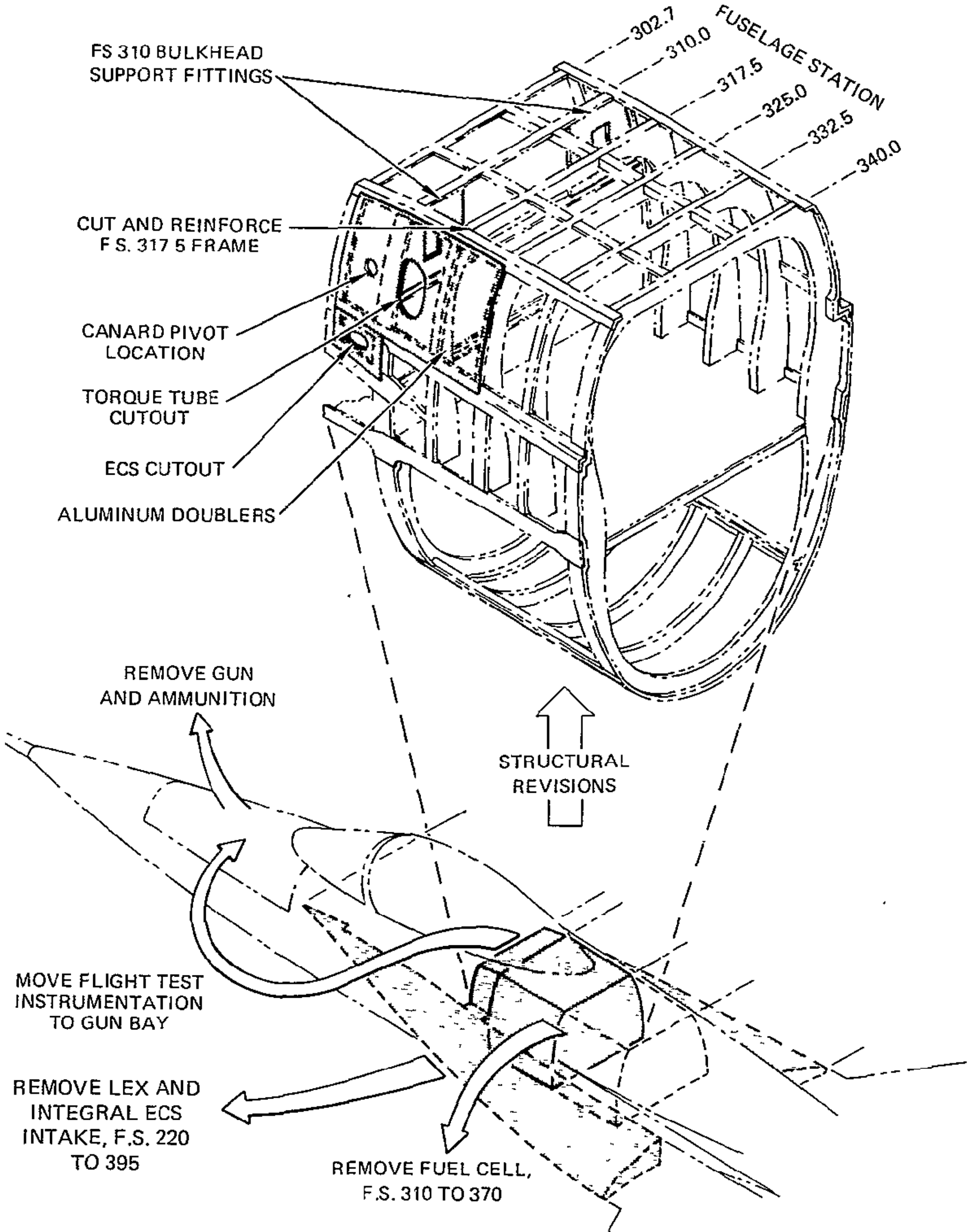



**FIGURE 19. MODIFICATIONS FOR CANARD**
**(SEE ALSO DWG. NO. 6671, APPENDIX B)**

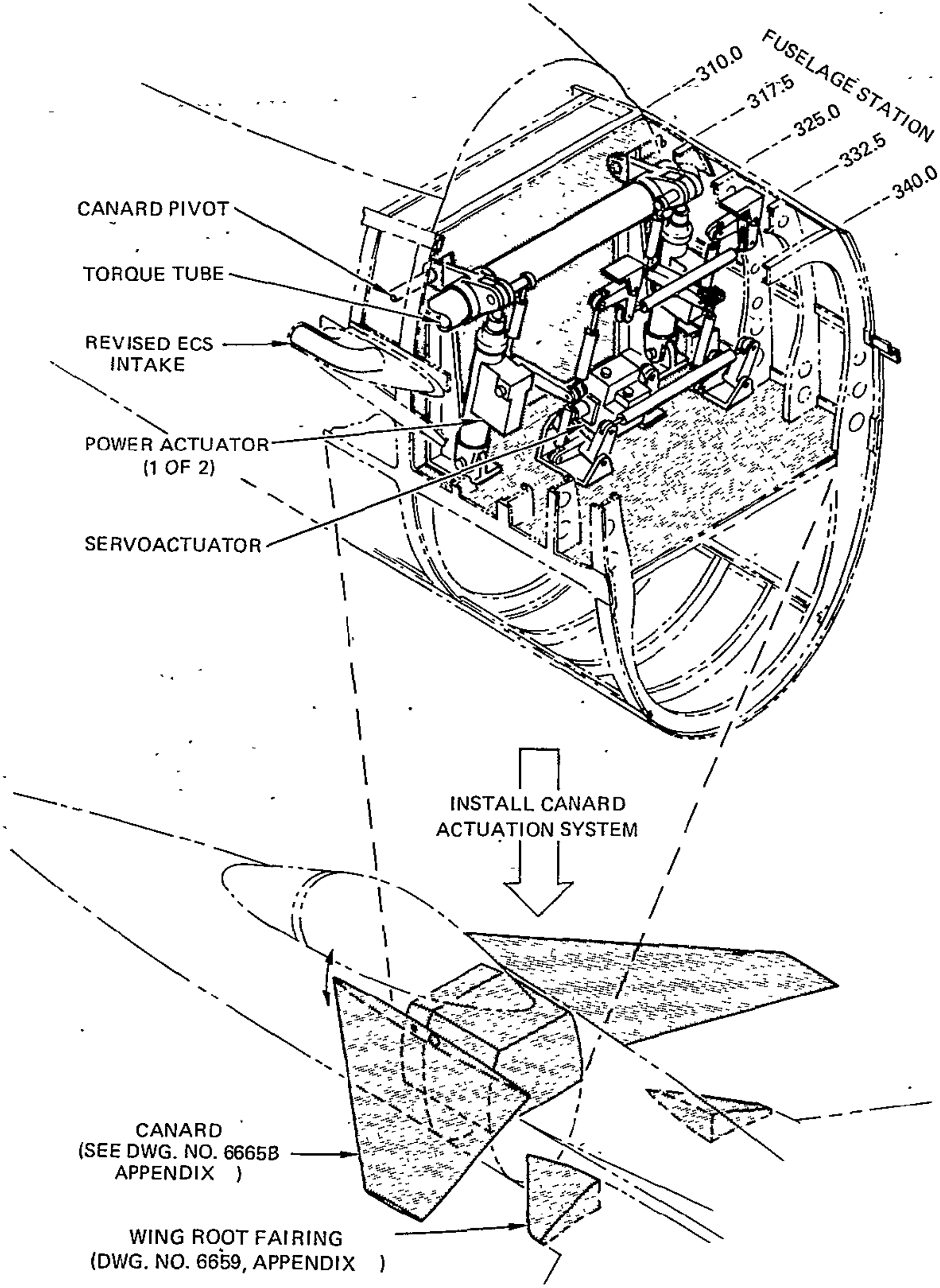



**FIGURE 19. MODIFICATIONS FOR CANARD (CONT.)**

to the steel spar form the root closure. A machined aluminum dart is used at the leading edge. The aluminum skin panels will be step tapered by either chemical milling or machining.

Dwg. No. 6665, Appendix B, provides a layout of the canard assembly. Pertinent geometrical statistics are listed in Table 2.

TABLE 2. YF-17 CANARD PHYSICAL CHARACTERISTICS

| | |
|---|---|
| PLANFORM PARAMETERS | |
| CANARD AREA | 5.37 meter$^2$ (57.8* FT$^2$) |
| ASPECT RATIO | 2.84 |
| TAPER RATIO | 0.234 |
| THICKNESS RATIO | 0.05 |
| SWEEP ANGLE, c/4 | 45 DEG. |
| SPAN | 473.66 cm (186.48 IN.) |
| ROOT CHORD | 270.10 cm (106.34 IN.) |
| TIP CHORD | 63.12 cm (24.85 IN.) |
| MAC | 159.66 cm (62.86* IN.) |
| WING STATION, MAC | 126.37 cm (49.75*IN.) |
| WING STATION, ROOT | 50.8 cm (20.0 IN.) |
| PIVOT INTERCEPT, % MAC | 15.4 |
| *Exposed Surface | |
| STRUCTURAL PARAMETERS | |
| SKIN MATERIAL | ALUMINUM |
| TYPE OF PIVOT | TORQUE TUBE |
| ACTUATOR PITCH STIFFNESS PER SIDE | 46080 KgM (4.0 x $10^6$ IN. LB/RAD) |
| TORQUE TUBE ROLL STIFFNESS PER SIDE | 103680 KgM (9.0 x $10^6$ IN. LB/RAD) |
| STEEL SPAR SEGMENT STIFFNESS | EI = 799490 KgM (69.4 x $10^6$ LB. IN.$^2$)<br>GJ = 7995 KgM (0.694 x $10^6$ LB. IN.$^2$)<br>LENGTH = 35.56 cm (14 IN.) |

Removal of the YF-17 LEX requires design and fabrication of a wing root fairing to refair inboard sections of the wing. The wing root fairings will be riveted assemblies with formed sheet aluminum, machined aluminum substructure, and fiberglass/epoxy cover skins. Each assembly (L. H. and R. H.) will be comprised of a machined aluminum leading edge dart, laminated fiberglass cover skins, four sheet formers, an aft sheet closing former, two machined attach fittings, three machined backup fittings, upper inboard and aft inboard formed sheet corner angles, seven formed sheet clips, and three splice straps. Existing moldlines will be retained aft of FS 388.5 to allow use of existing tooling for all machined details, inboard aft corner angles, and aft closing formers. Drawing No. 6659, Appendix B, shows the fairing design.

YF-17 ECS ram air scoops are incorporated in the wing leading edge extensions. Removal of these extensions, as noted above, necessitates redesign and installation of ECS ram air scoops at FS 306, 47 CM (18.50 inches) above the horizontal reference plane, on each side of the fuselage. The scoops will be fabricated of molded fiberglass laminate with an erosion protection coating and will be attached to existing fastener locations. Drawing No. 6671, Appendix B, includes a rendering of the revised ECS design.

## 1.6 Preliminary Structural Analysis

Wing Root Fairing/Fuselage Stress Checks. Based on predicted loading conditions, preliminary stress checks were performed for the modified YF-17 forward fuselage structure, wing root fairing, and redesigned aft structure. Results show that the wing root fairing itself is not stress-critical and that adequate load paths exist to absorb the revised loading conditions in the forward fuselage area. Analysis of the load paths provided by the cantilevered relocated mount fitting and revised supporting aft structure indicates that there will be no problem in transmitting the engine loads to the YF-17 airframe.

Canard Aeroelastic Analysis. Using a combination of computer optimization techniques and preliminary performance analysis, the YF-17 canard design was reviewed to insure its ability to meet the divergence and flutter speed requirements dictated by a Mach = 0.9, sea level design flight condition.

Conventional preliminary design hand calculations were performed to substantiate the structural integrity of the support tube, spar, root rib, and aluminum honeycomb core. Recently refined computer codes were used to develop a canard skin thickness distribution which would provide a panel design strong enough to withstand the design loading criteria. The resulting thickness distribution, shown in Table 3, will be held constant from leading to trailing edge to reduce manufacturing costs.

TABLE 3. CANARD THICKNESS DISTRIBUTION, CM (IN).

| | LE → | | | | → TE |
|---|---|---|---|---|---|
| ROOT | 0.2286 (0.09000) | 0.2286 (0.09000) | 0.2286 (0.09000) | 0.2286 (0.09000) | 0.2286 (0.09000) |
| ↓ | 0.1902 (0.07487) | 0.1902 (0.07487) | 0.1902 (0.07487) | 0.1902 (0.07487) | 0.1902 (0.07487) |
| ↓ | 0.1524 (0.06000) | 0.1524 (0.06000) | 0.1524 (0.06000) | 0.1524 (0.06000) | 0.1524 (0.06000) |
| ↓ | 0.1153 (0.04538) | 0.1153 (0.04538) | 0.1153 (0.04538) | 0.1153 (0.04538) | 0.1153 (0.04538) |
| TIP | 0.0762 (0.03000) | 0.0762 (0.03000) | 0.0762 (0.03000) | 0.0762 (0.03000) | 0.0762 (0.03000) |

SKIN WEIGHT = 19.323 Kg (42.6 LBS) PER SIDE

The final canard design was checked to insure that adequate divergence and flutter speed margins were maintained. Based on a minimum required dynamic pressure margin of 40% and a flutter speed margin of 15% for the Mach = 0.9, sea level condition, it was found that the canard design is dictated by the loads requirements of Figure 8, and that neither divergence nor flutter margin present a problem.

It should be emphasized that the stress checks and aeroelastic analysis performed herein is preliminary in nature, and was done to insure that there were no major shortcomings in the proposed design revisions in regard to stress tolerance and aeroelastic effects. An in-depth structural analysis is anticipated during full scale development which will involve further development of loading criteria, extensive computer modeling, detailed stress checks, and model flutter testing.

## 1.7 Mass Properties Analysis

Weight Changes. Changes in the YF-17 weight engendered by the proposed modifications to the engine and aircraft are listed in Table 4. Two weight breakdowns are shown: one for the YF-17 with ADEN only, and one for the YF-17/ADEN with canard. Note that while the canard-configured version actually weighs less due to removal of the forward fuel cell to accommodate the canard actuation system, the cell removal also affects flight endurance capability, as will be seen in Section 3. Both breakdowns reflect the relocation of the YF-17 flight test instrumentation package to the gun bay; to make room for it the gun and ammunition package is removed and replaced by a more compact 907 kg (2000 lb.) ballast package to maintain a center-of-gravity location similar to the baseline YF-17.

Center of Gravity Characteristics. In Figures 19 and 20, the extent of travel of the aircraft center-of-gravity (c.g.) with fuel usage is shown as a percent of mean aerodynamic chord for the YF-17 with ADEN only (Figure 19) and the YF-17/ADEN/canard (Figure 20). Curves are shown in each figure for c.g. behavior with and without the flight test equipment. With the canard-configured YF-17/ADEN the forward fuel cell must be removed; its c.g. travel is therefore not shown in Figure 20.

As a prototype aircraft, the YF-17 is equipped with fuel transfer capability. This offers the possibility of operation over a range of aircraft weight and c.g. locations. The YF-17 with ADEN only has a stable in-flight static margin similar to that of the basic YF-17 (1.5%). The YF-17/ADEN with canard will integrate the canard into the pitch control system (as discussed in Section 2) and use it to maintain the same margin; however, with the availability of the canard the aircraft aerodynamic center can now be varied to produce up to -10% static margin with attendant trim drag benefits. This option is exercised in the flight performance estimates of Section 3.

TABLE 4. WEIGHT CHANGES DUE TO YF-17/YJ101 MODIFICATION, Kg (LBS)

| | YF-17/ADEN | YF-17/ADEN/ CANARD |
|---|---|---|
| BASELINE YF-17 | 11165 (24,616) | 11165 (24,616) |
| REMOVE | | |
| LEX | - | -126 (-277) |
| GUN | -273 (-602) | -273 (-602) |
| AMMUNITION | -127 (-280) | -127 (-280) |
| MISSILES | -156 (-343) | -156 (-343) |
| FORWARD FUEL CELL | - | -9 (-20) |
| FORWARD FUEL PUMP | - | -2 (-5) |
| FORWARD FUEL | - | -671 (-1480) |
| TOTAL REMOVED | -556 (-1225) | -1364 (-3007) |
| ADD | | |
| ADEN NOZZLES AND AFTERBODY STRUCTURE | +250 (+550) | +250 (+550) |
| BALLAST | +907 (+2000) | +907 (+2000) |
| CANARD | - | +77 (+170) |
| CANARD CONTROLS | - | +170 (+375) |
| MODIFIED LEX | - | +9 (+20) |
| TOTAL ADDED | +1157 (+2550) | +1413 (+3115) |
| NET CHANGE | +601 (+1325) | +49 (+108) |
| MODIFIED YF-17 | 11767 (25,941) | 11215 (24,724) |
| LESS USABLE FUEL | | |
| FORWARD CELL | -671 (-1480) | - |
| CENTER CELL | -1415 (-3120) | -1415 (-3120) |
| AFT CELL | -726 (-1600) | -726 (-1600) |
| MODIFIED YF-17 LESS FUEL | 8955 (19,741) | 9074 (20,004) |

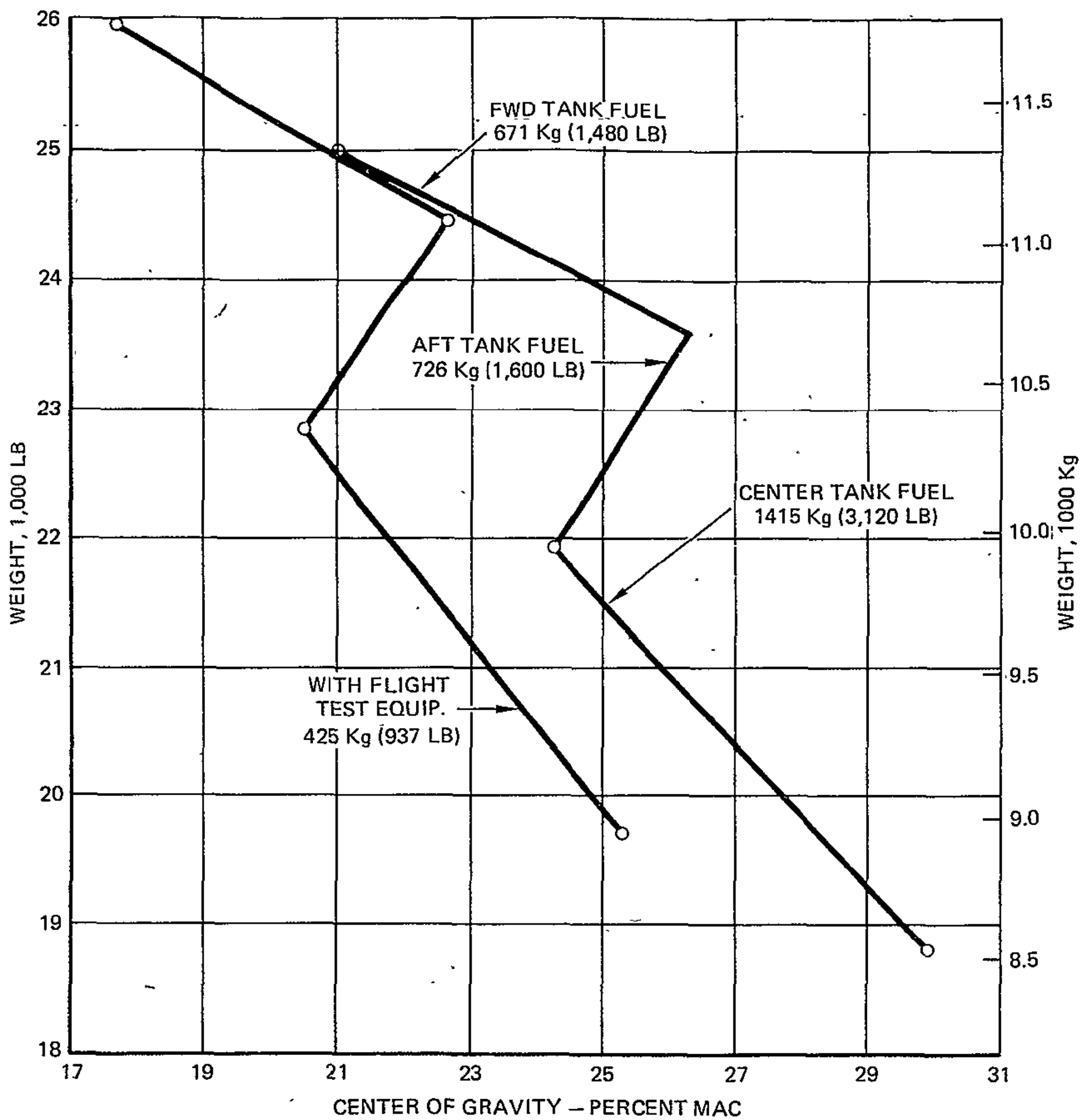



FIGURE 20. CENTER OF GRAVITY DIAGRAM – ADEN ONLY

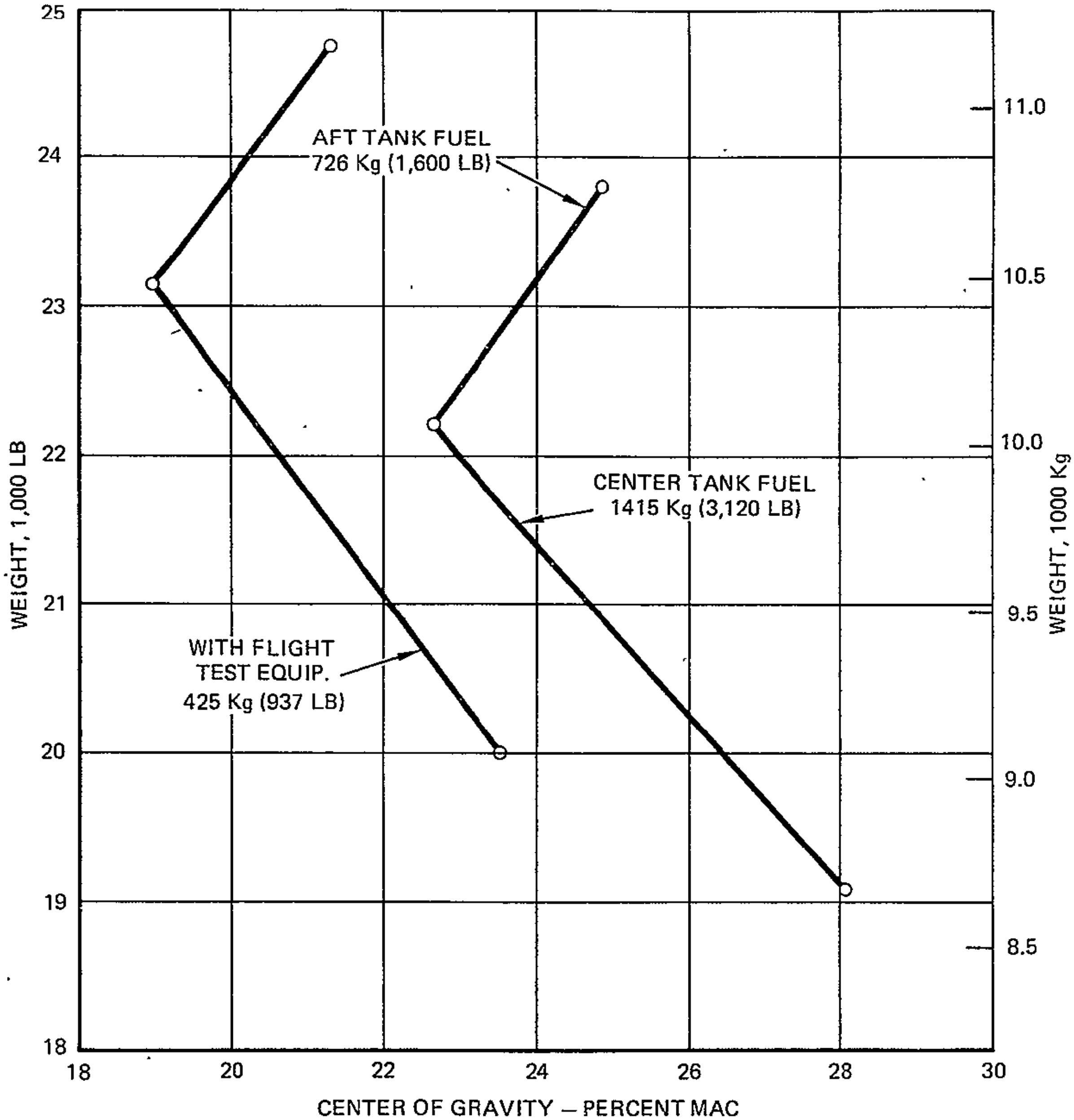



FIGURE 21. CENTER OF GRAVITY DIAGRAM — ADEN & CANARD

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# 2. CONTROL SYSTEM DESIGN

## 2.1 Method of Control Law Design

As a major part of the YF-17/ADEN modification, the capability of the YF-17 pitch control system will be expanded to manage the added forces generated by the vectored thrust and, if present, the forward-fuselage-mounted canard. The control law structure is built around the YF-17 Pitch Command Augmentation System (CAS) as shown in Figures 22 and 23. Optimal control analysis was applied to determine the best combination of physically realizable state variables and gains.

The new control modes were designed using multi-variable decoupling methods as explained by Falb and Wolovich in Reference 9. With a linearized system assumed, the aircraft description was converted to state variable form using those states most appropriate for the desired control modes. Pitch attitude and vertical velocity degrees of freedom were chosen as the primary outputs to be decoupled. A decoupling computer program was then used to define input and feedback matrices. Feedback around each decoupled mode was added to achieve desirable mode dynamics and the feedbacks were reduced to their lowest form.

The detailed analysis used to develop the modified control laws is contained in Appendix A.

## 2.2 Control Modes

Assuming the presence of the canard, four distinct modes of control were identified for implementation of the YF-17/ADEN/canard configuration.

Normal Mode. The normal mode of operation pertains to any flight condition that does not employ vectored thrust. In this mode the canard is active and is controlled as a function proportional to angle of attack in order to maintain as closely as possible the pitching moment versus angle of attack characteristics of the original YF-17 aircraft. Figure 24 diagrams the normal mode, showing a feedback loop added to the existing YF-17 control system for canard deflection. The canard feedback gain may be adjusted, if desired, to generate varying degrees of stability, giving the aircraft the capability for operation over a range of negative to positive stability margins.

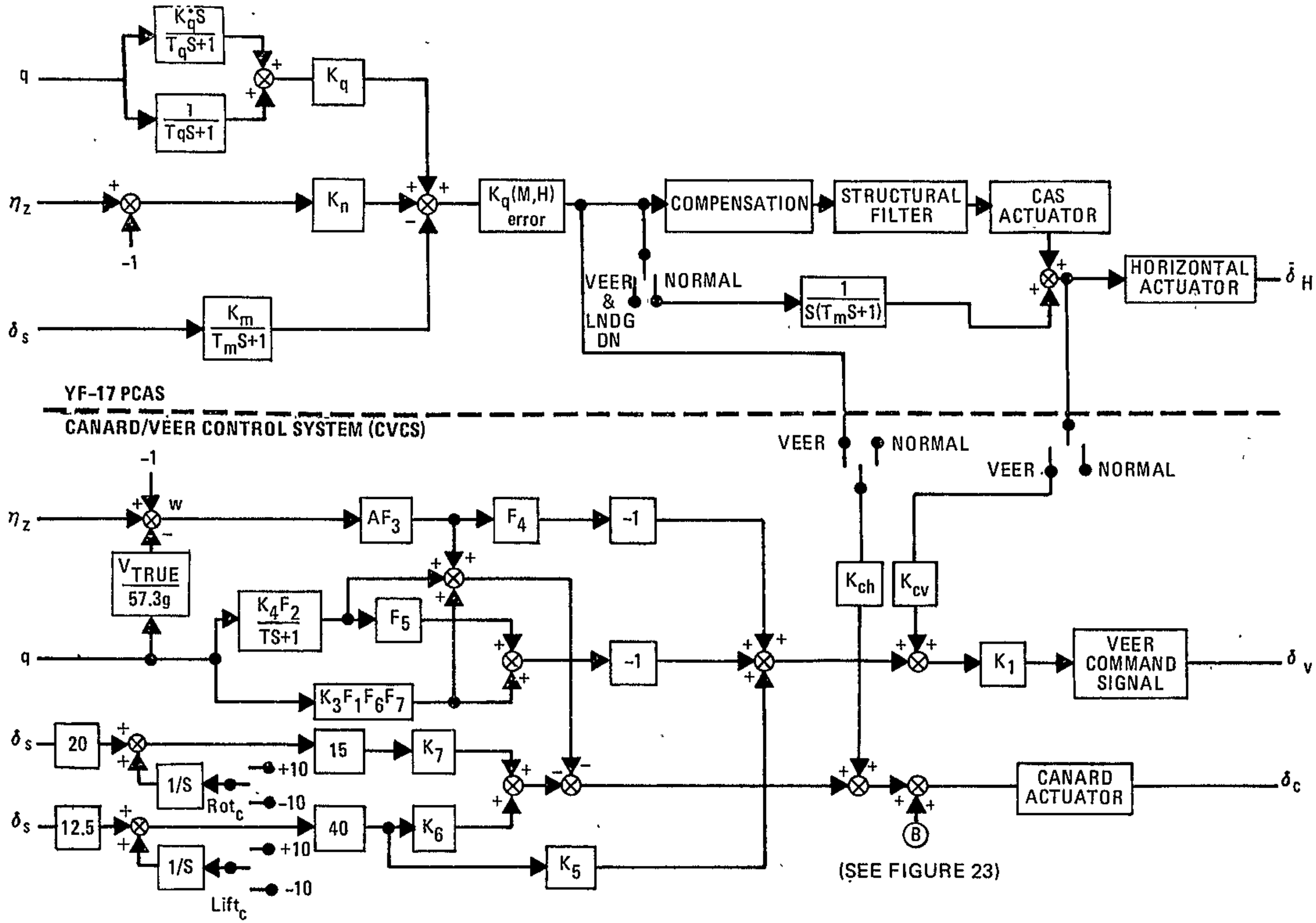


FIGURE 22. CANARD/VEER CONTROL SYSTEM

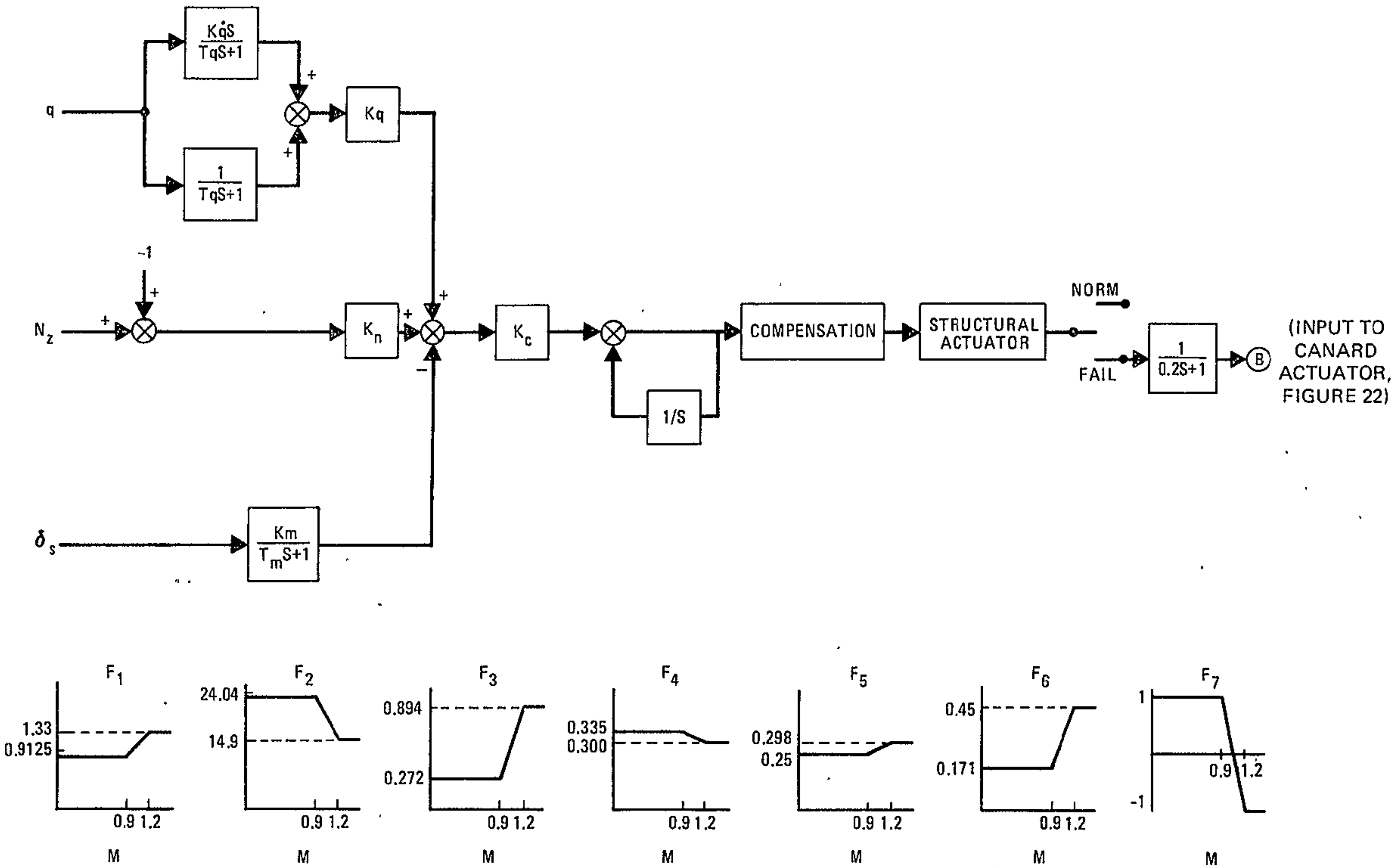


FIGURE 23. CANARD/VEER CONTROL SYSTEM (CONTINUED)

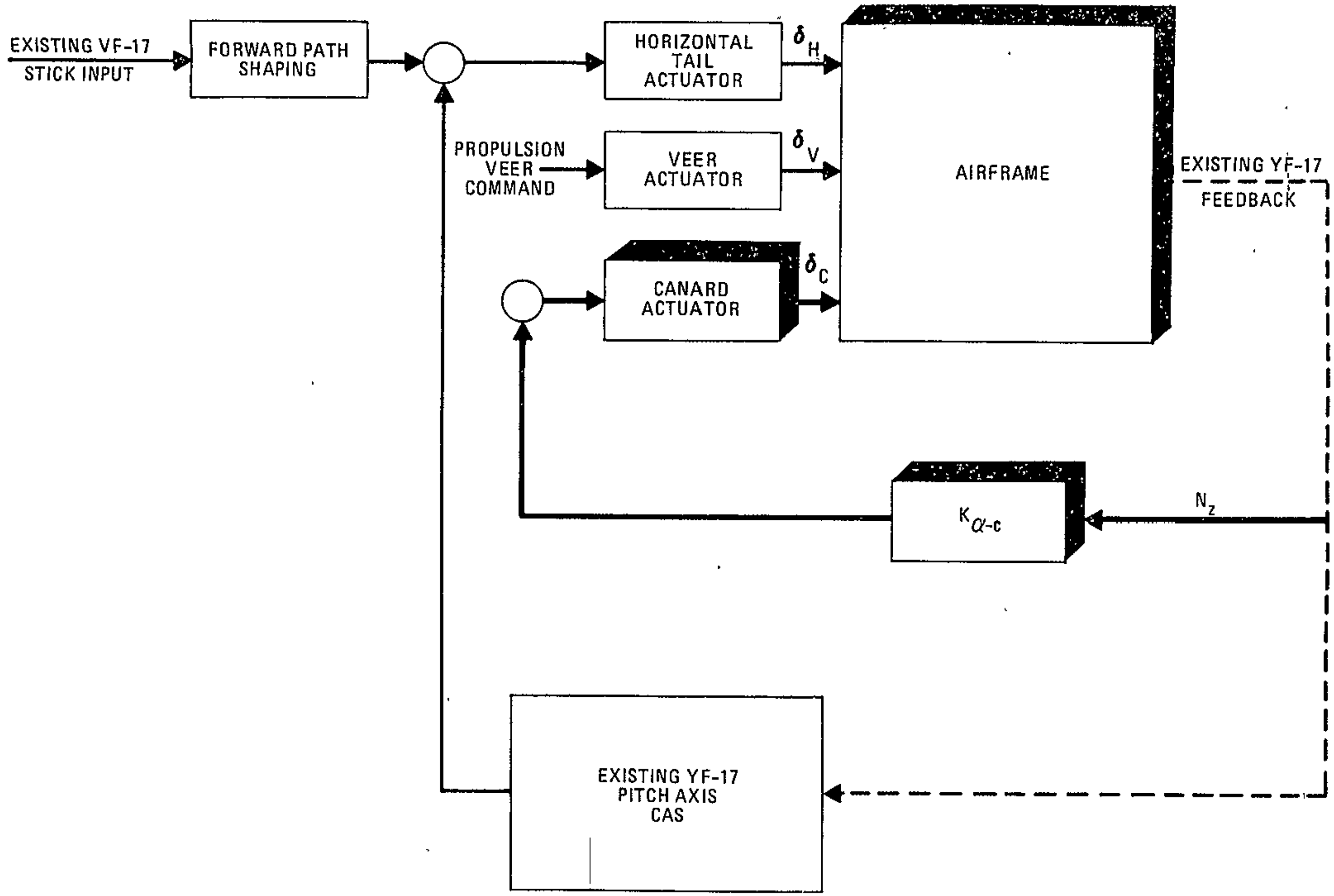


FIGURE 24. NORMAL MODE BLOCK DIAGRAM

The three additional control modes utilize varying inputs and feedbacks from the expanded pitch control system provided by the combination of the horizontal tail deflection ($\delta_H$), the thrust-vectoring VEER deflection angle ($\delta_V$), and the canard deflection ($\delta_C$). The block diagram for the additional control logic to accomplish this is shown in Figure 25. The three vectored thrust modes are characterized as follows:

Lift Mode. The purpose of the Lift Mode is to produce a change in the vertical path of the aircraft without a change in pitch attitude. To achieve this, the horizontal tail and VEER are deflected together, as shown in the vector diagram of Figure 26(A). The resulting moment is trimmed by the canard. Canard aerodynamic data indicate that the canard produces primarily a moment increment with little net effect on lift. Most of the vertical path response is produced by the combined lift of the vertical thrust component, the induced lift of the aircraft afterbody, and the horizontal tail lift.

Pointing Mode. The purpose of the pointing mode is to produce a change in aircraft pitch attitude without a resulting change to the flight path. The different pitch attitude (and angle-of-attack) that results produces a change in wing lift which is compensated for by a deflection of the horizontal tail and VEER. Moment trim is obtained by use of the canard. Because the wing is a powerful lift producer, only small changes in attitude can be obtained before the trimming surfaces saturate. Figure 26(B) diagrams the force moment balance for the pointing mode. The pointing capability can be increased slightly by deflecting the flaperon up, thus destroying part of the added lift developed by the wing due to higher angle-of-attack.

Deceleration Mode. The decel mode is designed to produce increased aircraft drag and resultant deceleration at constant engine power while maintaining aircraft attitude. As shown in Figure 26(C), this is accomplished by deflecting the thrust for maximum thrust loss along the wind axis (X) while counteracting the resulting lift and pitching moment with negative lift on the horizontal tail. X-axis thrust loss and horizontal tail drag produces the deceleration force.

## 2.3 Flight Simulator Verification

Approach. Following identification of the flight control laws required to implement the Canard VEER Control System (CVCS) for vectored thrust maneuvering capability, the modified system was modeled on the Northrop Large Amplitude Simulator, Wide Angle Visual System (LAS/WAVS) for a brief piloted checkout of the various control modes. Whereas the control laws were developed using linear optimal control

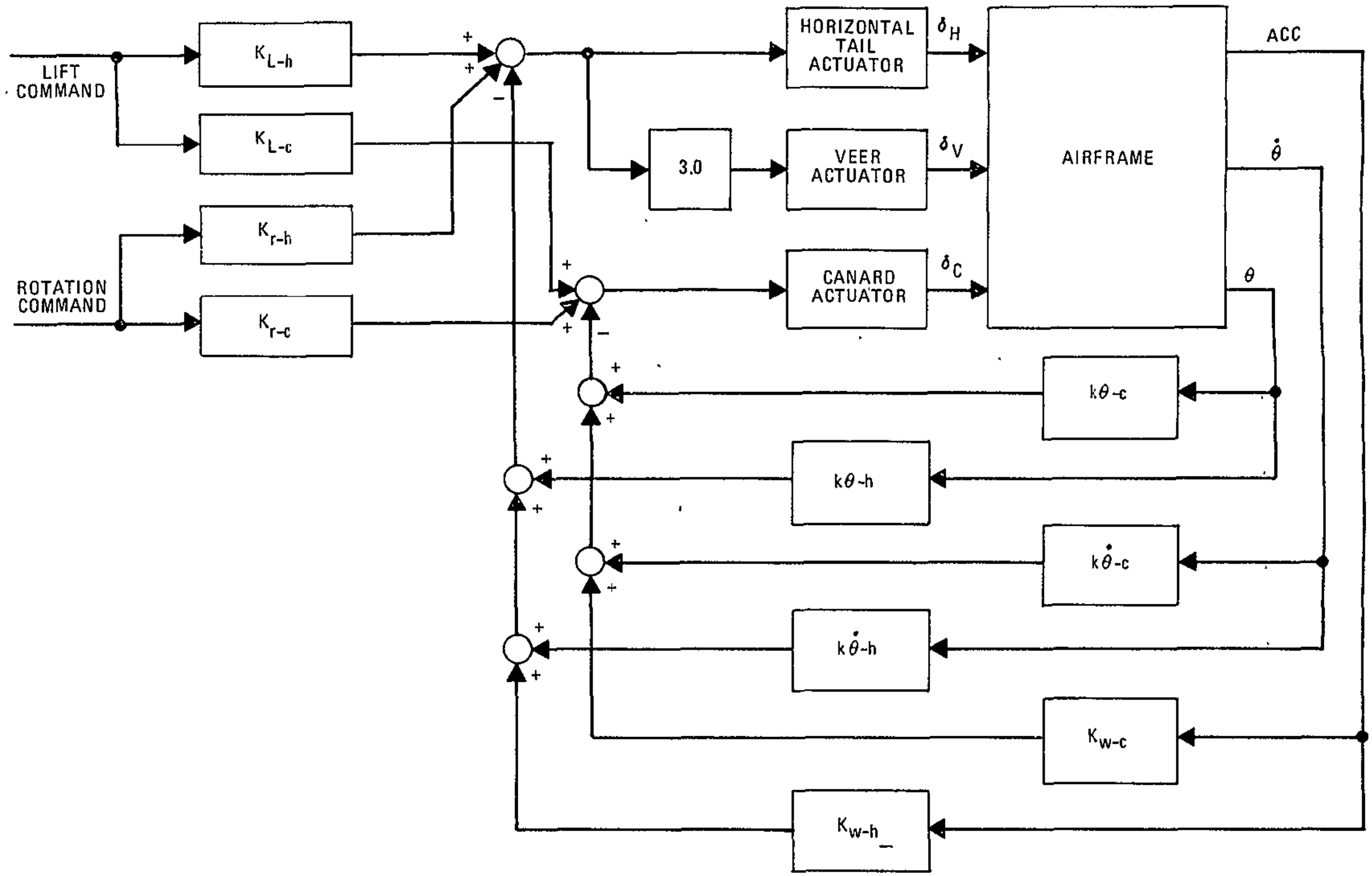


FIGURE 25. LIFT AND ROTATION MODE BLOCK DIAGRAM

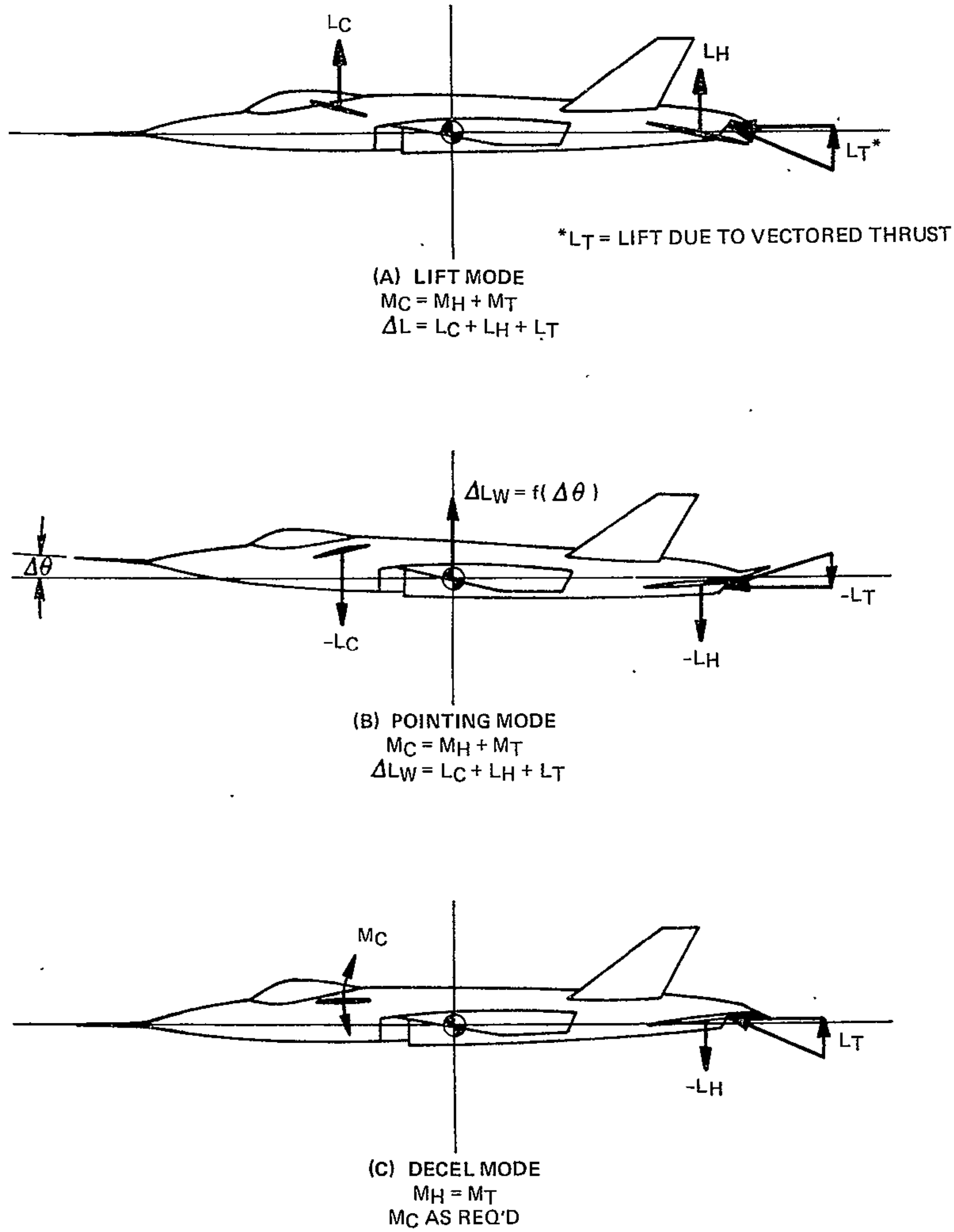


FIGURE 26. CONTROL MODE VECTOR DIAGRAMS.

equations, the LAS/WAVS simulator employed a complete and accurate model of the real system including non-linear aerodynamics and actuator models.

The aircraft's aerodynamic characteristics were used in the six degree of freedom (DOF) equations of motion to digitally calculate the aircraft response using a frame time of 0.016 second. These data were used to drive the piloted, five DOF motion system. The YF-17 Flight Control System, including the pitch Command Augmentation System (CAS) and the canard/ADEN nozzle control system were modeled on an analog computer which interfaced with the digital computer. The time variation of selected aircraft parameters were recorded by analog strip chart recorders.

The flight condition investigated had the YF-17 flying level and initially trimmed at 0.9 Mach number at 4570M (15,000 feet) with the aircraft center of gravity at 0.30 MAC. This corresponds to a stable, basic airframe maneuver margin of 1.5 percent.

To provide a meaningful tracking reference, a scaled aircraft was projected on the earth-sky background view ahead of the pilot. The range to the target aircraft was held constant at 610 M (2,000 feet) directly ahead of the YF-17 at the same flight condition. A fixed sight, with a 2 mil pipper and outer 50 mil reticle, was used by an experienced fighter pilot to tract the target aircraft. For each YF-17 configuration investigated, the target aircraft was initially tracked in steady flight, where the pilot maneuvered the YF-17 in pitch relative to the target to evaluate control response. After 2 or 3 minutes of this type of tracking, the target aircraft was given a "roller-coaster" sinusoidal maneuver that had a period of four seconds and a double amplitude altitude change that corresponded to six diameters of the reticle vertically. This type of tracking was evaluated for another 2 or 3 minutes.

Simulated Flight Modes. Seven YF-17 cases were evaluated by the simulator pilot. Because the modified YF-17/ADEN/canard control system was developed based on several specific flight conditions, auto-throttle control was used to hold airspeed at the condition being examined, thereby allowing the pilot to concentrate on evaluating the maneuvering characteristics of the aircraft.

- Case 1: Basic YF-17 - This case corresponded to the YF-17 as it is presently flown, with CAS on, and was flown to provide the pilot with a basis for comparison. Pilot comment indicated that the basic YF-17 demonstrated excellent tracking characteristics for both fixed and oscillating targets.
- Case 2: Canards Added - The second case simulated the effect of removing the LEX and adding the canards with a deflection capability of ±15 degrees relative to the fuselage centerline. Wind tunnel data indicated that adding

the canards would not affect the YF-17 lift or drag appreciably but the pitching moment would be influenced by angle of attack (AOA) changes and canard surface rotation. These effects were integrated into the response calculated by the digital computer. To minimize the destabilizing effect of the canards, a simple fixed gain control loop was added to the analog calculations such that the canard would be deflected to produce a stabilizing pitching moment in direct response to any AOA change. Upon completion of the target tracking evaluation runs, the simulator pilot commented that he could not detect any change in the YF-17 aircraft's tracking characteristics.

Pilot commentary was verified by the typical strip-chart recordings of Figures 27 and 28 for the first two cases of oscillating target tracking evaluation. Comparison of the traces shows no appreciable change in tracking performance when the canards are added.

For all the remaining cases, the YF-17 lateral CAS was left on, but the pitch CAS was turned off and replaced by the canard/ADEN nozzle/horizontal tail control system. In particular, the YF-17 forward loop integration in the pitch CAS which provides auto trim was turned off, and the pilot had to assume this task.

Movement of the pilot's center stick now produced control stick steering by blending canard, nozzle, and horizontal tail deflection. Fore and aft stick deflection was restricted to 6.35 CM (2.5 inches) about neutral; a deflection of that magnitude produced a change in aircraft pitch angle of six degrees (0.1 radian) and a climb rate of 10 percent of flight speed 229 CM per sec at 2290 CM per sec (90 fps at 900 fps). The pitch trim button or "coolie-hat" switch on the control grip was utilized to allow mechanization of a linear combination of the lift and rotation modes.

- Case 3: Pitch Control - This case evaluated the canard/ADEN/horizontal tail modified pitch control. Pilot comment indicated ease of tracking while maneuvering about a fixed target; however, when attempting to follow the oscillating target, the pilot complained that the nose was not as responsive without the pitch CAS on, and that it tended to wander. Figure 29 provides the traces for Case 3.
- Case 4: Pointing Mode - For this case, the "coolie-hat" switch was used to demonstrate aircraft pointing. When the switch was moved to the aft position, the aircraft rotated nose-up 0.5 degree in pitch and when moved to the forward position, 0.5 degree nose-down. Although the pilot could move the

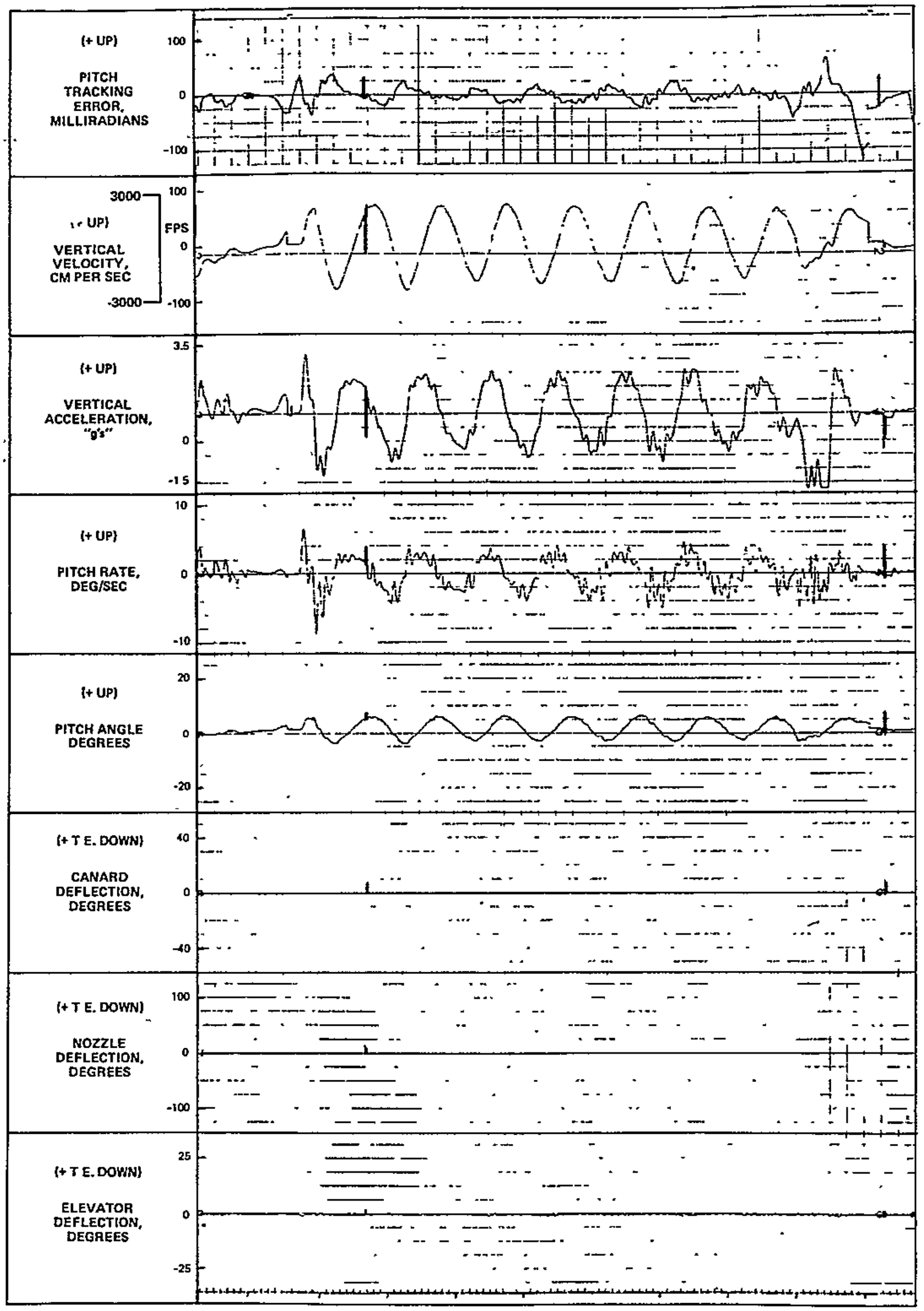


FIGURE 27. TYPICAL YF-17 RESPONSE DURING SINE-WAVE TARGET TRACKING WITH CAS ON

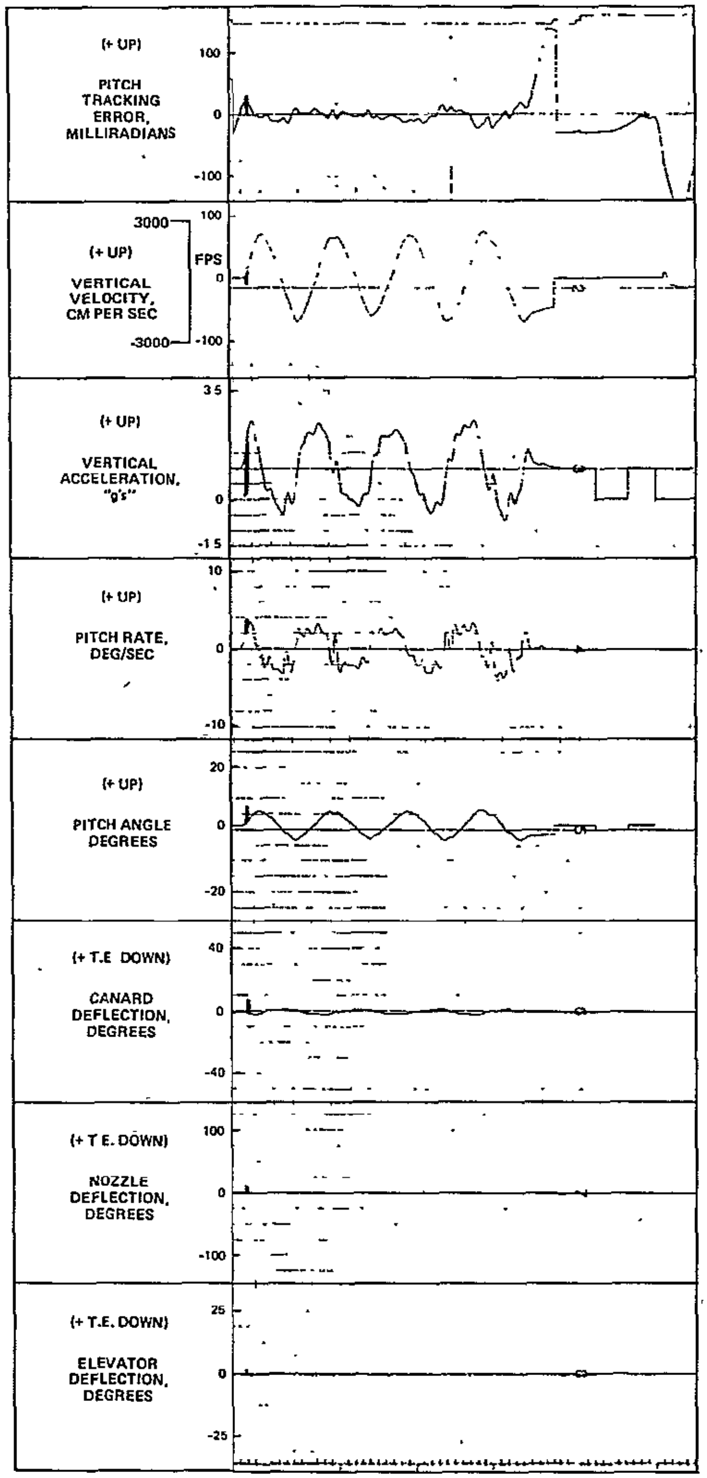


FIGURE 28. TYPICAL YF-17 RESPONSE DURING SINE-WAVE TARGET TRACKING WITH CAS ON AND WITH CANARDS DEFLECTING

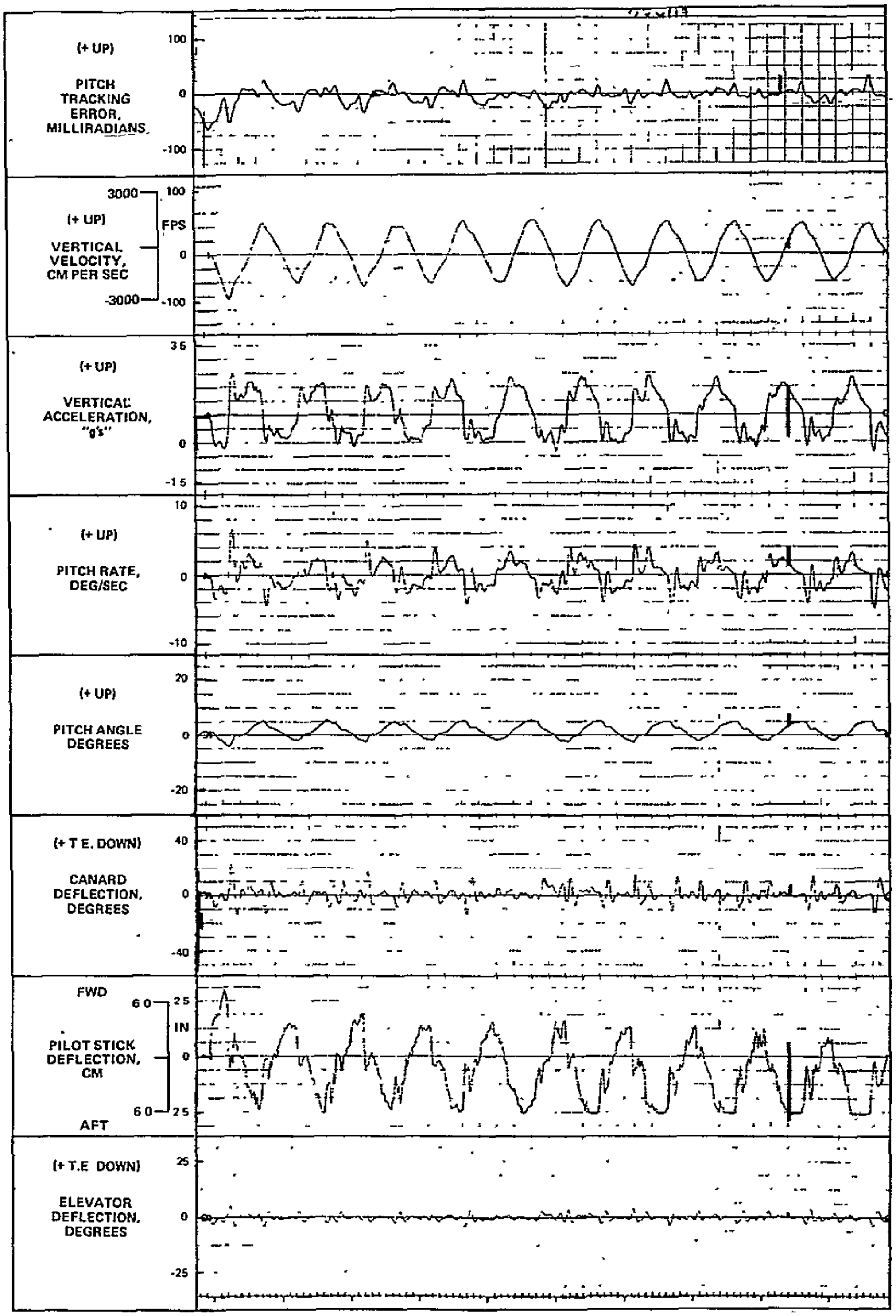


FIGURE 29. TYPICAL YF-17 RESPONSE DURING THE SINE-WAVE TARGET TRACKING USING A COMBINATION OF LIFT AND ROTATION MODES WITH PCAS OFF

center stick, it was not connected to the pitch control system. After tracking the fixed target, the pilot commented that moving the "coolie-hat" gave him the expected pitch response initially; however, he requested that the oscillating track amplitude be reduced by a factor of three before attempting that evaluation. After repeated attempts to track the oscillating target, the pilot commented that he could not adequately perform the task due to too much lag in the pitch response. Figure 30 presents a typical response obtained during the tracking of the fixed target.

- Case 5: Direct Lift - For the fifth case the "coolie-hat" switch was used for lift control instead of the pitch control evaluated in the previous case. When the pilot moved this switch to its aft position, the aircraft developed a 3.96 M/sec (13 fps) rate of climb. With the switch in the forward position, a 3.96 M/sec (13 fps) rate of descent resulted. This case was only evaluated using a fixed target. After several runs in both switch positions, the pilot commented that use of the switch did indeed change lift without changing pitch angle, however the response was sluggish. Figure 31 presents a typical response obtained for this case.
- Case 6: Direct Lift with Center Stick - The sixth case again used direct lift on the "coolie-hat" switch but in this case the center stick was also connected to the canard/VEER/horizontal tail control system. After tracking the fixed and oscillating targets, the pilot acknowledged the lift augmentation but complained of complications due to the other inputs. Figure 32 presents a typical response for this case.
- Case 7: Deceleration Mode - The seventh case used only the speedbrake switch and center stick. When the speedbrake switch was activated, the ADEN nozzle was deflected down, the horizontal tail was deflected trailing edge up to offset the nozzle lift, and the canrad was deflected to counterbalance the resulting pitching moment. The net effect was an increase in aircraft drag due to these control surface deflections which caused the aircraft to decelerate at 0.1 g or 0.98 $M/sec^2$ (3.2 $fps^2$). The auto throttle was connected and the pilot used his center stick for trim. This case was evaluated using a fixed target. This pilot pointed out that while deceleration was experienced, it was not outstanding. Figure 33 presents a typical response for this case.

Discussion of Simulator Results. Due to schedule requirements, the simulator investigations of the YF-17/ADEN/canard handling characteristics were limited mainly to verification of the modified control system concept. Lift, aircraft pointing, and

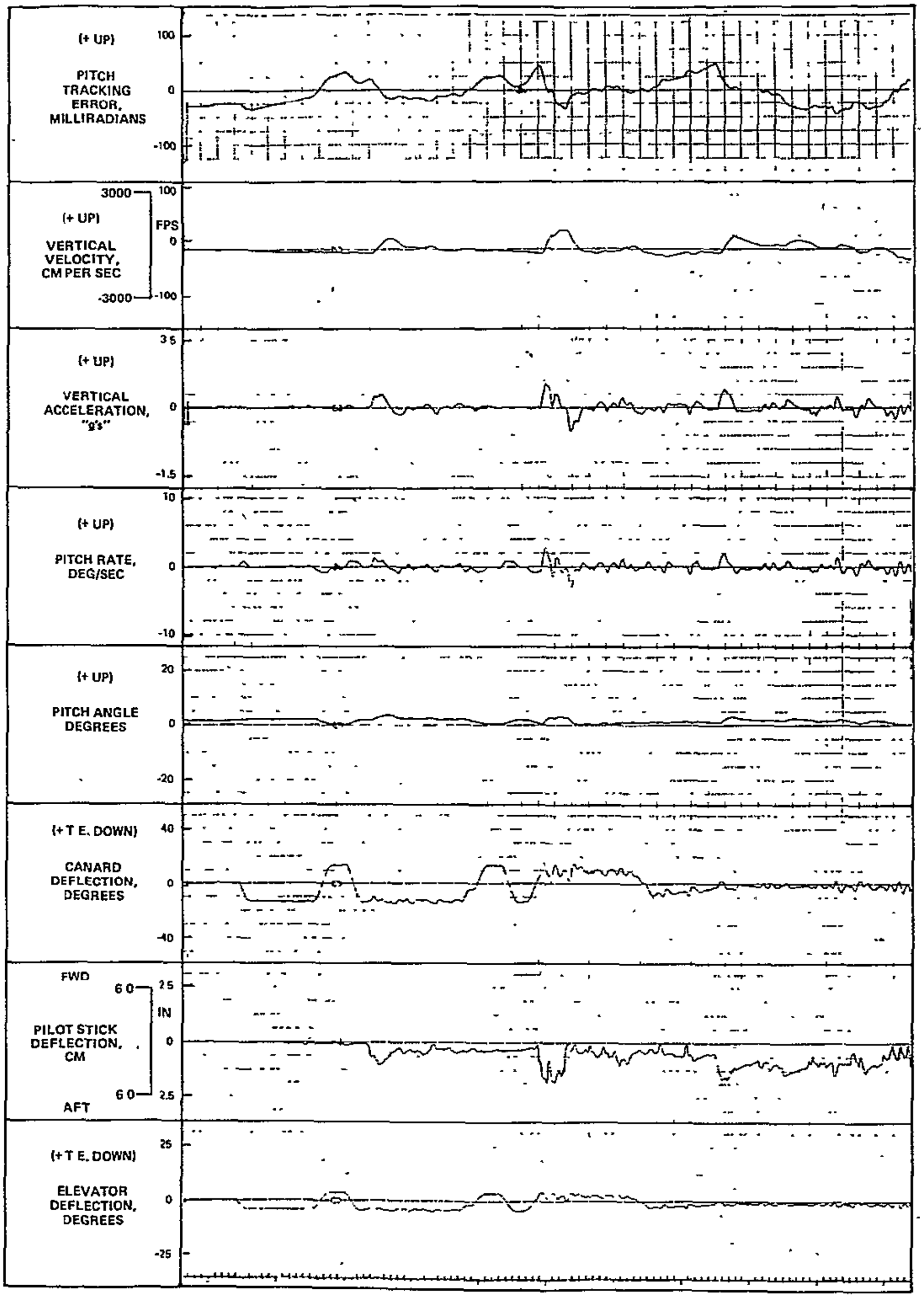


**FIGURE 30. TYPICAL YF-17 RESPONSE DURING FIXED TARGET TRACKING USING ONLY THE ROTATION MODE ON THE COOLIE-HAT**

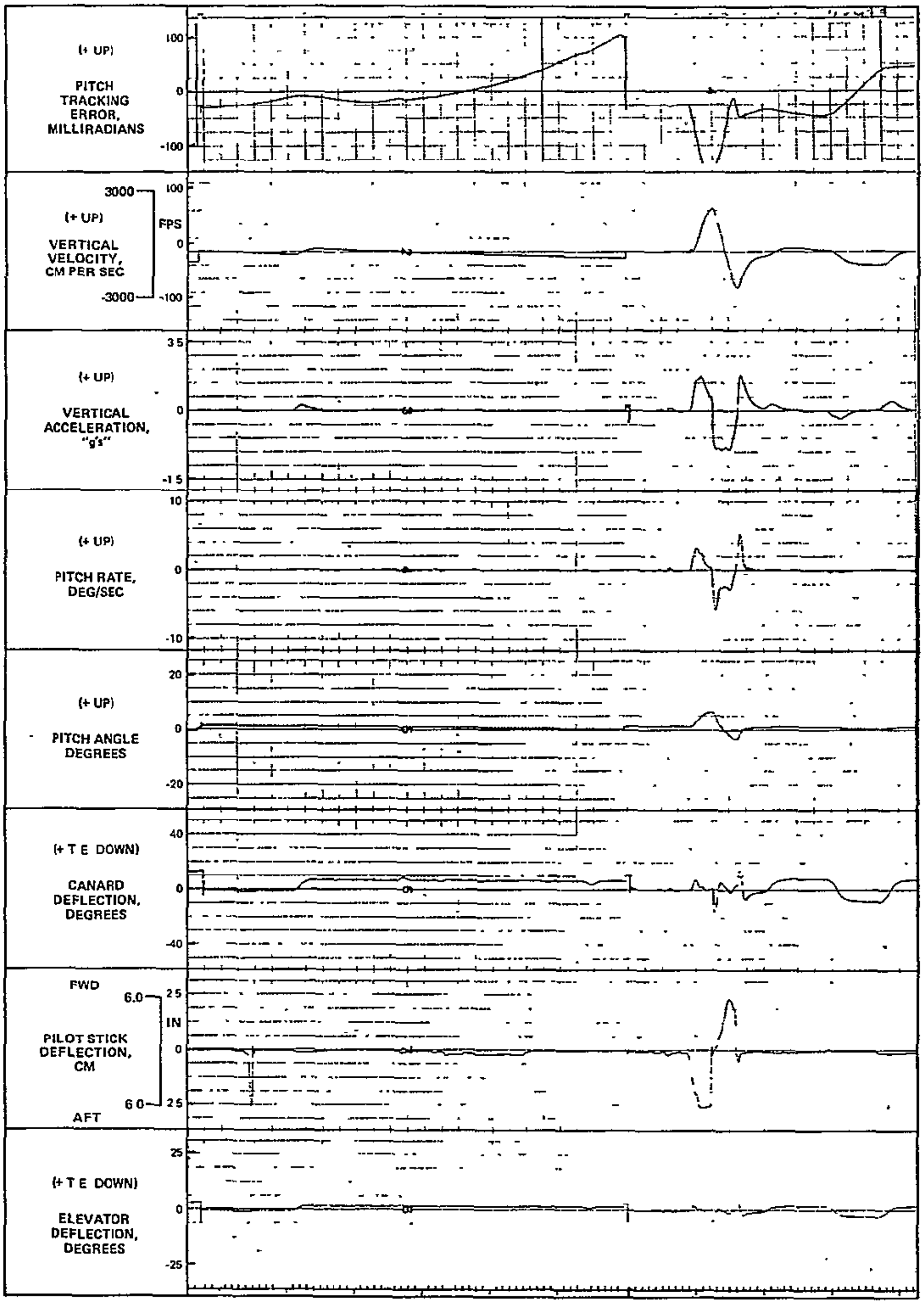


FIGURE 31. TYPICAL YF-17 RESPONSE DURING FIXED TARGET TRACKING USING ONLY THE LIFT MODE ON THE COOLIE-HAT

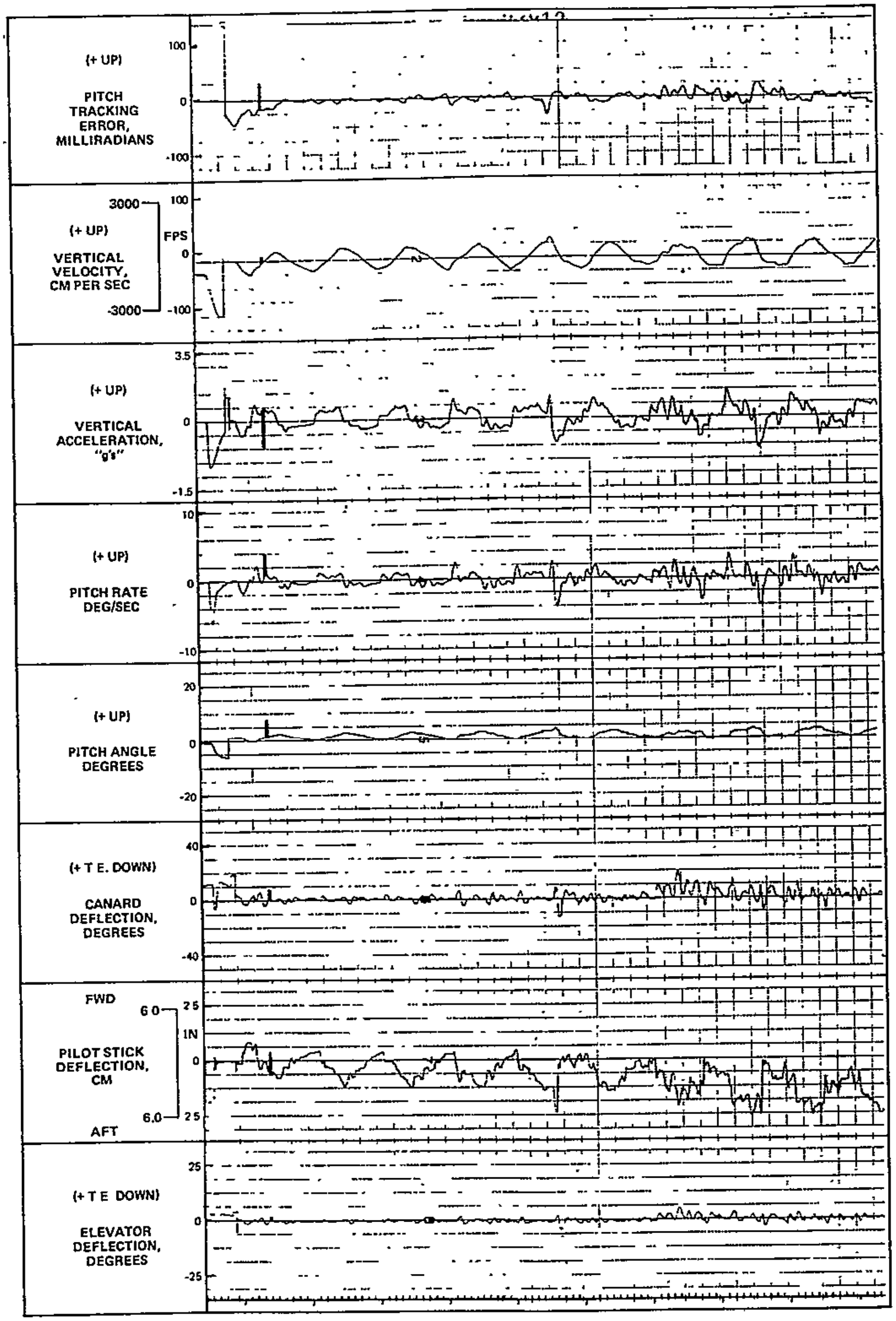


FIGURE 32. TYPICAL YF-17 RESPONSE DURING FIXED TARGET TRACKING USING THE LIFT MODE ON THE COOLIE-HAT AND THE COMBINED MODE ON THE CENTER STICK

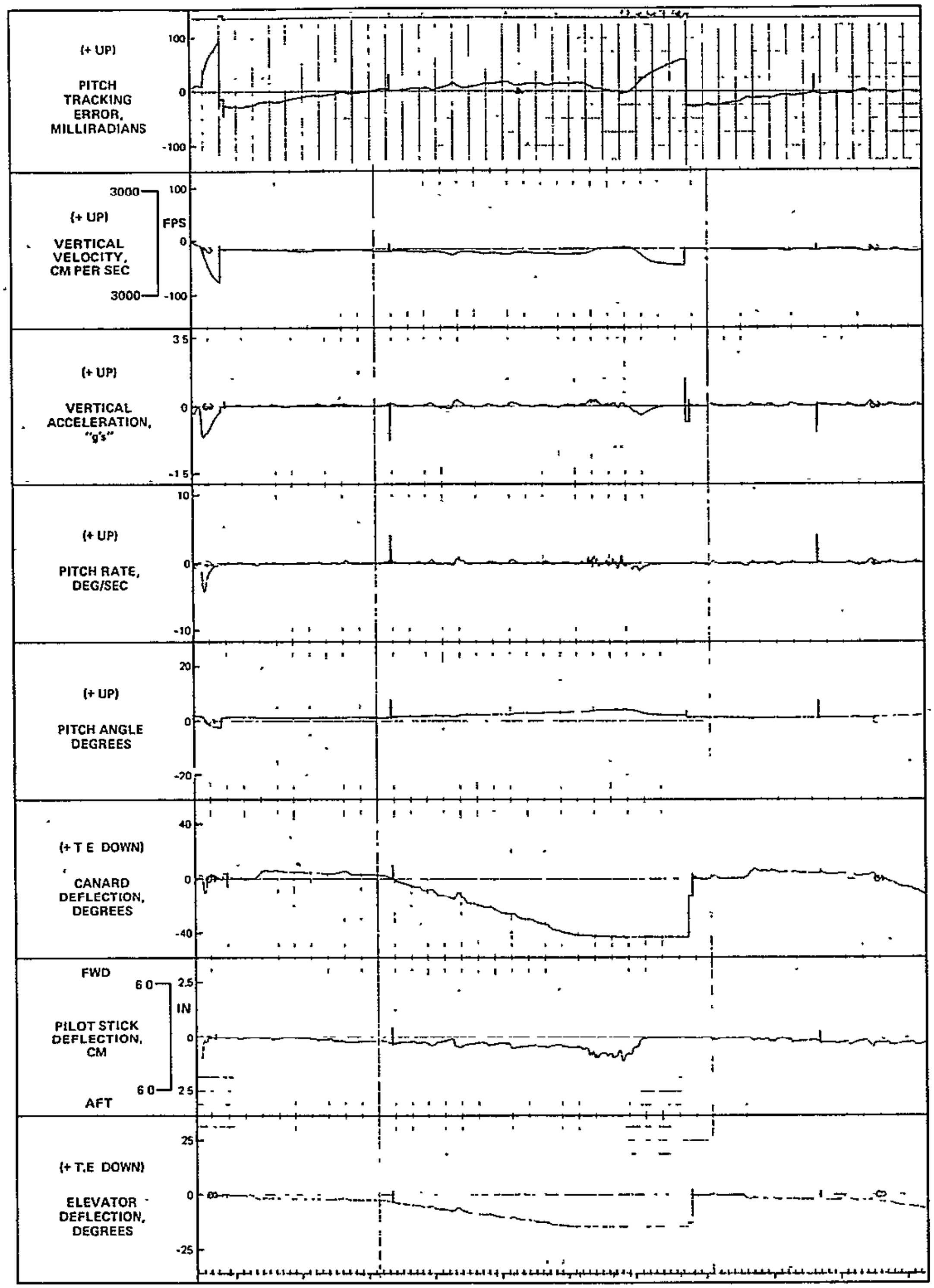


FIGURE 33. TYPICAL YF-17 RESPONSE DURING FIXED TARGET TRACKING USING ONLY THE DRAG MODE ON THE SPEEDBRAKE SWITCH

deceleration effects all manifested themselves as expected with the proper manipulation of the canard, vectored thrust, and horizontal tail. Some adverse handling qualities which were uncovered in this evaluation can be attributed in large part to the somewhat arbitrary implementation of the control laws required to perform the simulation studies in the time available. Further investigation would be desirable to optimize the system concept.

A significant observation on this simulator activity was the relatively small effectiveness of the canard/VEER/horizontal tail at the Mach 0.9, 4570M (15,000 foot) flight condition examined. At this high-g condition, the wing is so powerful in lift that only small attitude changes can be effective with the opposite net loads from the canard/VEER/horizontal tail. This serves to confirm that the strengths of 2-D vectored thrust lie in the lower q portions of the flight envelope where canard/nozzle/horizontal tail effectiveness would be more marked. Further simulator activity would be well-directed toward this regime. Use of a wing flap, aileron, or flaperon to "dump" lift on the wing should also be considered as an effective way to increase canard/VEER/horizontal tail authority for aircraft pointing.

## 2.4 Control Hardware Implementation

General Approach. In order to handle the expanded control requirements presented by the canards and the deflecting nozzle Variable Exhaust Expansion Ramp VEER), a digital flight control computer will be added to the existing YF-17 control system to provide the canard/VEER control (CVC). In the modified system the canard and VEER will be used to produce movement in the pitch axis; therefore, the pitch control augmentation computation task originally performed by the baseline system will be transferred to the CVC to facilitate the integration of the canard and VEER computational and hardware requirements. The CVC computer will provide sensor signal management, actuation control, and redundancy management/failure monitoring for both the VEER and the canard actuation systems and perform the control law computations for the horizontal tail, VEER, and canard surfaces. The conceptual arrangement of the modified pitch axis control is shown in Figure 34.

The lateral-directional control axes and the maneuvering flap control system will remain unchanged.

YJ101/ADEN Controls and Actuation. The engine exhaust nozzle ($A_8$) actuators will be of the same design as those used on the existing ADEN; i.e., cylindrical ram

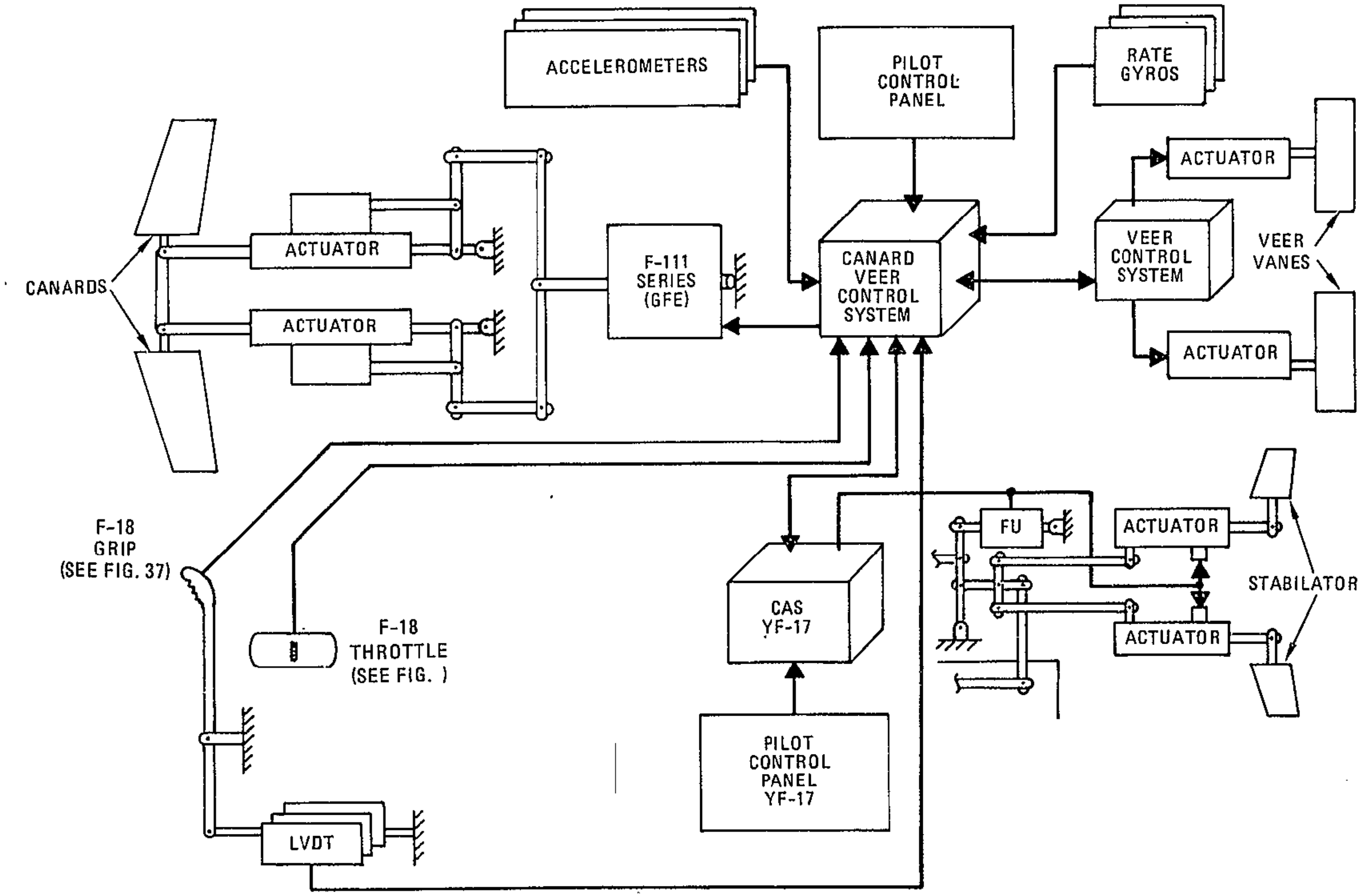


FIGURE 34. MODIFIED PITCH AXIS CONTROL

actuators are used, one on either side of the ADEN assembly. An electrical position linear variable differential transducer (LVDT) provides a feedback signal to the electrical control and to the aircraft.

The $A_8$ actuators will be controlled by the existing YJ101 nozzle control system with minor modifications to accommodate actuator differences from the JY101. The actuators will be positioned directly by an engine-driven, variable displacement hydraulic pump. The pump is controlled by a signal from an engine-mounted electrical control which in turn responds to an input demand from the engine main fuel control. Because the actuator stroke-to-area relationship on the ADEN differs from that required for the current YJ101, it will be necessary to modify the nozzle area versus power lever cam in the main fuel control, and to modify the electrical control by changing the fan speed-to-min. nozzle area limit schedule, the nozzle area-to-augmentor fuel schedule, and the hydraulic pump driver amplifier gain.

VEER actuation will be provided by three cylindrical ram actuators of the same design as those used for $A_8$ control, each with a load capability of at least 21000N (4800 lbs) and a stroke of 6.86CM (2.7 inches). These actuators are larger than necessary for the VEER but they will fit in the available space and using them will minimize program cost and simplify logistics. A collar will be added to the rod end of each actuator to limit the total stroke. Electrical position transducers (LVDT'S) will be included to provide a feedback signal for control.

Hydraulic power to the three rams will be supplied from the aircraft hydraulic system and metered by a single, two-stage electro-hydraulic servovalve. Control and failure monitoring the VEER actuation system will be accomplished by the CVC computer. In case of failure, the actuation system will revert to a hydraulic bypass/damper mode.

Canard Controls/Actuation. Figure 35 provides a perspective view of the proposed canard actuation system. In order to provide for safety of flight and full time availability of the canard as an active surface, a dual hydraulic series triplex secondary actuator used on the F-111 aircraft was chosen to provide the necessary redundancy and reliability for fail operational capability. In the event of a complete failure of the actuation system, the canard will fail to a neutral position, thereby avoiding the potential control and flutter problems associated with a free-floating failure mode. This actuator will provide the input to two dual hydraulic mechanical input/feedback power actuators to rotate the common torque tube and two attached canard surfaces about the canard

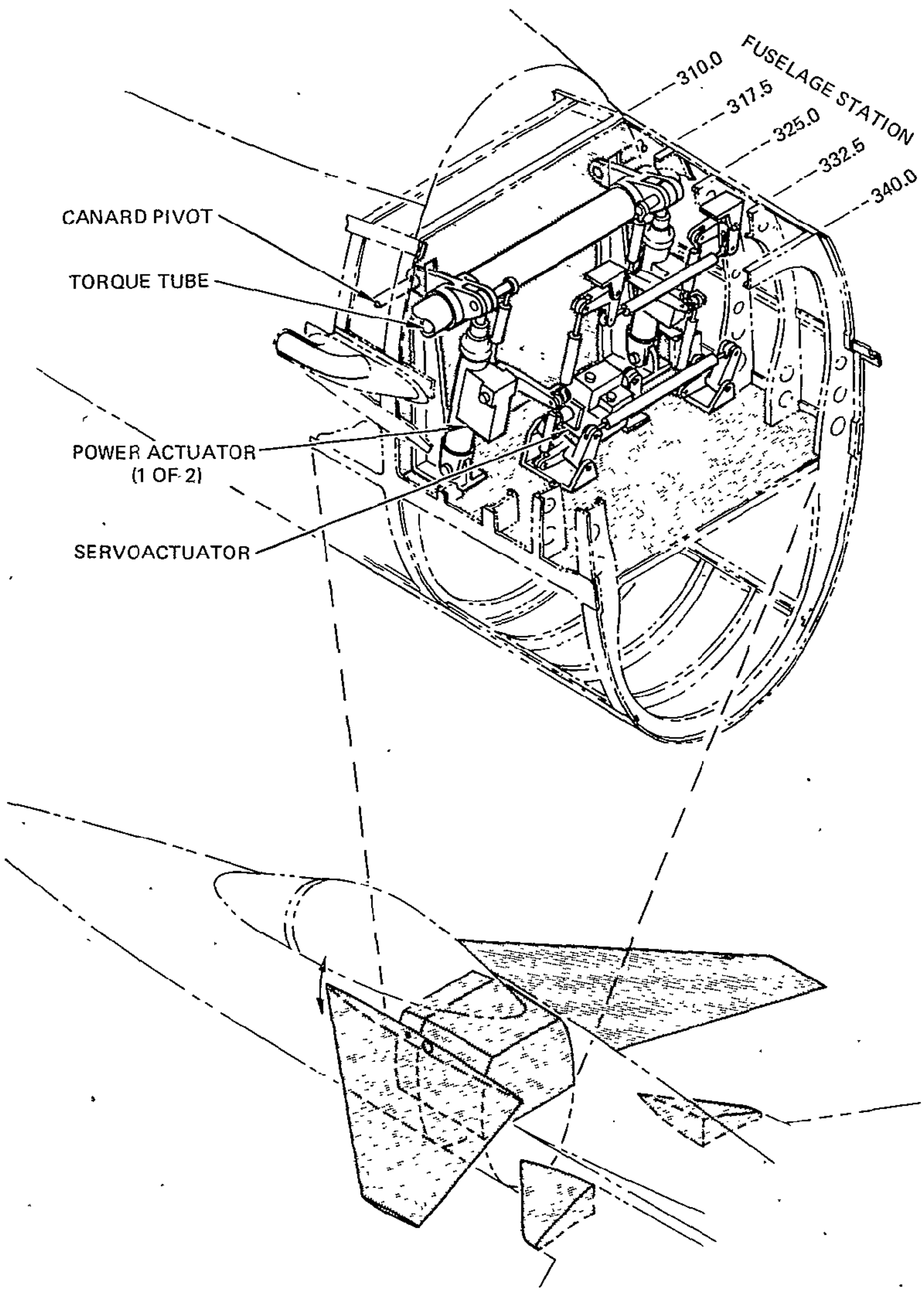


FIGURE 35. CANARD ACTUATION SYSTEM

pivot points. The power actuators are similar in design to the dual tandem hydraulic actuators used for the F-5 horizontal tail.

Canard/VEER Control (CVC) Computer. The digital CVC computer will incorporate all the new and modified pitch axis control functions required by the YF-17/ADEN system. To minimize design risk, the computer will be synthesized from fully developed and proven elements. The basic design will be triplex in order to satisfy the redundancy and actuation interface requirements associated with the utilization of canard surfaces. Mode logic, control law computations, and failure monitoring/redundancy management will be provided by three synchronous digital processors with nonvolatile memory.

With the addition of the triplex canard actuation, the opportunity exists if desired, to upgrade the dual redundancy (fail-safe) of the existing YF-17 pitch control augmentation actuation to triple redundancy (fail-operational/fail-safe) by providing for transfer of the horizontal tail pitch control function to the similarly effective canard and its triplex system in the event of a failure in the existing pitch CAS.

The interface to the VEER actuation system on each engine is simplex, with the required fail-passive characteristics provided by comparative monitoring between left and right VEER positions.

The proposed implementation would utilize the Sperry Flight Systems Model SDP-175 computers currently used in commercial aircraft applications (Figure 36). A brassboard, military version of this computer, Model MK-175, was extensively evaluated in a triplex arrangement on the Northrop Advanced Flight Controls Test Stand with excellent results. The same evaluation also validated the analog circuits involved in sensor and actuation interface, and redundancy management.

Sensors. Implementation of the modified YF-17/ADEN control laws will require sensing or normal acceleration, pitch rate, and pitch stick position to provide required stabilization and dynamic performance. These sensors are currently available on the YF-17 in dual redundant packages. To achieve the required triplex redundancy without incurring the cost of repackaging, another set of these dual sensors will be added to the existing system. The CVC computer will provide the signal shaping and synthesis as required; for example, angle-of-attack perturbations that may be required as a feedback parameter to compensate for the destabilizing effect of the canard surfaces would be synthesized from normal acceleration and pitch rate.

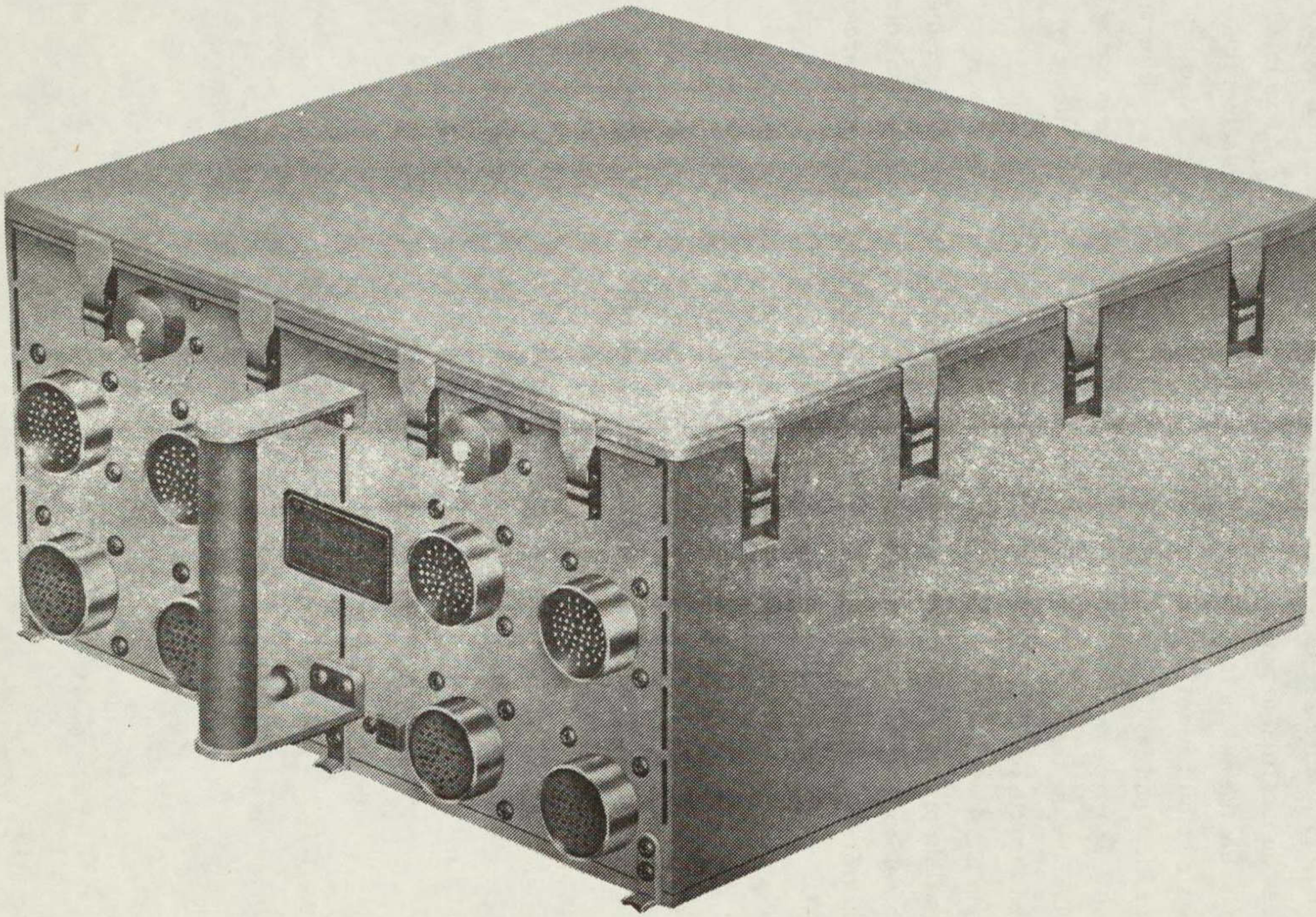

FIGURE 36. SPERRY FLIGHT SYSTEMS SDP-175 COMPUTER

Cockpit Controls. Figure 37 shows the modified cockpit layout for the YF-17/ADEN. The existing YF-17 control augmentation and flap controls will be retained. The YF-17 stick grip will be replaced with F-18A type stick grip with a four position switch that can be modified to perform as a control mode selector. As shown in Figure 37, placing the switch in the appropriate position the pilot would select the NORMAL (basic stabilization), LIFT, ROTATE (point), or DECEL mode. Vernier control of the LIFT and ROTATE modes will be provided by a thumbwheel type control located on an F-18A type throttle lever. When the DECEL mode is selected, control will be provided by the three-position, momentary-on speedbrake slide switch also located on the throttle lever.

The gain panel will be added to allow inflight adjustment of selected control parameters within preset limits, with the "N" setting representing the predetermined nominal gain selected for the given parameter, and the "1" and "2" settings providing the capability of varying the predetermined gain by plus and minus a selected percentage.

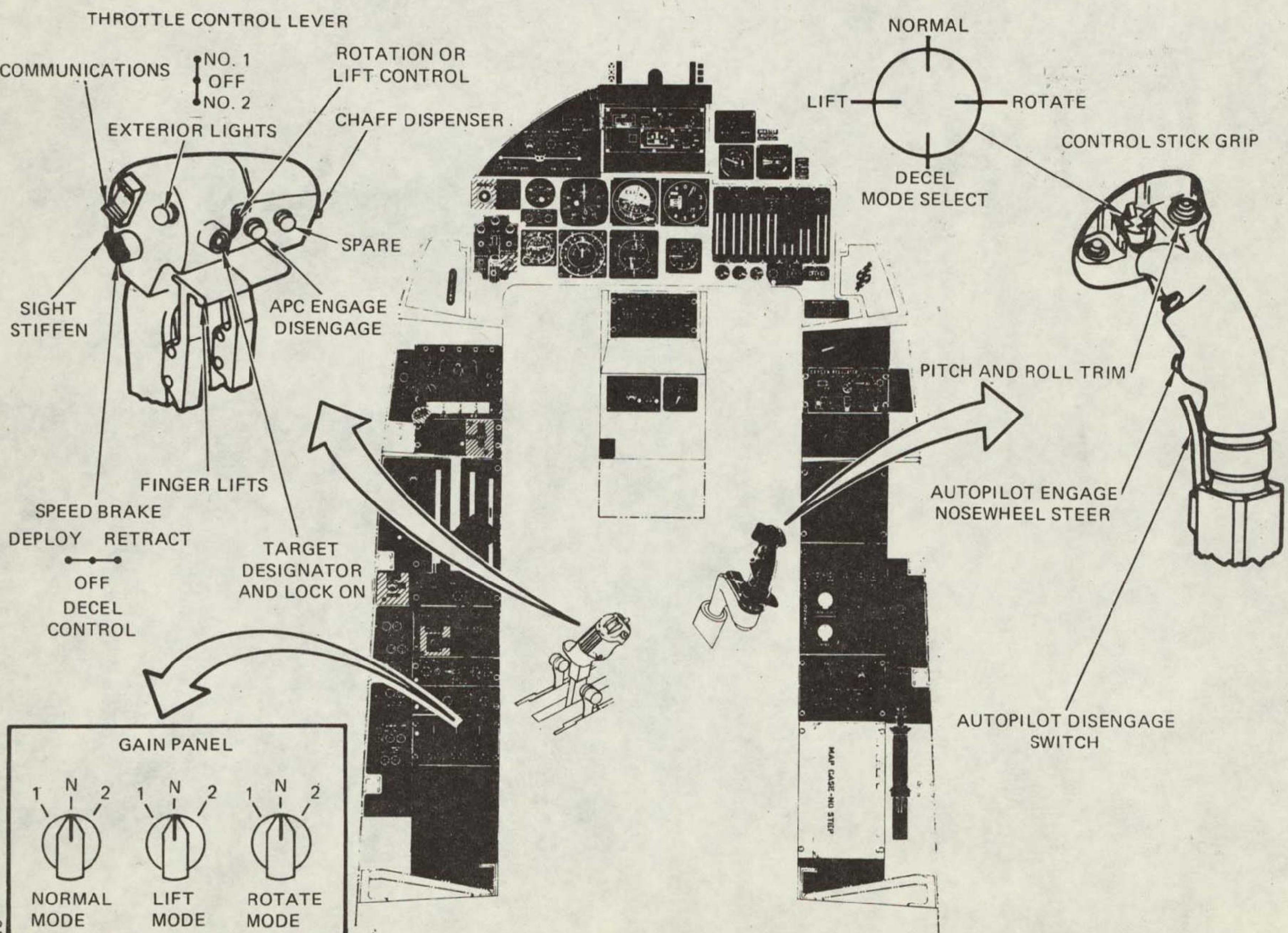


FIGURE 37. PILOT CONTROL INTERFACE

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# 3. YF-17/ADEN FLIGHT PERFORMANCE ASSESSMENT

This section provides an evaluation of aerodynamic performance changes caused by reconfiguration of the YF-17 aircraft to integrate the ADEN nozzle design. Performance is shown for the YF-17 modified strictly to integrate the ADEN nozzle (this configuration will be referred to as "YF-17/ADEN" or "ADEN only") and the canard modification which additionally removes the LEX and adds the shoulder-mounted canards (this configuration will be referred as "YF-17/ADEN with canard"). To provide background information, the ADEN nozzle/afterbody thrust-minus-drag characteristics and shoulder-mounted canard aerodynamics are developed first, followed by an overall assessment of the aerodynamic performance changes which derive from integration of the ADEN and canard. The additional capability provided by thrust reversing is illustrated through discussion of two hypothetical combat encounters. Potential takeoff and landing performance improvements available through thrust vectoring are also evaluated.

Because the YF-17 performance capability is classified information, flight performance results presented here are incremented from or normalized to baseline YF-17 performance.

## 3.1 ADEN/Afterbody Performance Effects

The aeropropulsive consequences of replacing the dual axisymmetric nozzle geometry of the YF-17 with the two-dimensional ADENs were established through the investigations conducted on the 0.10 scale F-18/ADEN integration at NASA Langley (Reference 6). Due to similarity of the YF-17 and F-18 designs, results of testing on the F-18/ADEN are expected to be fully representative of the YF-17/ADEN modification also.

The ADEN configuration, shown installed on the F-18 model in the Langley 16 ft. tunnel in Figure 37, was one of three non-axisymmetric nozzle design integrated with the F-18 airframe design and tested over a range of operating conditions. Also investigated were the GE 2-D convergent-divergent concept and the Boeing AIN variable center plug design. Using high pressure air to simulate the jet plumes, F-18/ADEN afterbody

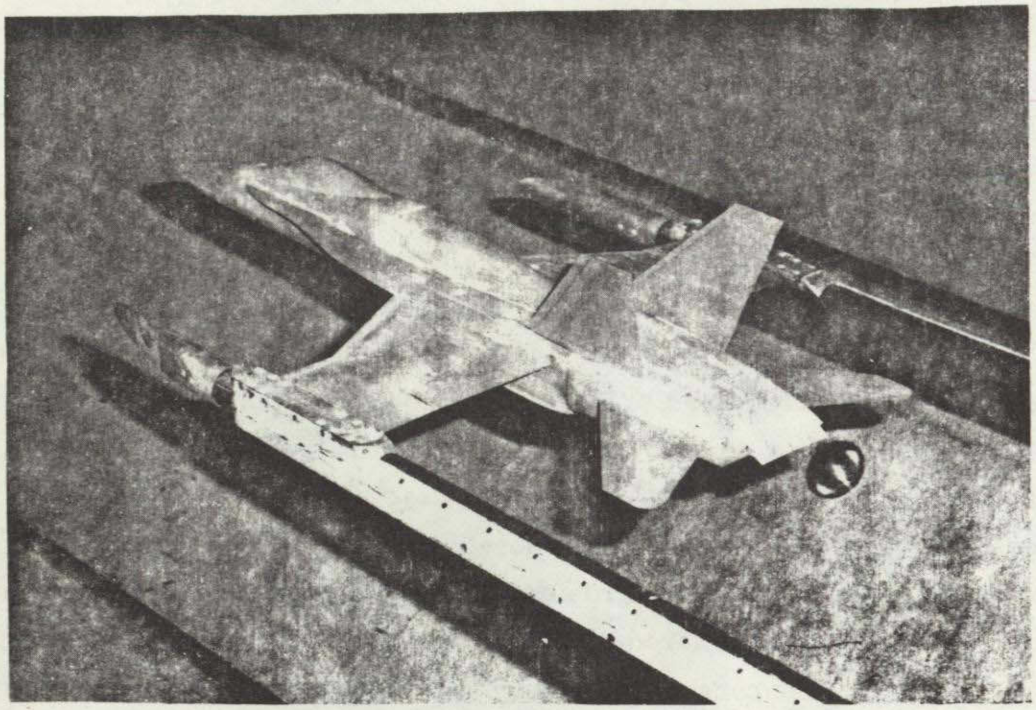

FIGURE 37. ADEN NOZZLES INSTALLED ON 0.10 SCALE F–18 MODEL IN NASA LANGLEY 16 FT. TUNNEL

aerodynamic data were obtained for the following matrix of variables:

$A_8$ = 16.13 $cm^2$ (2.5 $in^2$) (cruise) and 25.81 $cm^2$ (4.0 $in^2$) (reheat)

Nozzle pressure rate = off to 10

Angle of attack = -2° to +10°

Mach number = 0.6, 0.8, 0.9, 1.2

VEER angle = 0°, 7° up, 7° down, 20° down

Nozzle performance was also obtained at static conditions for all geometries investigated, and expanded Mach surveys were taken from Mach = 0.6 to 1.3 at a representative operating nozzle pressure ratio to define the drag rise characteristics.

Unvectored Nozzle Performance. As an initial step in the Langley investigations, the F-18 dual axisymmetric aft end was tested to establish a reference data base for comparison with the non-axisymmetric integrations. Data obtained generally agreed well with pretest predictions based on previous measurements of YF-17 nozzle/afterbody drag.

Following establishment of the dual-axisymmetric reference performance levels, measurements of the ADEN unvectored thrust-minus-drag characteristics were obtained. Typical static results for the ADEN and for the dual-axisymmetric aft ends are shown in Figure 38 for the cruise nozzle setting, and in Figure 39 for the reheat setting.

Figures 40 through 42 present wind-on data for representative flight conditions of Mach = 0.8, cruise nozzle, and Mach = 0.9 and 1.2, reheat nozzle.

A more general comparison is presented in Figures 43 and 44 in terms of the drag-oriented parameter $C_{T-D} = (F_G - D)/ qS_W$, to gain a better understanding of the ADEN integration in terms of aircraft performance. Comparisons of axisymmetric and ADEN thrust-minus-drag characteristics in this form are presented in Figure 43 for the cruise nozzle setting, and in Figure 44 for the reheat geometry. Within the

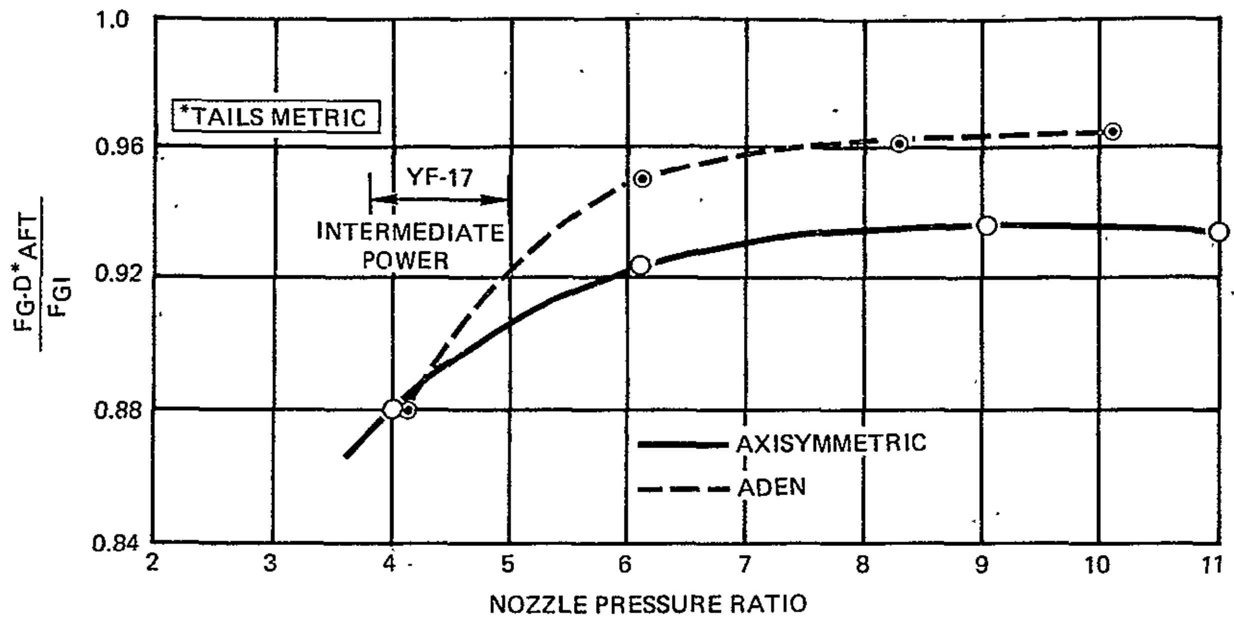


FIGURE 40. MEASURED PERFORMANCE OF F-18 AXISYMMETRIC AND ADEN AFT END INTEGRATIONS, CRUISE NOZZLE, MACH = 0.8

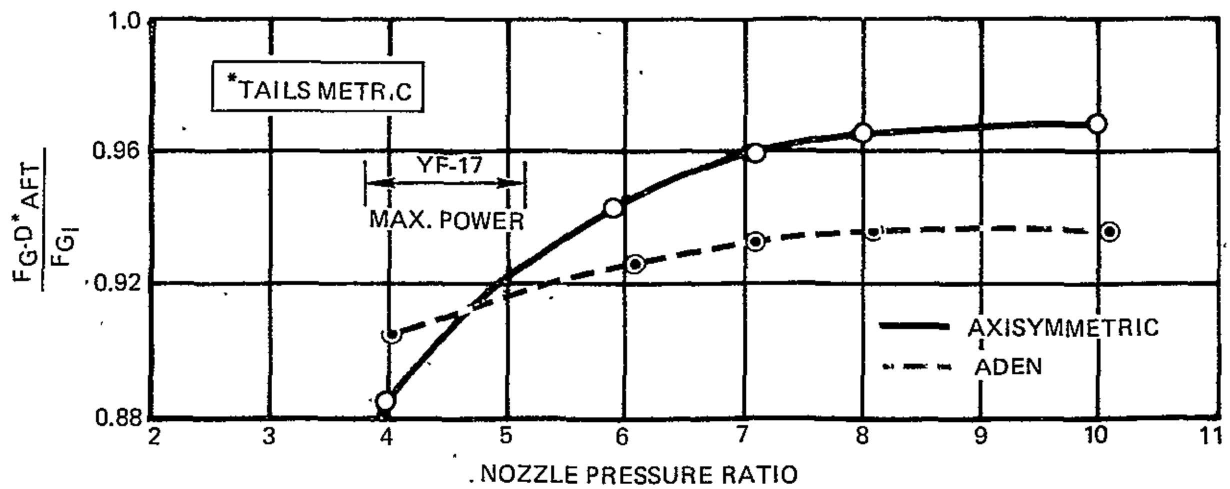


FIGURE 41. MEASURED PERFORMANCE OF F-18 AXISYMMETRIC AND ADEN AFT END INTEGRATIONS, REHEAT NOZZLE, MACH = 0.9

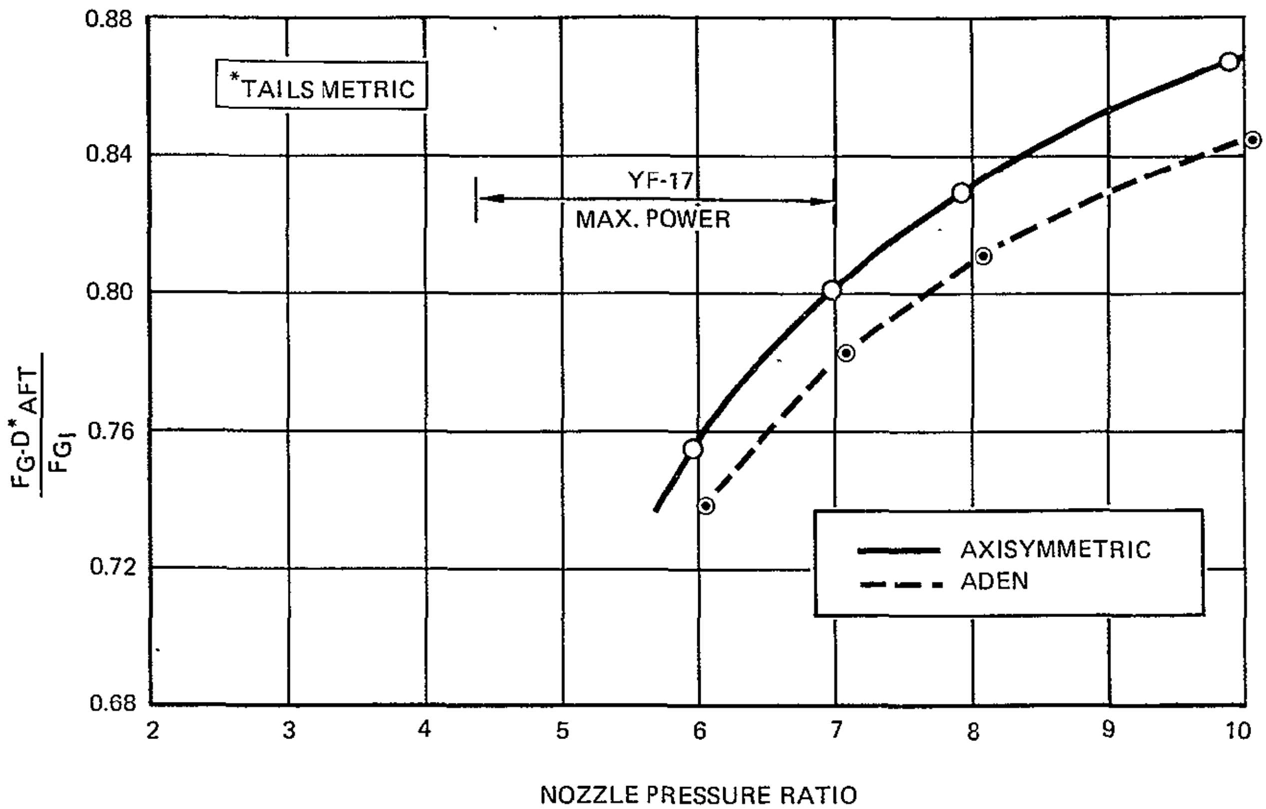


FIGURE 42. MEASURED PERFORMANCE OF F-18 AXISYMMETRIC AND ADEN AFT END INTEGRATIONS, REHEAT NOZZLE, MACH = 1.2

region of expected aircraft operation indicated on the figures, it is evident that thrust-minus-drag differences between the ADEN and axisymmetric integrations are minimal. This result was to be expected because, while the ADEN provides an excellent aft end blend with the YF-17, the F-18 dual axisymmetric integration has itself been proven in previous testing to be a low drag configuration.

Application of the F-18 incremental differences of Figures 43 and 44 to YF-17 performance at several representative flight conditions developed the YF-17 thrust-minus-drag performance differences shown in Figure 45. However, to properly account for the differences in the two nozzles, the aircraft performance must be additionally adjusted for the differences in cooling requirements and leakage. The ADEN non-axisymmetric design reduces the number of available pathways for leakage flow loss compared to the axisymmetric translating flap convergent-divergent (TFCD) design, and as a result requires less cooling flow (see comparison, Figure 13, Section 1.) For non-afterburning conditions, this results in slight to moderate performance improvements as shown in Figure 46. When the afterburner is employed, on the other hand, the ADEN cooling system produces a larger flow pressure loss (with less recoverable momentum) than the TFCD system. This loss, compounded by the unavail-

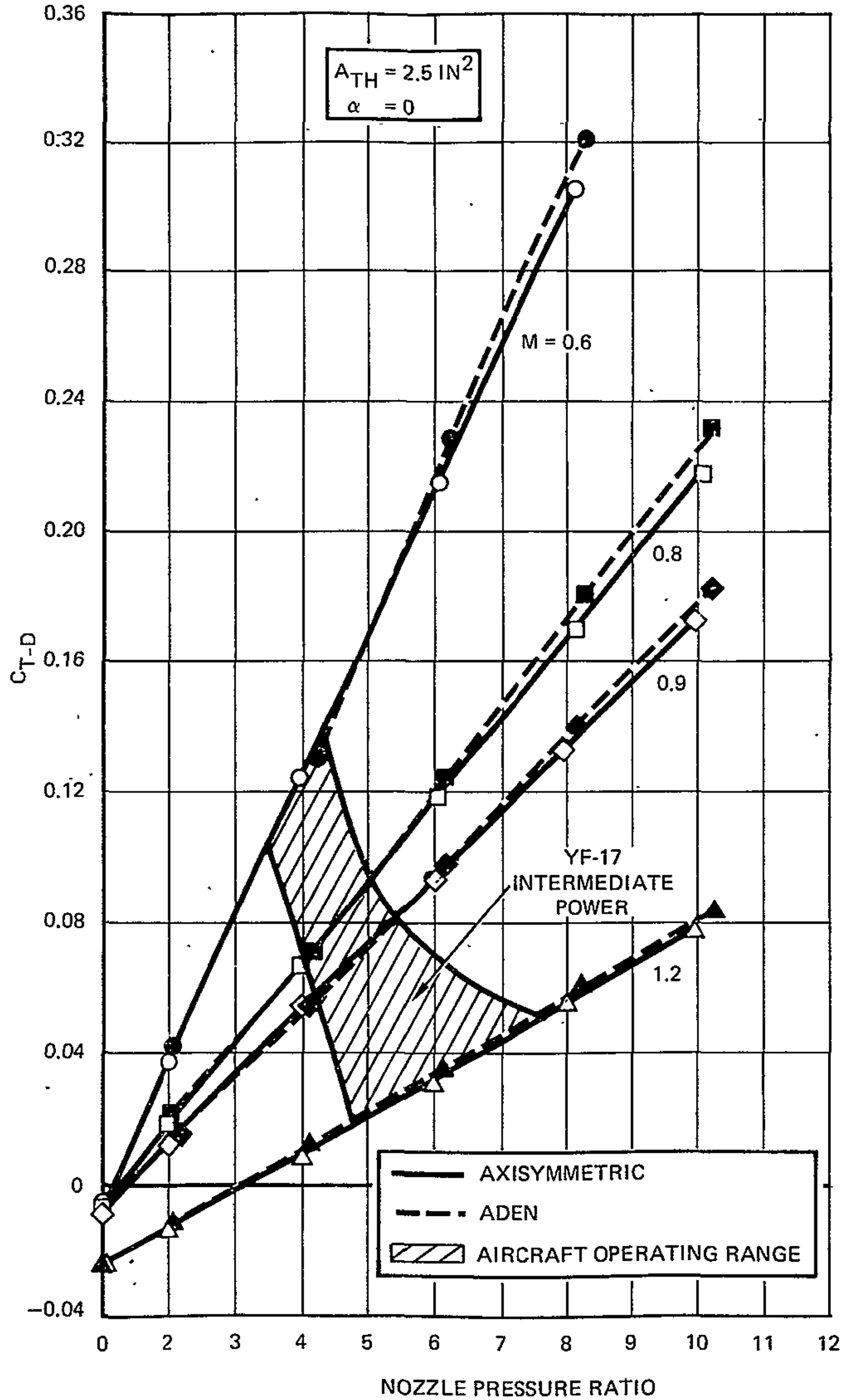


FIGURE 43. COMPARISON OF MEASURED F-18/ADEN AND F-18/AXISYMMETRIC CRUISE NOZZLE PERFORMANCE

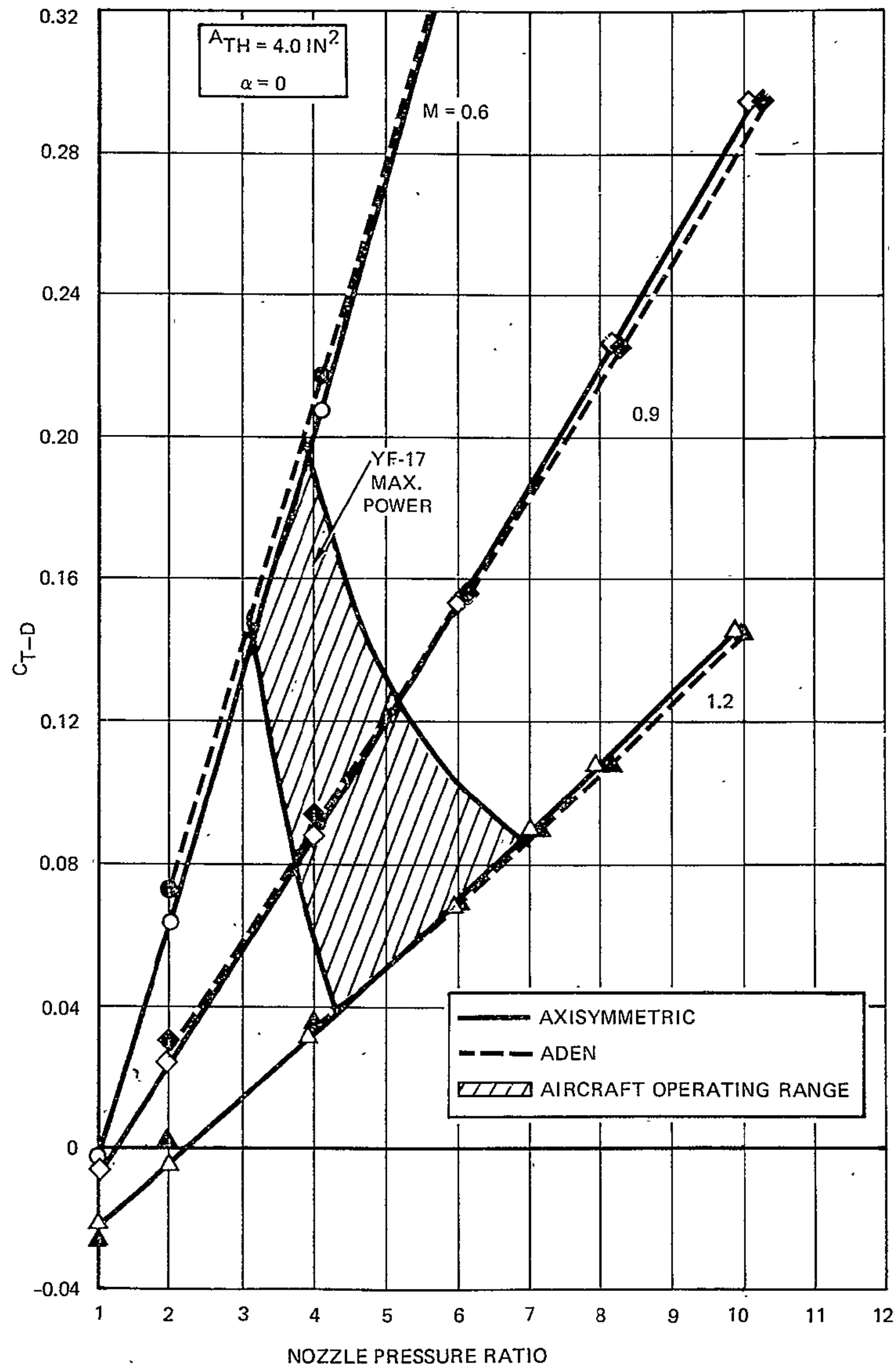


FIGURE 44. COMPARISON OF MEASURED F-18/ADEN AND F-18/AXISYMMETRIC REHEAT NOZZLE PERFORMANCE

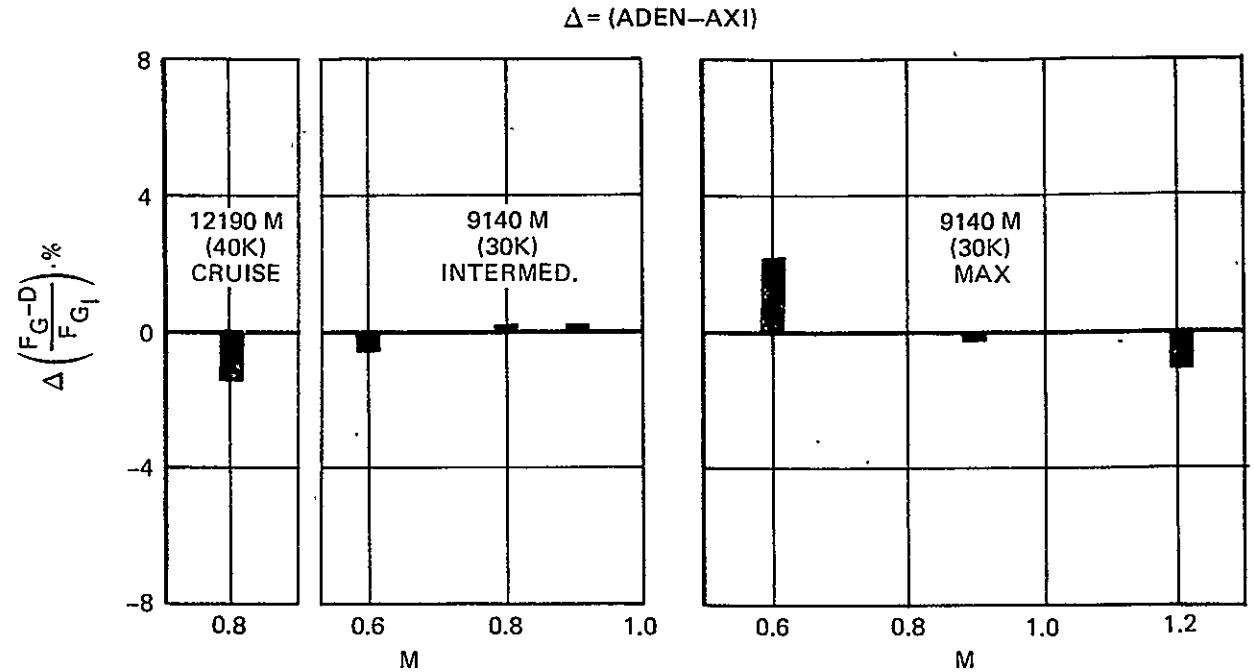


FIGURE 45. AERODYNAMIC PERFORMANCE DIFFERENCES BETWEEN YF-17/ADEN AND YF-17/AXISYMMETRIC NOZZLES.

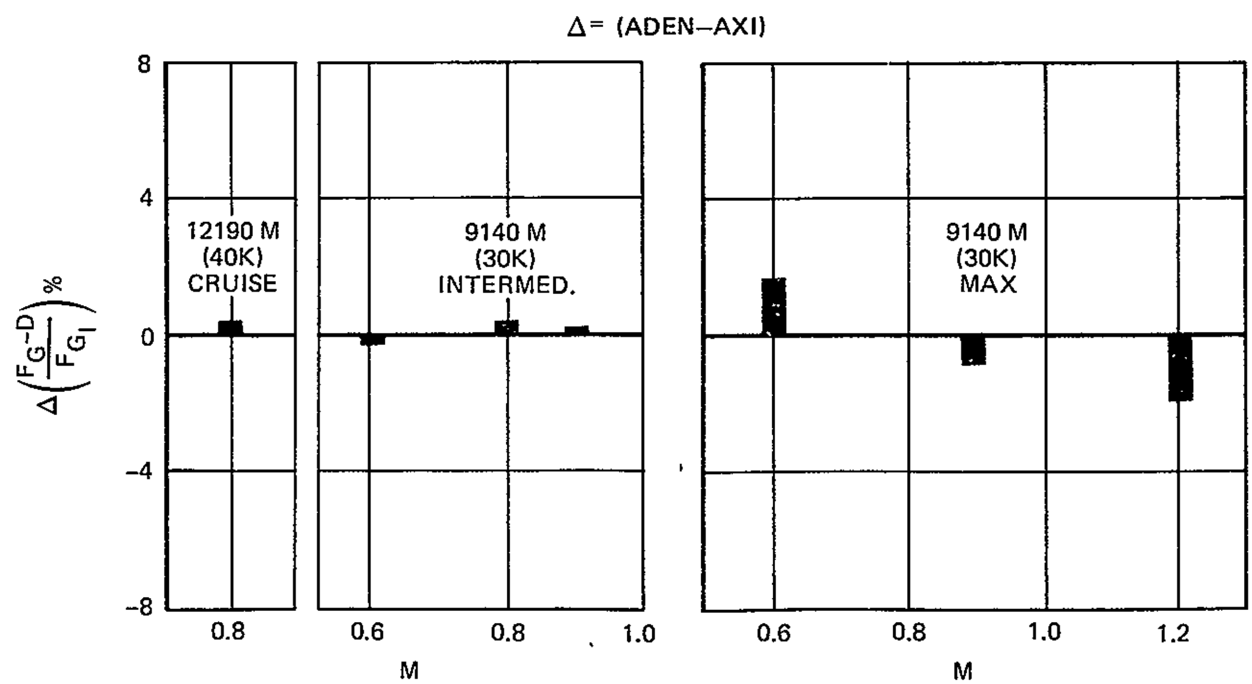


FIGURE 46. AERODYNAMIC PERFORMANCE DIFFERENCES BETWEEN YF-17/ADEN AND YF-17 AXISYMMETRIC NOZZLES, ADJUSTED FOR COOLING REQUIREMENT AND LEAKAGE.

ability of the VEER cooling flow for afterburning, results in the performance losses shown in Figure 46 for maximum power operation.

An added aspect of ADEN nozzle performance (which does not affect the axisymmetric design) is the generation of normal forces due to free plume expansion along the ADEN upper surface. This lift component varies in magnitude and location as a function of nozzle pressure ratio, and its effect when combined with the horizontal thrust component is to produce a resultant thrust at an effective vector angle. Figure 47 shows, for static conditions, how this effect operates to produce varying vector angles with pressure ratio. Also shown in Figure 47 is the prediction of this effect, based on method of characteristics approach, that analytically confirms the behavior of the expansion ramp normal force. The effect of this phenomenon in terms of $C_L$ variation on the F-18 model metric afterbody is shown in Figure 48 for several representative operating conditions.

Vectored Nozzle Performance. Langley test results of the ADEN at the vectored settings predictably indicated the presence of induced lift on the F-18 aft end. This phenomenom has been seen in previous testing of 2-D nozzles and can be attributed to changes in airflow, on aircraft surfaces near the nozzle exit, that are caused by deflecting the jet plume. The net effect of the altered flow is to produce a lift increment over and above that contributed by the vertical component of the vectored thrust. This

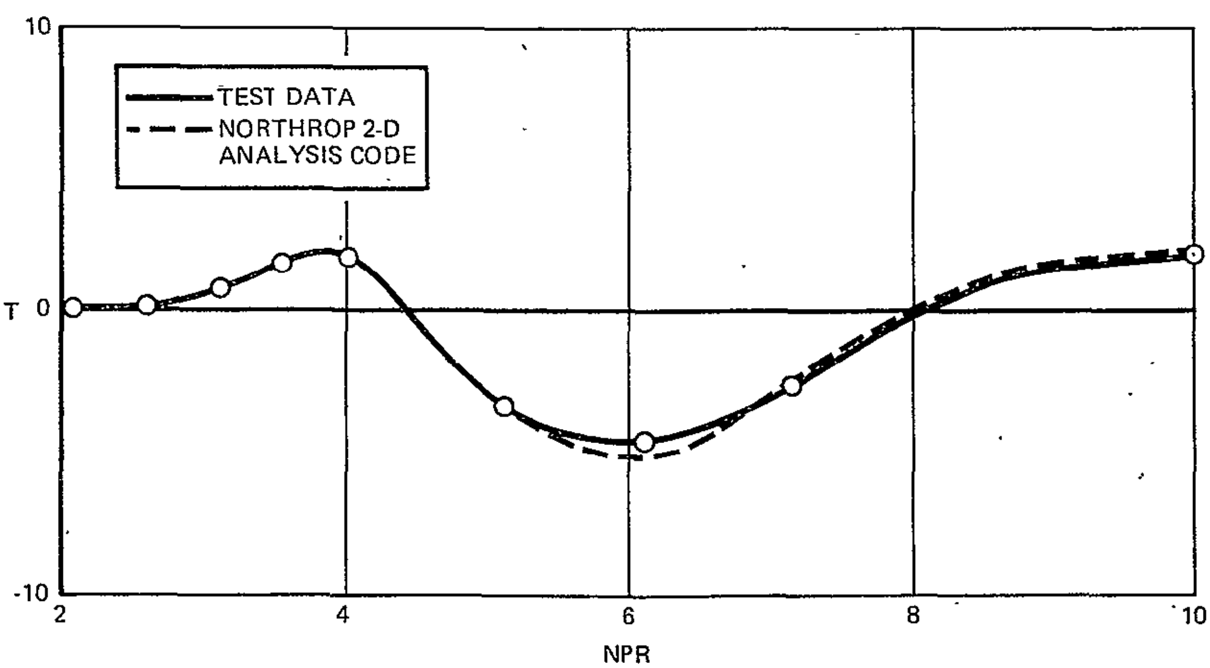


FIGURE 47. EFFECTIVE JET VECTOR ANGLE DUE TO VEER NORMAL FORCES, CRUISE NOZZLE, STATIC CONDITIONS, $\delta_V = 0^o$

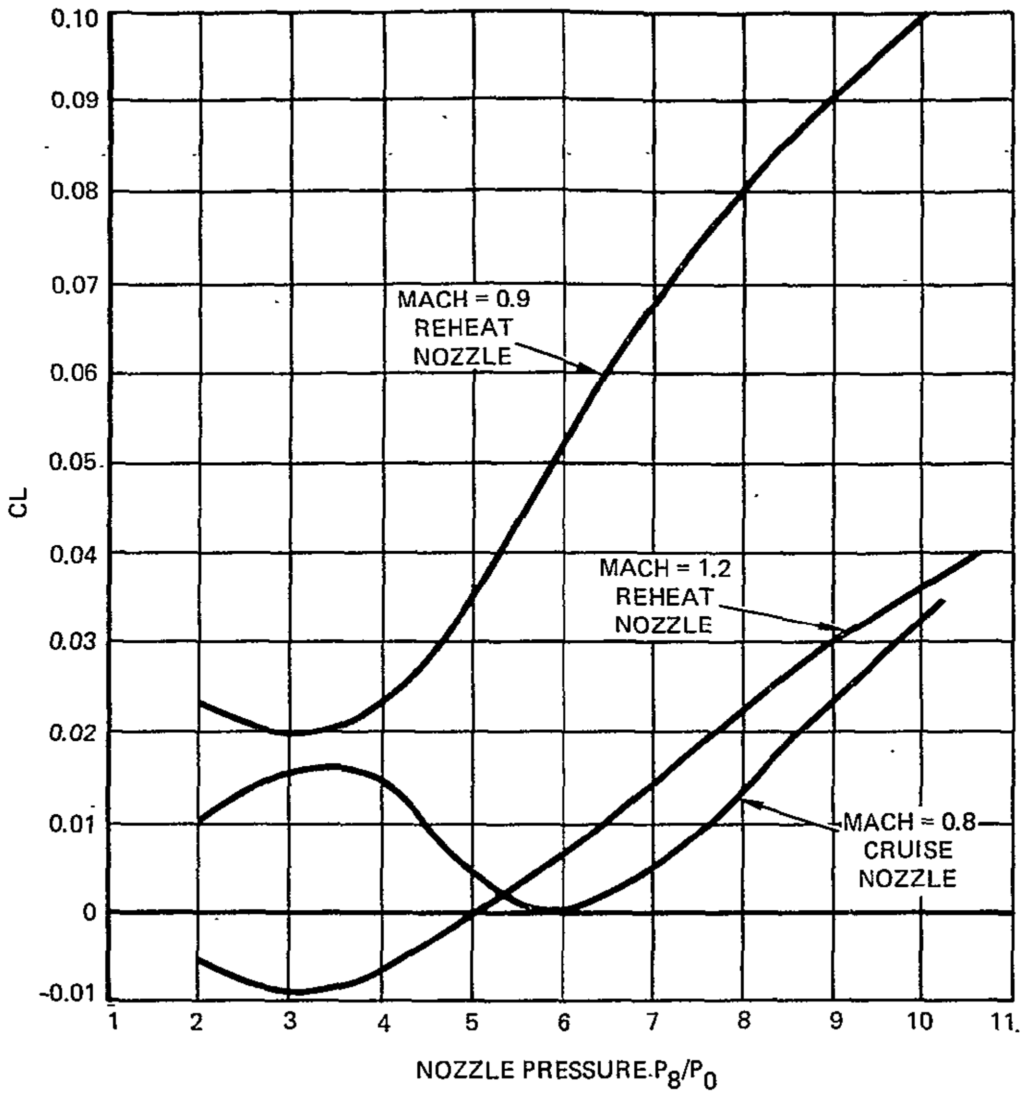


FIGURE 48. MEASURED LIFT COMPONENT ON THE ADEN NOZZLE, $\delta_V = 0°$

induced lift produces variations in the afterbody $C_L$ and effective thrust deflection angle $\delta_T$ with nozzle pressure ratio similar to those plotted in Figure 47 and 48. In evaluating the Langley data, it was discovered that induced lift behavior on the F-18/ADEN model could be generalized according to the lift amplification factor $C_L/C_T \sin \delta_T$, where $\delta_T$ is the effective thrust vector angle determined during static operation at various nozzle pressure ratios for a given VEER deflection, $\delta_V$. Generalized lift amplification in this form for a VEER deflection of 20° is presented in Figure 49.

The flow changes which cause induced lift effects also produce corresponding induced drag effects. While these effects do not generalize as well as lift, they tend to be significant and, as will be seen, ultimately offset any beneficial shifts in the drag polars due to induced lift. This was generally the effect during deflected thrust operation.

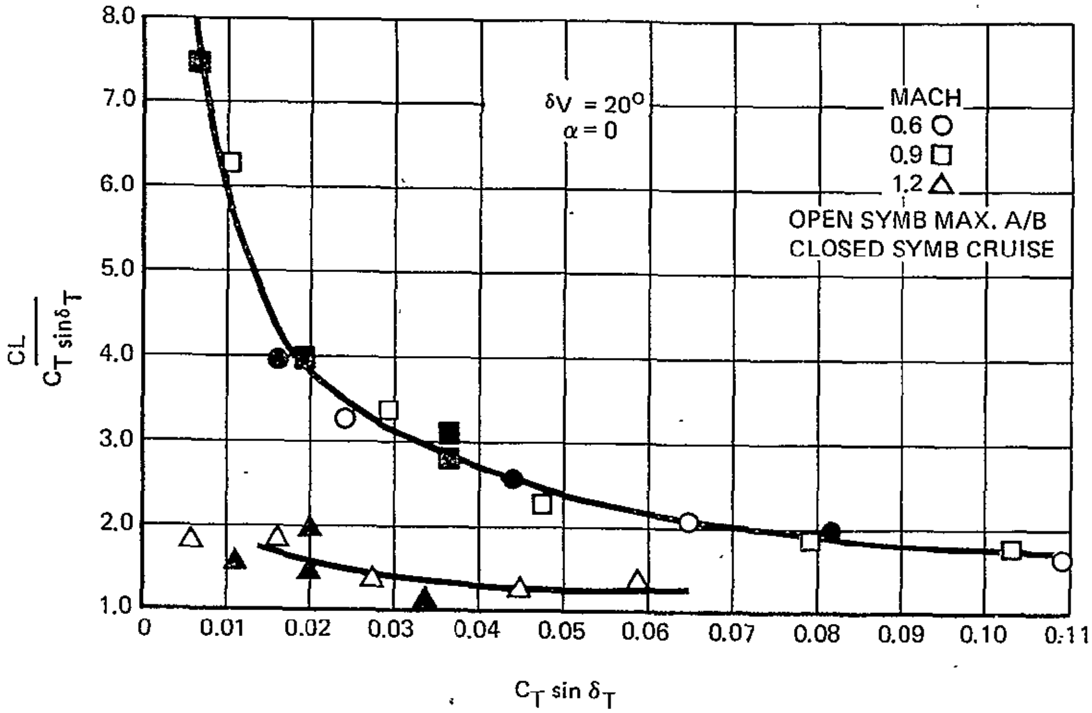


FIGURE 49. MEASURED LIFT AMPLIFICATION DURING VECTORING OF F-18/ADEN NOZZLE

### 3.2 Effect of LEX Removal/Canard Addition on YF-17 Aerodynamics

In this section, data will be presented to show the effect on the longitudinal and lateral-directional aerodynamics of the YF-17 baseline aircraft of removing the wing leading edge extension (LEX) and adding a shoulder-mounted trapezoidal canard of 58 ft.$^2$ exposed area. The data shown have been generated from canard development tests conducted by Northrop (Reference 8) and by NASA Langley Research Center (Reference 5).

Longitudinal Characteristics. Figures 50 and 51 present the effect of the canard on basic untrimmed longitudinal aerodynamics with flaps undefected at Mach numbers of 0.8 and 1.2. Inspection of the lift curves reveals that the canard configured aircraft has equal or slightly improved lift capability when compared to the baseline YF-17. However, it can be seen that, at positive deflection angles, the canard generates drag with essentially no increase in lift. This is because the increased downwash of the canard at positive incidence reduces the lift of the main wing panel. As expected, the addition of the canard produces a forward shift of the aerodynamic center which varies slightly with Mach number. Positive deflection of the canard is seen to produce a large

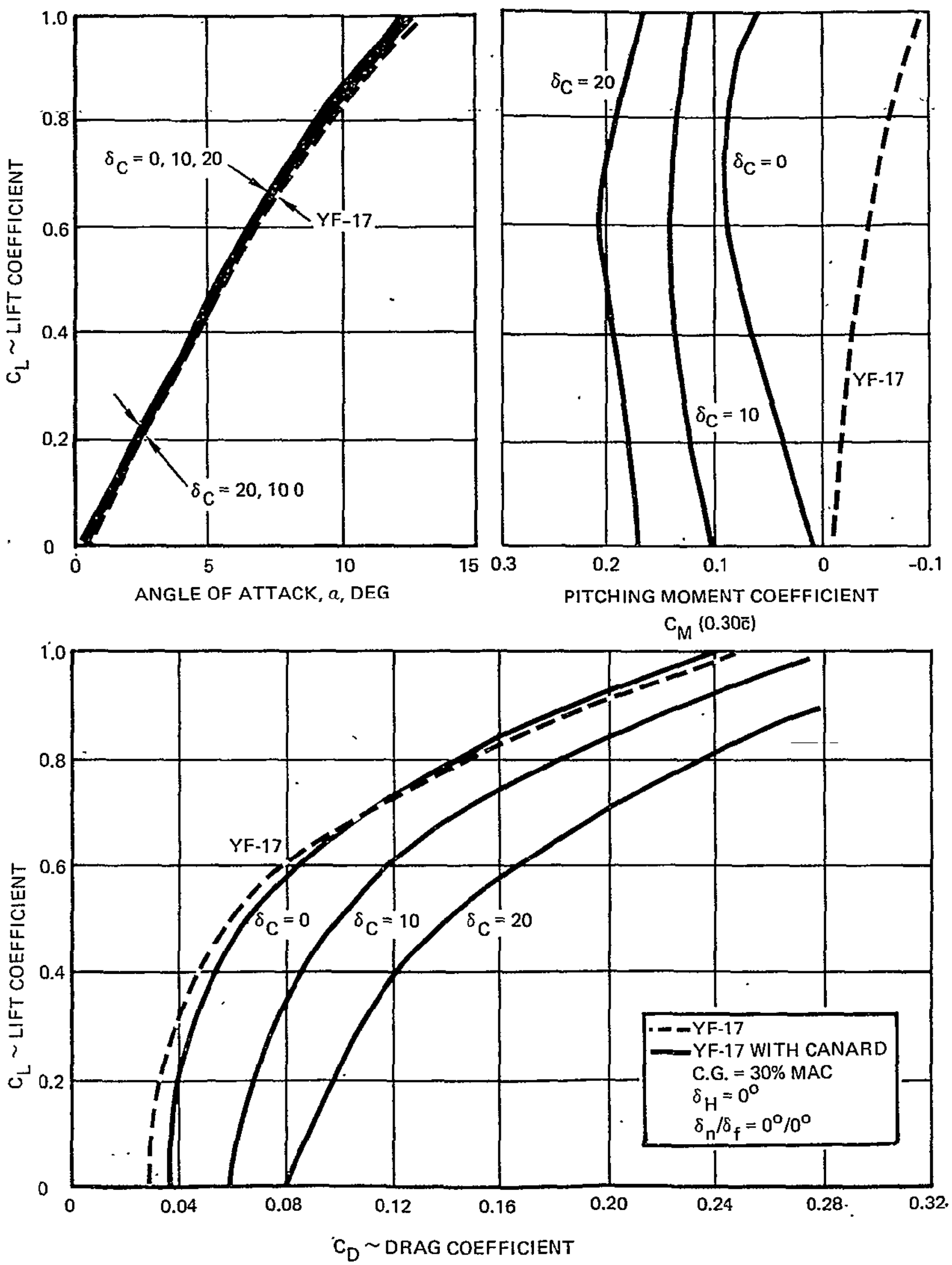


**FIGURE 50. EFFECT OF CANARD ON BASIC AERODYNAMIC PERFORMANCE, M = 0.8**

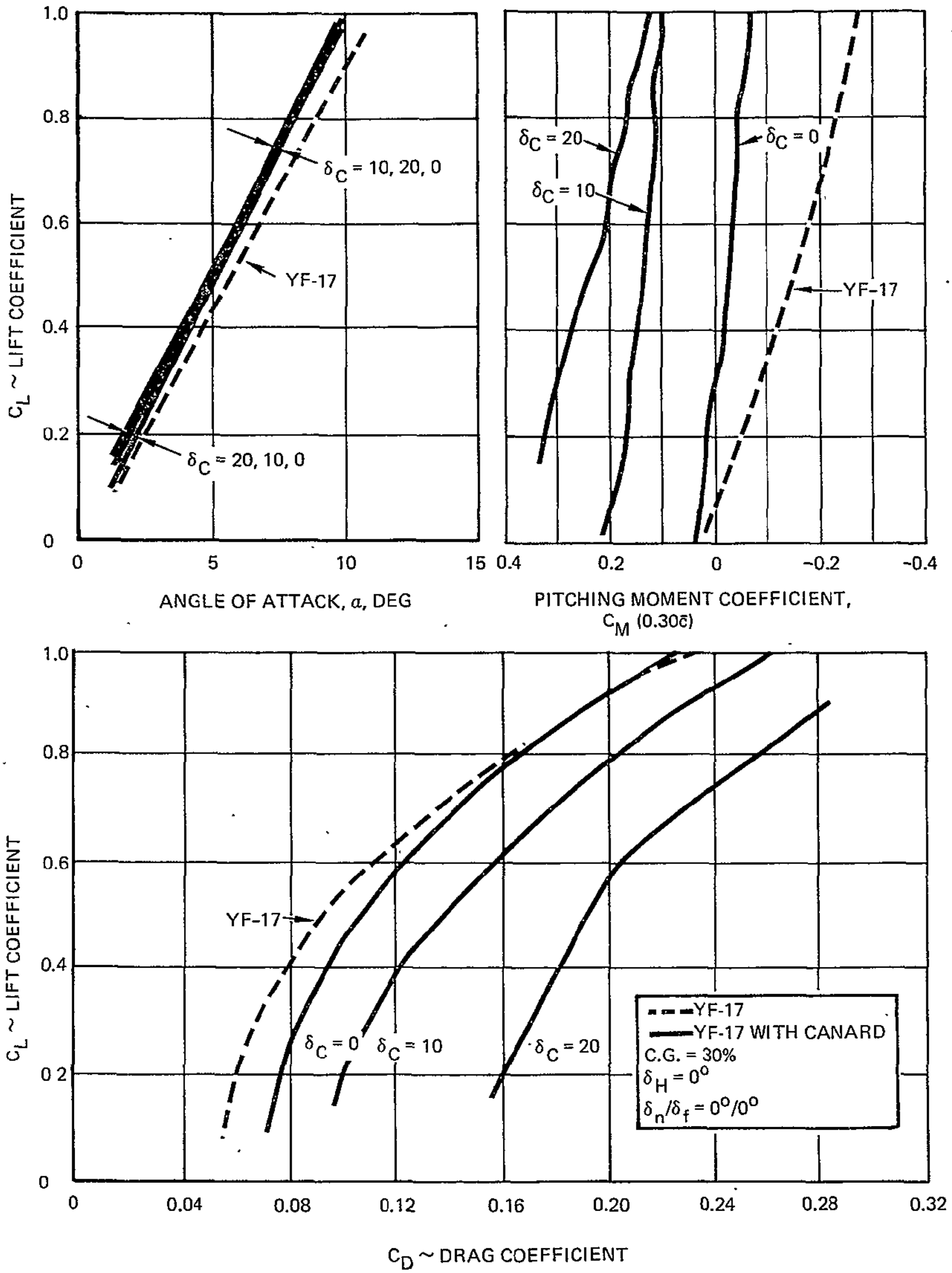


FIGURE 51. EFFECT OF CANARD ON BASIC AERODYNAMIC PERFORMANCE, M = 1.2

positive pitching moment which can be utilized to offset thrust deflection forces generated by the aft-mounted ADENs.

Optimum trimmed drag polars for flight conditions of Mach = 0.8 and 1.2 with unvectored thrust are presented in Figures 52 and 53 corrected to flight Reynolds numbers. Canard and horizontal tail deflection angles, computed for minimum trimmed drag at each lift coefficient, are also shown. Due to the large drag penalties associated with deflection of the low aspect ratio uncambered canard, the computed optimum canard deflection is near zero until moderate to high lift coefficients where the horizontal tail deflection saturates at -5°. It should be noted that these data are presented for the flaps undeflected. Canard-wing interactions with wing leading and trailing edge flaps set to produce nearly optimum camber distribution could conceivably alter the trends developed from the analysis of the flaps-up data.

With the canard installed, the forward shift of the aerodynamic center, coupled with the available center of gravity range with the ADEN nozzle installation, will allow the YF-17 ADEN/canard configuration to be balanced at a negative static margin of up to -10%, thereby reducing the canard deflection required to trim at a maneuver $C_L$ and consequently reducing the trim drag. Optimum trimmed polars for operation at -10% static margin are shown in Figures 54 and 55 for the same flight conditions as the 0% static margin polars of Figures 52 and 53.

Lateral-Directional Characteristics. In order to assess the incremental effect of adding a canard to the baseline YF-17 configuration, Northrop low speed tests of a shoulder-mounted canqrd were analyzed along with the NASA Langley data of Reference 5 on three canard configurations run in the LaRC 12 ft. low speed tunnel.

Figure 56 presents data from the Northrop tests (Reference 7) which show the effect on the lateral-directional departure parameter $C_{n_{\beta dynamic}}$ of first removing the LEX from the baseline YF-17, and then, the effect of adding the shoulder-mounted canard to the LEX-off configuration. These data are with leading and trailing-edge flaps undeflected. Figure 57 presents the same data with the flaps deflected to $\delta_n/\delta_f$ = 10°/12°. In each case, the canard produces a slight degradation in dynamic directional stability below approximately 20° angle of attack and a significant improvement at higher angles compared to the baseline YF-17. It should be noted that the optimum flap setting for maneuvering on the YF-17 is $\delta n/\delta_f$ = 25°/0°, and that with this flap setting, the level of $C_{n_{\beta dynamic}}$ for the YF-17 is significantly higher than for flaps up or partial flaps. Therefore, the stability levels shown in Figures 56 and 57 for the canard configuration can be expected to be similarly improved at an optimum flap setting.

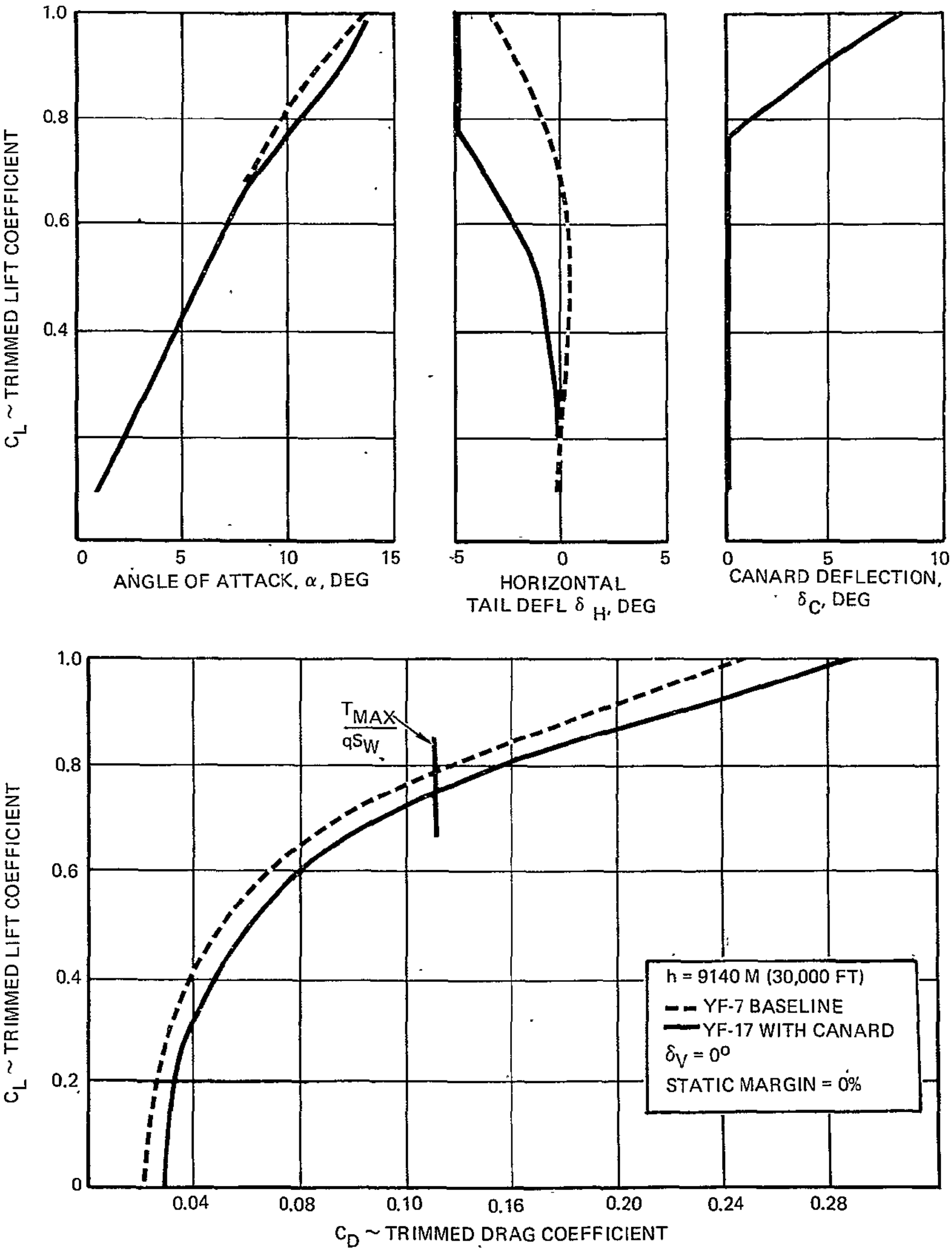


FIGURE 52. EFFECT OF CANARD (M = 0.8)

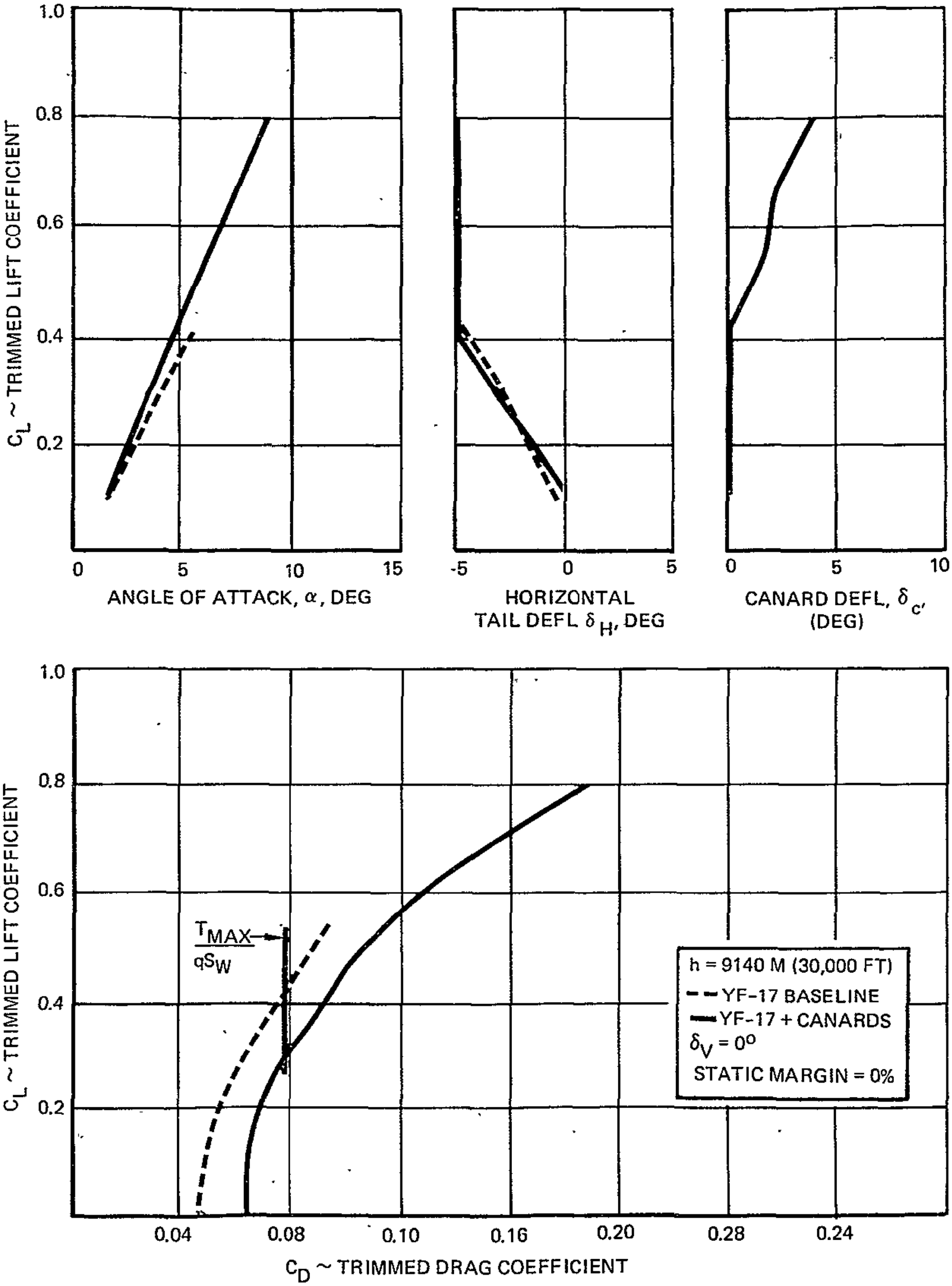


FIGURE 53. EFFECT OF CANARD (M = 1.2)

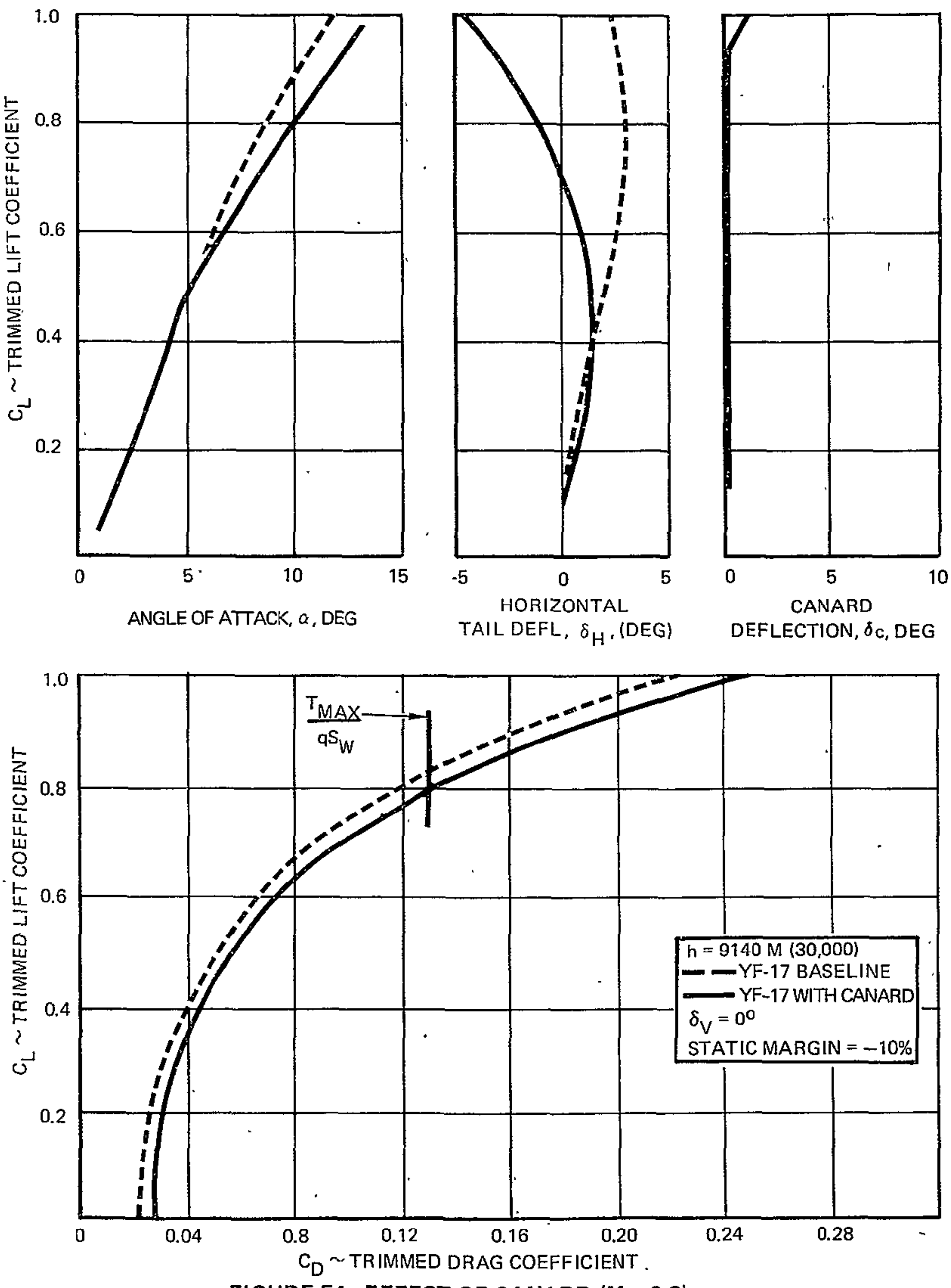


**FIGURE 54. EFFECT OF CANARD (M = 0.8)**

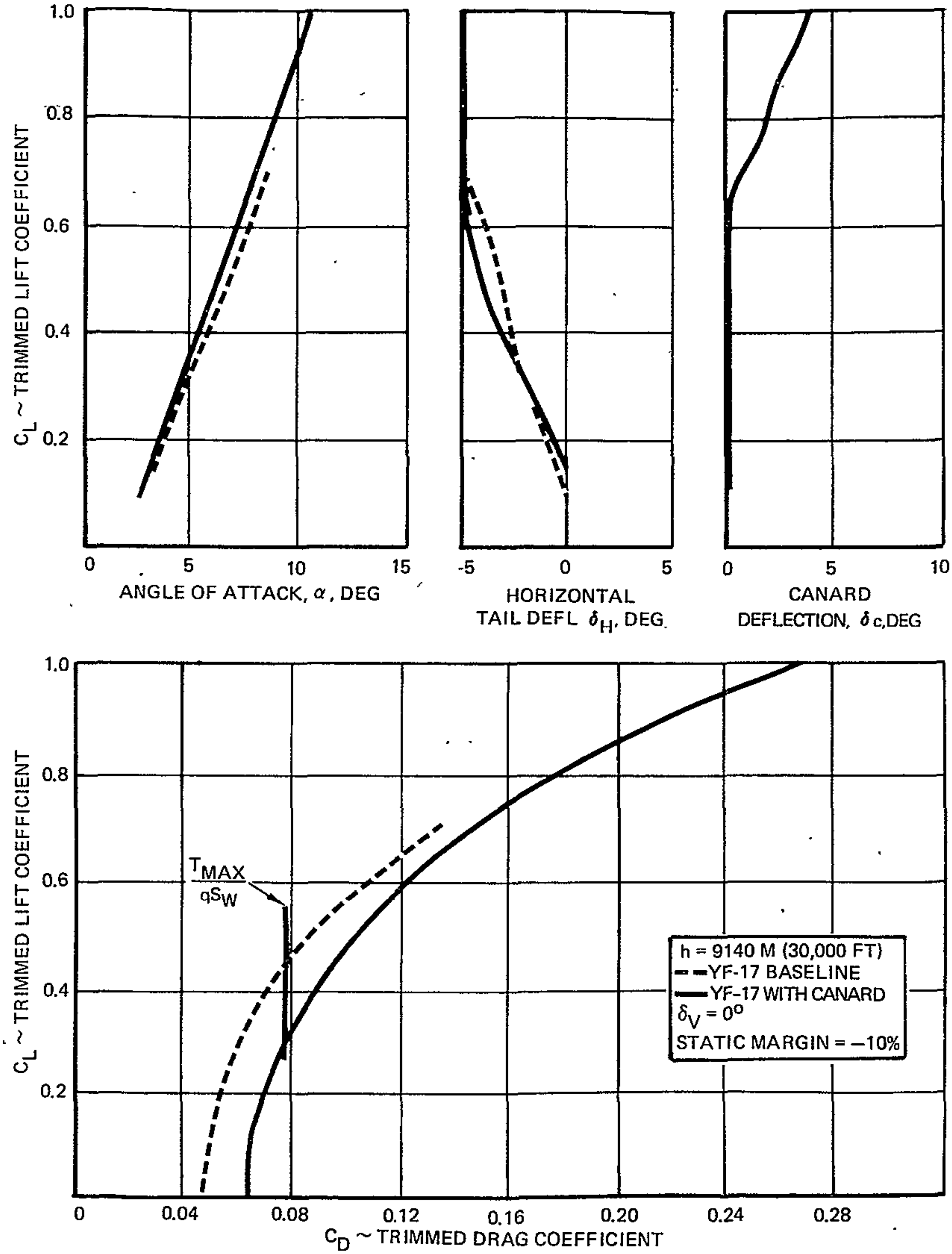


FIGURE 55. EFFECT OF CANARD (M = 1.2)

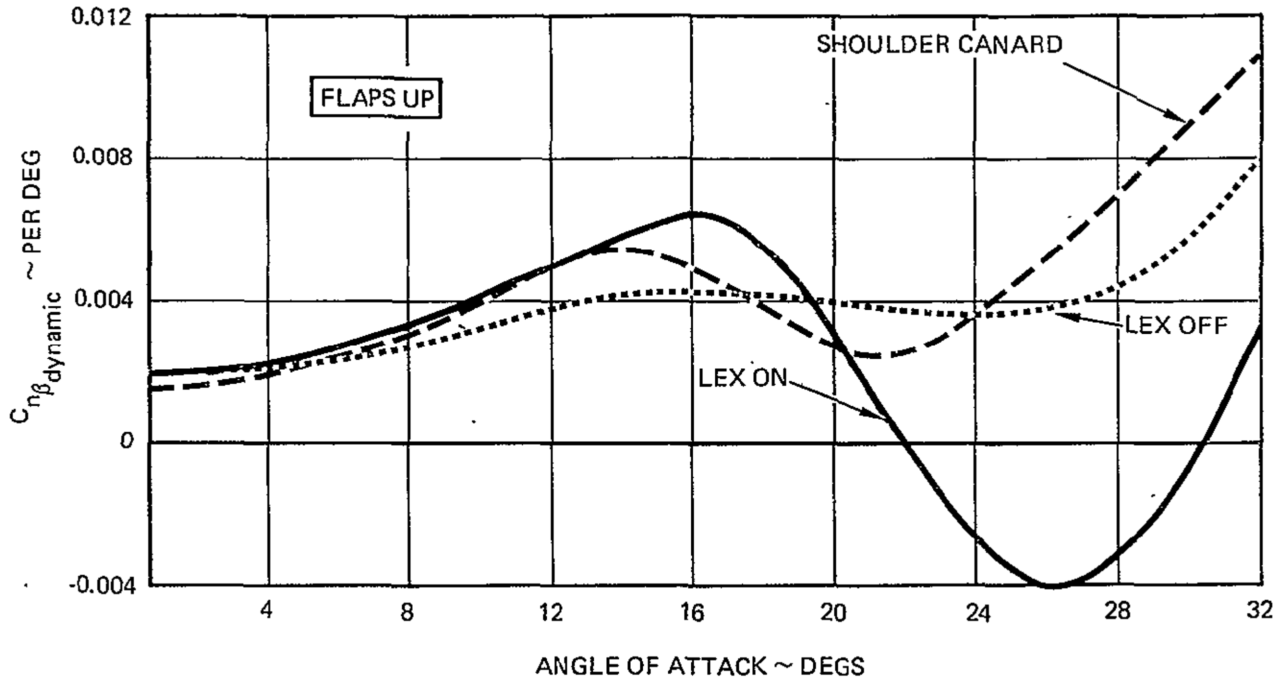


FIGURE 56. EFFECT OF CANARD, FLAPS UP

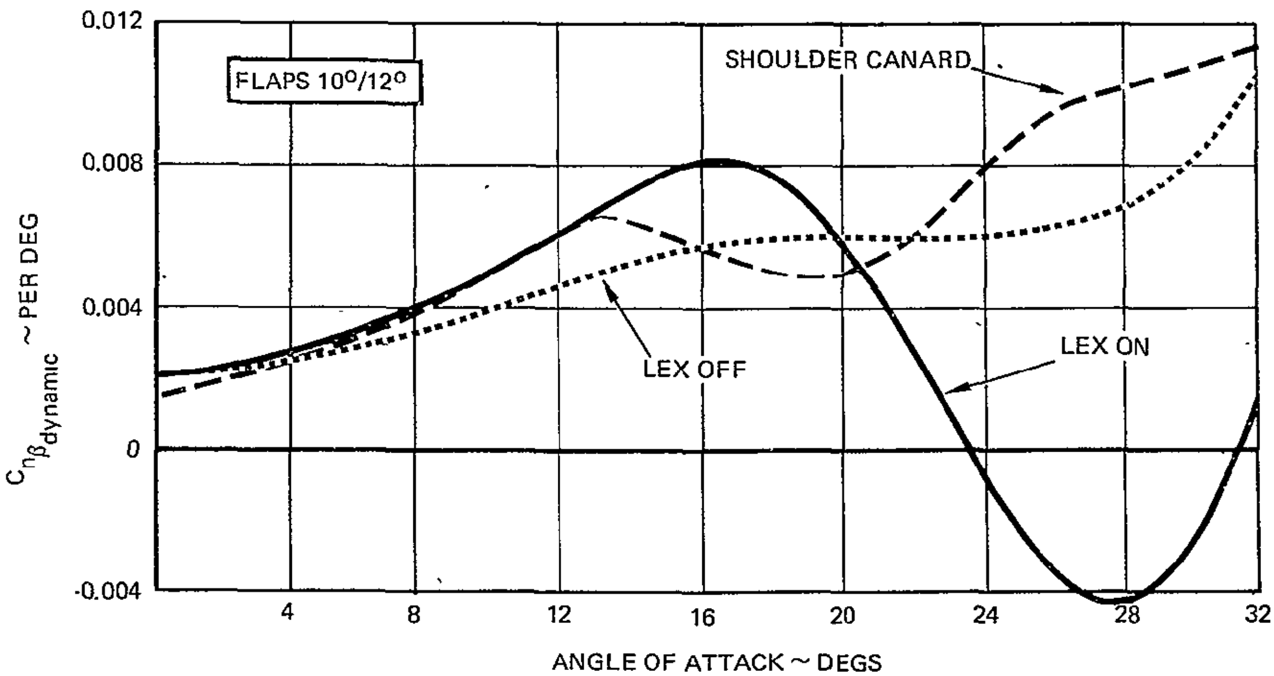


FIGURE 57. EFFECT OF CANARD, PARTIAL FLAPS

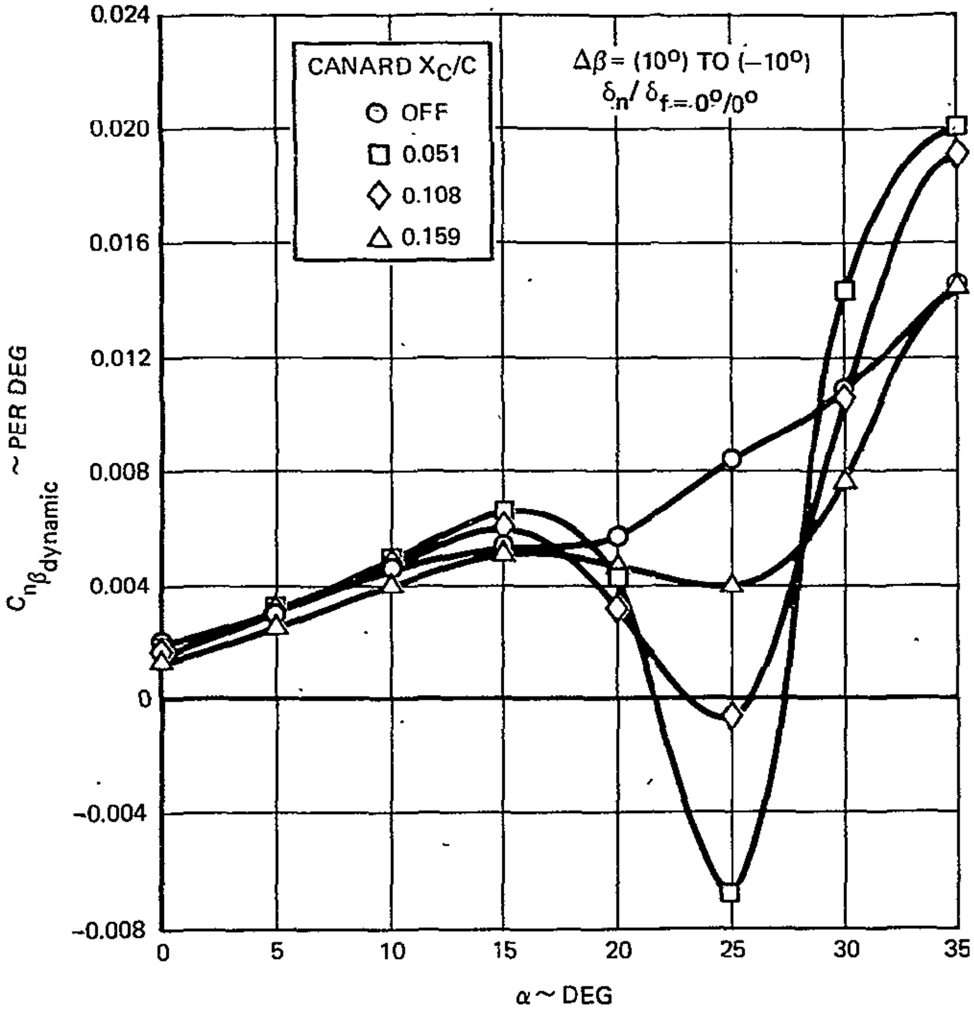


FIGURE 58. EFFECT OF CANARD LONGITUDINAL POSITION

Since the previous data are for a canard configuration which is slightly different from the final or preferred canard configuration, the NASA Langley canard test data were reviewed to determine the sensitivity of lateral-directional stability to changes in canard planform, location and area. Figure 58 presents the effect of longitudinal position of the Langley canard on $C_{n_\beta dynamic}$ in the stall angle-of-attack region. The data are seen to be very sensitive to canard position. The most forward canard position corresponds approximately to the position of the smaller, lower sweep Northrop canard, and the levels of $C_{n_\beta dynamic}$ for these configurations compare well. However, the extreme sensitivity to canard placement indicated by the Langley data suggest that further study of the lateral-directional characteristics of the final canard configuration should be undertaken prior to the design freeze.



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## 3.3 Effect of Thrust Vectoring on ADEN/Canard Aerodynamics

Longitudinal Effects. Trimmed vectored thrust drag polars at Mach = 0.8 and 1.2, shown in Figures 59 and 60, represent the optimum combination of canard, horizontal tail, and effective thrust deflection angles for minimum drag. Vectored thrust forces include the induced afterbody effects discussed in Section 3.1. Examination of the figures indicates that at low lift coefficients, minimum drag is achieved at very small positive effective thrust vectoring angles, due to the large drag penalties incurred when the canard is deflected to trim the aircraft in the vectored thrust mode. In fact, at moderate to high lift coefficients, minimum drag is obtained at a given lift coefficient by vectoring the nozzle to negative angles so that minimum canard deflection is always achieved. Only after the maximum negative effective thrust deflection angle of -2 degrees is reached does the canard come into play as a trim device.

Lateral-Directional Characteristics. Vectoring the ADEN nozzle is not expected to affect the lateral-directional stability of the aircraft.

## 3.4 Aircraft Performance Without Vectored Thrust

In this section, flight performance without thrust vectoring is evaluated for the ADEN-only configuration (identified as "YF-17/ADEN" or "ADEN only") and the ADEN/canard modification (identified as "YF-17/ADEN with canard"). Section 3.5 will provide an analysis of aircraft performance with vectored thrust.

Configuration Weights. Replacement of the YF-17 axisymmetric aft end with the ADEN installation results in a net weight increase of 1325 lbs. On the YF-17/ADEN with canard, this weight increase is offset by the necessary removal of the LEX and the forward fuel cell and contents to allow installation of the canard actuation system. The removal of the cell compensates for the total increase in weight due to the ADENs, canard actuation hardware, and canard. Consequently, the performance of the YF-17/ADEN with canard is evaluated at the same aircraft weight as the baseline YF-17.

On the YF-17/ADEN, the removal of the forward fuel tank and contents is not necessary and its retention is desirable from the standpoint of flight test endurance. (An increase in flight time of 10 minutes, from 50 minutes to an hour, has been estimated as representative.) Performance for this configuration is therefore presented at full fuel capability with the consequent ADEN weight penalty, and also at weight equal to the baseline YF-17 (which could be accomplished by off-loading fuel) in order to isolate the aerothermodynamic differences for this configuration.

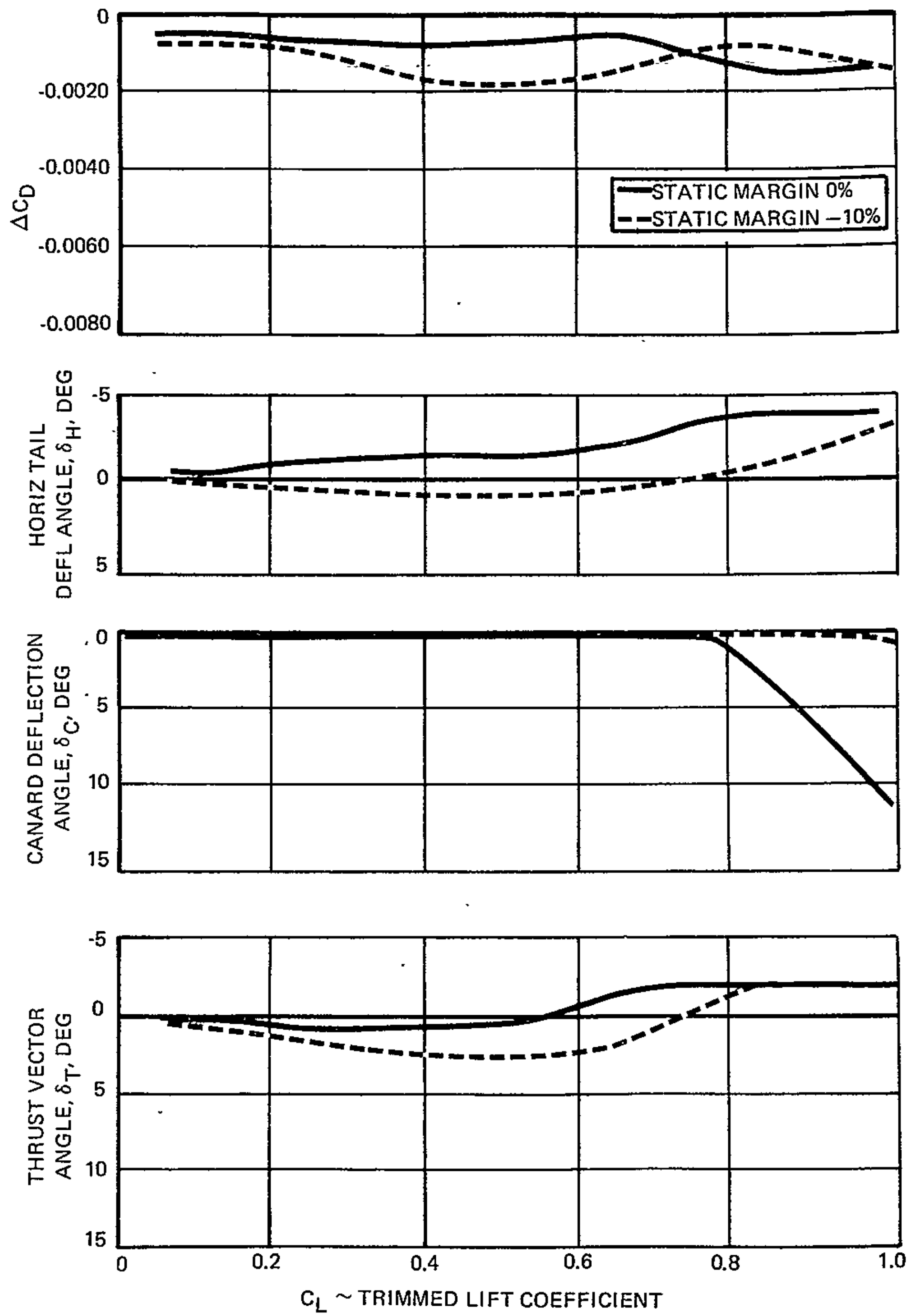


**FIGURE 59. EFFECT OF THRUST VECTORING**
**M = 0.8 / 9140 M (30K)**

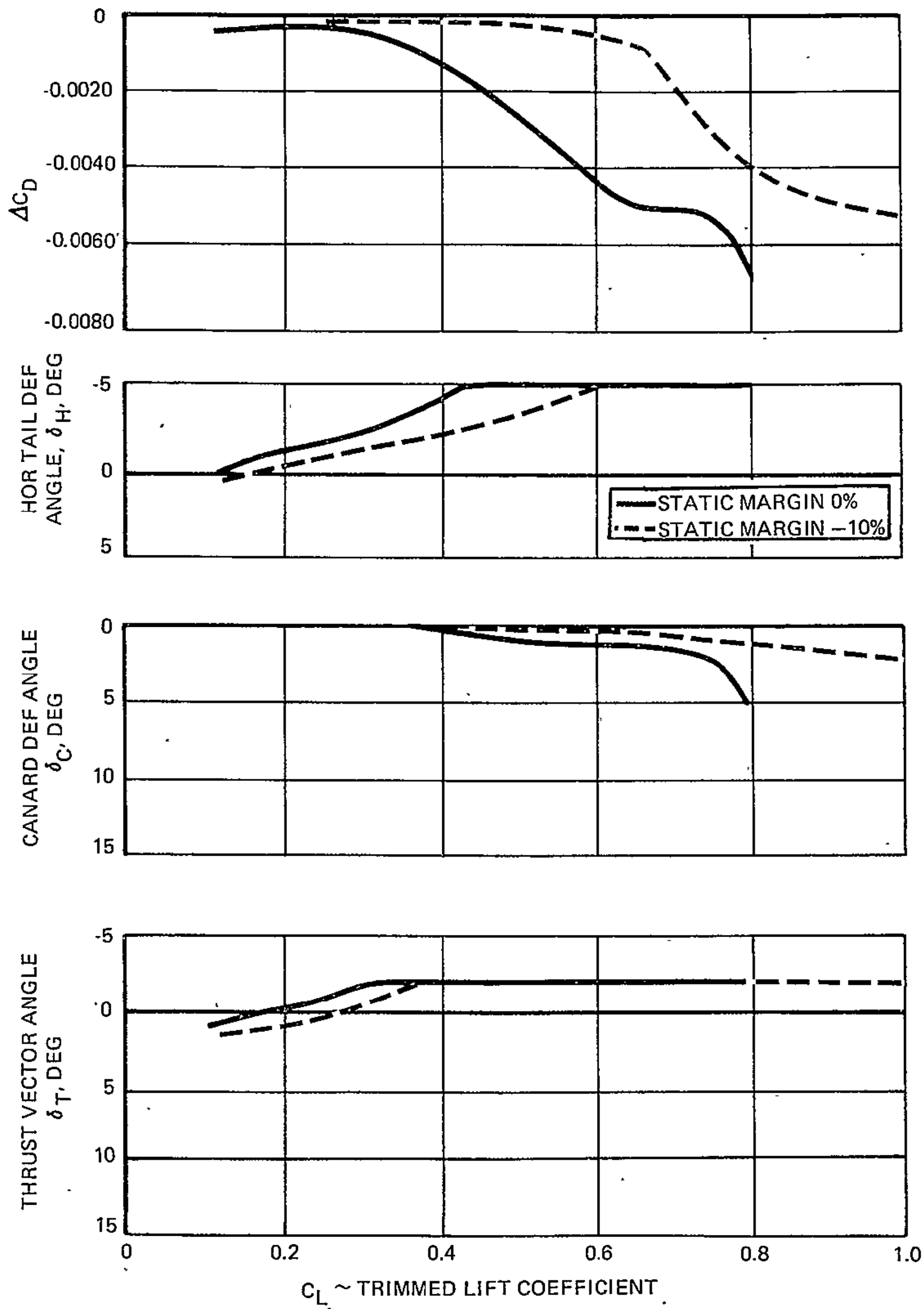


FIGURE 60. EFFECT OF THRUST VECTORING
M = 1.2 / 9140 M (30K)

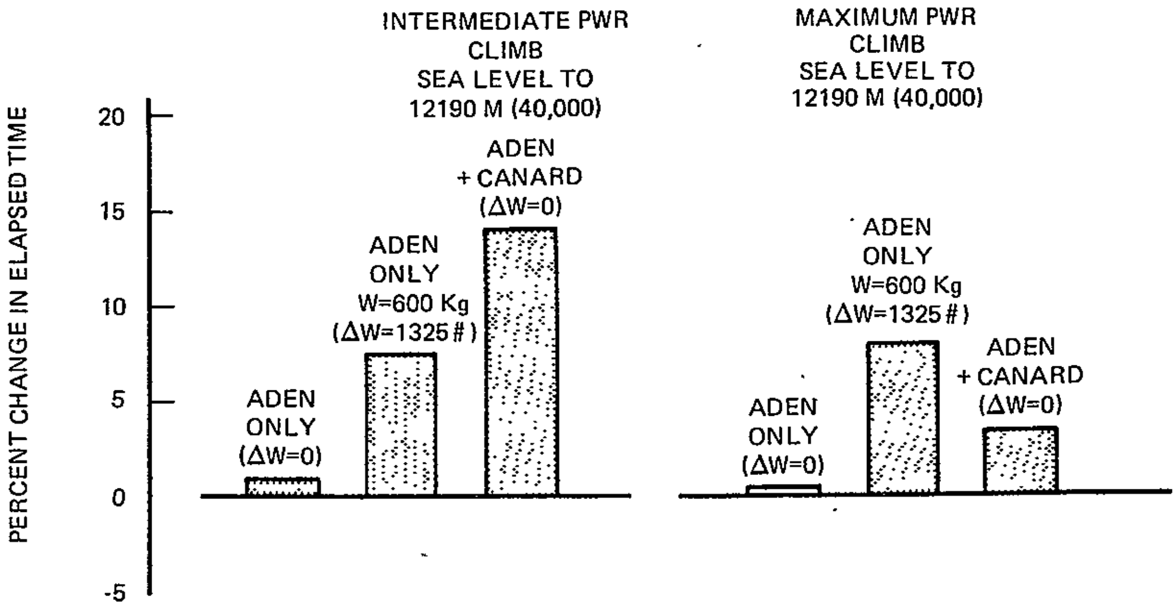


FIGURE 61. UNVECTORED CLIMB PERFORMANCE

Climb Performance. Figure 61 presents the incremental performance of the YF-17/ADEN and YF-17/ADEN with canard compared to the baseline YF-17 in climb.

Predictably, from the level of afterbody drag performance differences developed in Figures 43 and 44, both intermediate and maximum power climb performance of the YF-17/ADEN configuration unpenalized for weight are nearly indistinguishable from that of the baseline YF-17. When the weight penalty is included, the YF-17/ADEN aircraft suffers a noticeable increase in time to reach final altitude at both power settings. The YF-17/ADEN with canard exhibits the effects of the canard aerodynamics shown in Figures 50 and 51, requiring a significant increase in time to reach the 12190M (40,000 ft.) intermediate power climb ceiling, and a moderate amount of additional time to reach the 50,000 ft. maximum power climb ceiling.

Acceleration Performance. Acceleration characteristics of the various configurations are compared at altitudes of 3050 m and 9140 m (10,000 and 30,000 feet) for the aircraft accelerating from Mach = 0.6 to 0.95 at intermediate power, and for a maximum power acceleration from Mach = 0.6 to Mach = 1.2 at 10K and Mach = 1.3 at 30K (Mach 1.3 representing the current limit of available test data on the drag characteristics of the ADEN integration). As can be seen in Figures 62 and 63 the same pattern emerges as did for the time-to-climb analyses; that is, for the YF-17 with ADEN only, unpenalized for weight and operating at intermediate power, the acceleration time does not differ greatly from the baseline YF-17. When the weight penalty is included, some degradation appears. When this evaluation is made for maximum power accelerations, an advantage develops for the ADEN only configuration at the lower altitude which is

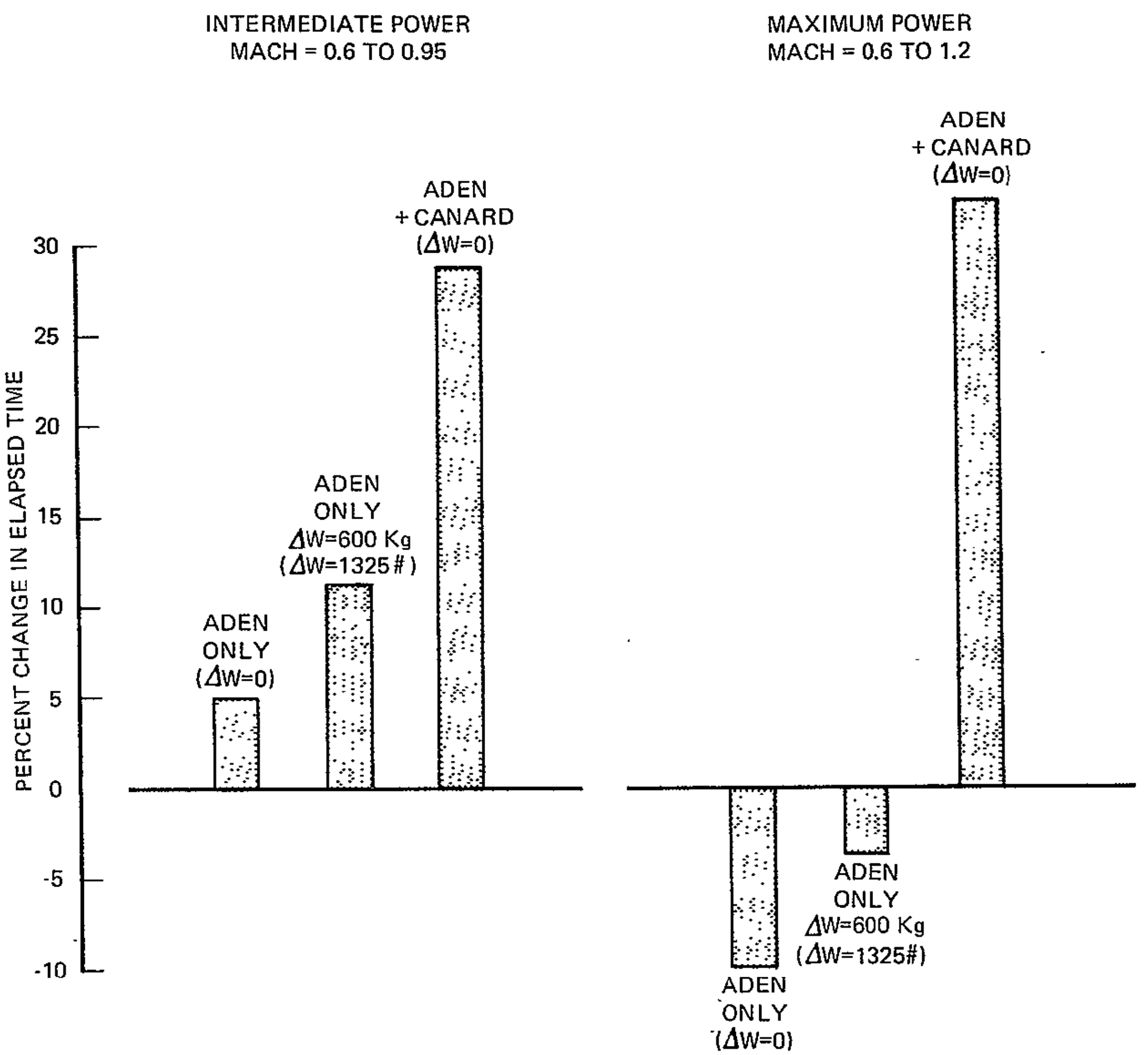


**FIGURE 62. UNVECTORED ACCELERATION PERFORMANCE**
**(h = 3050 m (10,000 ft)**

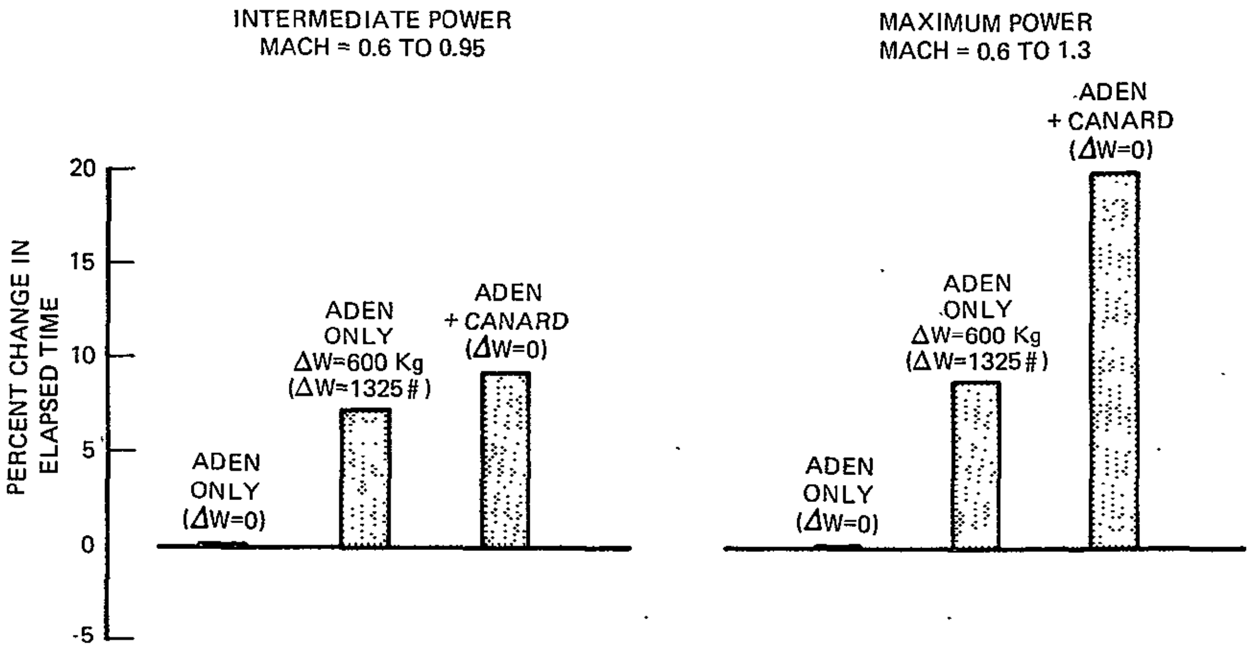


FIGURE 63. UNVECTORED ACCELERATION PERFORMANCE (h = 9140 m (30,000 ft)

sufficient to overcome the weight penalty. At the higher altitude, the performance is once again comparable with no weight penalty and degrades slightly with the weight penalty included. The YF-17/ADEN with canard exhibits large increases in acceleration time which is indicative of the increased minimum drag associated with the canard, especially at the higher Mach numbers.

The detrimental effect of the canard, it is felt, derives in large part from the relatively rudimentary development the canard-configured concept has undergone to this point compared to the highly refined wing/LEX combination on the baseline YF-17. Further optimization of the canard/wing aerodynamics during the detailed design phase is expected to improve the currently-exhibited inferior performance of the YF-17/ADEN with canard.

Cruise Performance. The cruise performance of each configuration was evaluated at the altitude and Mach number that yielded the best specific range (distance traveled per pound of fuel consumed). This condition, while slightly different for each configuration, fell within the range of Mach = 0.8 to 0.85 at altitudes from 12190 m to 13720 m (40,000 to 45,000 ft.). Figure 66 summarizes the percent change in specific range from the YF-17 baseline for the configurations of interest. As with the previously evaluated climbs and accelerations, the ADEN-only aircraft without weight penalty has a slightly

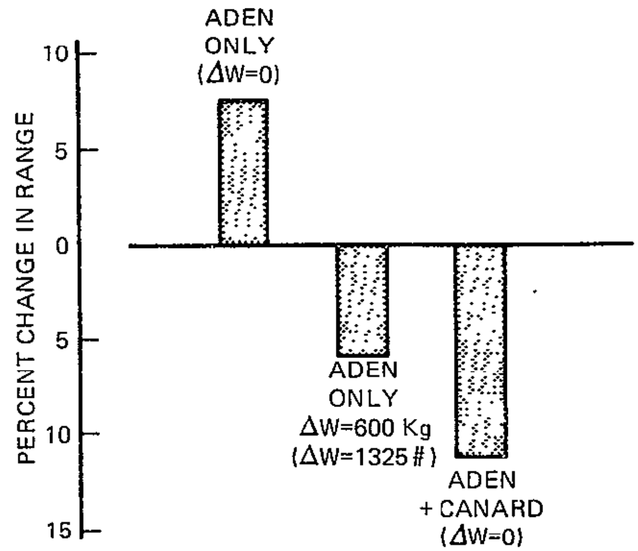


FIGURE 64. UNVECTORED CRUISE PERFORMANCE (OPTIMUM MACH – ALTITUDE)

improved specific range; when the weight penalty is included, specific range is slightly worse. On the YF-17/ADEN with canard, specific range is further reduced.

Specific Excess Power and Maneuver Performance. Figures 65 and 66 present the excess power and maneuver performance characteristics of the YF-17/ADEN with canard when compared to the baseline YF-17 at Mach = 0.8 and 1.2. Specific excess power ($P_S$) has been normalized to YF-17 specific excess power at 1 g, and turn rate is normalized to YF-17 maximum turn rate. As shown in Figure 65 for Mach = 0.8, the YF-17/ADEN with canard at 0% static margin shows some moderate degradation in both $P_s$ and turn rate; operation at -10% static margin restores the sustained turn rate capability to that of the baseline YF-17. At Mach = 1.2 (Figure 66), $P_s$ and turn rate capability of the YF-17/ADEN with canard at 0% static margin has degraded noticeably compared to the baseline YF-17; operation at -10% static margin does little to improve the situation other than to slightly increase the sustained turn rate.

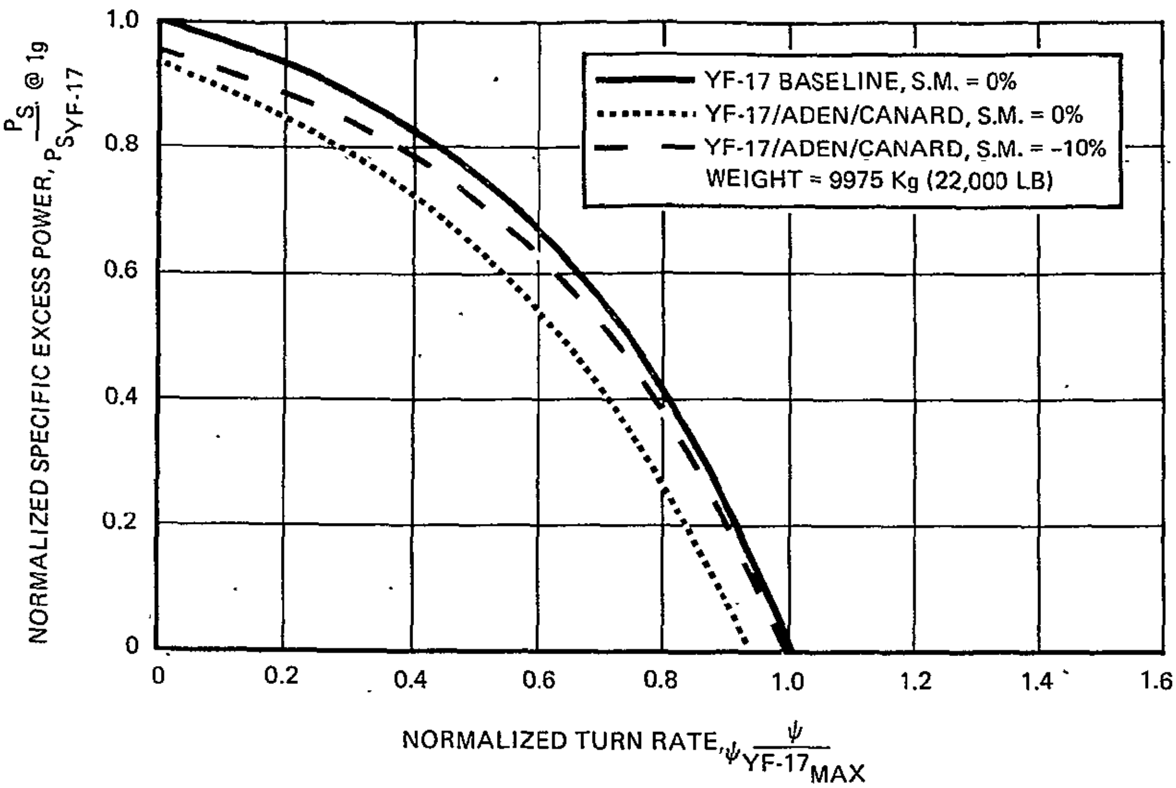


FIGURE 65. EXCESS POWER AND MANEUVER PERFORMANCE, MACH = 0.8

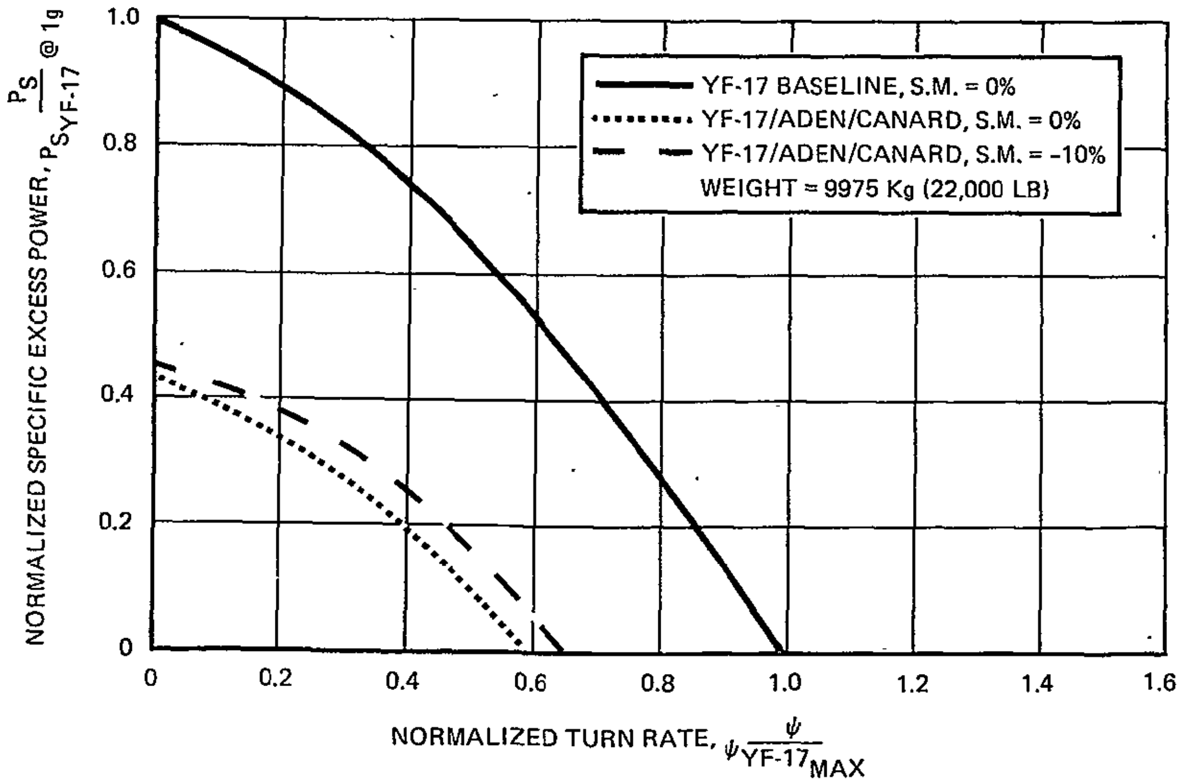


FIGURE 66. EXCESS POWER AND MANEUVER PERFORMANCE, MACH = 1.2

## 3.5 Aircraft Performance With Vectored Thrust

Figure 67 provides a summary of the expanded performance capability that can be expected for the YF-17/ADEN when the ADEN thrust vectoring capability is utilized in combination with the shoulder-mounted canard.

Excess Lift Development. Excess lift at cruise angle of attack can be developed on the YF-17/ADEN with canard by vectoring the thrust and increasing the engine power. In this way, engine thrust available in excess of that required to overcome aircraft drag is used to maintain the thrust-equal-to-drag condition with the horizontal thrust component while at the same time developing an added lift force with the vertical component. This component joins with lift developed on the horizontal tail, and with lift developed in deflecting the canard to hold the aircraft in its original trimmed attitude. Employing this mode at the Mach = 0.8, 9140M (30000 ft.) condition, it was found that 0.5g excess lift could be developed, at which point the canard and horizontal tail deflection limits established for th:s study were reached. (15° and 5° respectively) At the Mach = 1.2 condition, these limits were not encountered and all the available excess thrust at 20° deflection was converted to obtain 1.25g's of excess lift. In analyzing this mode of operation, it was found that the YF-17/ADEN with canard actually prefers to develop excess lift on the horizontal tail and canard, with vertical thrust coming into play only at the point the horizontal tail reaches its deflection limit and an alternate trim force is required to balance the canard lift.

Fuselage Pointing Capability. Another advantage in the decoupling of pitching moment from lift generation afforded by the availability of thrust vectoring and canard forces is the ability to use canard/horizontal tail/vectored thrust deflections ($\delta_c/\delta_H/\delta_T$) - to trim the aircraft at a pitch attitude other than its trimmed angle-of-attack flying with unvectored thrust. However, use of $\delta_c$, $\delta_H$, and $\delta_T$ to perform this manuever at Mach = 0.8 resulted in a fuselage rotation of only 1.2°. At Mach = 1.2, the rotation was essentially non-existent. A prime factor in this limited capability is the strong lift production from the basic YF-17 wing. Rotating the fuselage also rotates the wing and generates large changes in wing lift that must be counter-acted to maintain the aircraft in a trimmed condition. The authority available through $\delta_c$, $\delta_H$, and $\delta_T$ is largely consumed in providing this counter action, leaving little additional moment generating capability for large rotations of the aircraft. It has been suggested that, during the detail design phase, investigations should be made into the possibility of using the wing control surfaces to counteract wing lift changes due to angle-of-attack changes, leaving the $\delta_c/\delta_H/\delta_T$ authority available for increased pointing capability.

- EXCESS LIFT AT CRUISE ANGLE OF ATTACK:
  - +0.5 g AT 0.8M/9140 M (30,000 FT)
  - +1.25 g AT 1.2M/9140 M (30,000 FT)
- FUSELAGE POINTING CAPABILITY
  - 1.2 DEG AT 0.8M/9140 M (30,000 FT)
  - NEGLIGIBLE AT 1.2M/9140 M (30,000 FT)
- 14-16 KNOT REDUCTION IN MINIMUM SPEED
- LOW SPEED CONTROLLABILITY IMPROVED
- NEGLIGIBLE CHANGE IN SUSTAINED TURN RATE
- TAKEOFF GROUNDROLL REDUCED 61 M (200 FT)
- LANDING:
  - APPROACH SPEED REDUCED 9.5 KNOTS
  - GROUND ROLL REDUCED 11-13%

FIGURE 67. YF-17/ADEN CANARD PERFORMANCE SUMMARY, VECTORED THRUST

Minimum Speed at Partial Power. By deflecting the ADENs, the minimum speed of the YF-17/ADEN with canards can be reduced by 14 to 16 knots, due to small induced afterbody lift increments and to direct lift derived from the deflected thrust. Speed reduction is limited by the available canard and horizontal tail deflections for trim.

Maneuvering at Low Dynamic Pressure. Figure 68 demonstrates the contribution that vectored thrust can offer to YF-17 maneuvering during low Mach number, low q conditions. As shown, under these conditions angular acceleration produced in the pitch plane by the horizontal tail alone approaches zero. Use of thrust vectoring in this situation allows retention of pitch acceleration capability regardless of horizontal tail effectiveness. This is particularly important to an aircraft such as the YF-17 which is capable of trimming out in a high lift/drag attitude at low speeds, thereby undergoing rapid deceleration into the speed regime of Figure 68, where, as shown, vectored thrust pitch authority rapidly becomes a desired added capability.

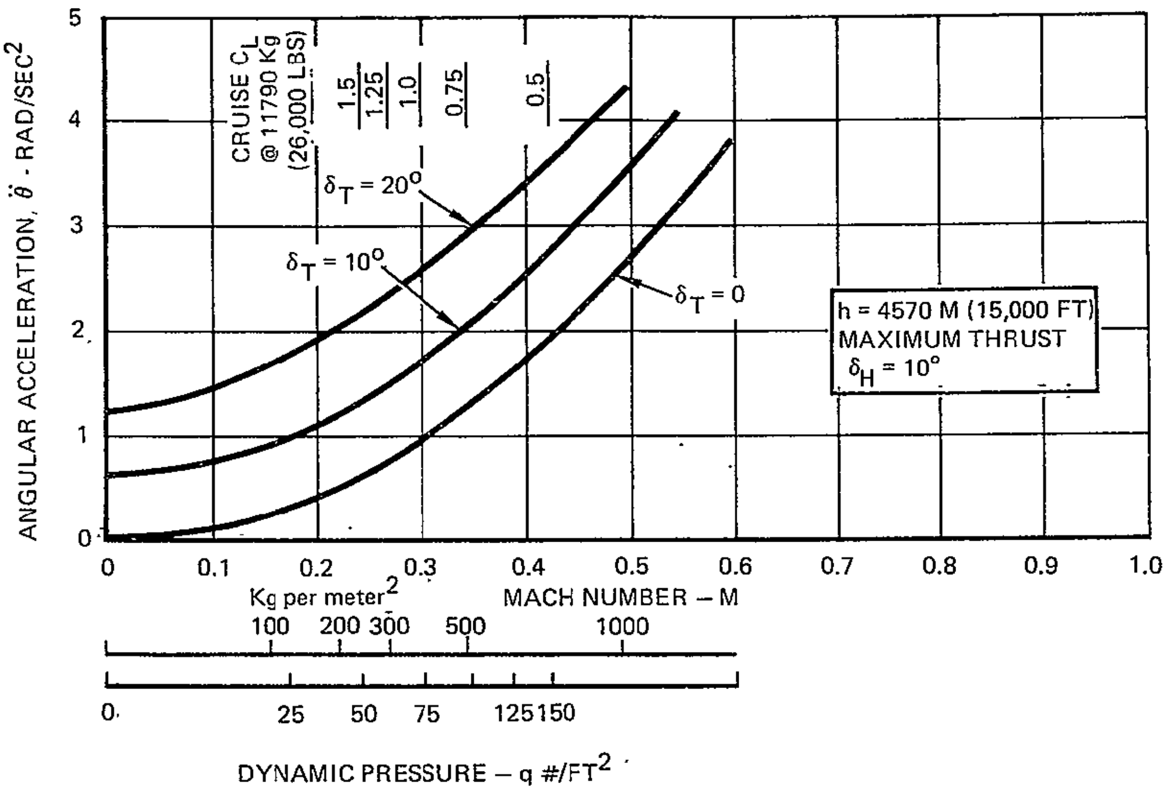


FIGURE 68. PITCH ACCELERATION CAPABILITY OF HORIZONTAL TAIL PLUS THRUST DEFLECTION

Specific Excess Power and Maneuver Performance. Vectored thrust operation offers little improvement in specific excess power/turn rate over unvectored thrust performance of the YF-17/ADEN with canard, except for slight improvements at high negative values of specific excess power.

Deceleration Through Vectored Thrust. Although this manuever was evaluated as a rapid means of inducing deceleration by vectoring to maximum deflection for horizontal thrust loss and trimming with negative $\delta_H$ for additional drag, the fact that it is performed at high power settings severely limits the deceleration force produced. If deceleration capability over and above that offered with the existing YF-17 speedbrake is desired, it will be more effectively developed through implementation of the in-flight thrust reverser concept discussed in Section 1.

Effect of Thrust Vectoring on Takeoff Performance. To determine the effect of thrust vectoring on the takeoff performance of the YF-17/ADEN with canard, analysis was made of the take-off sequence up to main gear lift off (MGLO) performed with and without the utilization of vectored thrust. Table 5 delineates the assumptions for the unvectored thrust takeoff; Table 6 provides the same information for takeoff with vectored thrust employed.

| TAKEOFF SEGMENT | POWER | $\delta_H$ | $\delta_C$ | $\delta_T$ |
|---|---|---|---|---|
| BRAKE RELEASE TO NOSEWHEEL LIFTOFF | MAXIMUM | $0^o$ | $0^o$ | $0^o$ |
| NOSEWHEEL LIFTOFF | MAXIMUM | $-12^o/-6^o$ | $0^o/15^o$ | $0^o$ |
| MAIN GEAR LIFTOFF ($\theta = 10^o$) | MAXIMUM | $-12^o/-6^o$ | $0^o/15^o$ | $0^o$ |

TABLE 5. TAKEOFF, UNVECTORED THRUST

| TAKEOFF SEGMENT | POWER | $\delta_H$ | $\delta_C$ | $\delta_T$ |
|---|---|---|---|---|
| BRAKE RELEASE TO NOSE-WHEEL LIFTOFF | MAXIMUM | $0^o$ | $0^o$ | $0^o$ |
| NOSEWHEEL LIFTOFF | MAXIMUM | VARIABLE ($-12^o$ MAX) | $15^o$ | MAXIMUM TRIMMABLE |
| MAIN GEAR LIFTOFF | MAXIMUM | VARIABLE ($-12^o$ MAX) | $15^o$ | MAXIMUM TRIMMABLE |

TABLE 6. TAKEOFF, VECTORED THRUST

For the unvectored ADEN case, full advantage of the canard is taken to reduce the horizontal tail deflection required at the rotation speed. This alone provides an increased trimmed lift coefficient of approximately .06 at the takeoff pitch attitude. When vectored thrust is employed, the full deflection of the canard is required to trim the moment generated by the vectored thrust and the induced afterbody lift. Therefore, with thrust deflected to the maximum trimmable angle, full trailing edge-up horizontal tail deflection is required to rotate the aircraft. In each case, the nozzle deflection angle is set at zero from brake release until nosewheel liftoff in order to have maximum acceleration thrust available until liftoff is attempted. Also, it is assumed that neither case is nosewheel liftoff limited; that is, that the net effect of the canard and ADEN nozzle deflections on the longitudinal characteristics of the basic YF-17 will be negligible.

Figures 69 and 70 present the canard pitch effectiveness and the effect of the canard on lift used in the takeoff analysis. The data is based on measurements of Reference 7.

Figure 71 shows the effect of thrust deflection on main gear lift off velocity. As can be seen, a reduction in velocity of approximately two knots can be achieved by deflecting the canard to its maximum deflection before employing thrust deflection. The nose-up moment from the canard allows some unloading of the horizontal tail at rotation, with a consequent increase in total lift of the configuration. The maximum nozzle deflection is limited by the ability of the horizontal tail to provide adequate nose wheel liftoff capability.

The effect of vectored thrust in terms of ground roll is shown in Figure 72.

Effect of Thrust Vectoring and Reversing on Landing Performance. The effect of thrust vectoring on landing approach speeds and ground roll distances was computed for a typical three degree glide slope, no-flare landing. As thrust levels on landing are relatively low, the maximum VEER deflection angle of 20 degrees can be utilized without saturating the canard trim capability. Under these conditions, therefore, the maximum reduction in approach speeds is achieved at the highest power setting that does not produce accelerated flight. The no-flare landing approach attitude provides a higher thrust level than a flared landing approach attitude.

Figure 73 indicates the approach speed reduction which can be achieved at the current maximum allowable VEER deflection of 20 degrees. Analysis was extended to greater angles to determine what further speed reduction could be obtained before the canard trim authority was saturated.

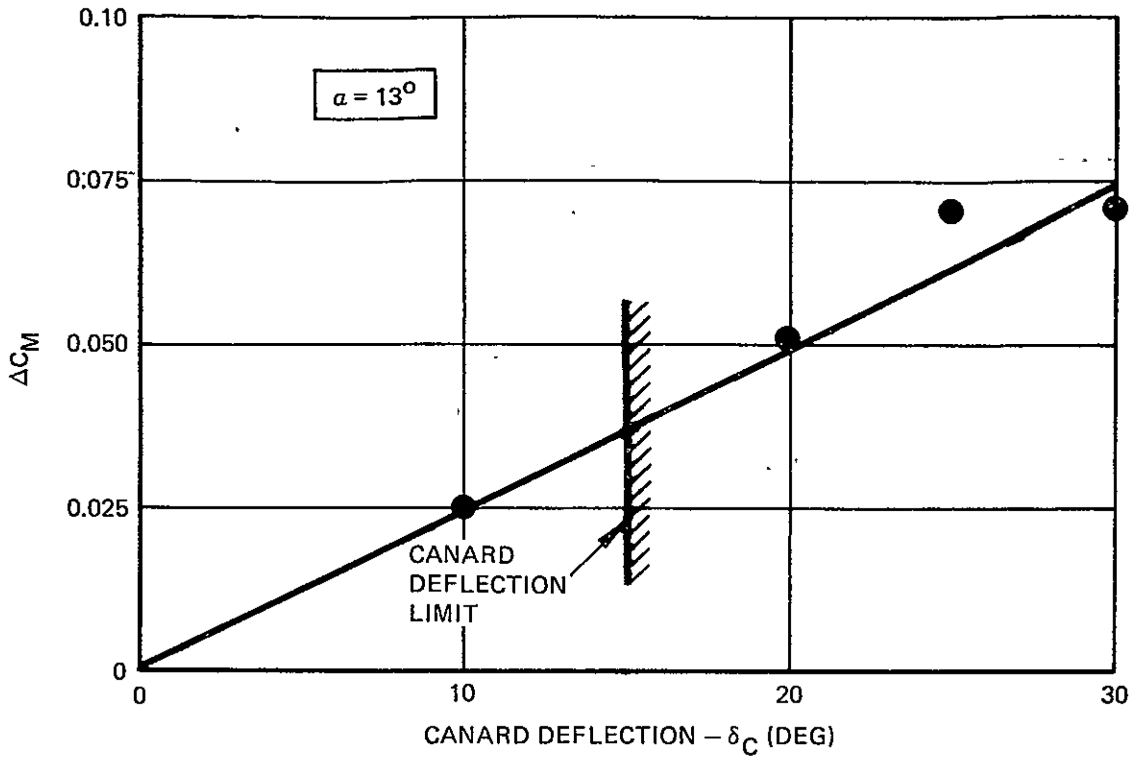


**FIGURE 69. CANARD EFFECTIVENESS**

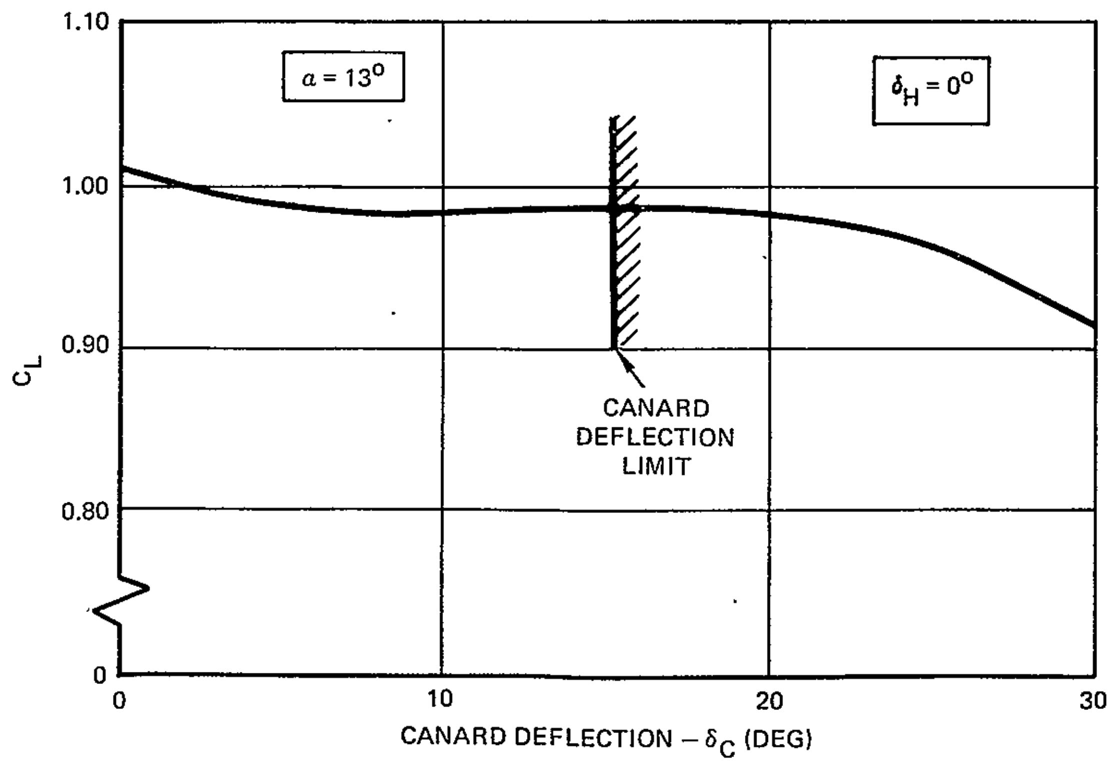


**FIGURE 70. CANARD EFFECT ON LIFT**

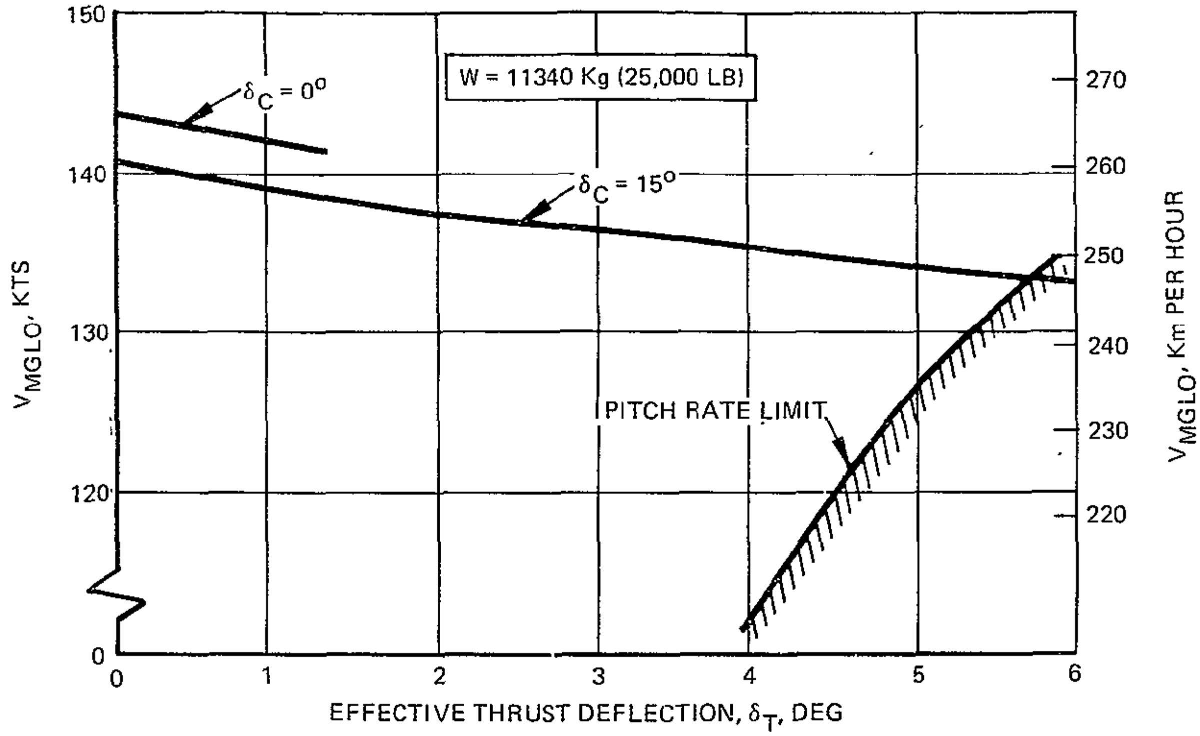


FIGURE 71. EFFECT OF THRUST DEFLECTION ON TAKEOFF SPEED

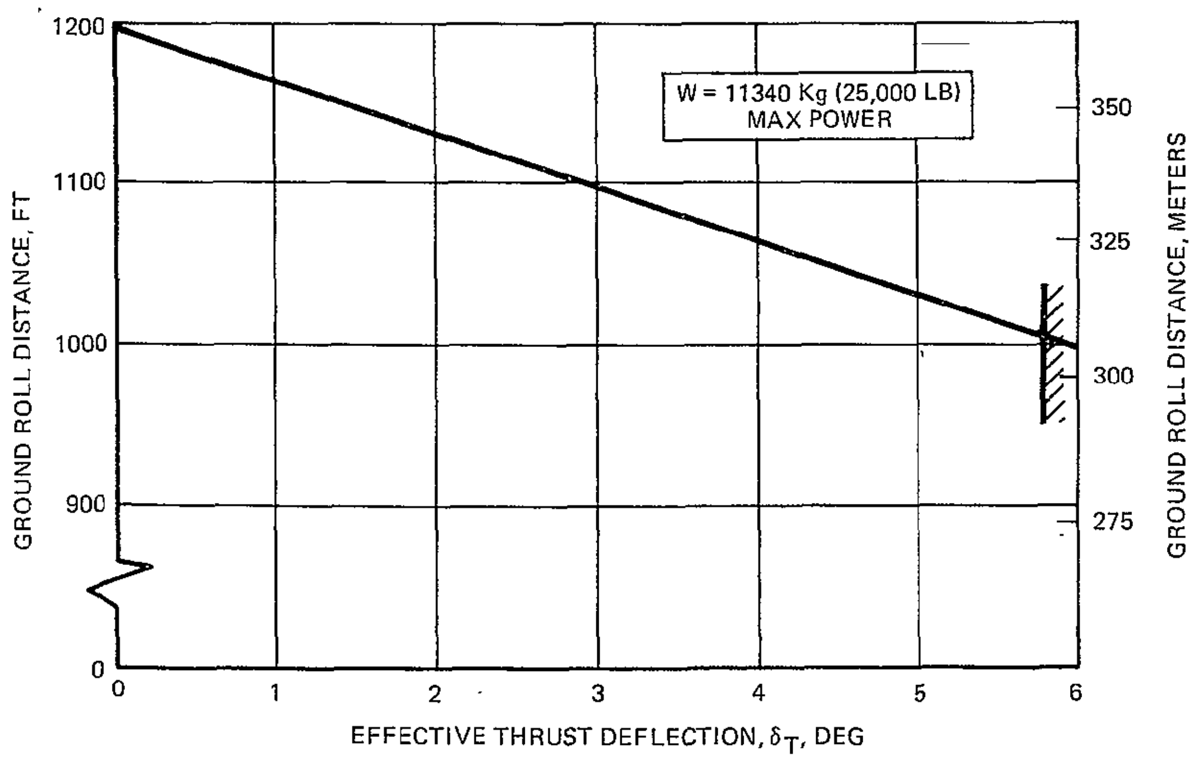


FIGURE 72. EFFECT OF THRUST DEFLECTION ON TAKEOFF GROUND ROLL

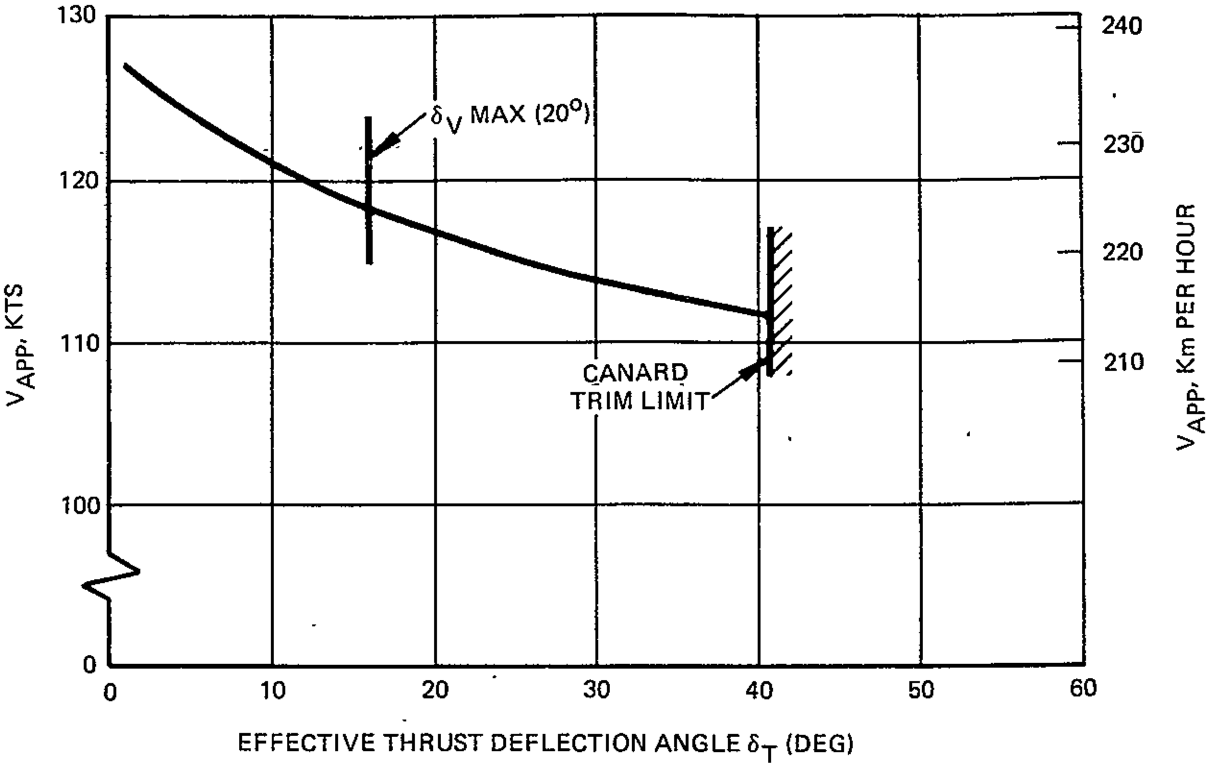


FIGURE 73. EFFECT OF THRUST VECTORING ON APPROACH SPEED

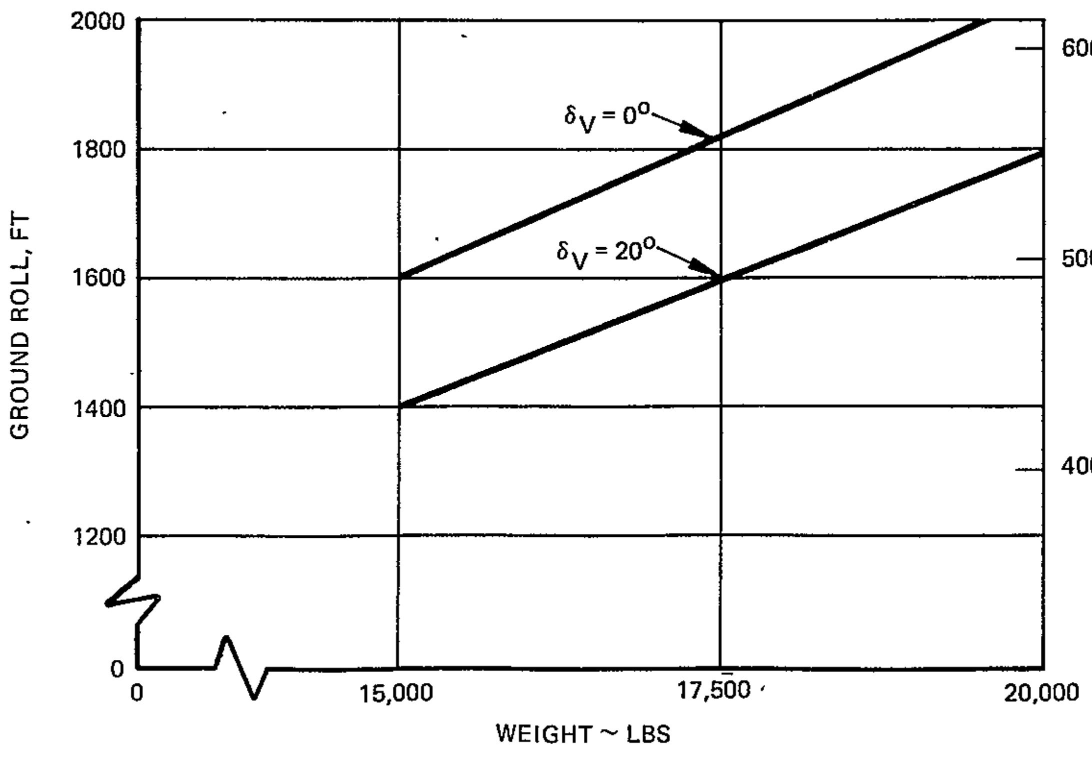


FIGURE 74. EFFECT OF MAX VEER DEFLECTION ON LANDING GROUND ROLL DISTANCE

The payoff in terms of landing ground roll for the maximum VEER deflection of 20 degrees is shown in Figure 74.

A preliminary estimate was also made to determine the reduction in ground roll that could be obtained if the thrust reverser were available for use during landing. Assuming deployment of the reverser at touchdown and a nominal reverser effectiveness of 60%, it was calculated that the YF-17 ground roll at a typical landing weight on a dry surface could be reduced by approximately 56% with the use of a reverser. A reverser becomes even more effective when the landing is being made on a wet or icy runway.

### 3.6 Effect of In-Flight Thrust Reversing on Maneuver Performance

In order to establish the desirability of incorporating the block and turn reverser concept discussed in Section 1 into the full-scale YF-17/ADEN modification, studies were made to determine the impact of thrust reversing capability on YF-17/ADEN performance potential.

Based on test results of a number of similar reverser designs, an inflight reversing efficiency of 60% of available gross thrust was used as representative of performance that could be obtained with the proposed concept. In-flight deceleration of the YF-17 employing reversed intermediate power thrust was calculated over a range of flight speeds at altitudes of 3050M (10,000 ft.) and 10670M (35,000 ft.) to produce the performance shown in Figure 75. For comparison, deceleration performance is also shown at the same conditions for the baseline YF-17 utilizing its speedbrake, with throttles chopped to idle. As expected, the thrust reverser offers a much greater deceleration capability. The dropoff in speedbrake deceleration force exhibited at higher Mach numbers is due to hinge-moment-limited maximum deflection angles.

<u>Head-on Engagement.</u> The consequences of the reverser deceleration advantage were illustrated by analytically simulating a one-on-one head-on engagement of the YF-17 with a high performance threat where both aircraft are initially operating at Mach = 1.2, 3050M (10000 ft). The combat scenario assumed that both the threat and the YF-17, upon visual identification, would pull a maximum decelerating turn in an attempt to gain a heading advantage. This maneuver drives both aircraft to the velocity where maximum lift and turn rate are developed. After reaching this point the load factor is reduced and engine power increased to maintain speed and minimize decay in the turning rate. The YF-17 with speedbrake and the version with thrust

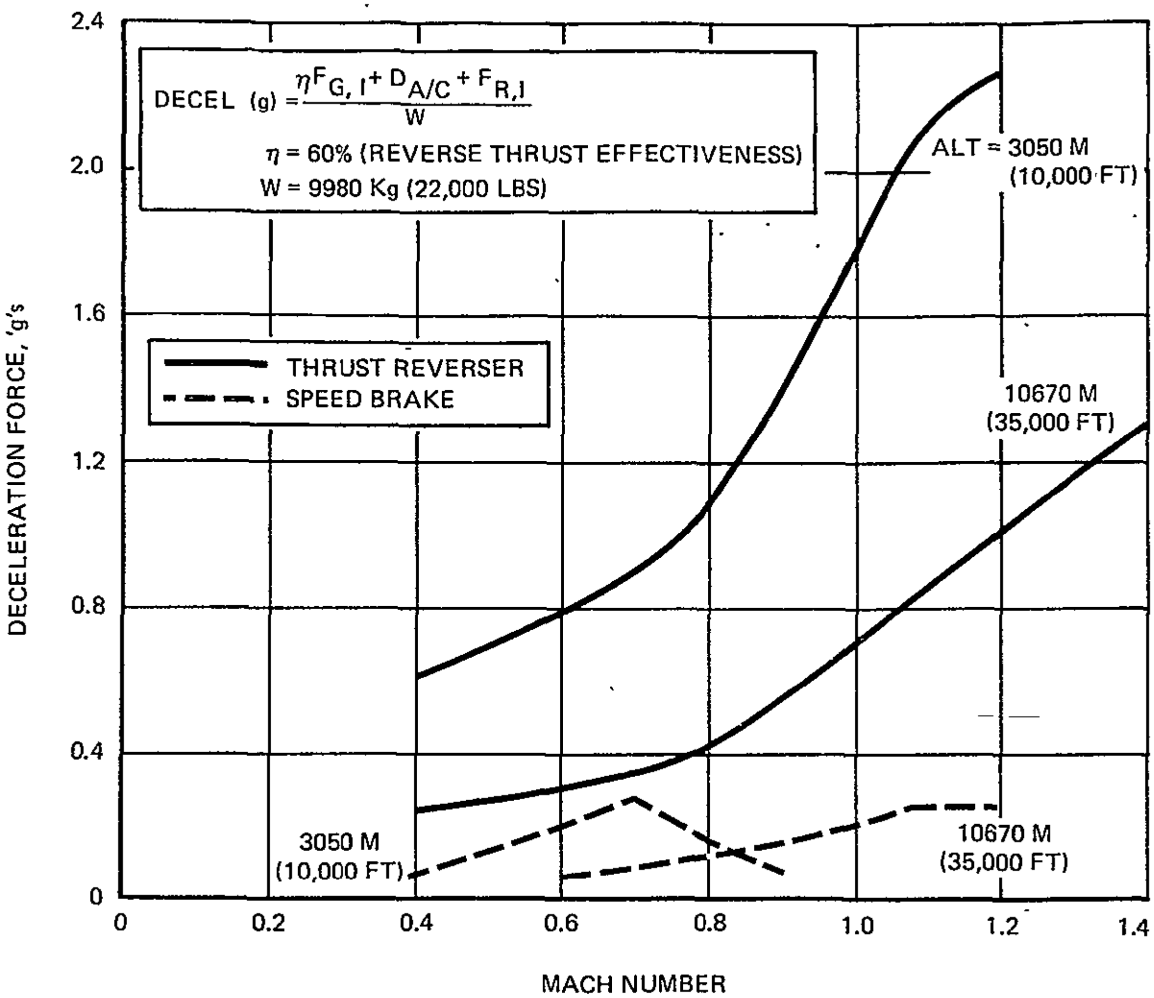


**FIGURE 75. DECELERATION CHARACTERISTICS OF THRUST REVERSER-EQUIPPED AND SPEEDBRAKE-EQUIPPED YF-17**

reverser were evaluated for this type of encounter and yielded the results contained in Figures 76 through 79. Figure 76 shows the deceleration rates, and Figure 77 the turning rates of the three aircraft configurations during the encounter. In Figure 77, it can be seen that the threat (due to an inherently higher drag configuration) decelerates to is peak turning rate faster than the YF-17 with either speedbrake or reverser, but that its peak turn rate is lower. Figure 76 and 77 illustrate the key contribution of the reverser; i.e., it allows the YF-17 to decelerate at the same rate as the threat and to reach its peak turning rate earlier than the speedbrake-equipped YF-17.

The consequences of this performance are shown in Figures 78 and 79; that is, the thrust reverser configuration enters the gunfiring envelope for the threat (within a range of 3000 feet in a 60° aft cone) in approximately 33 seconds, whereas the speedbrake configuration does not enter the same envelope until over 8 seconds later. As Figure 79 shows, even though the YF-17 enjoys a peak turning rate advantage over the threat, deceleration available with the speedbrake does not allow the aircraft to begin converting this turning rate to heading gains until approximately 20 seconds into the encounter.

It is also noteworthy that the reverser-equipped aircraft is operating at intermediate power during this maneuver and can therefore disengage from combat at intermediate forward thrust whenever desired by merely stowing the reverser. The speedbrake is used at engine idle power and several seconds are required to transition from idle to intermediate power for disengagement.

Rear Approach Gunfiring Engagement. In another scenario, reverser-equipped YF-17s were pitted against a speedbrake-equipped defender in a rear-approach gunfiring attack. Figure 80 diagrams a typical encounter with maneuvering initiated at a range of 914M (3000 ft). Upon becoming aware of the attacker, the defender, operating initially at Mach= 0.9, deploys the speedbrake and enters a 7g level turn in an attempt to cause the attacker to overshoot. The attacker, conversely, attempts to avoid overshoot while tracking the defender for maximum gunfiring opportunity. As indicated in Figure 80, the speedbrake-equipped attacker exceeds the gunsight tracking load limit at four seconds into the turn, and at slightly over six seconds reaches the maximum turn rate allowed by aircraft structural limits. As a higher turn rate is required to remain within the defender's trajectory, the attacker must cease tracking, i.e., overshoot. When equipped with a reverser, however, the YF-17 utilizes the enhanced deceleration capability to maintain gunsight tracking for almost six seconds, and never

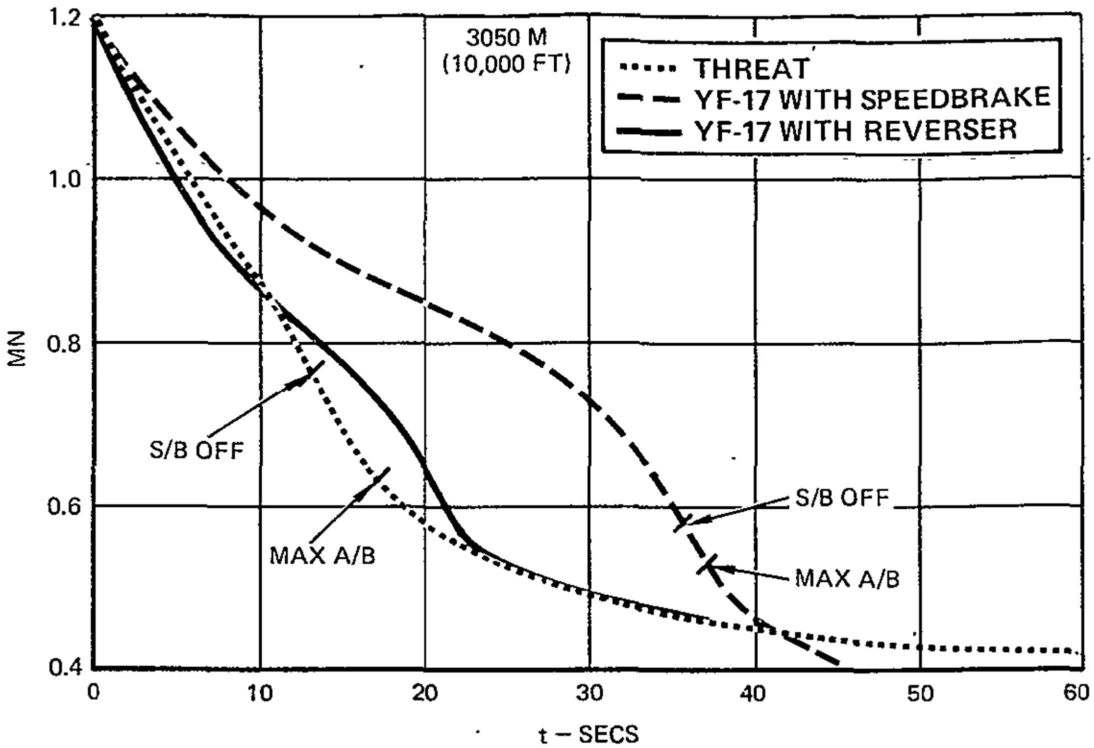


FIGURE 76. DECELERATION PERFORMANCE OF THRUST REVERSER AND SPEEDBRAKE-EQUIPPED YF-17 AGAINST COMMON THREAT

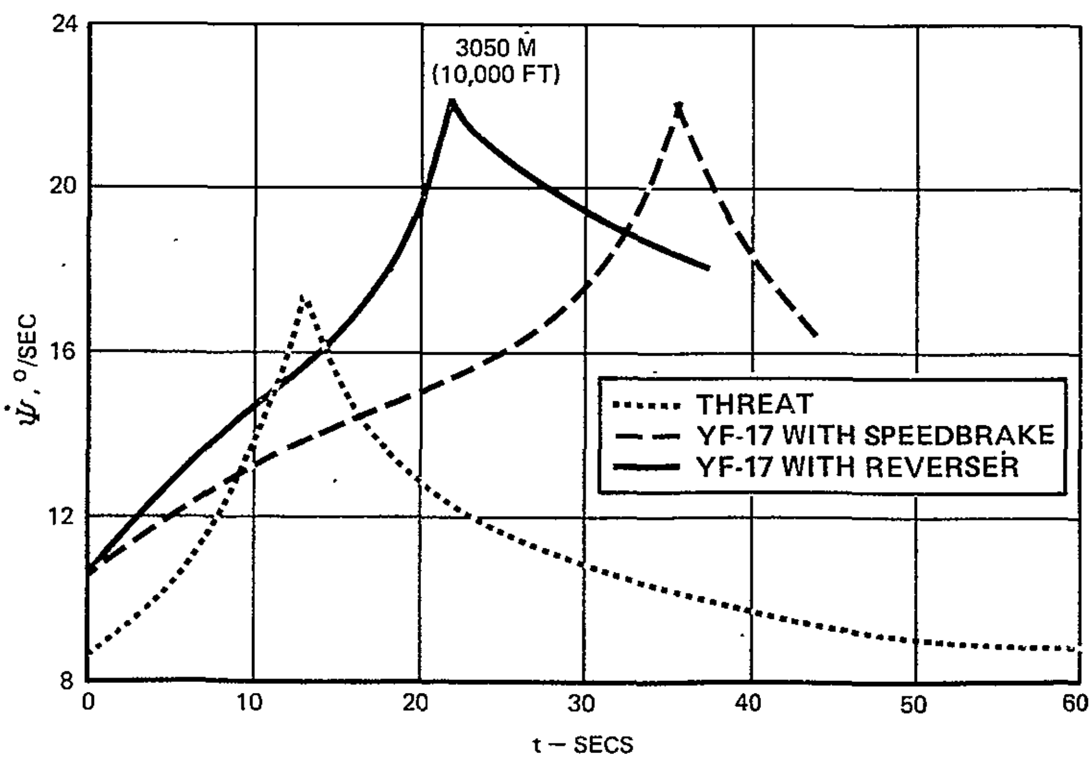


FIGURE 77. TURNING RATE OF THRUST REVERSER AND SPEEDBRAKE-EQUIPPED YF-17 AGAINST COMMON THREAT

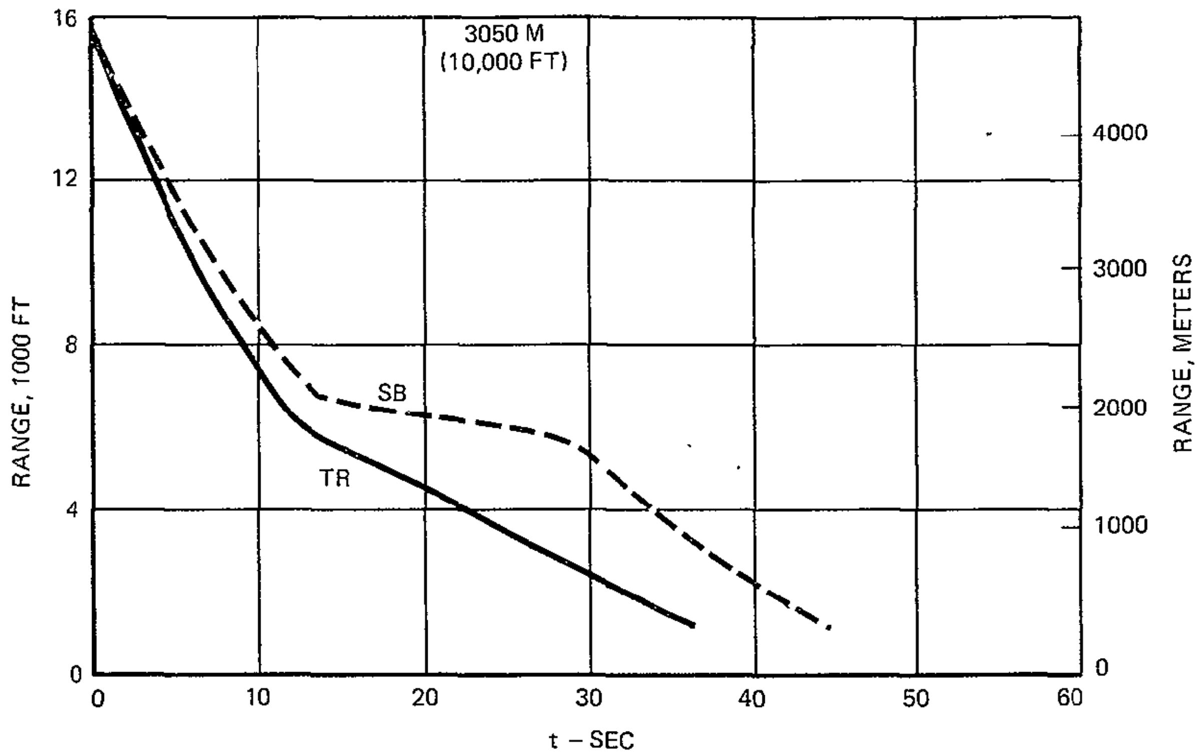


FIGURE 78. CLOSING PERFORMANCE OF THRUST REVERSER AND SPEEDBRAKE-EQUIPPED YF-17 AGAINST COMMON THREAT

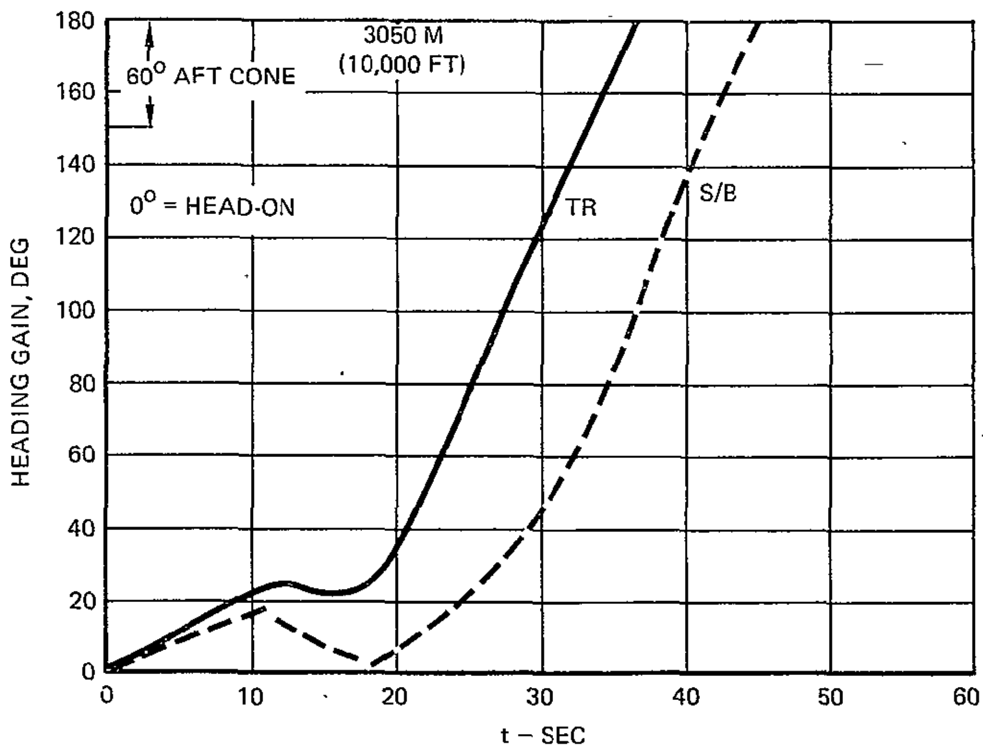


FIGURE 79. HEADING GAIN OF THRUST REVERSER AND SPEEDBRAKE-EQUIPPED YF-17 AGAINST COMMON THREAT

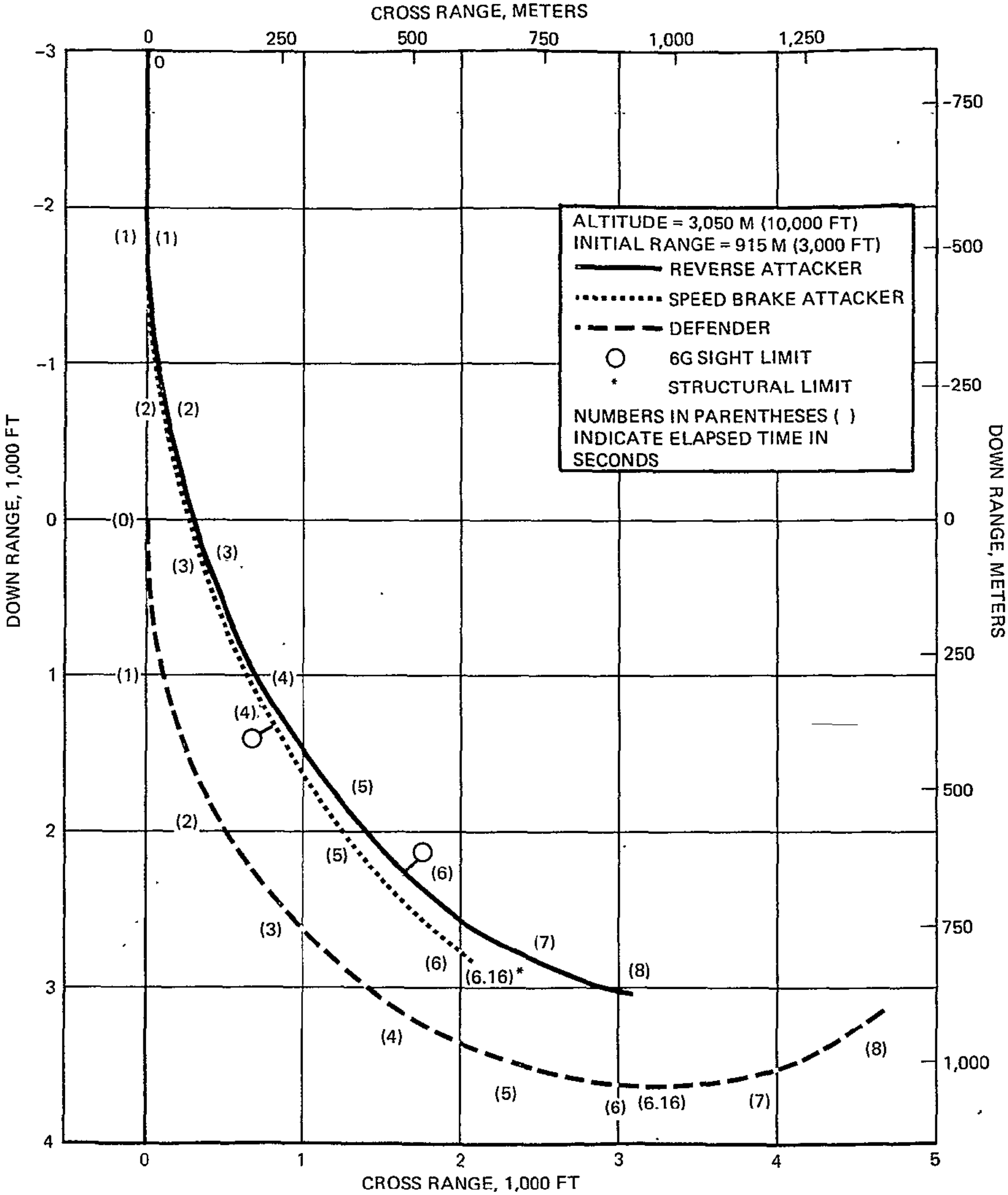


FIGURE 80. REAR ACQUISITION TRAJECTORIES OF THRUST REVERSER AND SPEEDBRAKE EQUIPPED YF-17 AGAINST COMMON THREAT

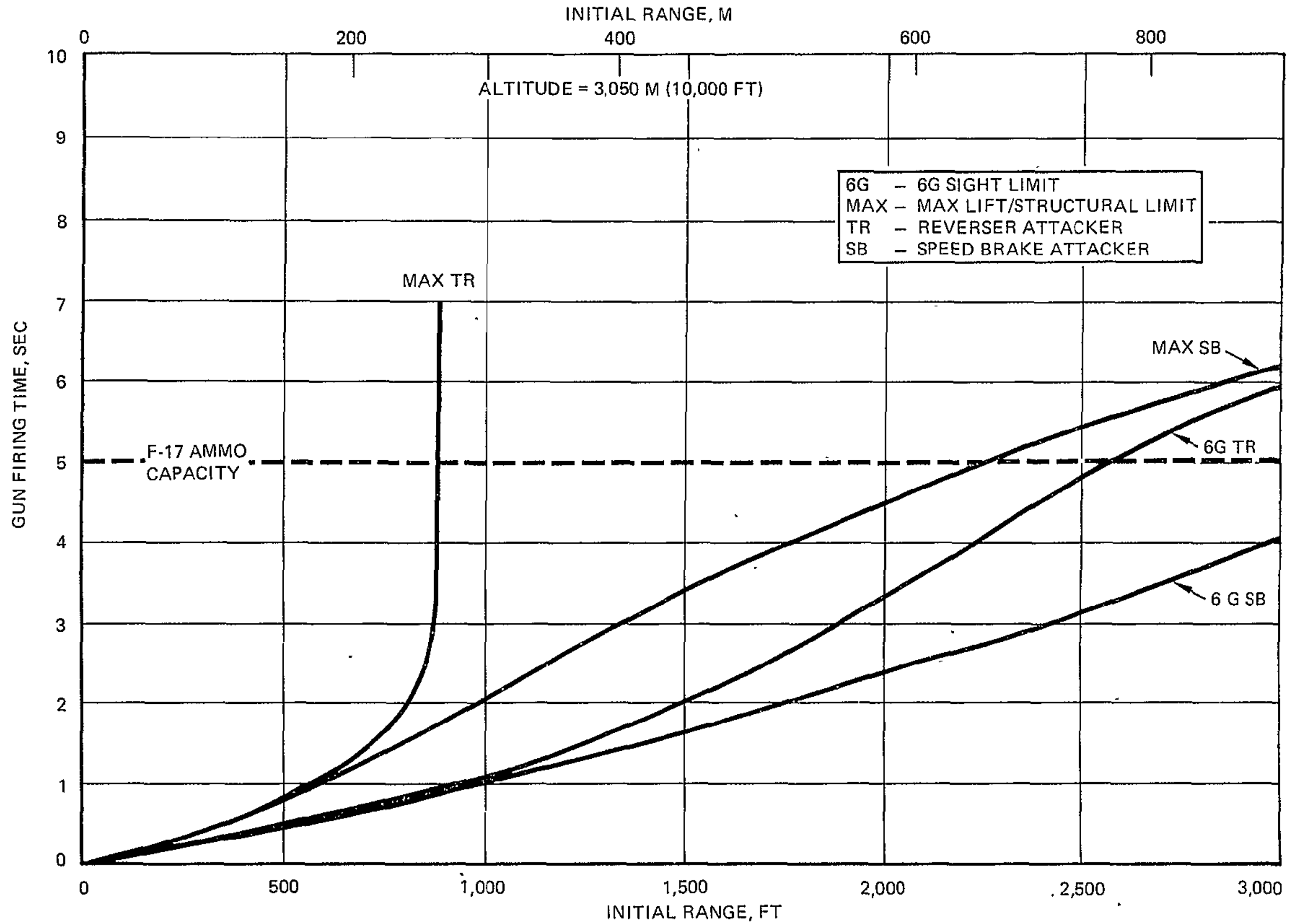


FIGURE 81. AVAILABLE GUN FIRING TIME FOR VARIOUS INITIAL SEPARATION DISTANCES, REVERSER AND ATTACKER EQUIPPED YF-17

does exceed aircraft structural limits that would require departure from the defender's trajectory.

Figure 81 summarizes the results of a number of such analyses for varying initial separation distances at an altitude of 3050 M (10,000 ft). It is evident that, as the initial range increases, the reverser affords an increased available time for gun-firing before the 6g sight limit is reached. Curves are also shown for elapsed time until overshoot is imminent due to aircraft structural limitations. Note that, for initial ranges greater than 274 M (900 ft.), the reverser prevents overshoot from occurring, whereas with the speedbrake overshoot eventually occurs in all cases analyzed.

Similar studies were run at 10670 M (35,000 feet); however, the effects of increasing altitude reduce the thrust available for deceleration as well as the aircraft maximum lift capability, and at 10670 M (35,000 feet) the reverser is no longer capable of preventing overshoot. The advantages of in-flight thrust reversing therefore would appear to be best applied at lower altitudes.

# 4. PROGRAM PLAN AND COST

This section describes the program plan and estimated cost for full-scale development, flight qualification, and flight test support of the YF-17/ADEN aircraft.

The overall program plan, scheduled to be accomplished in 39 months, is summarized in Figure 82. The initial detail design, hardware procurement and fabrication, and system verification testing will be pursued independently by G. E. and Northrop on a coordinated basis. As the program progresses, G. E. and Northrop efforts will be combined to jointly oversee the integration and preflight checkout of the YJ101/ADEN in the modified YF-17. The joint effort will also provide support for the final 12 month flight test program to be performed by NASA Dryden.

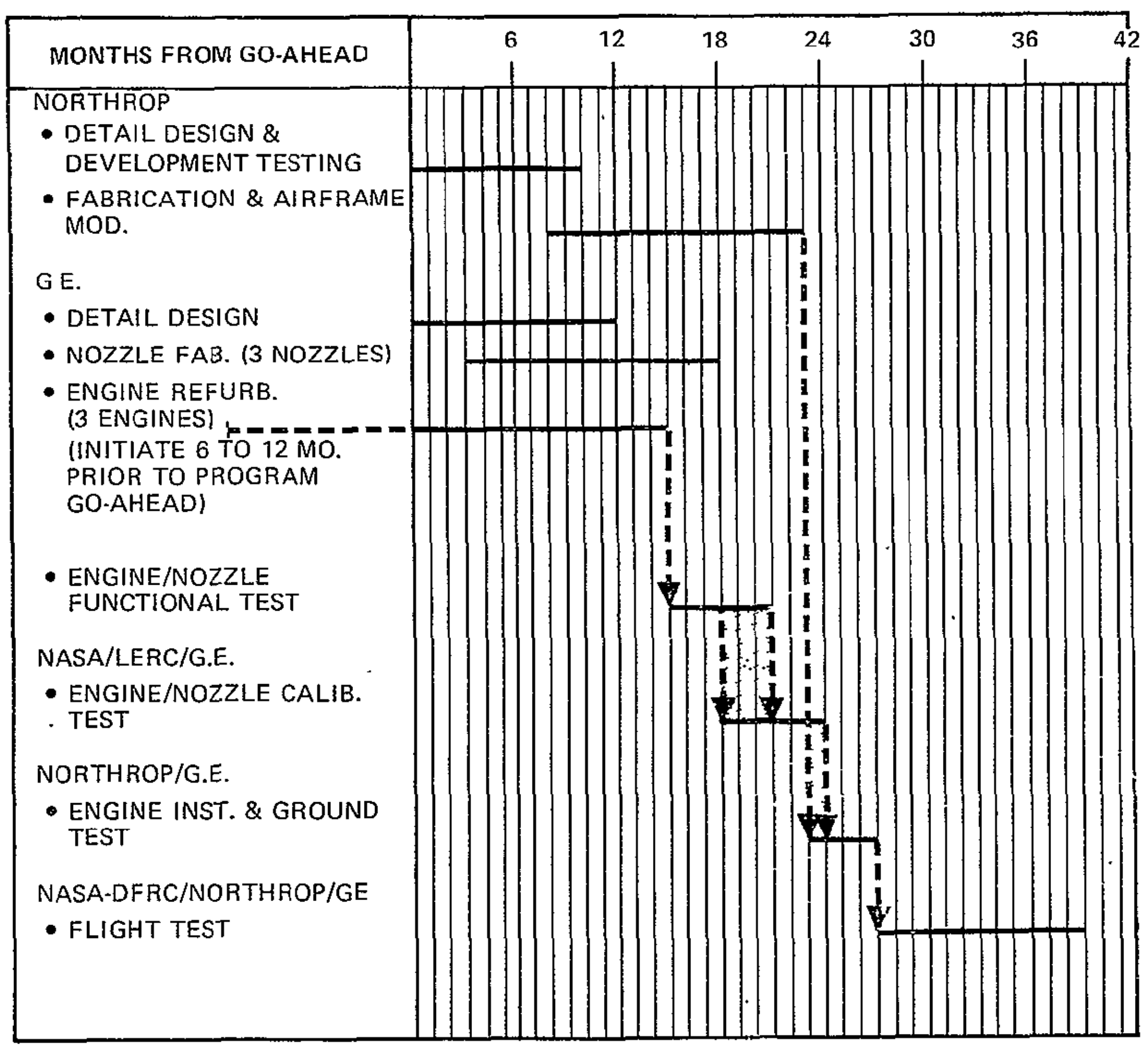


FIGURE 82. OVERALL YF-17/ADEN MODIFICATION PROGRAM SUMMARY

Following sections will provide a breakdown of the program from G.E. and Northrop points of view, highlighting key concerns such as existing hardware availability and condition for modification, new hardware procurement, and low cost emphasis to guide the formulation of the final program plan. Estimated program cost breakdowns and overall cost are presented at the conclusion of the program description.

## 4.1 G.E. YJ101/ADEN Modification Program

Figure 83 provides a more detailed look at projected G.E. responsibilities during the full-scale modification phase of the YF-17/ADEN program. Efforts during this phase will be concentrated on finalizing the various ADEN detail designs, developing manufacturing drawings, and fabricating and obtaining necessary hardware.

Exhaust Duct and Nozzle Detail Design. As shown in Figure 83, GE has projected a twelve month effort to accomplish the detailed design of the ADEN YJ101 augmentor, nozzle actuators, modified control, and ground support equipment. Particular attention will be paid to those elements of nozzle mechanical design which become more critical in a non-axisymmetric, as opposed to an axisymmetric, design. These include:

- Deflection of flat walls under pressure
- Distortion of flat walls due to thermal gradients in structural ribs
- Dimensional stability of flat inner walls due to non-uniform skin temperatures (hot streaks)
- Effect of deflections and distortions on operating clearances and leakage control sealing effectiveness
- Severe vibration excitation potential in flat panels between ribs and resulting fatigue problems
- Efficient distribution and control of cooling flow
- Control of leakage at the interfaces of moving parts.

The final product of this detail design effort will be manufacturing drawings suitable for use in fabrication.

Instrumentation. Effort will also be applied during the detail design effort to define the instrumentation required on the engine and exhaust system to accomplish the following objectives:

- Monitoring of engine and nozzle operating conditions to assure safe operation of the system.

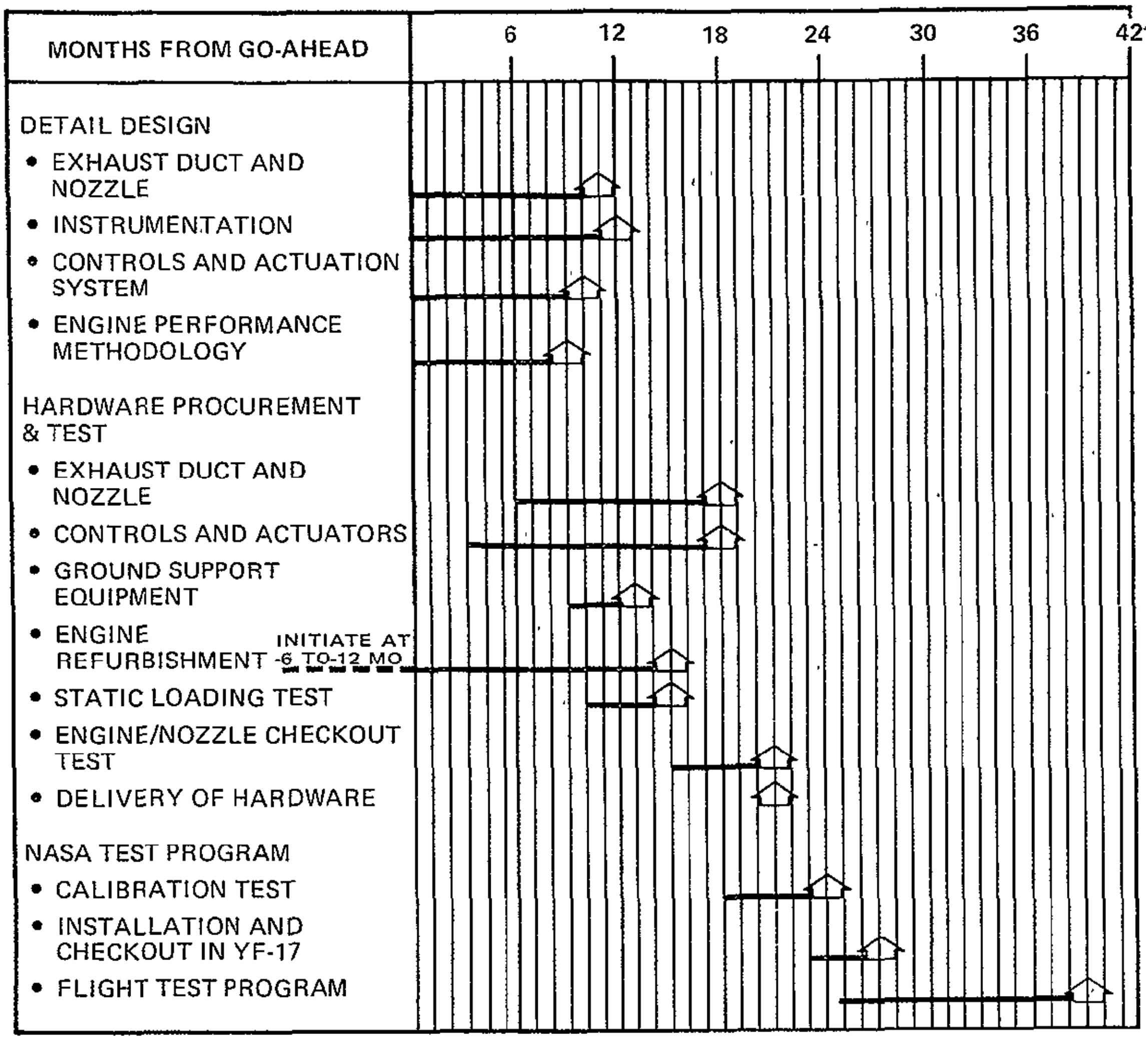


FIGURE 83. G.E. YJ101/ADEN MODIFICATION PROGRAM SCHEDULE

- Determination of cooling effectiveness and pressure loads in critical nozzle areas.
- Calculation of engine thrust in-flight based on results from the altitude cell calibration test.
- Measurement of actuator travels and rates.
- Identification of nozzle vibration characteristics.

Types of instrumentation required will include static and total pressure taps, thermocouples to measure gas and metal temperatures, vibration pickups, and actuator position indicators.

Control and Actuation System. Also scheduled by G.E. during the detail design period are the control schedule definition and identification of required board modifications to accomplish the one main engine control change and three electrical changes identified as necessary for the control system redesign. $A_8$ and VEER actuator designs will be finalized; as noted in the review of control system changes, the same actuator will be employed for both applications with a stroke-limiting collar added to the VEER actuators.

Engine Performance Methodology. Efforts will be initiated at the start of detail design to develop the data reduction programs needed to calculate engine and nozzle performance during flight test. The YJ101 engine cycle deck will be modified to integrate the results of eventual preflight calibration testing so that it can be used to identify in-flight thrust and inlet weight flow values.

Exhaust Nozzle and Duct Hardware. As detail designs become finalized and manufacturing drawings become available, hardware procurement and fabrication will begin. Manufacturing methods and planning will be tailored to produce cost effective demonstrator hardware within the allotted time frame. The manufacturing effort will be closely followed by Design Engineering to assure that the quality and cost objectives are maintained throughout the production process. Because of the time required to fabricate a demonstrator nozzle, manufacture of some long lead items are scheduled to begin during the detail design phase of the program. To accommodate this requirement, manufacturing drawings of these items will be the first released during the detail design effort after the final nozzle design is established and approved by NASA.

The basic hardware to be procured to the YJ101/ADEN modification will be:

- 3 YJ101, refurbished
- 3 ADENs, 2 new and 1 modified/refurbished
- 3 augmentor sections, 2 new and 1 modified/refurbished
- 3 VEERS, new
- 3 sets engine/nozzle controls, modified YJ101
- 3 sets (2) $A_8$ actuators, 2 new sets and 1 existing set
- 3 sets (3) VEER actuators, new

The three YJ101s are currently being utilized in the YJ-17 flight test program and are Government Furnished Equipment (GFE).

As noted, two completely new ADEN nozzles will be fabricated; the third or back-up nozzle will be the existing ADEN demonstrator nozzle designed, fabricated and tested under NAVAIR R&D Project 4566 (Reference 1). This nozzle, however, will require modifications including the relocation of the actuators, the addition of a VEER, a new mount configuration, the removal of the V/STOL deflector, and addition of a tapered upper casing surface as discussed in Section 1. New augmentors complete with a new fuel system will be required for all three engines. A conversion kit to change from right to left hand engine installation will also be required. This kit will include a fuel supply manifold and electrical leads for the igniter and flame detector.

Controls and Actuation Equipment. Procurement of controls and actuation hardware will begin during the detail design effort to allow adequate time for fabrication and testing of the hardware prior to installation on the engine. The main engine control and the electrical control will both be modified as discussed in Section 2. Each unit will then be bench tested. At the same time, actuators for the ADEN and VEER will be manufactured and tested individually. A test will then be conducted on the assembled controls and action system to assure hardware compatibility and to verify satisfactory operation of the system prior to installation on the engine.

Ground Support Equipment. Three rubber wheeled dollies will be procured for the transportation, maintenance, and storage of the augmentor/exhaust nozzle assemblies. The dollies will be existing models modified to accept the YJ101/ADEN assembly. All other ground support equipment, such as starting carts, already exists at Edwards AFB and can be utilized without modification.

YJ101 Engine Refurbishment. A major consideration and pacing item in the YF-17/ADEN program is the refurbishment of the three YJ101 engines that will be required in order to pursue the flight test phase. At the completion of the current YF-17/YJ101 flight test program in 1981, the engines will have been extended to the limits of their original intended design life and a major overhaul of all three engines will be necessary if they are to be further utilized for the YF-17/ADEN program. Based on a projected schedule of one hour of flight testing per week for 12 months, (about 50 hours) plus preflight checkout runs, each refurbished engine must be capable of 50 hours extended life. The refurbishment has been estimated to require from 21 to 27 months and, as indicated in Figure 82, if the reworked engines are to be available for the scheduled checkout tests, the refurbishment process must be initiated 6 to 12 months prior to the start of the ADEN detail design.

The engine refurbishment is planned to be funded as a separate program. Figure 5-C provides a detailed schedule of the overhaul process. At the inception of the refurbishment, the history of the three YJ101 engines will be reviewed and an assessment of the remaining life of the critical and long lead time parts will be made. Hardware releases will be made at contract go-ahead for those parts pre-judged as requiring replacement. Based on teardown/inspection results, additional parts will be identified for procurement or repair.

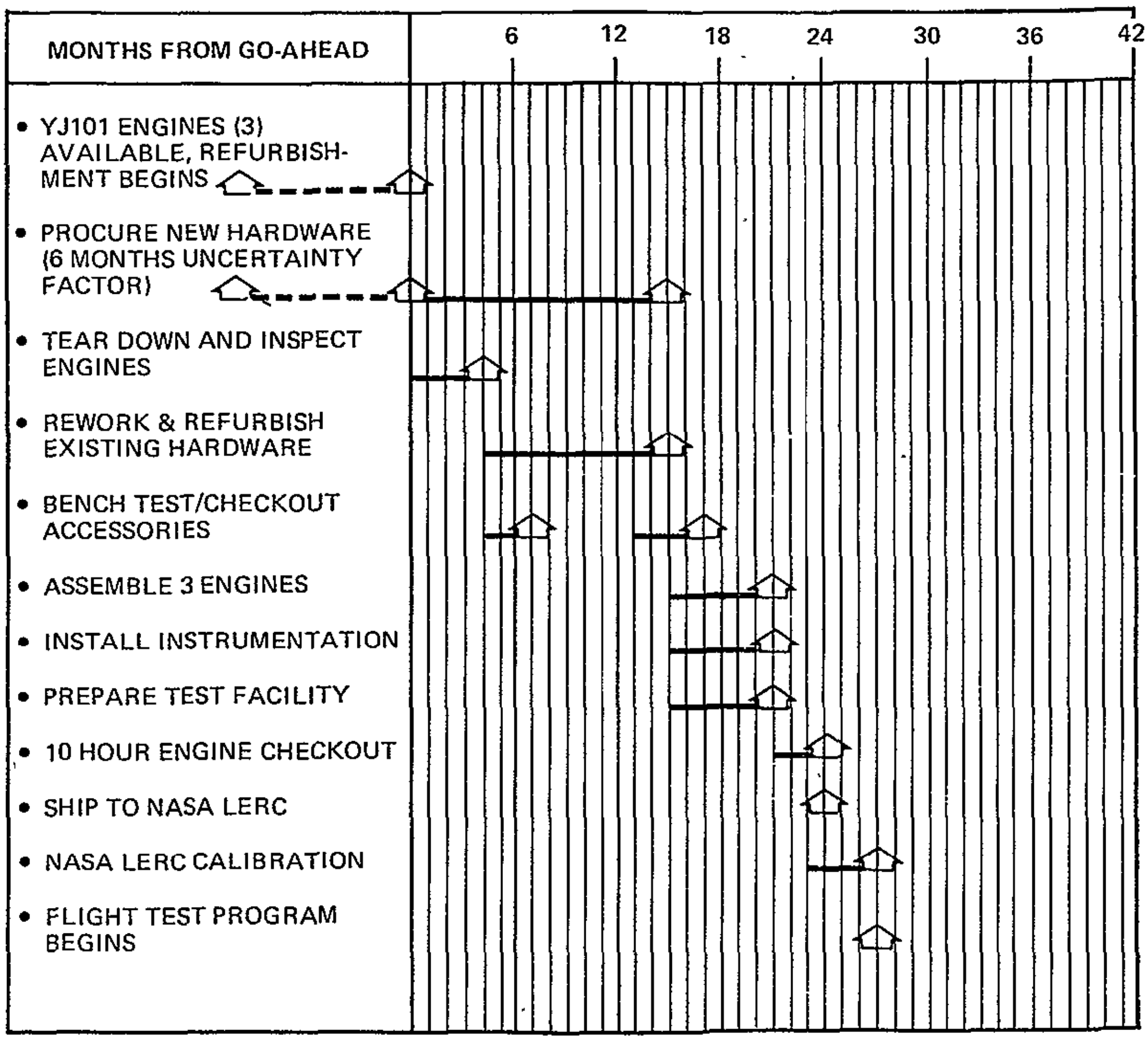


FIGURE 84. G.E. YJ101 ENGINE REFURBISHMENT PROGRAM SCHEDULE

The three engines will be completely torn down and laid out to permit inspection of all parts. Rotating clearances will be measured during tear down and accessories will be functionally bench tested. Structural, rotating and other key parts will be penetrant inspected. Table 7 lists the hardware expected to be required for refurbishment and available spares.

| ITEM | QTY. (SETS) |
|---|---|
| HP TURBINE WHEELS | 3 |
| HP TURBINE NOZZLES | 5 |
| HP TURBINE BUCKETS | 5 |
| LP TURBINE BUCKETS | 5 |
| HP TURBINE SIDE PLATES | 3 |
| LP TURBINE NOZZLES | 5 |
| LP TURBINE SHROUDS | 3 |
| HP TURBINE SHROUDS | 3 |
| HP COMPRESSOR BLADES | 2 |
| LP COMPRESSOR BLADES | 2 |
| HP COMPRESSOR VARIABLE VANES | 2 |
| LP COMPRESSOR VARIABLE VANES | 2 |
| HP COMPRESSOR FIXED VANES | 3 |
| BEARINGS AND SEALS | 5 |

TABLE 7. YJ101 REQUIRED REFURBISHMENT AND SPARES HARDWARE

In addition, it is anticipated that the controls and accessories, rear-frame, front-frame, and combustors, will require repair and rework during the refurbishment effort. Instrumentation required for flight testing will be installed at this time.

At least one complete set of assembly tools and handling equipment is assumed to still be available at the start of the refurbishment effort. As the current YJ101 program is expected to end in 1981, instructions to store the tooling at that time are advised.

Static Loading Test. At the completion of the engine refurbishment, a static load test of one engine/nozzle will be performed to verify the structural integrity of the engine casing and mount arrangement with the increased span between mounts that results from relocating the rear mount aft to react the thrust vector loads as described in Section 1.2. The static loads will be applied at the center of gravity of major components to simulate the "g" loads during flight maneuvering. At the same time, normal loads will be applied to simulate thrust vectoring. In addition to the measurement of deflections in the engine casing, the engine will be rotated at low speed to demonstrate rub free engine operation under a simulated 10 "g" static loading with vectored thrust.

Engine/Nozzle Ground Checkout Test. All three engine/exhaust nozzle sets will complete a 5-10 hour preflight test before being delivered to NASA. These tests will be run at the G.E. Edwards Flight Test Center to demonstrate the following items:

- The structural integrity of the engine/nozzle during dry and augmented operation.
- The integration and operation of the exhaust nozzle actuator system and controls.
- The effectiveness of the nozzle cooling system.

Upon the successful completion of the preflight tests, the engine/nozzle sets will be given a comprehensive visual inspection.

Delivery of Hardware. Following ground checkout, the three engine/nozzle hardware sets will be shipped intact to NASA Lewis for altitude chamber testing. Each engine/nozzle assembly will remain intact for the remainder of the program unless the need for major repairs or overhaul arises. This will minimize changes in operating characteristics, thereby providing flight test data of greater accuracy than would be attainable if engines and nozzles were interchanged.

NASA/LeRC Calibration Test. NASA Lewis will conduct calibration tests of each engine/nozzle assembly in an altitude test chamber. Thrust, inlet weight flow, fuel flow, ambient pressure, and engine/nozzle internal temperatures and pressures will all be measured over a wide range of engine operating conditions in the test chamber. During this test the effects of afterburner fuel distribution on surface temperatures will also be evaluated. General Electric will provide engineering support for the calibration program to assist NASA with test planning, pretest predictions, on-site test coverage to monitor performance and integrity of engine and nozzle hardware, and data analysis to generate the required calibration curves. The test results will be used to update the YJ101 flight thrust calculation computer program to determine the inflight engine thrust based on the measured parameters. It will also adjust the thrust and fuel flow to a reference (Std) day condition. Fifteen to twenty hours total testing is estimated for each engine nozzle assembly.

Prior to the engine/ADEN calibration tests, instrumentation checkout runs are recommended where the engine is run with a reference (conic) nozzle to provide verification that the instrumentation, data acquisition, and data reduction systems are working properly, and to provide an evaluation of the accuracy of thrust and flow measurements. An existing conic nozzle from previous ADEN test programs should be available for the checkout runs.

Utilization of the three-component thrust measurement stand used for previous YJ101/ADEN testing is planned, with modifications required to adapt the stand to the NASA Lewis facility before the scheduled test period.

Following the NASA Lewis calibration tests, the YJ101/ADEN assemblies will be ready for installation and checkout in the modified YF-17. At this point, G.E. and Northrop efforts will combine in a joint support program, reviewed in later sections. In sections immediately following, the Northrop program leading up to the joint support phase will be reviewed.

## 4.2 Northrop YF-17 Airframe Modification Program

Airframe Detail Design. As shown in the milestone chart of Figure 85, Northrop is planning a ten month period to optimize and finalize the detailed designs for the canard, forward fuselage modifications, shortened LEX, modified aft fuselage, modified control system, and placement of flight test equipment and ballast. A prime consideration in the detailed design will be emphasis on low cost. Every effort will be made to utilize off-the-shelf and government furnished equipment wherever possible. The detailed designs will also be oriented toward ease of restoration of the aircraft to its original configuration after the YF-17/ADEN flight test program. The final product of the detail design effort will be manufacturing drawings suitable for fabrication and procurement of hardware.

Development Testing. As an initial part of the airframe detail design, the canard design will be refined and evaluated to thoroughly define the YF-17/canard flowfield characteristics and consequent altered aerodynamic performance. Using an existing 8% model of the YF-17 modified to incorporate the canards, a low speed test will be performed in the Northrop 7 x 10 ft tunnel to refine the canard planform and to obtain inlet flowfield characteristics with the canard/short LEX configuration. The finalized configuration will then be tested in a large scale government facility (tentatively AEDC) to obtain the transonic/supersonic performance characteristics.

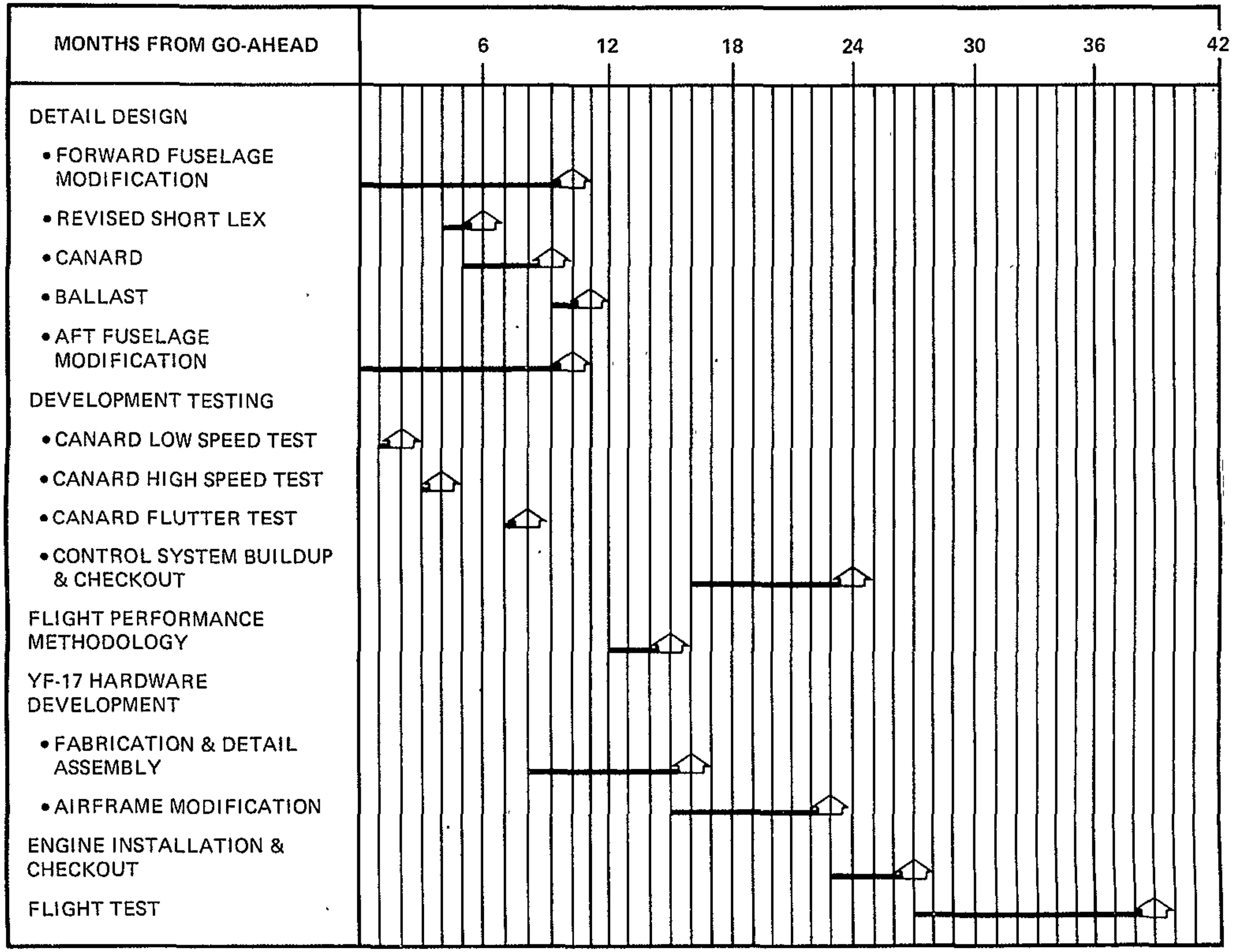


FIGURE 85. NORTHROP YF-17 AIRFRAME MODIFICATION PROGRAM SCHEDULE

The canard design will also be tested for structural integrity. A static test will be run on the full-sized canard to 110% of the design critical loading condition. Wind tunnel flutter tests will be run on two 0.125 scale half-span models of the canard to determine the subsonic and transonic flutter characteristics.

Testing is tentatively scheduled for August 1979 in the NASA Ames 9 x 7 tunnel to extend the aft end aerodynamic data base developed in the NASA Langley 16 ft. tunnel further into the supersonic regime. Results of the Langley and Ames testing will provide a thorough description of the aerodynamic performance characteristics of the F-18/ADEN integration. Given the similarity of the F-17 and F-18 configurations, plus the extensive storehouse of aerodynamic data available on the YF-17 aircraft with axisymmetric nozzles, it is felt that sufficient information is available to predict the YF-17/ADEN aft end aerodynamic characteristics without incurring the cost of additional testing on a completely representative configuration.

YF-17 Control System Detail Design and Testing. As part of the Northrop detail design effort, the modified control laws will be finalized, and software required to implement the revised control system will be identified through use of the Northrop software development facility. The finalized system will be built upon the Northrop Advanced Flight Controls Test Stand to fully establish the hardware requirements and to verify control system safety and performance. Further flight simulator studies will be performed to expand the preliminary simulator investigations of Section 2.3 in order to determine how the expanded control system capability might be best utilized during the flight test phase.

YF-17 ADEN Performance Prediction Methodology. The final aerodynamic performance predictions for the YF-17/ADEN will be used in conjunction with the modified G.E. YJ101 engine cycle deck to assess overall aircraft performance during the flight test phase. In order to do this, a drag bookkeeping system will be defined to insure that Langley and Ames results defining the YF-17/ADEN throttle-dependent afterbody drag are properly integrated with baseline throttle-independent drag levels determined on the canard-modified 8% aerodynamic force model with sting-distorted aft end. When the bookkeeping methodology has been established, predicted YF-17/ADEN aerodynamic and engine cycle performance will be generated for the entire flight test envelope.

Hardware Development. After the 10 month design period, Northrop efforts will concentrate on modification of the YF-17 to accept the YJ101/ADEN. The aircraft will be bailed by the Navy to NASA and shipped to Northrop's Hawthorne facilities where a 13 month period is planned for hardware fabrication and airframe modification.

One shipset of modified hardware will be procured. The overall airframe and canard hardware requirements have been discussed thoroughly in the configuration design sections 1.4 and 1.5; the reader is referred to these sections for the specifics of these requirements. Efforts will be made to employ existing tooling and fixtures wherever possible in the fabrication process. Soft tooling will be employed to fabricate new hardware that does not lend itself to existing tooling.

Following modification the aircraft will be trucked to Edwards AFB for integration of the YJ101/ADEN and joint G. E. /Northrop checkout of the YF-17/ADEN system over a 4 month period.

### 4.3 G. E. /Northrop Hardware Integration and Preflight Checkout

As shown in the summary milestone chart of Figure 82, the calibrated G. E. YJ101/ADEN assemblies and the modified YF-17 airframe will be available at Edwards for the 4 month integration and checkout phase 23 months after program go-ahead. Under NASA direction, G. E. and Northrop engineering personnel will coordinate the installation of the YJ101/ADENs into the YF-17 to insure proper interfacing of the systems. Following installation, ground tests will be performed to verify that all systems are functioning satisfactorily as expected. A tie-down thrust calibration test will be performed at Edwards AFB to verify the predicted static thrust characteristics of the YJ101/ADEN as installed in the YF-17.

The flight control system will be subjected to limit cycle and ground resonance tests. A weight and balance test will also be performed on the assembled aircraft system. When the YF-17/ADEN has been judged to be performing satisfactorily according to ground checkout testing, the aircraft will be turned over to NASA Dryden for the flight test phase.

### 4.4 NASA DFRC/Northrop/G. E. Flight Test Phase

Program Support. As noted previously, YF-17/ADEN flight testing is tentatively scheduled for one hour per week over a 12 month period. During this phase of the program, NASA Dryden will be responsible for flight test planning and prodedure as well as on-site maintenance of the flight test aircraft.

G. E. will provide an engine/nozzle system flight test engineer for on-site coverage throughout the test program. In addition, aeromechanical and controls engineers completely familiar with the YF-17/ADEN program will be on-call to provide a total of up to 15 man months effort. The on-call manpower will be utilized as needed to support the flight test engineer with data analysis, exhaust system inspections, troubleshooting, and anticipation of potential problems with controls, engine, and nozzle performance/operations.

Northrop will provide full-time/on-site support in the person of a nozzle/afterbody engineer well-versed in the YF-17/ADEN program, and will have qualified engineering personnel familiar with the YF-17/ADEN modified structure, controls system, and aircraft aerodynamics on-call to provide troubleshooting and support as required for a projected total of 24 man-months.

Engine Nozzle Inspection & Maintenance. Periodic inspection of the augmentor/nozzle will be conducted by G. E. personnel at NASA Dryden to insure the structural integrity of the hardware throughout the flight test program. These inspections will be made after the first and second flights, at the end of the first, second, and third months of operation, and every three months thereafter for a total of seven inspections. The inspection will require a partial disassembly of the exhaust system and will include a visual inspection of all hardware, including the actuation system, engine mounts, cooling linear slots, nozzle flaps, and VEER. Radiographic or dye penetrant inspection will be recommended for all hardware showing unusual changes or distressed areas that could affect the performance or structural integrity of the nozzle. Damaged or defective parts will be either repaired or replaced.

In addition to the periodic inspections, selective maintenance of the nozzle will be scheduled to include the lubrication of all nozzle bearings and sliding components as required.

Engine maintenance procedures ordinarily require a periodic evaluation (P. E.) for overhaul of each engine after 50 hours of operation; however, the program presented here is structured so that careful scheduling of ground checkout and flight time on the three engines will fulfill the 50 hours of flight time required for the program while avoiding the need for a P. E. on any of the engines. This allows a significant reduction in estimated cost for the G. E. portion of the overall program.

YF-17 Extended Flight Test Life - The YF-17 originally performed as the Northrop prototype flight test aircraft for the lightweight fighter competition. As such, it was designed for a normal 2000 hour life and initially cleared for 300 hours of flight testing. At the completion of the lightweight fighter competition, the aircraft had exceeded 300 hours of flight time. A complete safety evaluation of the aircraft was performed by Northrop at that point under the direction of the Navy, whereupon it was recommended that the allowable life be extended to 600 hours. The Navy granted the extension, subject to review in 100 hour increments. The aircraft has currently been cleared to 400 hours, and based on that evaluation, no problems are anticipated in the eventual fulfillment of the 50 hour YF-17/ADEN program.

## 4.5 Program Cost

The overall program described above will be funded as separate contracts to G. E. and Northrop. The engine refurbishment will be funded as a separate NASA program and as such will not be directly chargeable to the YF-17/ADEN program. Cost estimates are provided here for reference, however. All costs quoted are in 1978 dollars.

Table 8 shows the estimated cost breakdown for the G. E. program represented in Figure 83 for design, development, fabrication, and verification testing of the YJ101/ADEN engine/nozzle system as well as flight test support. The cost of implementing the thrust reverser concept is not included in these figures.

TABLE 8. COST OF YJ101/ADEN MODIFICATION AND GENERAL ELECTRIC SUPPORT OF FLIGHT TEST PROGRAM (1978 DOLLARS)

| | |
|---|---|
| DETAIL DESIGN | $ 514,000 |
| HARDWARE FABRICATION, INSTRUMENTATION, ASSEMBLY (THREE) | 2,696,000 |
| CONTROL & ACTUATION HARDWARE | 286,000 |
| VERIFICATION TESTING | 310,000 |
| FUEL | 32,000 |
| PROGRAM MANAGEMENT & REPORTS | 324,000 |
| PREFLIGHT TEST SUPPORT | 224,000 |
| FLIGHT TEST SUPPORT | 279,000 |
| TOTAL | $4,665,000 |

Table 9 shows the estimated cost breakdown for the Northrop program represented in Figure 85 for the design, development, modification and fabrication required to alter the YF-17 aircraft, as well as flight test support. Breakdowns are presented for the configuration with and without canard. If restoration of the YF-17 to its original state is deemed necessary at the end of the YF-17/ADEN flight test program, an additional cost of $551,000 would be incurred for the canard configuration. $53,000 would be required to restore the aircraft without canard.

TABLE 9. COST OF YF-17 AIRFRAME MODIFICATION AND NORTHROP SUPPORT OF FLIGHT TEST PROGRAM (1978 DOLLARS)

| | WITH CANARD | WITHOUT CANARD |
|---|---|---|
| CANARD DES., FAB., INSTL., & FWD FUS. MOD. | 2,140,000 | – |
| CONTROL SYSTEM MODIFICATION | 1,897,000 | 1,306,000 |
| AFT FUSELAGE MOD. | 1,701,000 | 1,701,000 |
| TRANSPORTATION | 97,000 | 97,000 |
| FACILITIES | 34,000 | 34,000 |
| FLIGHT TEST SUPPORT | 146,000 | 146,000 |
| PROGRAM MANAGEMENT AND REPORTS | 310,000 | 310,000 |
| TOTAL | 6,325,000 | 3,594,000 |

Summing the totals of Tables 8 and 9, the total cost directly chargeable to the YF-17/ADEN 2-D nozzle flight demonstration program is therefore projected to be 11.0 million dollars for the YF-17/ADEN with canard, and 8.3 million dollars if the canard is not included as part of the design.

The cost of the engine refurbishment program presented in Figure 79 is shown in Table 10.

TABLE 10. COST OF G.E. YJ101 ENGINE REFURBISHMENT (1978 DOLLARS)

| | |
|---|---|
| ENGINEERING | $ 190,000 |
| HARDWARE | 2,502,000 |
| TOOLS | 516,000 |
| INSTRUMENTATION | 122,000 |
| TEARDOWN, INSPECTION, REPAIR, ASSEMBLY, CHECKOUT | 1,608,000 |
| TOTAL | $4,938,000 |

Adding the cost of the separately funded engine refurbishment program, the total cost to accomplish the YF-17/ADEN program is estimated at 16.2 million dollars with canard, and 14.0 million dollars without canard.

## CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be derived as a result of this study:

- Modification of the YF-17 to incorporate ADEN nozzles and canards has been established as a timely, low risk effort, due in particular to the advanced state of development of the ADEN nozzle for the YJ101 engine, and considerable preliminary development work which shows the required changes to the aircraft structure and control system to be straightforward in nature. The time to accomplish the required modifications is estimated to be 27 months from go-ahead, followed by a 12 month flight research program.

- The cost to accomplish the modification and perform a flight research program on the YF-17/ADEN/canard configuration, including refurbishment of three YJ101 engines, is estimated to be 15.9 million dollars. This price is significantly lower than estimates advanced for other 2-D technology manned flight demonstrators.

- The integration of the ADEN nozzle design into the YF-17 aircraft produces negligible thrust-minus-drag improvements over the already low drag dual axisymmetric design. The minor thrust-minus-drag differences are not sufficient to offset the weight penalty of the ADEN nozzles, and as a result aircraft performance, in terms of cruise range, acceleration, and climb performance, is reduced.

- Analysis has established that the incorporation of the ADEN thrust vectoring capability into the YF-17 with deflecting canards available will produce some modest returns in terms of direct lift generation, aircraft pointing capability, and takeoff/landing ground roll reduction. A noteworthy increase in pitch control at low dynamic pressure is also available. It should be recognized that the capability offered with the ADEN and canard has been defined through analysis of several preconceived modes of aircraft operation and quantified according to classical energy maneuverability parameters; it may eventually be discovered that these new sources of lift production and attitude control may find their best application in as-yet-unconceived maneuvers and tactics, unavailable to conventional fighters, that will be discovered only through manned flight investigation on the modified YF-17.

- With the incorporation of a thrust reverser, the versatility of the aircraft during combat maneuvering will be further enhanced, and the capability will exist for significantly reducing the landing roll distance.
- Conclusions regarding IR and RCS characteristics are presented in Volume II of this report; for convenience it will be briefly stated here that the ADEN nozzle integration should offer improved aircraft survivability against both IR and RCS threats through a combination of signature reduction and aircraft maneuverability. The IR analysis indicates that the total hot plume radiation is reduced, that the signature is greatly reduced in most of the upper hemisphere, and that the lower hemisphere signature can be maintained equal to conventional axisymmetric nozzles with adequate cooling.

A number of recommendations can be made with regard to follow-on effort in this program:

- It is recommended that the YF-17/ADEN modification program be pursued. The program offers an excellent and economical opportunity to gain experience in the practical aspects of implementing 2-D nozzle technology, and will provide a unique manned flight research vehicle for the investigation and evaluation of expanded maneuver capability, improvements in takeoff and landing performance, and IR/RCS signature reductions available through the proposed modifications.
- In settling on a final configuration, the canard-configured aircraft, although more expensive, is recommended as the preferable design in that thrust vectoring STOL benefits and in-flight thrust vectoring air combat tactics could be quantified at a relatively small increase in program cost.
- Incorporation of a thrust reverser into the ADEN design is also recommended for the additional contribution it provides to combat maneuverability and landing performance. In-flight reversing has long been a candidate for flight research.
- During the development testing planned for the follow-on phase, attention should be directed toward expansion of the canard-configured YF-17 aerodynamic data

base such that the canard design can be better integrated into the existing YF-17 configuration.

- An area that appears to offer considerable potential for development of innovative concepts is the design and application of the aircraft control system for expanded maneuver capability. Results of this study have indicated a number of subjects that should be considered for follow-on investigation; i. e., optimization of the control system loops, feedbacks, and gains utilized in the thrust vectoring and reversing modes, wing lift cancellation to amplify pointing capability, and potential untrimmed transient aircraft maneuvers, to name several.

- Pending go-ahead for the follow-on phase defined in Section 4, it is felt that some near-term activity would be advisable to sustain investigative momentum in areas related to this program. In this way, a valuable lead-in is provided to the program of Section 4 while further strengthening the technical foundations upon which the proposed modification plan will rest. Several subjects suggest themselves for immediate follow-on investigation:

  - Expansion of the canard aerodynamic data base to optimize the canard approach on the YF-17/ADEN.

  - Further development and quantification of maneuver capability available with thrust vectoring and canards; one-on-one simulation to determine how it can be applied to combat tactics.

  - Optimization of the modified pitch control system.

  - Preliminary design of the block-and-turn thrust reverser concept; identification of the aerodynamic effects of ADEN thrust reversing through testing on the 0.10 scale F-18 model.

## APPENDIX A

## METHOD FOR MODIFYING YF-17 PITCH CAS FOR ADEN AND CANARD

The objective of this analysis was to design control modes that would exercise the potential degrees of freedom available with the addition of the Aden nozzle and canard control to the YF-17. Lift without rotation and rotation without lifting were the major degrees of freedom to be investigated. In addition, a drag mode and an "identical YF-17 mode" were to be designed. The desire was to have a feasibility demonstration rather than a full aircraft design.

Aerodynamics. Two flight conditions were analyzed. Linearized aero data at M = 0.9, H = 4572 M (15,000 ft.) and M = 1.2, H = 9140 M (30,000 ft.) were utilized The equations were put into the state variable form:

$$\dot{X} = AX + BU$$

where for M = 0.9 H = 15,000 ft.

$$A = \begin{bmatrix} -0.1420E-01 & 0.4990E-01 & -0.3414E+00 & -0.5618E+00 \\ -0.8520E-01 & 0.2373E+01 & 0.1638E+02 & -0.1770E-01 \\ -0.2280E-01 & 0.1014E+01 & -0.1871E+01 & 0.8000E-03 \\ 0.0 & 0.0 & 0.1000E+01 & 0.0 \end{bmatrix}$$

$$B = \begin{bmatrix} 0.1207E+00 & -0.1512E+00 & 0.0 \\ -0.5789E+01 & -0.7233E+00 & 0.0 \\ -0.3796E+02 & -0.5702+01 & 0.1754E+02 \\ 0.0 & 0.0 & 0.0 \end{bmatrix}$$

For M = 1.2 H = 30,000 ft.

$$A = \begin{bmatrix} -0.1850D-01 & -0.2630D-01 & -0.2153D+00 & -0.5619D+00 \\ -0.1640D-01 & -0.1463D+01 & -0.2087D+02 & -0.5900D-02 \\ -0.1930D-01 & -0.1149D+01 & -0.1755D+01 & 0.3000-03 \\ 0.0 & 0.0 & 0.1000D+01 & 0.0 \end{bmatrix}$$

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$$B = \begin{bmatrix} 0.5000D-01 & -0.8931D-01 & 0.0 \\ -0.4850D+01 & -0.5895D+00 & 0.0 \\ -0.3380D+02 & -0.3997+01 & 0.1650D+02 \\ 0.0 & 0.0 & 0.0 \end{bmatrix}$$

The state and control variables are:

$$\bar{x}^T = [u, w, \dot{\theta}\ \theta] \quad \bar{u}^T = [\delta_e, \delta_p, \delta_c]$$

Control Modes. Five modes of flight were designed for the modified aircraft.

In the NORMAL MODE, the nozzle is not deflected. The canard is used to restore the normal YF-17 flying qualities. Artificial $M_\alpha$ is generated by the canard to compensate for that lost by adding the canard.

In the LIFT MODE, the nozzle, elevator, and canard are deflected to generate lift without rotating the aircraft.

In the POINTING MODE, the nozzle, elevator and canard are deflected to rotate the aircraft without changing the lift.

In the DRAG MODE, the nozzle, elevator and canard are deflected to increase the drag without rotating or changing the lift of the aircraft.

In the COMBINED MODE, a linear combination of the LIFT MODE and the POINTING MODE is commanded. Its purpose is to fly the airplane so that the LIFT, POINTING, and DRAG MODES can be perturbation modes.

Figures 22-24, Section 2, diagram the revised aircraft-control system.

Actuator Dynamics. The canard actuator dynamics were selected to be equal to the horizontal dynamics. The dynamics is approximated by a first order system $-\frac{30.3}{S+30.3}$. VEER dynamics of $\frac{30.3}{S+30.2}$ was selected. Slower VEER dynamics would cause minor degradation in decoupling control.

Axis Decoupling Methods. Falb and Wolovich (Reference ) have given the necessary and sufficient conditions for decoupling a multivariate system. The linearized plant represented by the equations

$$\dot{\bar{x}} = A\,\bar{x} + B\,\bar{u}$$

$$\bar{y} = C\,\bar{x}$$

can be decoupled if and only if the matrix B* is nonsingular:

$$B^* = \begin{bmatrix} C_1 \ A^{d1} \ B \\ C_2 \ A^{d2} \ B \\ \vdots \\ C_m \ A^{d_m} \ B \end{bmatrix}$$

where: $\bar{x}$ = n vector called the state

$\bar{u}$ = m vector called the control (or input)

$\bar{y}$ = n vector called the output

A = n x n matrix

B = n x m matrix

C = m x n matrix

The integers $d_i, \ldots d_m$ are defined by

$$d_i = \min \{j = 1, \ldots n-1 \text{ such that } C_i A^j B \neq 0\},$$

or $d_i = n-1$ if $C_i A^u B = 0$ for all j, where $C_i$ is the $i^{th}$ row of C and $A^j$ is the $j^{th}$ power of the matrix A.

A fundamental result is that the system can be decoupled by a pair of matrices F* and G* whenever

$$B^* = \begin{bmatrix} C_1 \ A^{d1} \ B \\ C_2 \ A^{d2} \ B \\ \vdots \\ C_m \ A^{d_m} \ B \end{bmatrix}$$

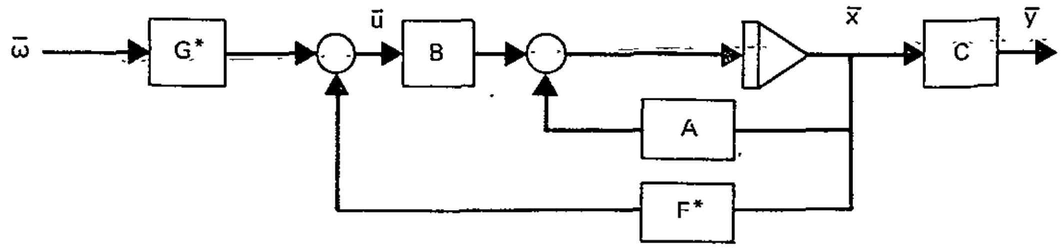
is nonsingular. Furthermore, the decoupling pair F* and G* can be taken to be

$$F^* = -B^{*-1} B^*$$

$$G^* = B^{*-1}$$

$$A^* = \begin{bmatrix} C_1 \ A^{d1} +1 \\ \vdots \\ C_m \ A^{d_m} +1 \end{bmatrix}$$

The Matrix Block diagram of the decoupled system becomes:




DECOUPLING PROCEDURE

The decoupling procedure was accomplished as follows:

1. The aircraft description was converted into state variable form with U, W, $\dot{\theta}$ and $\theta$ being the state variables.
2. The coordinates were rotated so that the new state variables were U, $V_Y$, $\dot{\theta}$ and $\theta$.
3. The elevator and nozzle were slaved together to act as one control and the canard was separate. The outputs to be decoupled were defined to be $V_Y$ and $\theta$.
4. The decoupling program was run and the actuators were added and the feedback and input matrices were added to the system.
5. Dynamics were added to the lift and rotation modes by adding feedback from the mode outputs to the mode inputs.
6. All the feedbacks were reduced to their lowest form.

The resulting control laws are as follows:

M = 0.9 H = 4572M (15K)

Feedback

$$\delta_e = +0.0788\, w - 0.135\dot{\theta} - 6.57\theta$$

$$\delta_p = 3.0\, \delta_e$$

$$\delta_c = +0.196\, w - 0.782\dot{\theta} - 22.45\theta$$

Feed Fwd

$$\begin{bmatrix} \delta_e \\ \delta_c \end{bmatrix} = \begin{bmatrix} 0.1256 & 0. \\ 0.3961 & 0.0570 \end{bmatrix} \begin{bmatrix} \delta L_C \\ \delta Rot_C \end{bmatrix}$$

$$\delta_p = 3.0\, \delta_e$$

$M = 1.2$ $\quad\quad$ $H = 9140M$ (30K)

Feedback

$$\delta_e = 0.232\, w + 0.2515\dot{\theta} - 8.703\theta$$

$$\delta_p = 3.0\, \delta_e$$

$$\delta_c = 0.7138\, w + 5.01\dot{\theta} - 25.35\theta$$

Feed Fwd

$$\begin{bmatrix} \delta_e \\ \delta_c \end{bmatrix} = \begin{bmatrix} 0.1511 & 0 \\ 0.4191 & 0.06061 \end{bmatrix} \begin{bmatrix} \delta L_C \\ \delta Rot_C \end{bmatrix}$$

$$\delta_p = 3.0\, \delta_e$$

## APPENDIX B

## LAYOUT DRAWINGS

Contained herein are layout drawings for the following revisions to the YF-17 structure:



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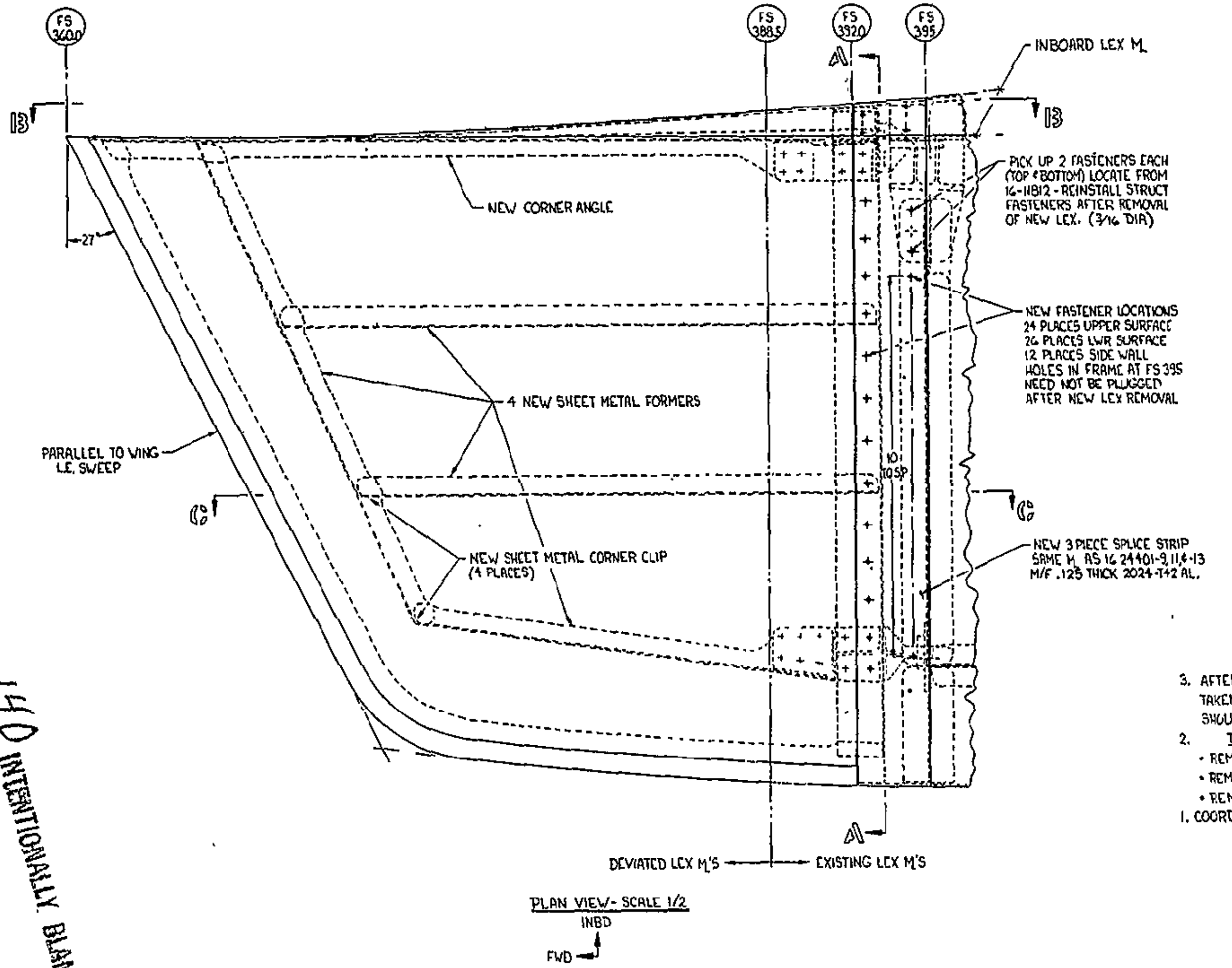


3. AFTER REMOVAL OF EXISTING LEX CARE SHOULD BE TAKEN IN PROVIDING PROPER STORAGE. COST ESTIMATE SHOULD INCLUDE A PROTECTIVE STORAGE CRATE.
2. <u>TO REMOVE EXISTING LEX</u>
   - REMOVE SHEAR BOLT @ FS 395.0
   - REMOVE 36 SCREWS ATTACHING AFT FAIRING STRIP
   - REMOVE 8 BOLTS ATTACHING LEX TO FUSELAGE
1. COORDINATE WITH L/O AD 6455

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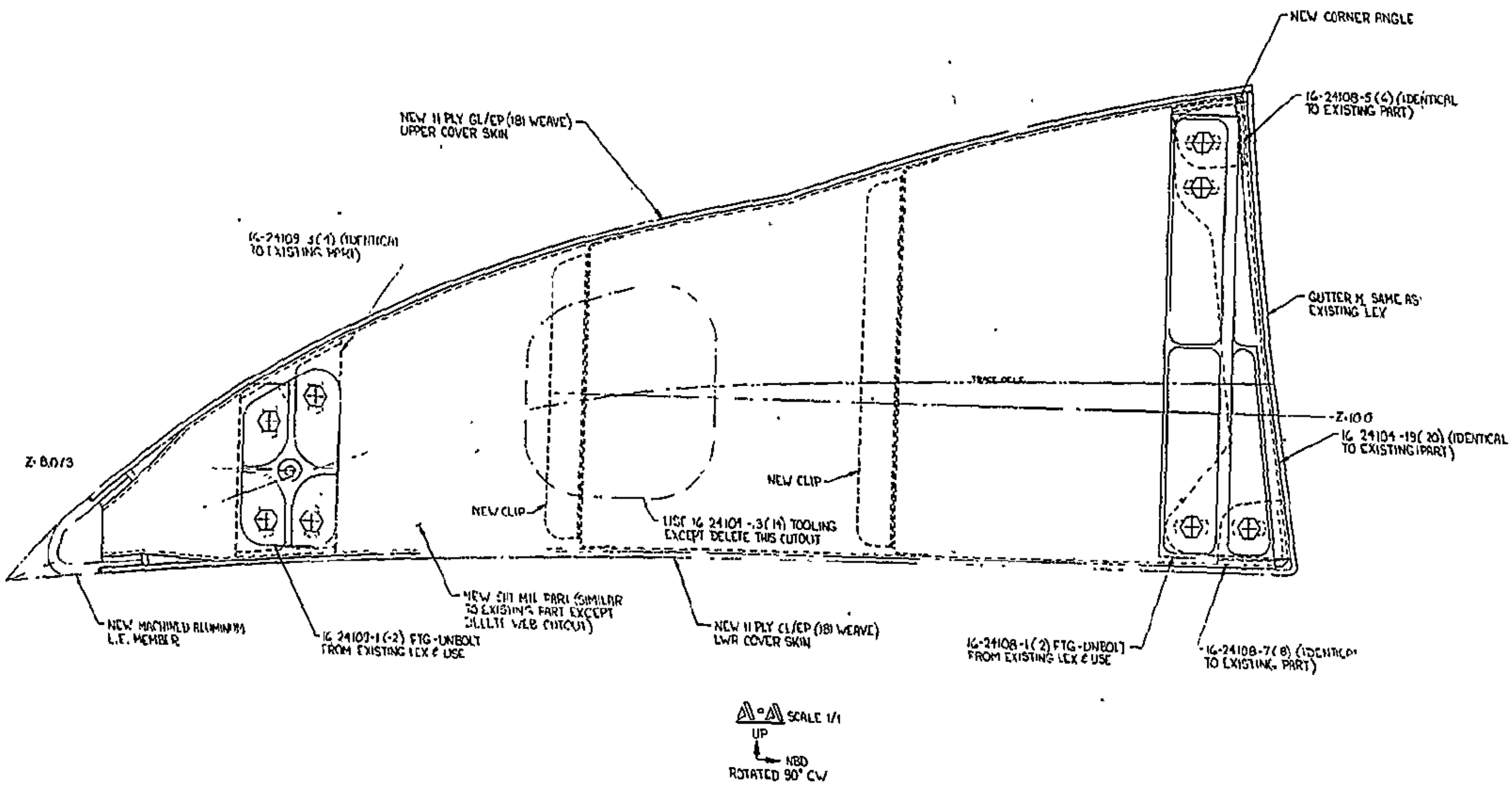
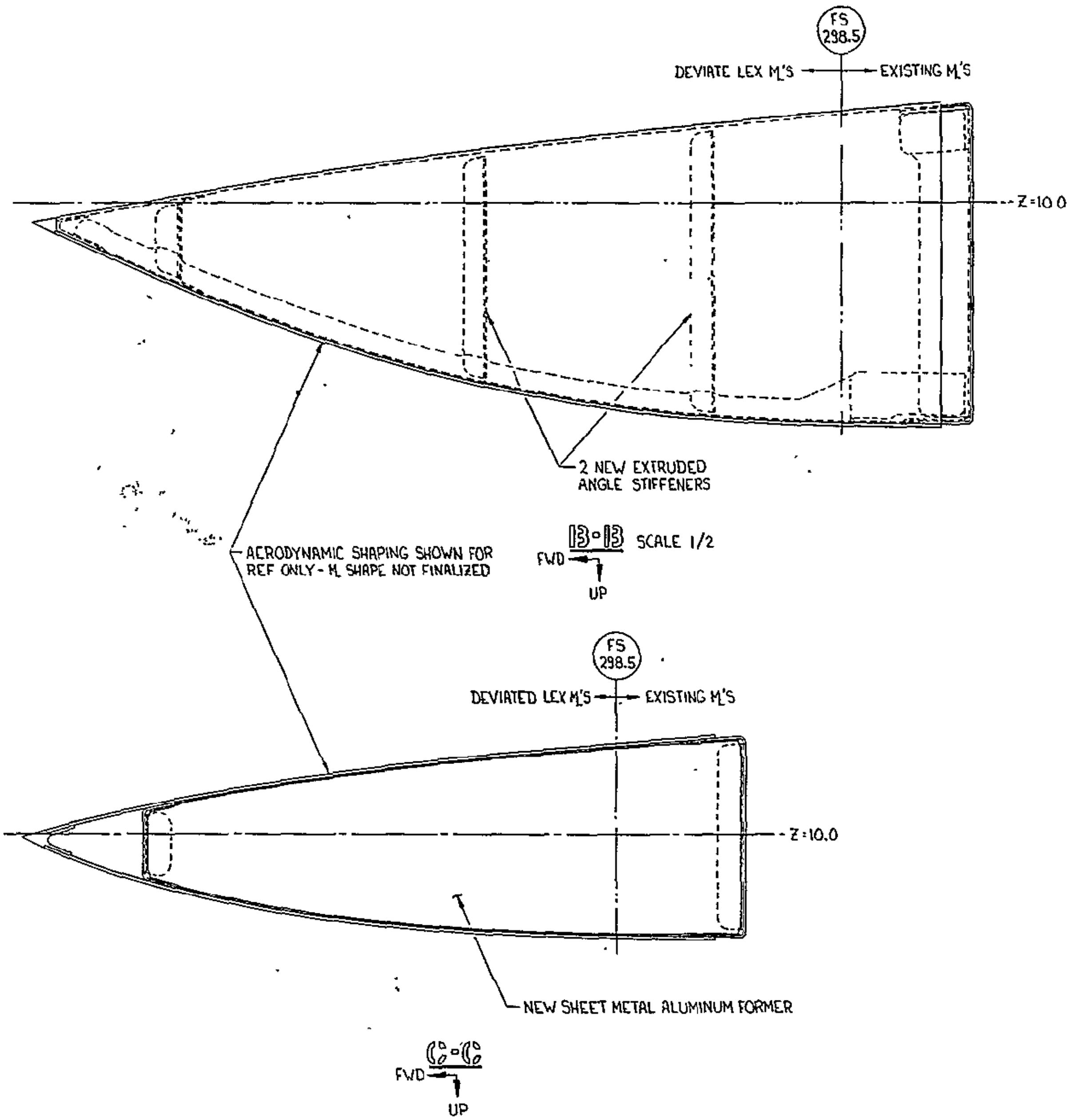
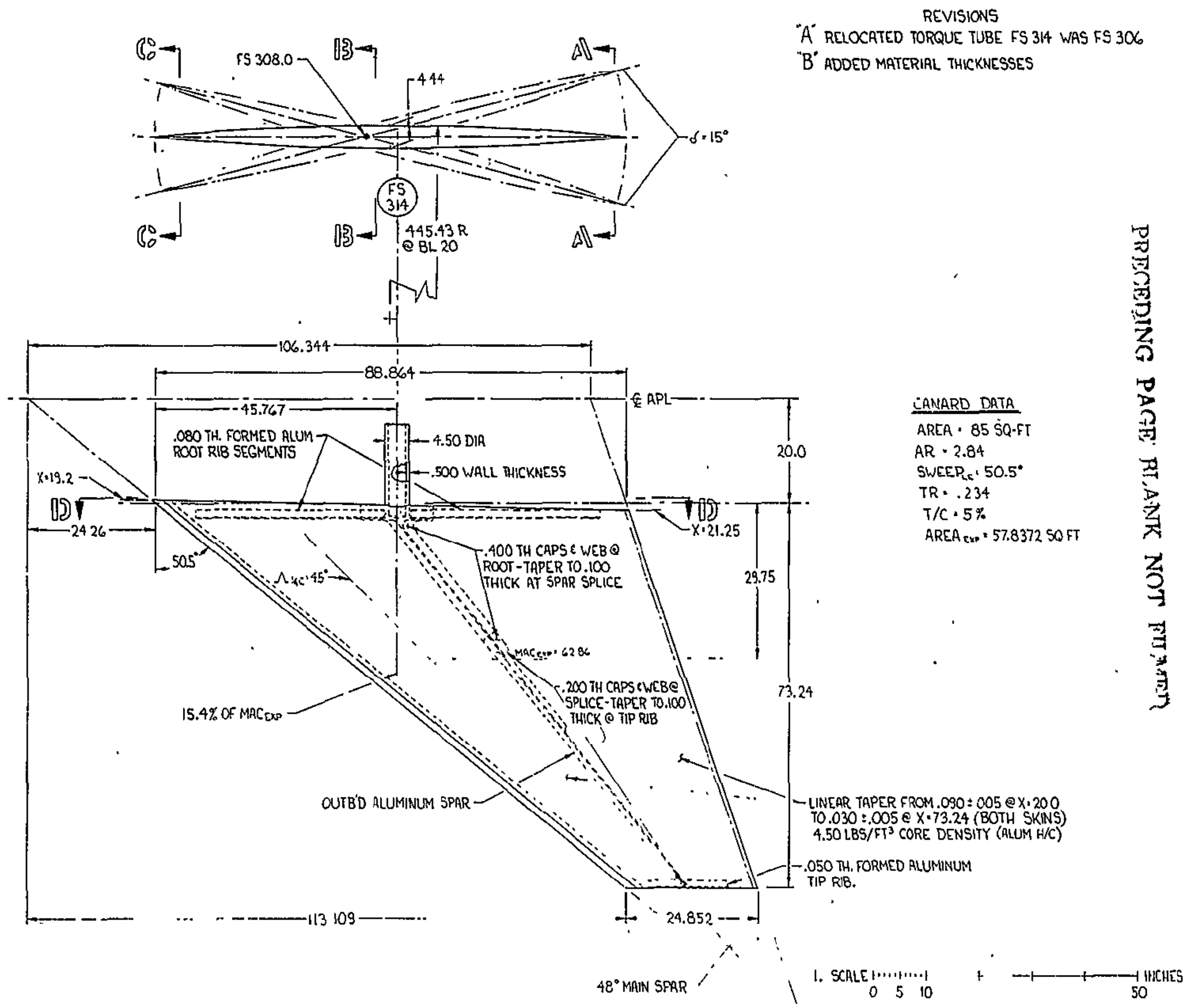
WING ROOT FAIRING (REVISED LEX) (PAGE 1 OF 3)



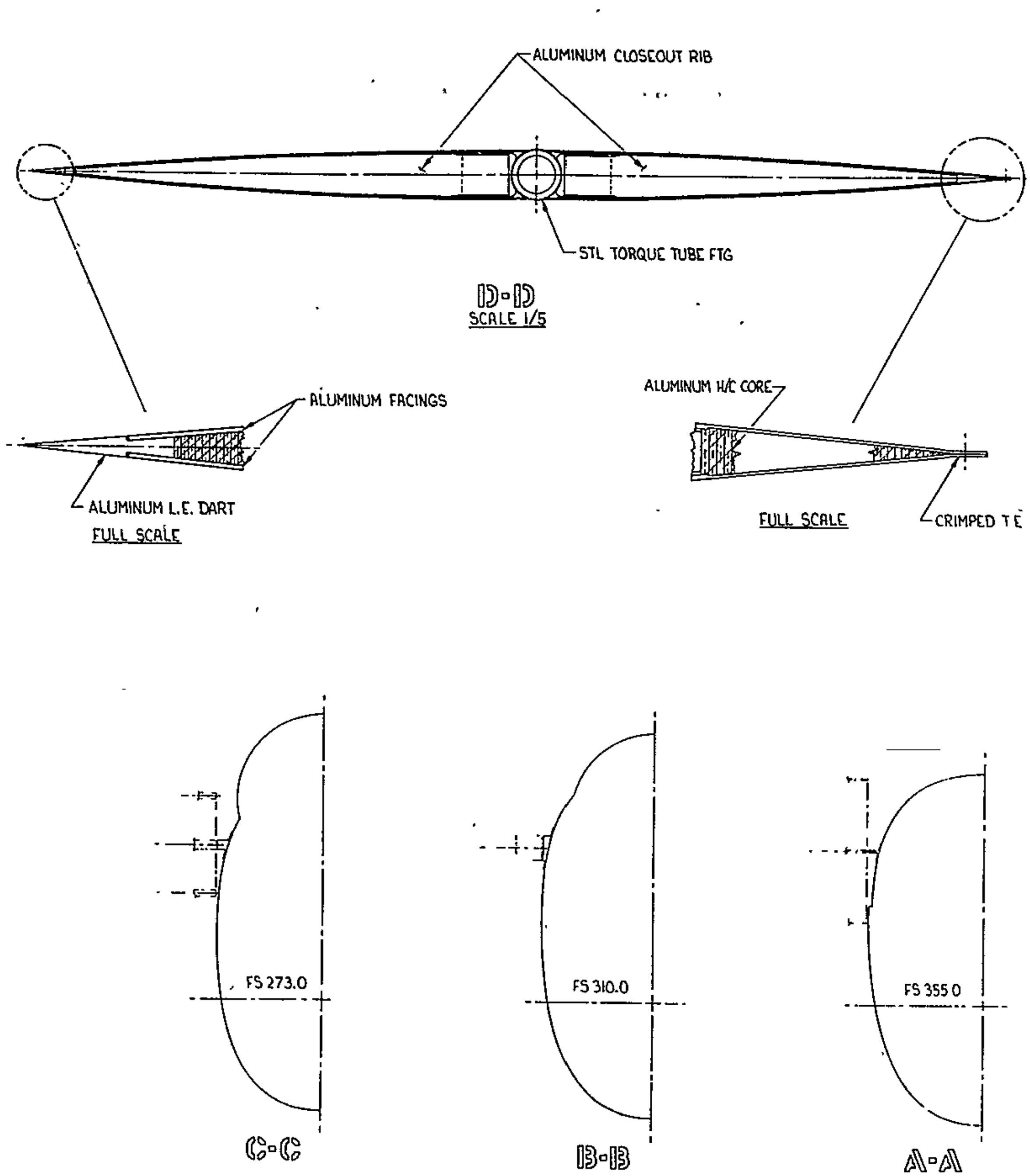

WING ROOT FAIRING (REVISED LEX) (PAGE 2 OF 3)



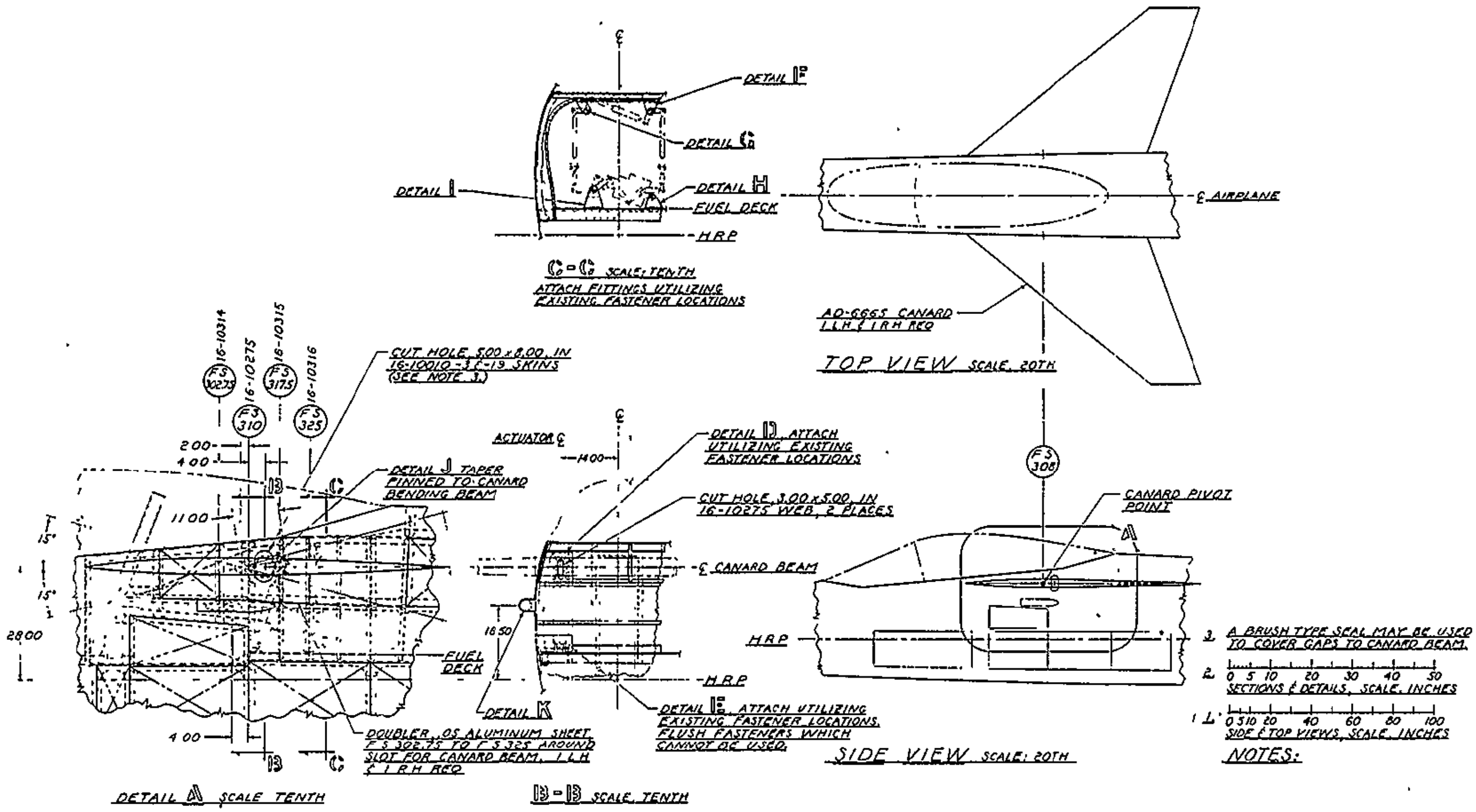

WING ROOT FAIRING (REVISED LEX) (PAGE 3 OF 3)




CANARD (PAGE 1 OF 2)

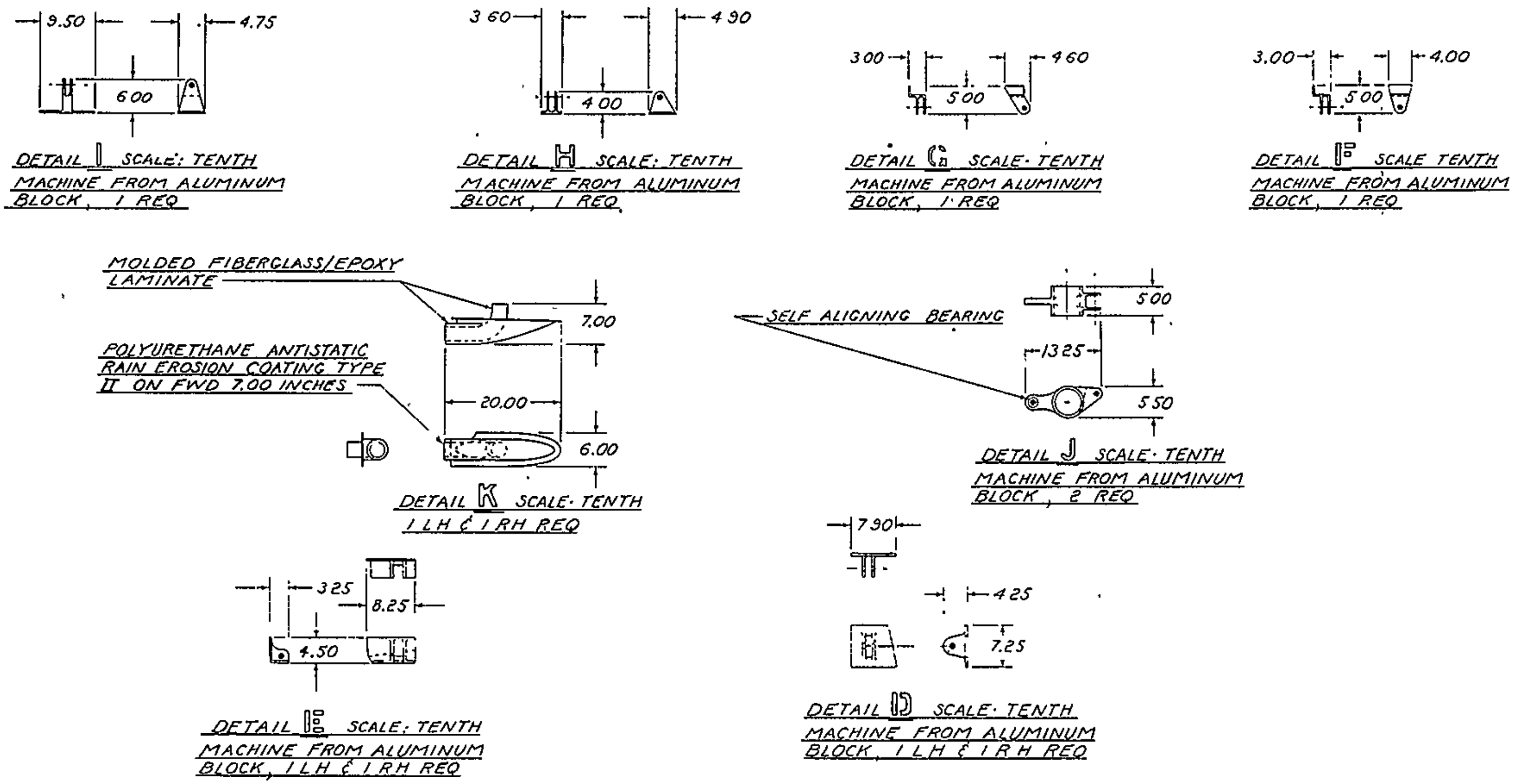



CANARD (PAGE 2 OF 2)

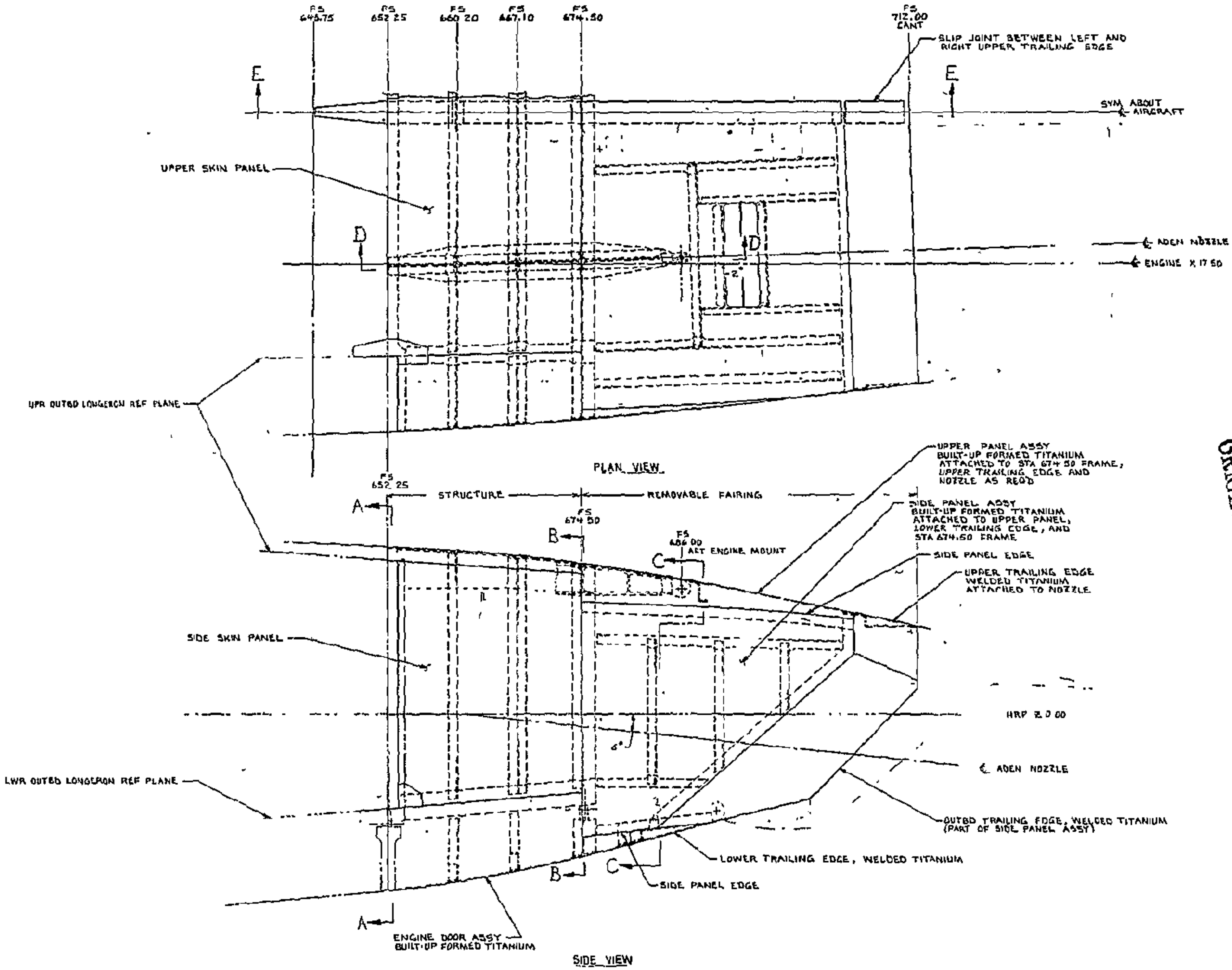





FORWARD FUSELAGE STRUCTURAL REVISIONS (PAGE 1 OF 2)

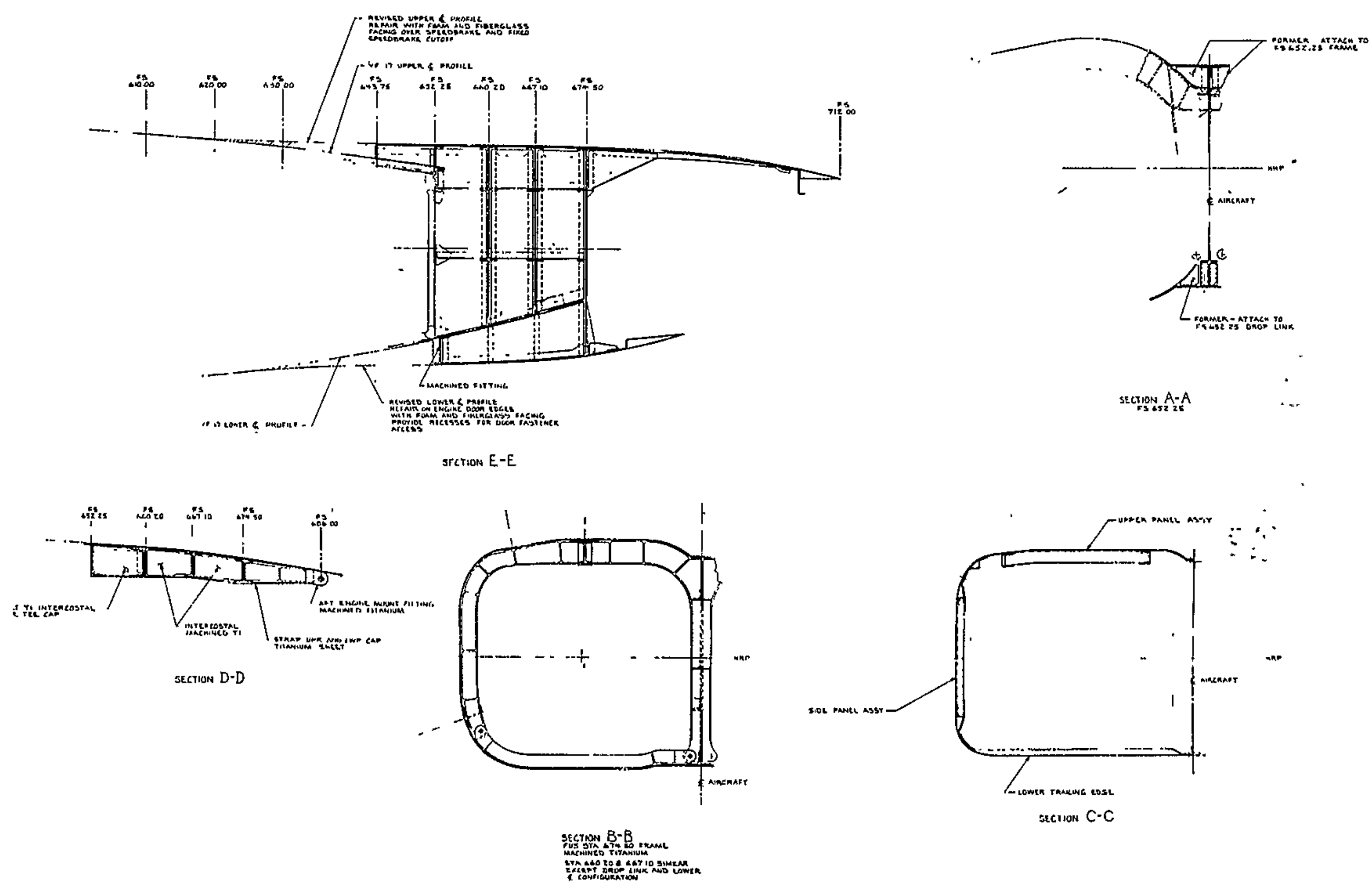



FORWARD FUSELAGE STRUCTURAL REVISIONS (PAGE 2 OF 2)

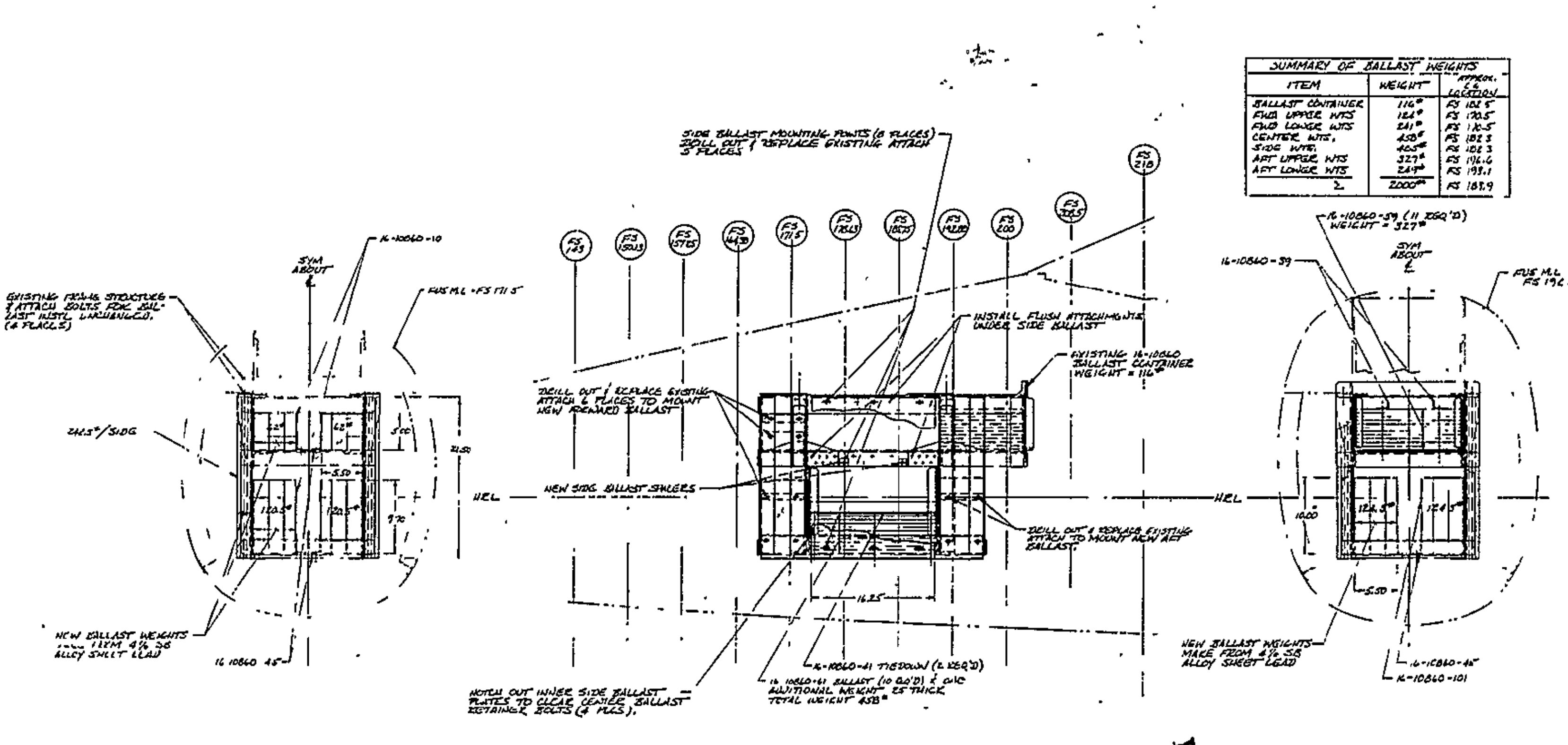





AFT FUSELAGE STRUCTURAL REVISIONS (PAGE 1 OF 2)




AFT FUSELAGE STRUCTURAL REVISIONS (PAGE 2 OF 2)




**SUMMARY OF BALLAST WEIGHTS**

| ITEM | WEIGHT | APPROX. C.G. LOCATION |
|---|---|---|
| BALLAST CONTAINER | 116# | FS 182.5 |
| FWD UPPER WTS | 124# | FS 170.5 |
| FWD LOWER WTS | 241# | FS 170.5 |
| CENTER WTS. | 450# | FS 182.3 |
| SIDE WTS. | 465# | FS 182.3 |
| AFT UPPER WTS | 327# | FS 196.6 |
| AFT LOWER WTS | 249# | FS 193.1 |
| Σ | 2000# | FS 183.9 |

VIEW LOOKING INBOARD AT LEFT SLUG

BALLAST INSTALLATION

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|---|---|---|
| 1. Report No<br>NASA CR-144882 | 2. Government Accession No. | 3. Recipient's Catalog No. |
| 4. Title and Subtitle<br>YF-17/ADEN System Study | | 5. Report Date<br>July 1979 |
| | | 6. Performing Organization Code |
| 7 Author(s)<br>N. S. Gowadia and W. D. Bard (Northrop Corp.) and W. H. Wooten (General Electric Co.) | | 8. Performing Organization Report No. |
| | | 10 Work Unit No. |
| 9. Performing Organization Name and Address<br>Northrop Corporation<br>3901 West Broadway<br>Hawthorne, Calif. 90250 | | 11. Contract or Grant No<br>NAS4-2499 |
| 12. Sponsoring Agency Name and Address<br>National Aeronautics and Space Administration<br>Washington, D.C. 20546 | | 13. Type of Report and Period Covered<br>Contractor Report - Final |
| | | 14 Sponsoring Agency Code |

15. Supplementary Notes

NASA Technical Monitor: Frank V. Olinger, Dryden Flight Research Center

This report covers the unclassified portion of the YF-17/ADEN study. The classified portion, which deals with infra-red/radar cross-section (IR/RCS) data, is reported in NASA CR-144883.

16. Abstract

The objective of this study was to evaluate the YF-17 aircraft as a candidate nonaxisymmetric nozzle flight demonstrator. This report summarizes (1) configuration design modifications, (2) control system design, (3) flight performance assessment, and (4) program plan and cost.

Two aircraft configurations were studied. The first was modified as required to install only the augmented deflector exhaust nozzle (ADEN). The second one added a canard installation to take advantage of the full (up to 20°) nozzle vectoring capability. Results indicated that: (1) the program is feasible and can be accomplished at reasonable cost and low risk; (2) installation of ADEN increases the aircraft weight by 600 kg (1325 lb); (3) the control system can be modified to accomplish direct lift, pointing capability, variable static margin and deceleration modes of operation; (4) unvectored thrust-minus-drag is similar to the baseline YF-17; and (5) vectoring does not improve maneuvering performance. However, some potential benefits in direct lift, aircraft pointing, handling at low dynamic pressure and takeoff/landing ground roll are available. A 27 month program with 12 months of flight test is envisioned, with the cost estimated to be $15.9 million for the canard-equipped aircraft and $13.2 million for the version without canard.

The feasibility of adding a thrust reverser to the YF-17/ADEN was also studied.

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| 17. Key Words (Suggested by Author(s))<br>Propulsion<br>Nonaxisymmetric nozzles<br>Airframe integration | 18. Distribution Statement<br>Unclassified - Unlimited |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22 Price* |
|---|---|---|---|
| Unclassified | Unclassified | 172 | $6.25 |

*For sale by the National Technical Information Service, Springfield, Virginia 22161*