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Final Report

FEASIBILITY STUDY OF AN F-106 AIRCRAFT FOR STOL FLIGHT RESEARCH

Prepared under Contract NAS 4-2554 by
The Boeing Company

June 1980

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National Aeronautics and
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H. L. Dryden Flight Research Center
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The objective of this program was to study key aspects of the feasibility of using a NASA F-106 aircraft as a vehicle for accomplishing research into technologies appropriate to STOL (short take off and landing) capability for typical military tactical aircraft. The study expanded upon a previous NASA-funded study of the same aircraft as a promising configuration for two-dimensional nozzle flight research.
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Approved: Mark B. Sussman Date: 7-15-80

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Program Manager

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A/B	Afterburner
a.c.	Aerodynamic center
ADEN	Aerodynamic Deflector Exhaust Nozzle
ADG	Accessory Drive Gearbox
ALT	Altitude
APU	Auxilliary Power Unit
AR	Nozzle Aspect Ratio
B.L.	Buttock Line
C	Chord
C_D	Drag Coefficient
C_{f_g}	Thrust Coefficent
c.g.	Center of gravity
C_ℓ	Rolling Moment Coefficient
C_L	Lift coefficient
C_y	Side force coefficient
$\bar{C}_R$	Rudder chord
$\bar{C}_V$	Vertical tail chord
C_V	Nozzle velocity coefficient
$\bar{C}_W$	Wing chord
DH	Double hinge
EFCS	Elecronic Flight Controls System
F_G	Gross thrust
F_N	Net thrust
F_{RAM}	Ram drag
F.S.	Fuselage Station
g	Force of gravity
GE	General Electric Company
gal/min	Gallons per minute
GW	Gross weight
h	Aircraft altitude
hp	Pressure elevation of runway
h/c	Height-to-chord ratio
Hp	Horsepower
HEP	Hydraulic elevon control
IAS	Indicated air speed
IMS	Integrated Mean Slope

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kcas	Knots corrected air speed
KEAS	Knots equivalent air speed
K_{int}	Wing/Canard interference factor
kn	Knots
KSI	Kilopounds per square inch
kVa	Kilovoltampere
LEc	Leading edge mean aerodynamic chord
M	Mach number
MAC	Mean Aerodynamic Chord
M/B	Missile bay
n	Load factor
NASA	National Aeronautics and Space Administration
nmi	Nautical miles
NPR	Nozzle pressure ratio
P.D.	Preliminary design
PS	Engine power setting
PTO	Power takeoff
P_{T3}/P_{T2}	Compressor pressure ratio
q	Freestream dynamic pressure
QSRA	Quiet Shorthaul Research Aircraft
RALS	Remote Augmented Lift System
S_C	Canard area
SFC	Specific fuel consumption
SH	Single hinge
SLS	Sea level static
STOL	Short takeoff and landing
S_W	Wing area
T-D	Thrust-minus-drag
T.E.	Trailing edge
TOGW	Takeoff gross weight
T_8	Exhaust gas temperature
V_H	Structural high speed
V_L	Structural limit speed
V_R	Restricted speed maximum maneuver
V_S	Stall speed

VSCF	Variable speed constant frequency
V_T	Vertical tail
$\overline{V}_v$	Vertical tail volume
W	Aircraft weight
α	Angle-of-attack
β	Sideslip angle
δ	Elevon authority
δ_A	Aileron deflection angle
δ_{AL}	Left aileron deflection angle
δ_{AR}	Right aileron deflection angle
δ_C	Canard deflection angle
δ_e	Elevon deflection angle
δ_H	Horizontal tail deflection angle
δ_N	Nozzle deflection angle
δ_R	Rudder deflection angle
$\delta_{R_{MAX}}$	Maximum rudder deflection angle
δ_V	Thrust deflection angle
η	Spanwise coordinate
θ	Thrust deflection angle
Λ	Sweep angle
Λ_{HL}	Sweep angle at hinge line (deg)
$\Lambda_{HL_{RUD}}$	Sweep angle at hinge line, rudder (deg)
μ	Braking coefficient
ℓ_N	Nozzle moment arm
ℓ_v	Rudder moment arm
ϕ	Bank angle

1.0 SUMMARY

Boeing has completed under Phase 1 of NASA Contract NAS4-2554, a feasibility study of the F-106 aircraft as a research vehicle for flight test evaluation of advanced non-axisymmetric nozzle concepts (see Reference 3.2A.3-8). This document describes the Phase 2 studies to extend the prior work by evaluating the feasibility of the F-106 to accomplish STOL research tasks.

The increased sophistication of the enemy threat necessitates increased capabilities of an advanced strike aircraft both at the airfield and over hostile territory. This advanced aircraft must be capable of taking off and landing at a base which has been attacked, where in effect the runway length has been shortened and the surface degraded. To be more survivable during penetration, it must retain the ability to fly at supersonic speeds with reduced detectability in order to avoid more sophisticated threats and maintain cost effectiveness as a weapon system.

Improving the STOL capabilities of a supersonic design point airplane imposes more stringent requirements on the propulsive, aerodynamic, structural and flight control systems of advanced aircraft. In consequence, the aircraft designer faces a need for a validated data base upon which to evolve designs to minimize takeoff and touchdown speeds while accommodating high speed constraints. The objective of the current program was to analyze and establish the feasibility of several F-106 configuration modifications for innovative airframe/powerplant integration which could allow research of key advanced technologies required for short takeoff and landing capability.

Since the basic F-106 aircraft was not designed for STOL, modifications are required to achieve the higher usable lift coefficients and increased propulsion capabilities required for STOL operation. These changes to the aircraft were conceptually designed and evaluated for controllability in flight, aerodynamic feasibility, structural adequacy, and the suitability and affordability to research probable STOL features of an advanced

aircraft. Design features considered included: high vector angle nozzles, increased control surface sizes and sophistication, effective reverse thrust, specially designed landing gear modifications and others. Since funding was limited, the intent of the study was not to accomplish a complete preliminary design and analysis, but rather to explore the feasibility of several potential modification concepts. In addition, planning estimates of program costs and schedules were developed.

To support the feasibility investigation, four* candidate F-106 modifications differing in powerplant integration, aerodynamic and configurational characteristics were selected from an initial group of 8, with NASA concurrence, for evaluation. All configurations assumed use of the GE F-404 engine and the two-dimensional, aerodynamic deflector exhaust nozzle (ADEN). These are described briefly below:

- Modification #1 incorporated underwing, pod-mounted engines and a forward fuselage canard to balance trimming of thrust vectoring. The nozzles were located at the wing trailing edge for best development of wing-induced lift.

- Modification #3 incorporated a special wing root insert which accommodated each engine pod such that nozzle vectoring forces could be located close to the aircraft center of gravity. An aft horizontal tail was added for trim.

- Modification #5 incorporated twin engine pods located at the base of the vertical tail. The nozzles are positioned well to the aft of the vehicle to provide large moment arms for vectoring moments. The intent is that the nozzles replace the elevons for pitch control, thus enabling the elevons to be optimally deployed as flaps for increased aerodynamic lift.

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* One additional configuration was added to the three required by the contract.

- Modification #7 incorporated overwing, pod-mounted engines and a forward fuselage nose jet or Remote Augmented Lift System (RALS) for trim of thrust vectoring. The RALS system uses engine fan air to establish a secondary thrust force for trim which is essentially independent of aircraft "q" (flight speed).

Based on preliminary design analysis and formulation of representative flight test programs for each study configuration, the following major conclusions were drawn concerning program feasibility and scope:

(1) A modified F-106B, with thrust reverse, reasonably improved braking capability and some automation to effect short braking and thrust reverse actuation times was shown to be capable of achieving a 1000 foot landing roll if approach speeds could be reduced to the range of 120 to 130 knots. Achievement of this speed was selected as a design goal for the configuration modifications. Additionally, aircraft controllability for landing and taking off with one engine failed was taken as a design objective.

(2) Configuration modifications to enhance low speed capability and controllability were developed and analyzed to a preliminary design level to ensure the feasibility of: configuration operational compatibility; structural load paths; actuation and other mechanical systems; and weight and balance. The controllability in flight and the equilibrium airspeeds sustainable were then analyzed. The resulting capabilities and limiting factors for each of the configurations were determined to be:

<u>Modification #1</u>

Equilibrium flight speeds in the range 125-130 knots should be sustainable with 10 to 15 degrees of thrust vectoring at light gross weights with 3% static margin. If the aircraft could be satisfactorily operated at neutral stability, then airspeed could be reduced to about 120 knots with 15 to 20 degrees of thrust vectoring. Risk areas requiring further design and analysis to corroborate estimates made for the current study include: canard lift capability (with flap) and interference with the wing; ability to structurally integrate the 2880 lbs of nose ballast.

Modification #3

Equilibrium flight speeds in the range 130-135 knots should be sustainable with 20 to 25 degrees of thrust vectoring at 3% static margin. Risk areas requiring further design and analysis to corroborate estimates made for the current study include: horizontal tail lift capability which is limiting in pitch control; improved capability to reconcile the narrow range of configuration opportunities which satisfy engine-out lateral and directional control. In addition, this modification was analyzed for two quite different longitudinal wing locations with neither being completely satisfactory. It is likely that an intermediate location could yield better results.

Modification #5

Equilibrium flight speeds in the range 125-130 knots should be sustainable with about 30 degrees of upwards deflected nozzle in combination with 15 degrees of down elevon. This configuration proved to be the simplest design approach and introduced the fewest uncertainties. One risk area requiring further design and analysis is evaluation of failure modes and redundancy requirements on the nozzle actuation system which, for this concept, is functioning as the primary longitudinal flight control.

Modification #7

Equilibrium flight speeds in the range 110-120 knots should be sustainable with 15 to 25 degrees of thrust deflection. Risk areas requiring further design and analysis to corroborate estimates made for the current study include: location and operability of the RALS system at ground level without interference to adjacent structure or systems; detail design and implementation of the RALS assembly including the interface with the F-404 system. An attractive implementation concept for demonstration would be to leave the main F-404 engines intact and to power the RALS nozzle with a separate, dedicated engine housed in the fuselage. This approach is likely to be less expensive as well.

(3) Configuration modifications #1, 3, and 7 are each suited to evaluating the development and operation of two dimensional thrust vectoring nozzles and integration with their respective pitch trimming techniques, i.e. canard, aft horizontal tail and auxiliary nose jet (RALS). Thrust-induced lift would be best researched on modification #1, although some lesser levels of induced lift would be anticipated for the other modifications. All three configurations would establish the effects of vectoring on lateral and directional control as well. Configuration modification #5, in contrast, would enable research of the nozzle and its use as a primary aircraft control (pitch).

(4) A flight test program for any of the study configurations will be paced by the nonaxisymmetric nozzle development and engine integration. A moderately paced program including static and altitude cell testing of the engine/nozzle, and taxi and initial flightworthiness tests of the modified aircraft would require a maximum of 4-1/2 to 5-1/2 years prior to the first research flight depending on the study configuration. Probably this schedule could be improved upon since no effort was made to develop a minimum-flow-time schedule.

(5) Budgetary contractor costs for the total development program (engine and airframe manufacturer) were estimated parametrically. Costs varied between $30 million to $45 million depending on the study configuration. No effort was made in this preliminary evaluation to establish a minimum cost program. It is judged, however, that further evaluation could identify means to reduce the estimates given.

2.0 INTRODUCTION AND STUDY OVERVIEW

The objective of this program was to study key aspects of the feasibility of using a NASA F-106 aircraft as a vehicle for accomplishing research into technologies appropriate to STOL (short take off and landing) capability for typical military tactical aircraft. The study expanded upon a previous NASA-funded study of the same aircraft as a promising configuration for two-dimensional nozzle flight research.

Boeing and other airframe manufacturers have studied non-axisymmetric nozzle concepts for nearly 10 years. These nozzles have offered improved aft-end geometries and reduced drag. Other government-funded programs have provided estimates based on model tests of both the aerodynamic benefits and the structural penalties for a variety of non-axisymmetric nozzle concepts. Recent USAF-sponsored weapon system effectiveness studies show requirements for aircraft speed, maneuverability, short-field-length capability, and stealth to contend with the increasingly sophisticated enemy threat. Studies by several groups have shown that the 2-D nozzle potential for clean aft end geometry, in-flight thrust vectoring, reversing, and for lower levels of radar cross-section and infrared signature can help the airplane meet these requirements.

Boeing has developed and applied STOL technology for transport-type aircraft in part of its USAF YC-14 and NASA Quiet Short Haul Research Aircraft (QSRA) programs.

The basic solutions to minimizing field length involves: maximizing both the propulsive and aerodynamic lift in order to minimize lift off and landing speed; high thrust for takeoff; and high reverse thrust along with effective mechanical brakes for landing. All these basic capabilities must be accomplished with the minimum weight, drag, and fuel flow for a vehicle which is designed for a supersonic cruise mission.

The addition of propulsive lift can be a significant factor to reducing minimum flight speed because the engine thrust does not deteriorate with reduced flight speed while aerodynamic lift reduces with velocity squared. However, propulsive lift must be integrated with the aircraft carefully in order that pitching moments can be trimmed with reasonable control techniques. Balancing these propulsive moments can be aided somewhat by relaxed stability techniques, but must be tempered by the increased dynamic demands placed upon the control system.

The minimum takeoff distance requires a high vehicle thrust to weight ratio which tends to be compatible with the engine requirements for supersonic flight. However, efficient supersonic wing designs tend to require high angles of attack at low speed causing the need for long landing gear to permit ground clearance. Both wing flaps and propulsive lift aid in generating higher lift at a given angle-of-attack, which reduces this clearance problem. During takeoff, the control authority must be sufficient in order to rotate the aircraft rapidly to lift off attitude and minimize the ground roll distance. For some configurations, thrust vectoring could act as a pitch control device to help this rotation requirement.

The minimum landing distance requires both a precision touchdown at the end of the runway, and a total retarding-force-to-weight ratio comparable to that of takeoff. The precision touchdown which minimizes dispersion will necessitate a higher glide slope and elimination of a flare maneuver. Since the engine will be aiding lift at approach, turbine speed will be higher which results in faster maximum reverse thrust. Rapid engine spool up and deployment of an effective reverser, along with an effective braking system will be required in order to match the takeoff distance of a high thrust to weight vehicle. Careful integration of the reverser with the airframe is also required.

The data base for vectoring nozzles and the performance of various applicable trim techniques at STOL conditions is presently limited. Much of the data base inadequacy can be alleviated by analysis and design studies, wind tunnel investigations, static nozzle and engine tests and flight simulator studies. However, Boeing experience with its recent YC-14 vectored thrust STOL transport prototype and past experience in integrating the advanced high bypass ratio propulsion systems into the 747 aircraft suggests that flight research is both desirable and necessary to compensate for current inadequacies in analysis, wind tunnel test techniques, and full scale static engine tests. This need for flight research is particularly applicable when major departure from previous propulsion system designs (such as a highly-integrated, vectored thrust powerplant installation) is being considered.

Boeing studies have shown that successful development of such nozzles must address carefully the system integration of these nozzles with the airframe aerodynamics, structure, flight controls, powerplant and electronic warfare elements. Skeptics of STOL ask: Will practical design considerations such as mechanical layout, actuation systems and cooling and sealing requirements prevent development of a satisfactory thrust vectoring system? Can the nozzle vectoring/reversing forces and moments be efficiently integrated into the aircraft flight control system? Are current design approaches and cost estimates of possible production programs realistic? Because of questions such as these, it is necessary that technology readiness in terms of successful flight test confirmation of model and ground test data be demonstrated before aircraft manufacturers or government program managers will be willing to undertake the risks of incorporating this major new technology into production programs.

The present study reviews several aircraft configuration possibilities for such a flight research program using an F-106 aircraft to improve current understanding of the benefits and problem areas of STOL. An F-106 aircraft was selected for evaluation for several reasons:

- the wing planform and general arrangement is representative of an advanced tactical aircraft. The arrangement could then be evaluated for compatibility with possible wing-canard moment balancing schemes developed in preliminary design studies. Finally, the arrangement is judged to be capable of exploiting the aerodynamic influences of thrust-vectored induced lift.

- the modular construction of the aircraft appeared to lend itself to minimum cost research modifications

- previous NASA tests had established the practicality of outfitting the aircraft with auxiliary, podded engines. Moreover, NASA possesses two such aircraft, thus ensuring the opportunity of pursuing a program if shown desirable to do so.

To evaluate the feasibility of an F-106 flight research program, a four-task study was undertaken as shown in Figure 2-1. Boeing efforts were coordinated with The General Electric Company which had provided nozzle concepts, design data, and flight program planning support to a previous study.

The majority of the effort was expended in Tasks 1 and 2. Four candidate powerplant, aerodynamic, and configurational changes to the F-106B aircraft were selected for evaluaton of practicality and cost. Propulsion system installations, associated aircraft flight control and structural modifications and potential STOL performance were identified and evaluated. Budgetary estimates to make the required modifications and effect a typical flight test program were then briefly developed. Assumptions concerning responsibilities between an airframe manufacturer, engine manufacturer and NASA were defined and coordinated with the NASA program monitor. The output of the study is anticipated to support government planning and decision-making for proposed flight research efforts.

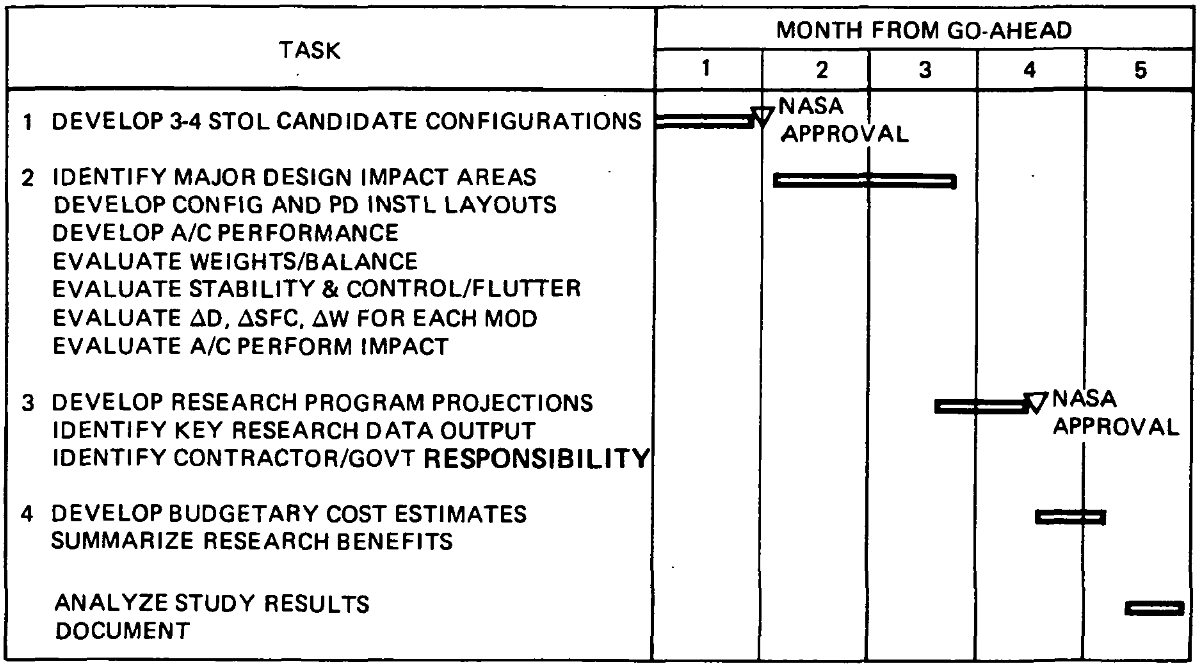

Figure 2-1. F-106 STOL Feasibility Study—Key Tasks

3.0 RESULTS

3.1 TASK I - CONFIGURATION IDENTIFICATION AND DEVELOPMENT

3.1.1 General Requirements

As described earlier, the F-106 aircraft was selected for this feasibility study because (1) the general arrangement simulates a candidate advanced aircraft whose configuration was dictated by efficient supersonic cruise and thrust vectoring requirements, and (2) NASA owns 2 F-106B aircraft, one of whch was previously used in a flight research program supporting the government SST effort.

Figure 3.1-1 shows an artist's concept of an advanced strike aircraft for which design and wind tunnel research efforts have been undertaken at Boeing. Two-dimensional exhaust nozzles have been located at the trailing edge of the highly swept delta wing. This positioning, based on existing wind tunnel studies, is believed to enable the best achievement of induced wing lift when the jet exhaust is vectored. Since the resultant of the vectored thrust and wing-induced forces does not act through the aircraft c.g., the canard surfaces are designed to counter the imposed pitching moment with further lift-directed forces. Moreover, for non-vectored supersonic cruise, the canard and wing placement has been designed for favorable aerodynamic interference to enhance the supersonic cruise efficiency of the aircraft.

Figure 3.1-2 is a general arrangement drawing of the F-106B aircraft. The B versions, which are operated by NASA, are two-seat trainers powered by a single Pratt and Whitney J75-P-17 turbojet engine. The propulsion system produces 24,500 lb of static thrust when operated with afterburner. Maximum dry static thrust is 16,100 lb. Twin side-fuselage-mounted inlets are located forward and above the 700 square foot wing.

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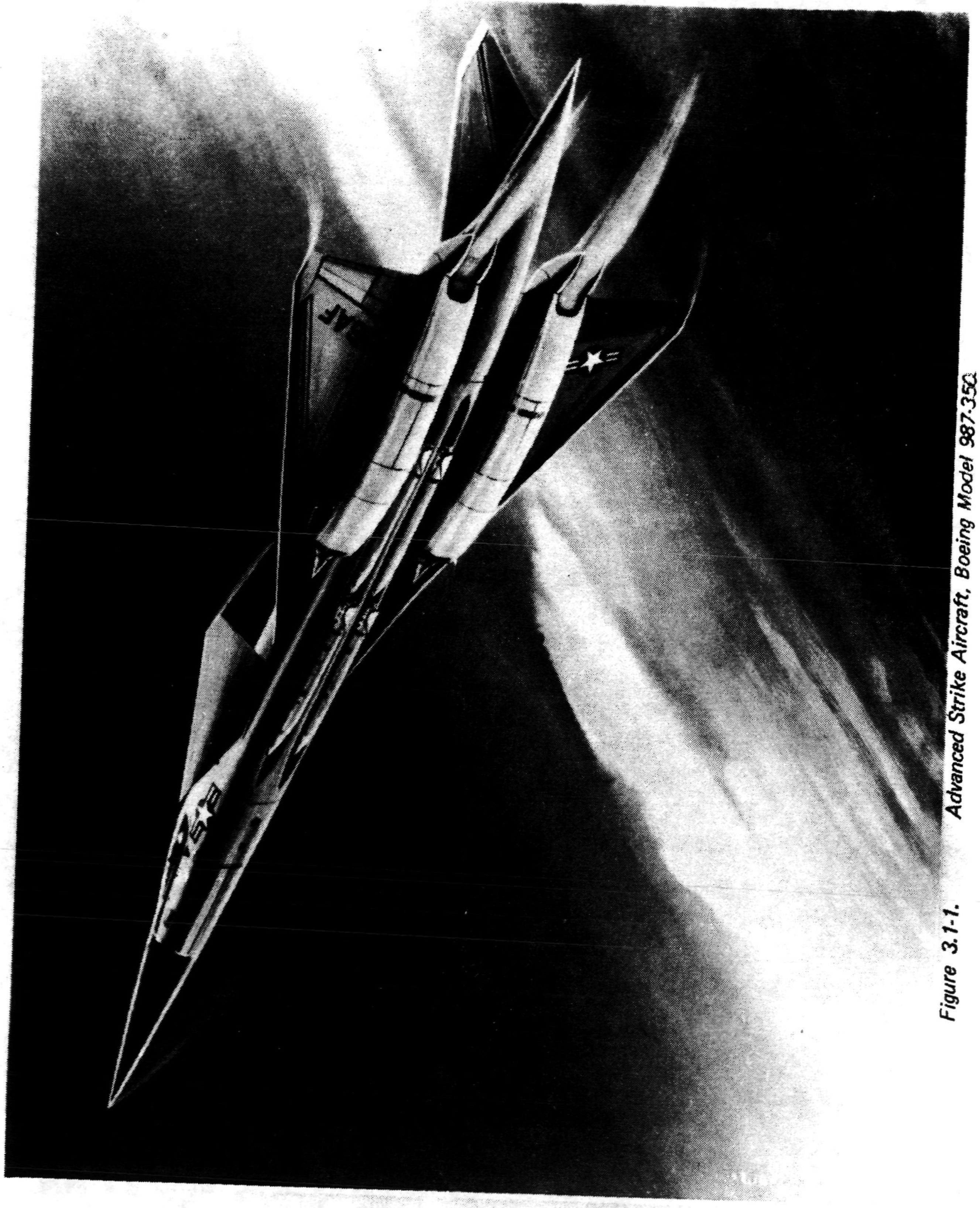


Figure 3.1-1. *Advanced Strike Aircraft, Boeing Model 987-350*

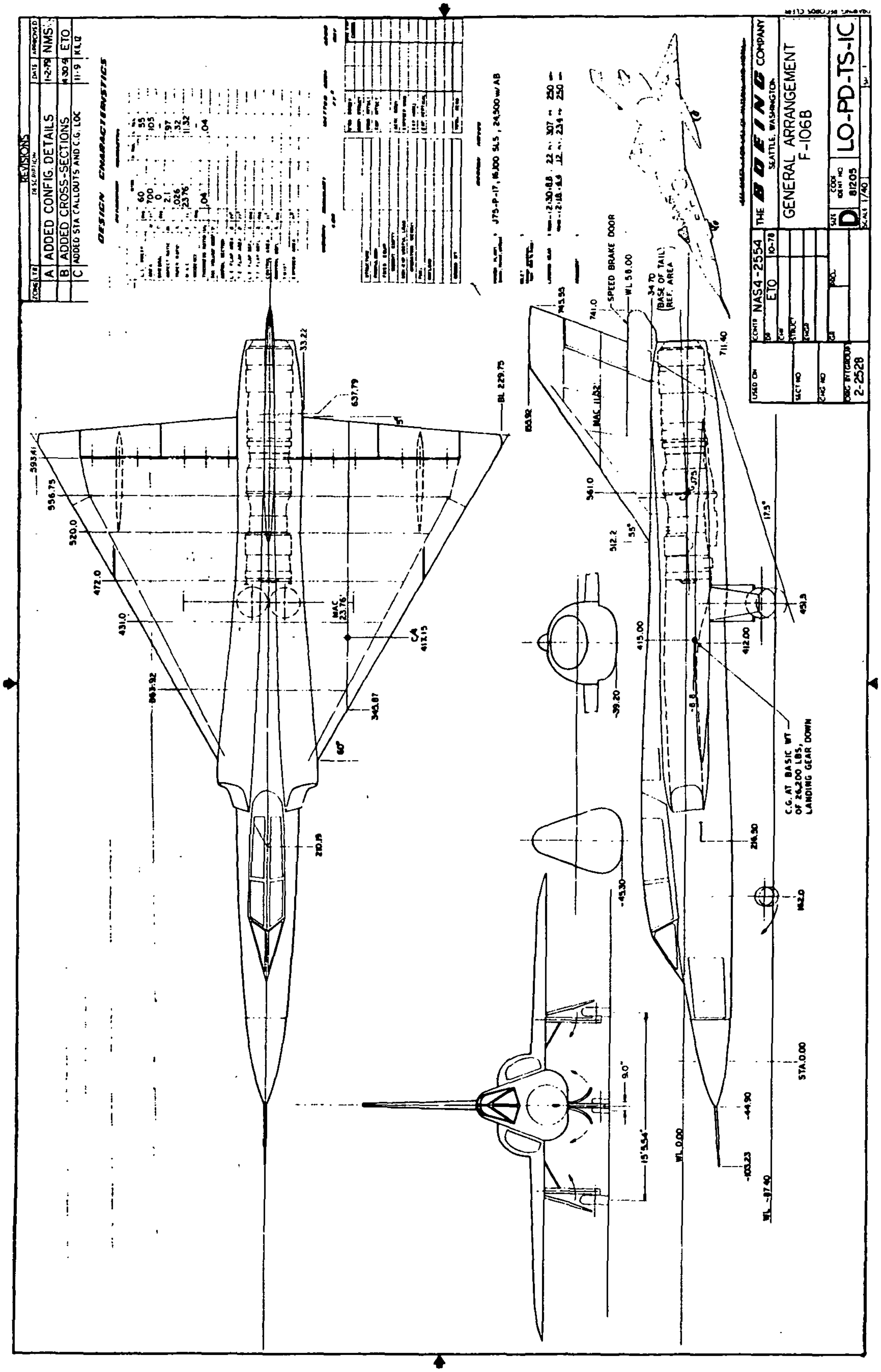


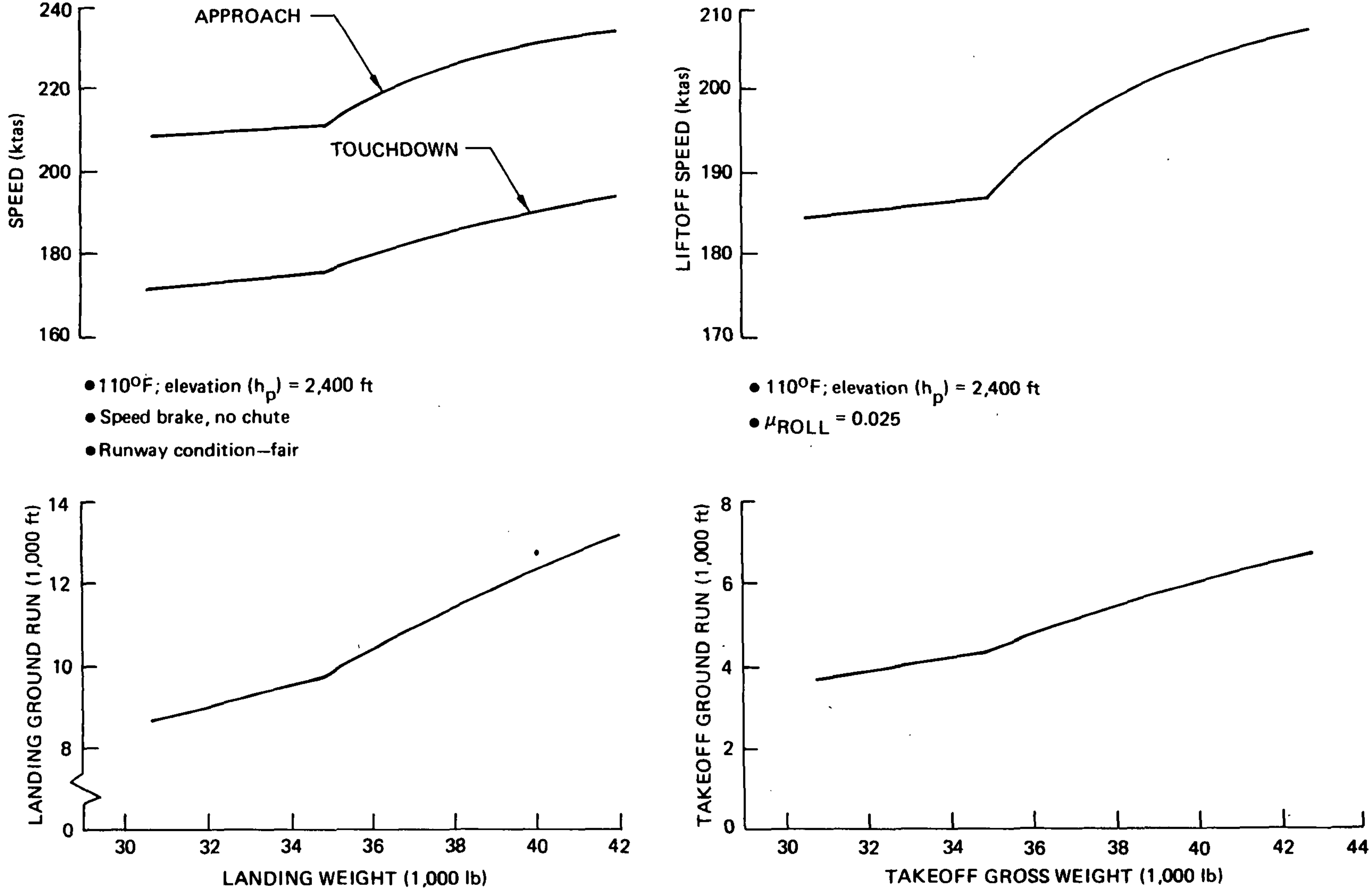
Figure 3.1-2. F-106B General Arrangement

The configuration modifications chosen for the present feasibility study were selected after some preliminary parametric analysis using the existing F-106B configuration as a point of departure. Based on the parametric studies, some general design guidelines and preliminary ground rules for developing the STOL modifications to the F-106 were defined. These are discussed in Sections 3.1.2 and 3.1.3, respectively. Finally, the four STOL configurations selected for the present study are described in Section 3.1.4.

3.1.2 Parametric Guidelines

The existing F-106B aircraft was developed for high speed performance and never compromised for STOL capability. Consequently, the aircraft requires several thousands of feet for both takeoff and landing. To help establish reasonable preliminary design goals, parametric analyses were made of key design variables such as takeoff and landing speeds, braking coefficients, levels of thrust reverse, etc. These were used to "ball park" requirements for achieving a 1000 foot ground roll. Since location of the powerplants plays a big role in the effectiveness and controllability of propulsive lift, engine placement was also treated parametrically. Consideration was also given to the failure case of one engine out since aircraft controllability for this condition has a major impact on the aircraft design. The trends from the parametric analysis are summarized below.

Initially, baseline field performance for the F-106B at 110°F and a pressure altitude of 2,400 ft was developed, see Figure 3.1.2-1. Takeoff performance is presented for maximum thrust. Landing performance is presented for speed brake deployed but no drag chute. Some difficulty in correlation of landing distances quoted in the flight manual with predictions made using Boeing preliminary design analysis was encountered. It is felt that this problem is due to unusually low braking coefficients for the F-106B.



- 110°F; elevation (h_p) = 2,400 ft
- Speed brake, no chute
- Runway condition—fair

- 110°F; elevation (h_p) = 2,400 ft
- μ_{ROLL} = 0.025

(a) LANDING SPEEDS AND GROUND RUN

(b) TAKEOFF SPEED AND GROUND RUN—MAXIMUM THRUST

Figure 3.1.2-1. Baseline Field Performance for the F-106B at 110°F and 2,400-ft Elevation

Subsequently, parametric landing ground run performance was developed for effective reverse thrust levels of 0, 6000 lb and 12,000 lb, see Figure 3.1.2-2. Effects of approach speed, braking coefficient and transition time are illustrated. The data reflect the flare, transition and stopping characteristics of the F-106B where applicable. An F-106B point is spotted on the figure (no reverser). These data suggest that with improvements to the braking system to provide reasonable braking coefficients (on the order of μ = .3-.4) and assuming thrust reverser effectiveness levels of between .25 to .50 (corresponding to 6000 to 12,000 lb of reverse thrust), then approach speeds of 110 to 135 knots together with rapid transition times should enable ground runs of about 1000 feet. Thus a landing speed of 120 to 130 knots was adopted as a "target" for the required STOL modifications.

Figure 3.1.2-3 was developed to help understand constraints on longitudinal placement of the F-404 engines. The parametrics relate ADEN nozzle vectoring angles, the vectored jet longitudinal moment arm, canard size required for pitch trim, elevon setting, and air speed. The data show that for an engine located so that the nozzle is at the wing trailing edge (for best induced lift, say) then an airspeed of 120 to 130 knots could be maintained with approximately 20° to 30° of nozzle vectoring. For these conditions, a canard of between 60 to 90 square feet, located at the forward fuselage station, would be required to trim the aircraft. These data were subsequently used to support the preliminary design studies.

Parametric charts were also developed to denote the effect of spanwise engine location and speed on rudder and aileron requirements for engine-out STOL operation. It was assumed for this parametric study that the F-106 would be modified to have two engines located off the fuselage centerline and a new larger rudder and vertical tail could be incorporated.

Figure 3.1.2-4 presents yawing moment due to an engine-out for four wing engine locations (η = 0.22, 0.4, 0.6, 0.8). Location η = 0.22 is the most inboard engine location feasible with thrust vectoring. The

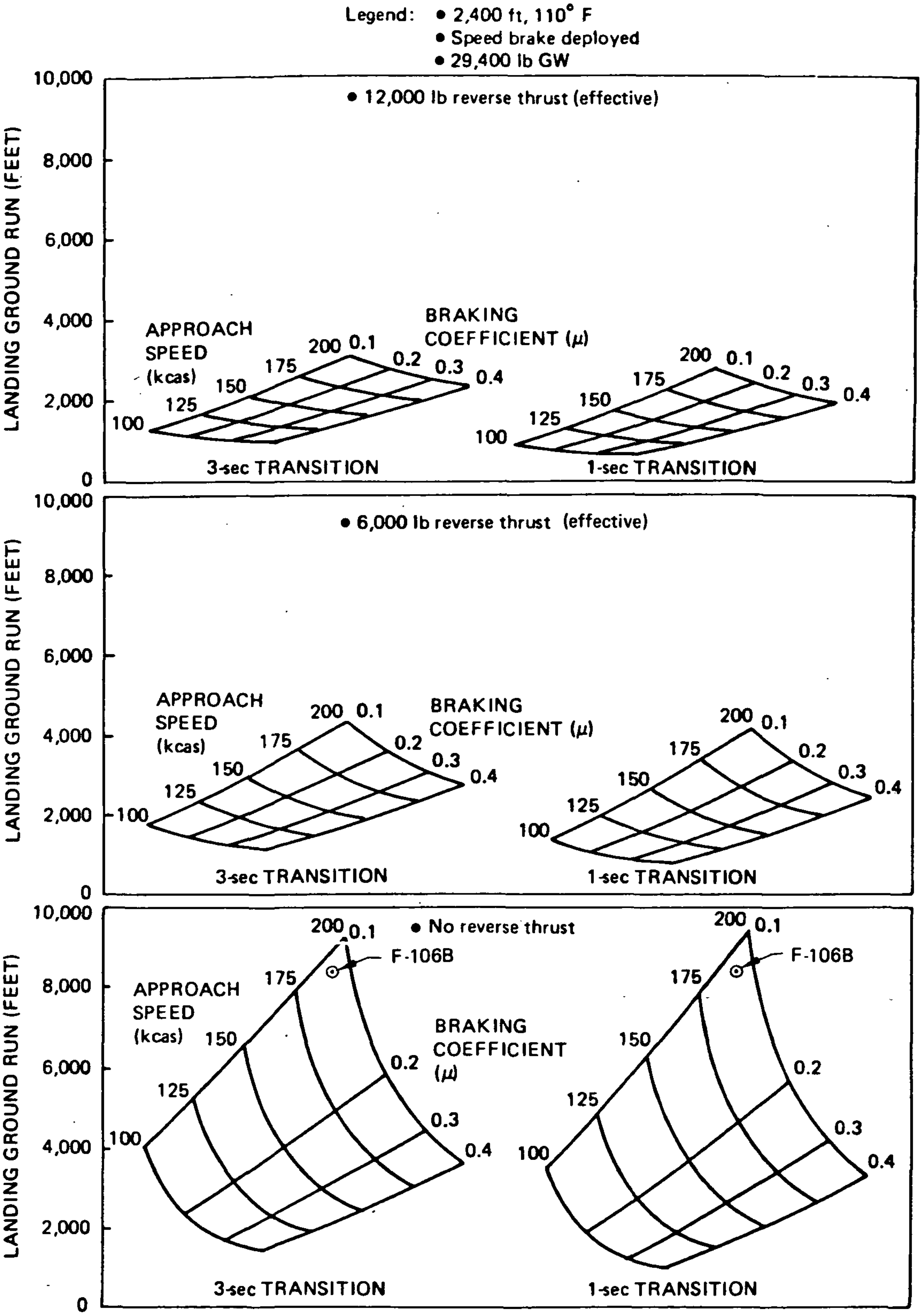


Figure 3.1.2-2. Landing Performance Parametric Estimates

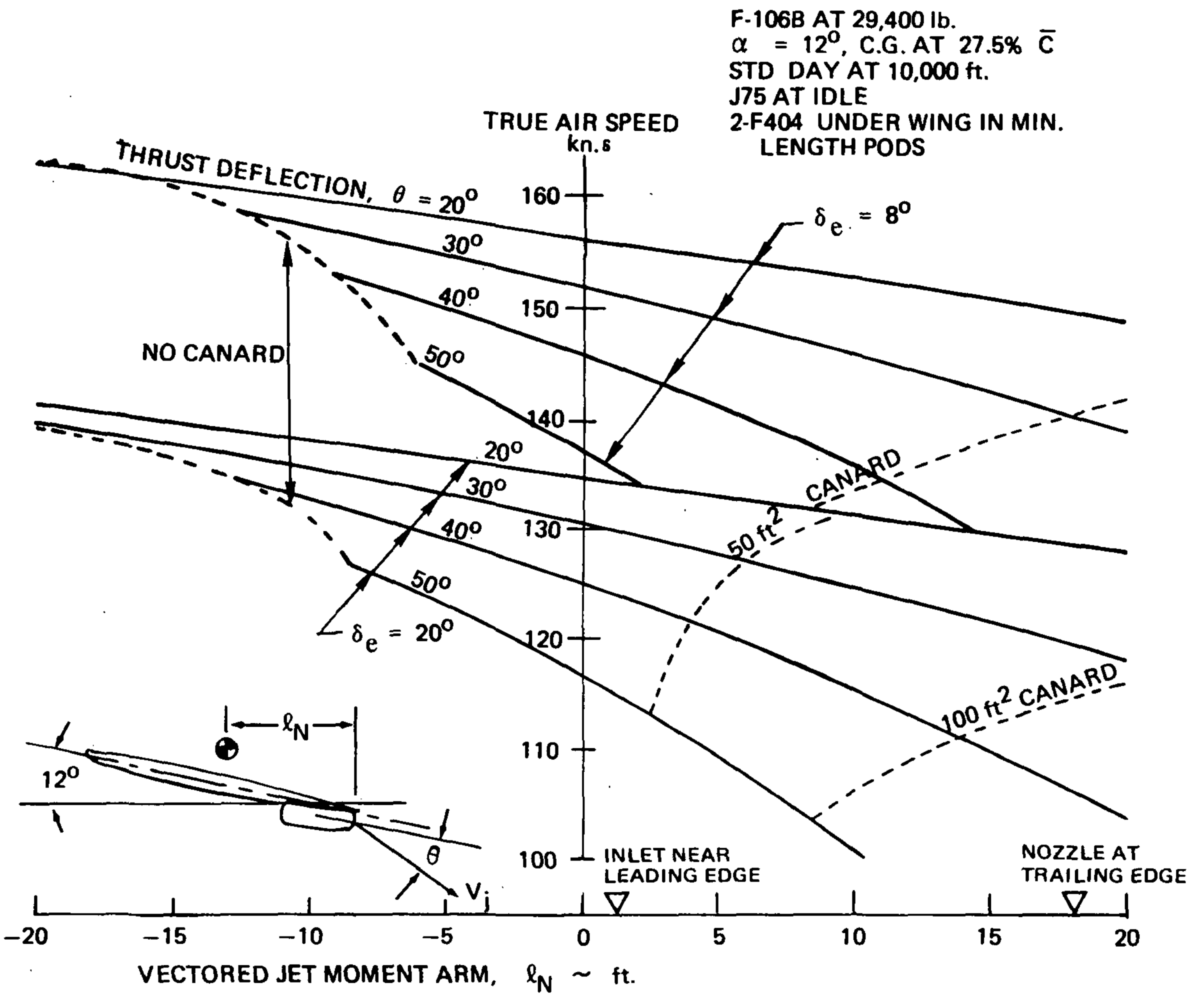


Figure 3.1.2-3. Parametric for Longitudinal Locations of Vectoring Nozzles

- Full-span rudder
- Rudder maximum deflection = 25 deg/25 deg or 25 deg
  - Root chords same as F-106 vertical tail
    - $\ell_V = 0.30\ C_W$ to $0.25\ \bar{C}_V$
      - No vectoring
      - $\beta = 0$ deg and $\theta = 0$ deg

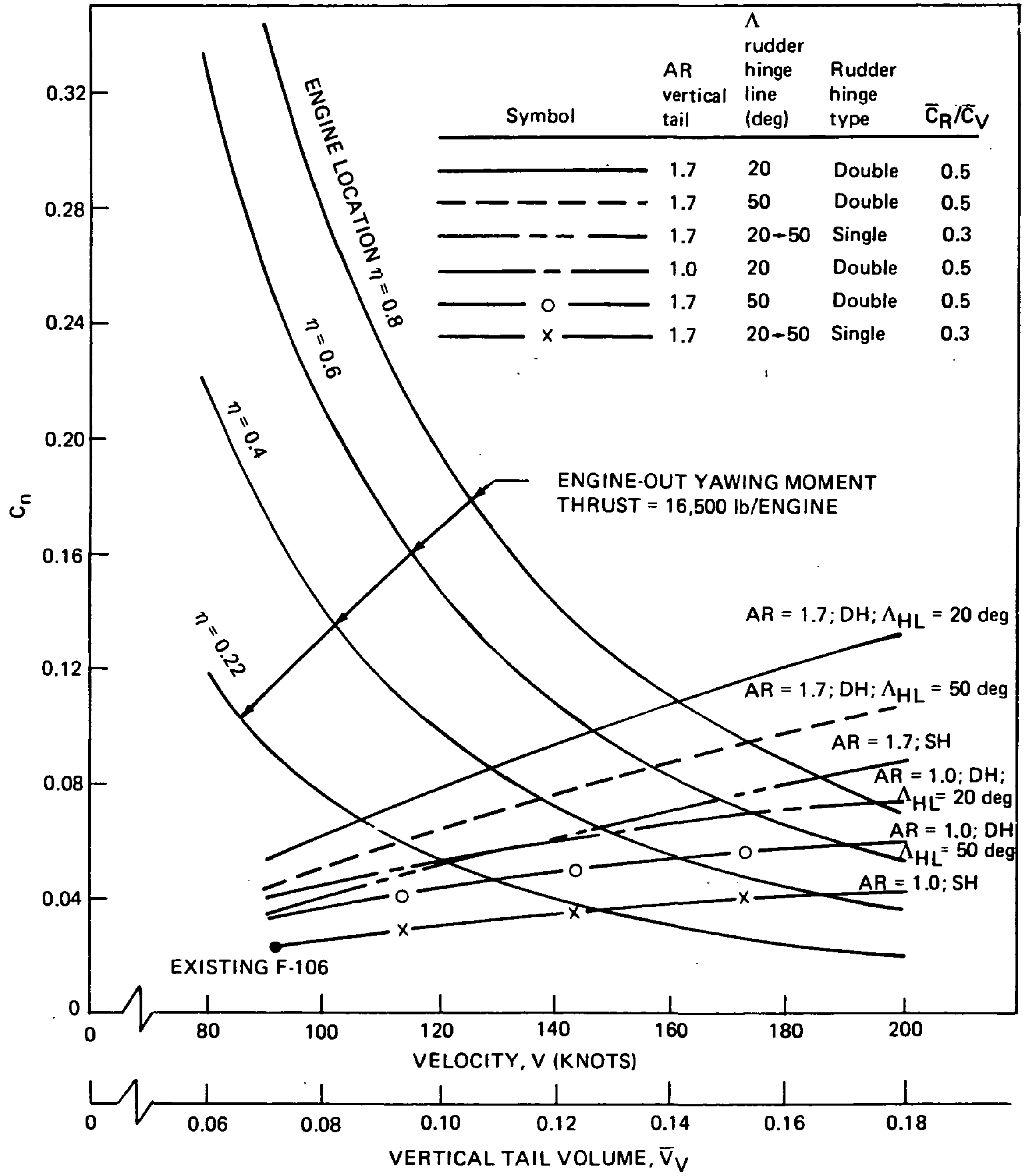


Figure 3.1.2-4. Engine-Out Yawing Moment and Available Yawing Moment for Various Vertical Tails and Rudders

figure also presents available yawing moments for six rudder/vertical tail combinations as a function of vertical tail volume. Data are for vertical tails of two aspect ratios, each having three rudder types. Aspect ratios are 1.0 or 1.7 with either double or single hinge rudders. Hinge line sweep for the double hinge rudders is 20° or 50°. Hinge line sweep for single hinge rudders has minor effects on rudder effectiveness for the vertical tails considered, therefore no variations with hinge line sweep are presented. Because of practical limits on attaching a new vertical tail, it was assumed the root chord and trailing edge sweep for the parametric vertical tails would be the same as those of the F-106 vertical tail.

From Figure 3.1.2-4 vertical tail volume, aspect ratio, rudder type and rudder hinge line sweep required to directionally control an engine-out condition as a function of speed and engine location can be determined.

Figure 3.1.2-5 presents the rolling moment resulting from each vertical tail/rudder combination for various tail volumes (sizes). This rudder-induced rolling moment must, in turn, be countered by a rolling moment from the ailerons.

Available aileron roll control was estimated for three aileron configurations. All are based on F-106 ailerons with either reduced span or reduced span and increased elevon chord. F-106 aileron deflection limit is seven degrees, but for the study, a maximum thirty degree deflection was assumed. Figure 3.1.2-6 presents aileron effectiveness for: (1) F-106 elevon chord with reduced span, (2) F-106 elevon chord increased 50% with reduced span, and (3) F-106 elevon chord increased 110% with reduced span and (4) F-106 basic elevon chord and span. No dramatic improvement in available roll control occurs with elevon chord increases. Increasing deflection from the 7° to 30° provides a 300% improvement. An improvement due to a double-hinged, 110% chord aileron was also evaluated for 20° deflection.

- Full-span rudder
- Rudder maximum deflection = 25 deg/25 deg or 25 deg
- Root chords same as F-106 vertical tail
  - ℓ_V = ℄ fuselage to $\bar{C}_V$
- No engine vectoring—no induced lift
  - β = 0 deg and θ = 0 deg

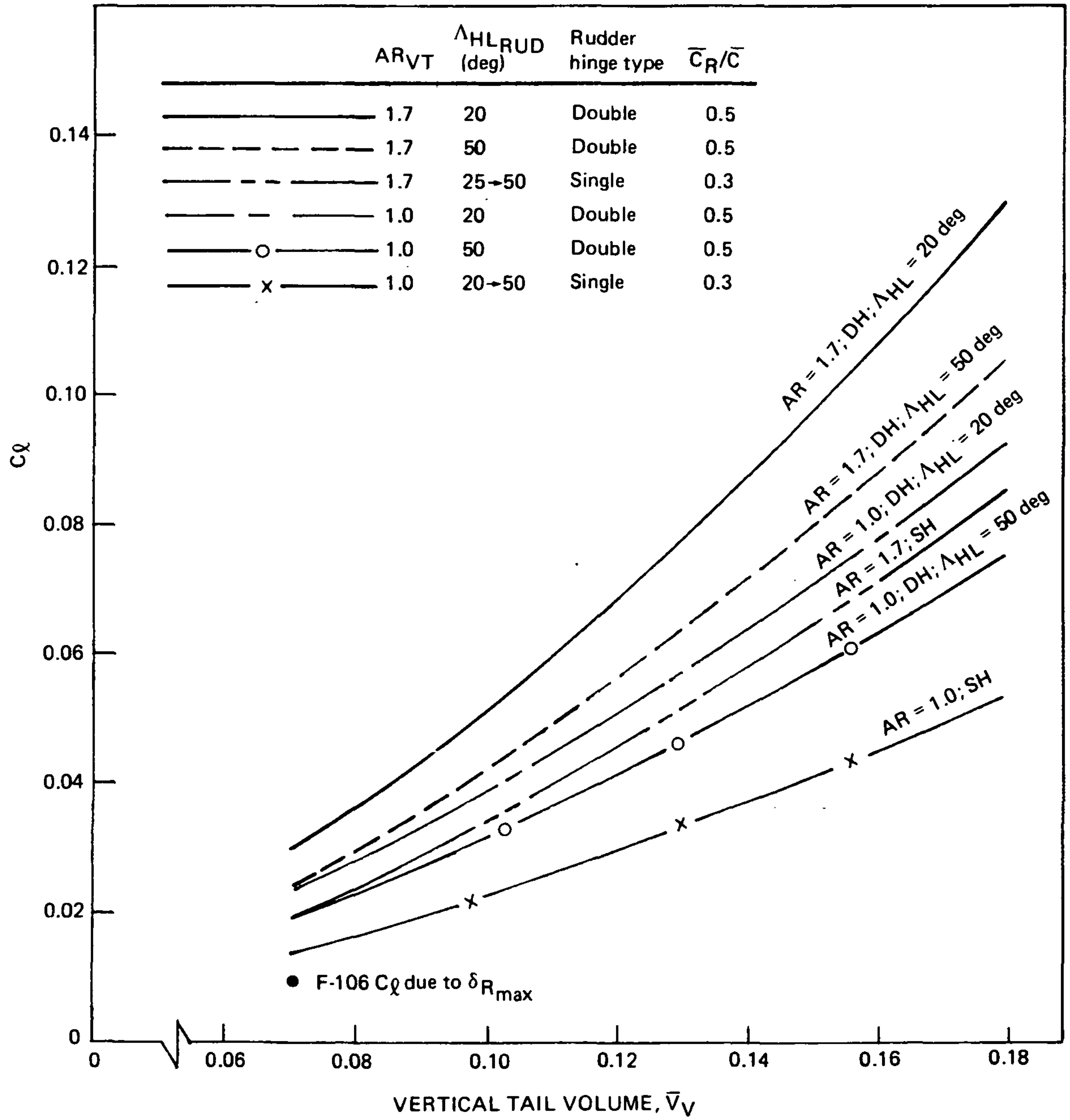


Figure 3.1.2-5. Effect of Maximum Rudder Deflection on Rolling Moment for Various Vertical Tails

- $M = 0.2$
- $\delta_A = (\delta_{AL} + \delta_{AR})/2$ (assumes asymmetric ailerons deflected equally)

Symbol	Aileron
————	F-106
—— - - ——	Reduced span—F-106 chord
– – – – – –	Reduced span—50% chord increase
—— - ——	Reduced span—110% chord increase

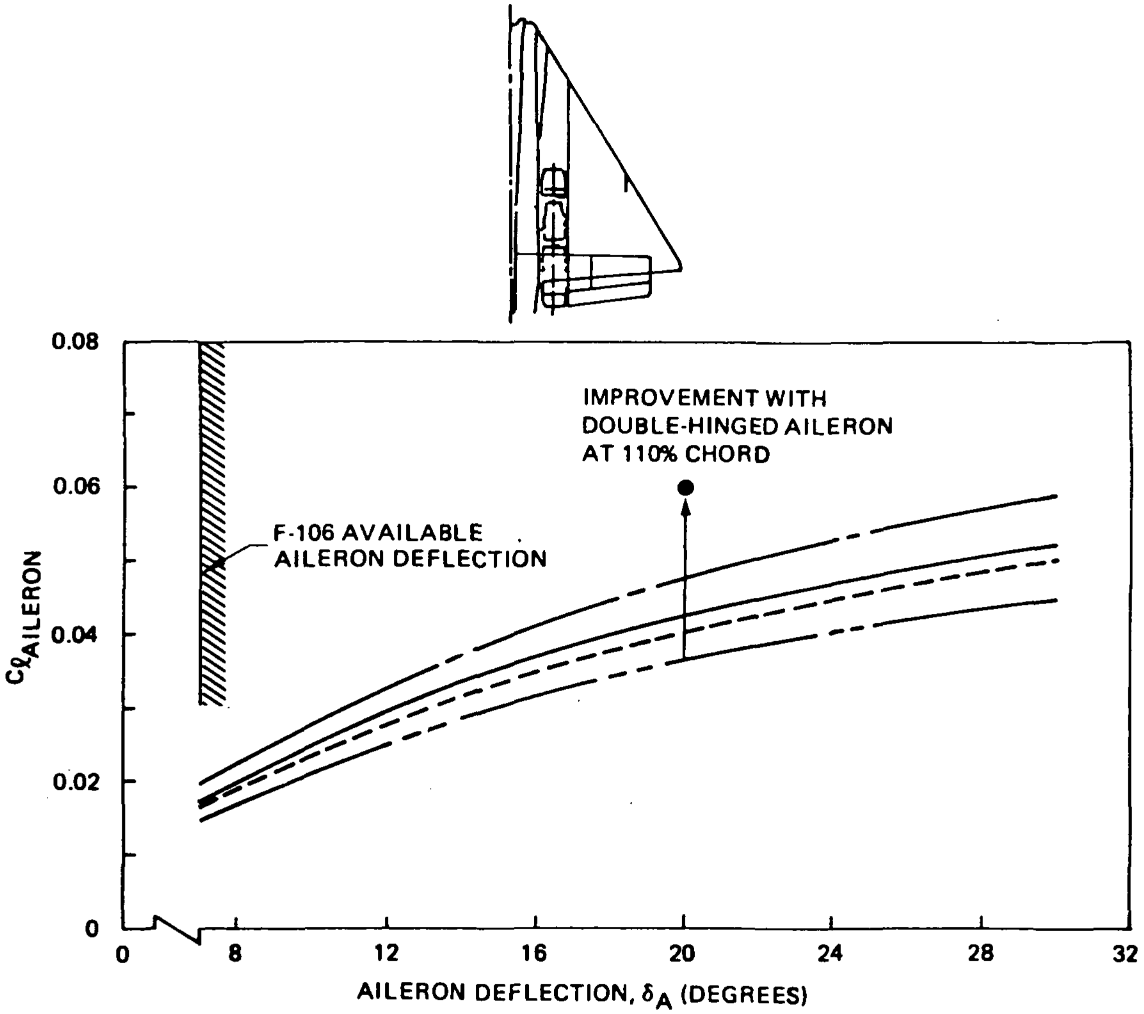


Figure 3.1.2-6. Available Aileron Roll Control

The above parametric data were used to improve understanding of how the F-106B might be modified for STOL capability. Initial conclusions drawn are summarized in Figure 3.1.2-7 and were used to support the initial STOL configuration concepts. It should be noted that subsequent to developing the configurations, further analysis as described in Section 3.2A was made for each individual STOL modification concept.

- Possible design requirements—
  - Must reduce engine-out moments
  - Need for improved yaw control
  - Yaw control difficult below 120 kn
  - Need to minimize roll moment imposed by yaw control
  - Allow some sideslip
  - Need increased roll control from elevons
  - Consider reallocation of roll and pitch authority
  - Allow some bank
  - Allow good engine nozzle to contribute to roll control
  - Short distances require good brakes plus thrust reverse plus quick deployment

Figure 3.1.2-7. Results of Parametric Studies

3.1.3 STOL Configuration Ground Rules

To ensure consistency of analysis methods, the following ground rules were adopted to govern initial analysis of F-106B modifications to provide STOL capability. These ground rules are based on preliminary parametric calculations developed to date and reflect an understanding of required design capability to achieve 1000 ft. STOL field lengths. The ground rules also reflect observed limitations of the F-106B which could prevent achieving these requirements without prohibitive expense.

1. MINIMUM AIRCRAFT SPEED SHALL BE 130 KNOTS

Considerations:

a. The basic F-106B, at max gross weight, lifts off at 207 kn after 6500 feet of ground run. At 31,000 lb gross weight, approach speed is 210 kn with a landing roll of 8700 feet.

b. Parametrics suggest that with a state-of-the-art braking system, thrust reverser and automated controls for performing the landing function, a 120 kn approach speed would achieve a 1000 ft. landing roll.

c. Parametric control calculations for engine-out suggest major modificatons to remedy deficiencies in both directional and roll control at 120 kn.

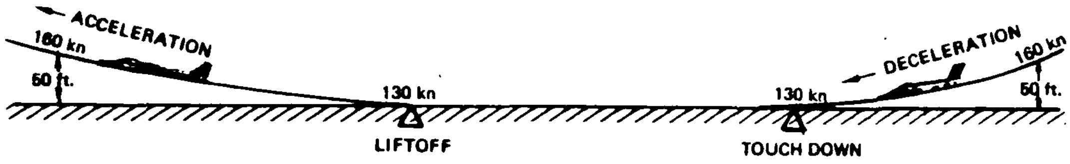
d. As a compromise between requirements and expected capabilities, 130 kn approach speed was selected for the initial sizing and analyses.

2. Upon engine out, the aircraft shall be able to maintain sufficiently low rate of sink ($\leq$ 10 fps) to limit landing gear loads to those judged to result in "damage to, but not structural failure of, the gear" (per the F-106B T.O.'s). This shall include possible use of special flight paths for STOL landing and takeoff demonstrations.

Considerations:

a. T.O. definition of allowable sink rates is given in Figure 3.1.3-1.

b. Figure 3.1.3-2 suggests that at 130 kn, the aircraft may require more thrust than is available to maintain the desired sink rate. For this reason, special flight paths, such as sketched below, may be considered.



3. Net thrust of the good engine is limited to 13,000 lbs of thrust and that on engine-out, the vectorable nozzle is deployed to counter roll moments.

Considerations:

a. Parametric control calculations suggest the need to minimize asymmetric yawing moments due to engine out, since rudder required to control yaw then imposes greater roll control requirements than are available.

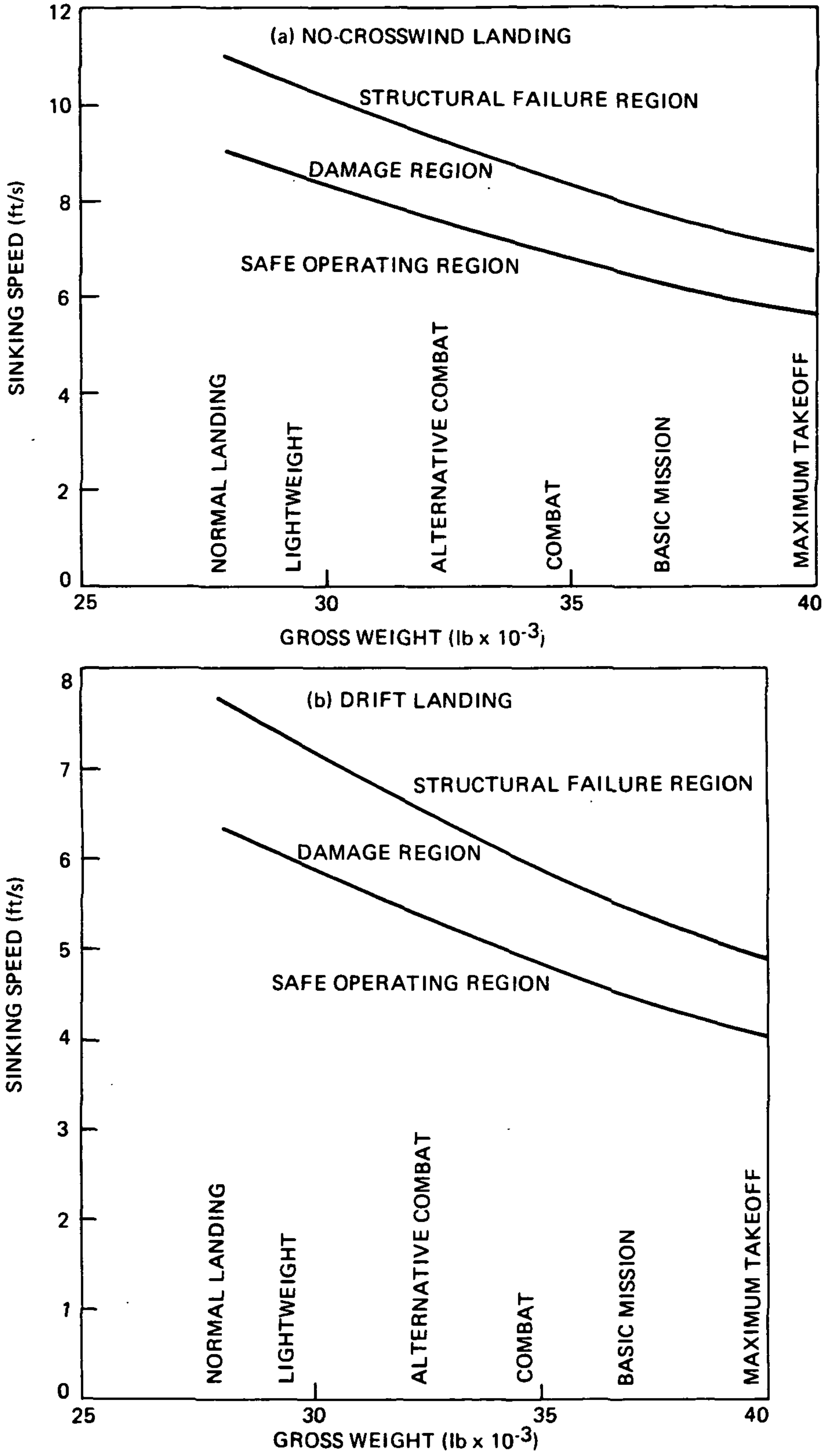


Figure 3.1.3-1. Sinking Speed Versus Gross Weight—F-106 Main Landing Gear

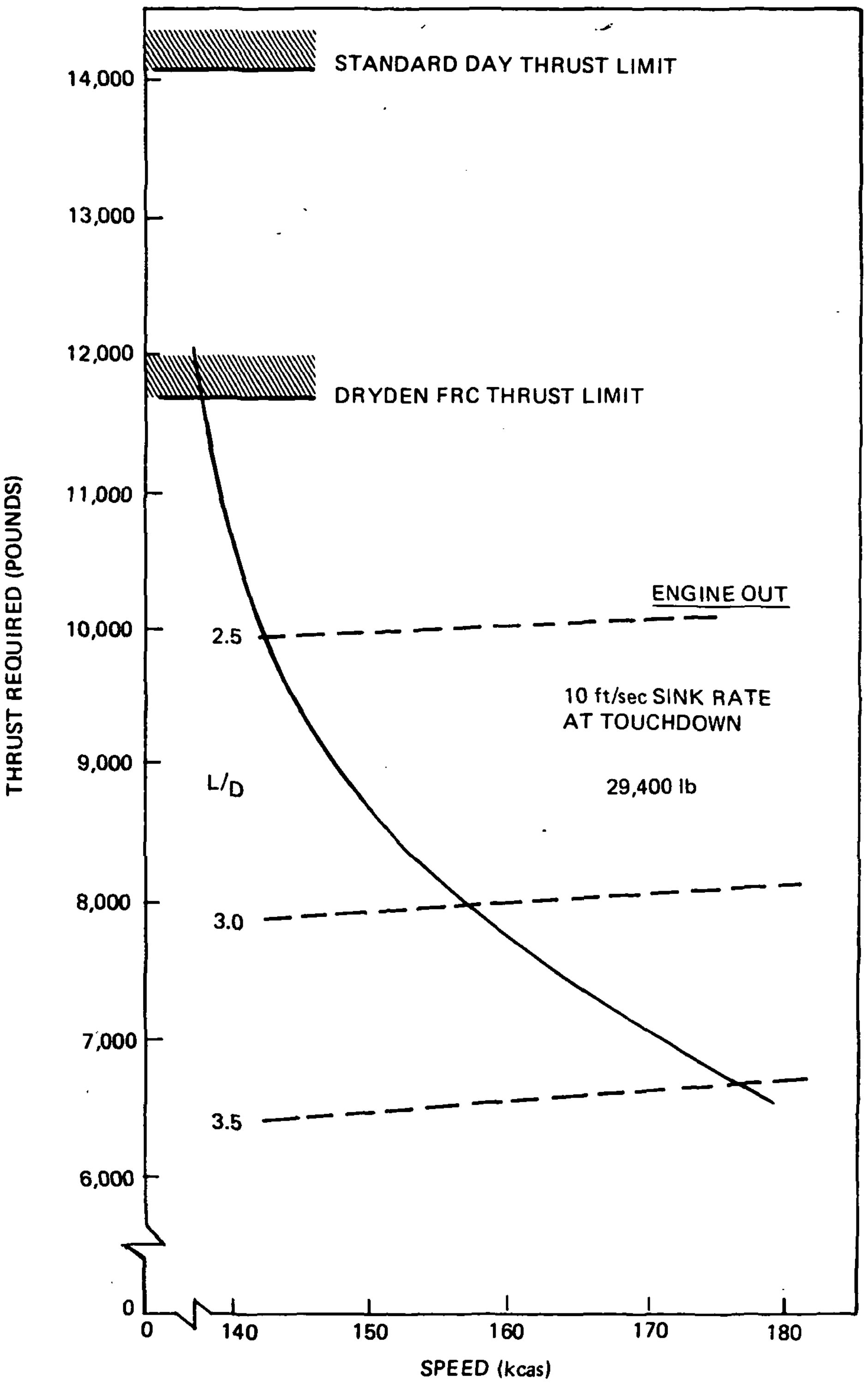


Figure 3.1.3-2. Engine-Out Thrust/Speed Relationship

4. On engine-out, the pilot shall be allowed 5° of sideslip and 5° of bank to help meet control requirements. The flight controls analysis shall allow for 15% control margins (directional and roll). F-106 elevons will be rerigged to allow ±30° of travel.

Considerations:

a. As a result of these restrictions, STOL demonstrations must be limited to non-gusty or low cross wind weather conditions.

5. Analysis shall allow for override of the existing F-106B α-limiter.

Considerations:

a. α-limits on the ground will be consistent with the modified configuration drawing.

b. The current F-106B is α-limited due to inadequate directional control. This constraint will be relaxed if consistent with anticipated modifications.

3.1.4 Selected Study Configurations

Initially, about 8-10 STOL modification concepts were developed by configuration engineers using the design guidelines and STOL ground rules of Sections 3.1.2 and 3.1.3 as a basis. (These modification concepts included variations in powerplant placement, trim technique, design for engine-out, liklihood of achieving jet-induced lift, retention of existing landing gear, and others.) Since the scope of the study precluded analysis of all the configuration concepts, a judgemental process was used to eliminate all but four. Selection criteria included:

- number and extent of design uncertainties
- capability of achieving research objectives of
  - ability to demonstrate STOL takeoff
  - ability to demonstrate STOL landing
  - capability to operate supersonically
  - ability to incorporate thrust reverser
- degree of design modification required

Since the selection process was largely judgemental, heavy emphasis was placed on retaining a variety of modification concepts in order that subsequent analysis yield a broad understanding of F-106 STOL configuration possibilities.

A summary of the selection considerations is given in Figure 3.1.4-1, Suffice it to say, modifications #1, 3, 5 and 7 were recommended and approved by the NASA monitor for further study. These four selected configurations are described briefly below.

MODIFICATION #1: (figure 3.1.4-2) was intended to use thrust vectoring together with jet-induced wing lift to provide the necessary lift capability for STOL. A canard is provided for trimming of the vectored thrust moments. The configuration lends itself to retaining the existing landing gear provided that a low-speed capability only was accepted. This is due to interference of the F-404 pods with satisfactory retraction of

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Figure 3.1.4-1. F-106 STOL Modification Configuration Assessment

Configuration	Configuration objective	Expected operating limitations	Key design problems and uncertainties	Will demonstrate STOL takeoff	Will demonstrate STOL landing	Operationally capable of supersonic speeds	Will allow retention of J75	Will produce induced-lift effects	Will allow incorporation of thrust reversing	Modifications required to as-drawn configuration or additional analysis required
Modification 1 LO-PD-TS-25	● Use TV to achieve induced lift and reduced speeds ● Retain existing landing gear	● Should be capable of low, transonic, and supersonic speeds ● Fixed-gear down	● Structural integration of canard ● Structural integration of pods * Aerodynamic center shift and aircraft balance ● Inlet distortion ● Kink in afterburner duct ● Canard-tail and canard-wing interference ● Tail size for directional control (CEI) ● Aileron power for roll control (CEI) ● Nose gear slush deflector ● Requires rerigging of elevons	Yes	Yes	No	No	Yes	Some	● Add all-moving ventral fin or tip fin ● 10-deg toe-out of engine nozzle (afterburner duct) ● For engine-out—good engine is used for roll ● Maximum available thrust = 13,000 lb/engine ● Landing gear extension ● Move nozzle somewhat forward ● Lower sweep of canard? ● Nose gear slush deflector ■ Structural loads of canard into body ■ Weight and balance ■ Area-ruling ■ Landing speeds ■ Elevon rerigging
Modification 2 LO-PD-TS-26	● Use TV to achieve induced lift and reduced speeds ● Retain existing gear	● Area-ruling probably compromises supersonic speeds ● Allows gear up	● Structural integration of canard ● Canard-inlet interference ● Aerodynamic center shift and aircraft balance ● Canard-tail and canard-wing interference * Satisfactory area-ruling for supersonic flight ● Tail size for directional control (CEI) ● Aileron power for roll control (CEI) ● Requires rerigging of elevons	Yes	Yes	Limited	No	Yes	Yes	● Redraw to bigger canard—relocate relative to inlet ● Add all-moving ventral fin ● 10-deg toe-out of engine nozzle ● For engine-out—good engine is used for roll ● Maximum available thrust = 13,000 lb/engine ■ Structural loads of canard into body ■ Area-ruling ■ Weight and balance ■ Elevon rerigging
Modification 3 LO-PD-TS-27	● Locate nozzles closer to CG ● Attempt to obtain some induced lift ● Improve controllability (CEI) using F-101 T-tail	● Should be capable of low, transonic, and supersonic speeds ● Allows gear up	* Structural loadpaths for wing pod integration with strut * Incorporation of surplus (new) landing gear ● Exhaust jet-aircraft structure temperature problem ● Gear location and aircraft rotation ● Flight control integration concept ● Aerodynamic center—CG relationships and balance ● Nose gear slush deflector ● Inlet-wing interference ● Area-ruling ● Rerigging of elevons	Yes	Yes	Yes	Yes	Yes	Some	● Add F-101 T-tail ● Add all-moving ventral(s) at aft ● Nose gear slush deflector ■ Analyze with and without J75 ■ Assume T-tail provides pitch control and elevons provide roll control ■ Integration of surplus landing gear ■ Structural loadpaths for wing

Figure 3.1.4-1. F-106 STOL Modification Configuration Assessment (Concluded)

Configuration	Configuration objective	Expected operating limitations	Key design problems and uncertainties	Will demonstrate STOL takeoff	Will demonstrate STOL landing	Operationally capable of super sonic speeds	Will allow retention of J75	Will produce induced-lift effects	Will allow incorporation of thrust reversing	Modifications required to as-drawn configuration or additional analysis required
Modification 4 **LO-PD-TS-29** **(probably obsoleted by mod 5)**										
Modification 5 LO-PD-TS-30	• Use nozzles as pitch-control device to enable elevons to generate higher $C_{L_{max}}$	• Should be capable of low, transonic, and supersonic speeds • Allows gear up	* Structural integration of engines • Nozzles become part of aircraft primary flight control system (redundancy requirements?) • Aircraft balance • Area-ruling • What are minimum STOL speeds; minimum control speeds? * *Rerigging of elevons*	Yes	Yes	Yes	No (Balance)	No	Yes	• Clock nozzle to put vectoring force through CG • Other aerodynamic refinements for improved $C_{L_{max}}$ —leading edge vortex tabs ■ Minimum STOL speeds ■ Minimum control speeds ■ Fixed nozzle positions for each flight
Modification 6 LO-PD-TS-34 (probably obsoleted by modification 3)	• Locate nozzles closer to CG • Attempt to obtain some induced lift • Improve controllability (CEI) using F-101 T-tail	• Should be capable of low, transonic, and supersonic speeds • Allows gear up	* Structural loadpaths for wing-pod integration with strut * Incorporation of surplus (new) landing gear • Exhaust jet-aircraft structure temperature problem • Flight control integration concept • *Aircraft—CG relationships and balance* • Nose gear slush deflector • Inlet-wing interference • Area-ruling • Rerigging of elevons							• Add all-moving ventrals at aft • Nose gear slush deflector ■ Analyze with and without J75 ■ Assume T-tail provides pitch control and elevons provide roll control during engine-out ■ Structural loadpaths for wing ■ Integration of surplus landing gear
Modification 7 RALS installation	• Use TV to achieve induced lift and reduced speeds • Minimize (or avoid) use of canard by using RALS installation to trim vectoring moments	• Should be capable of low, transonic, and *supersonic speeds* • Allows gear up	• RALS sizes and lengths • RALS development effort required • RALS afterburner jet interference with ground, tires, inlet, etc. • ADEN engine operation with full bleed for RALS • Integration of RALS with flight controls							• Use RALS installation number • Use in conjunction with overwing *installation, as in modification 2* ■ Inlet concepts

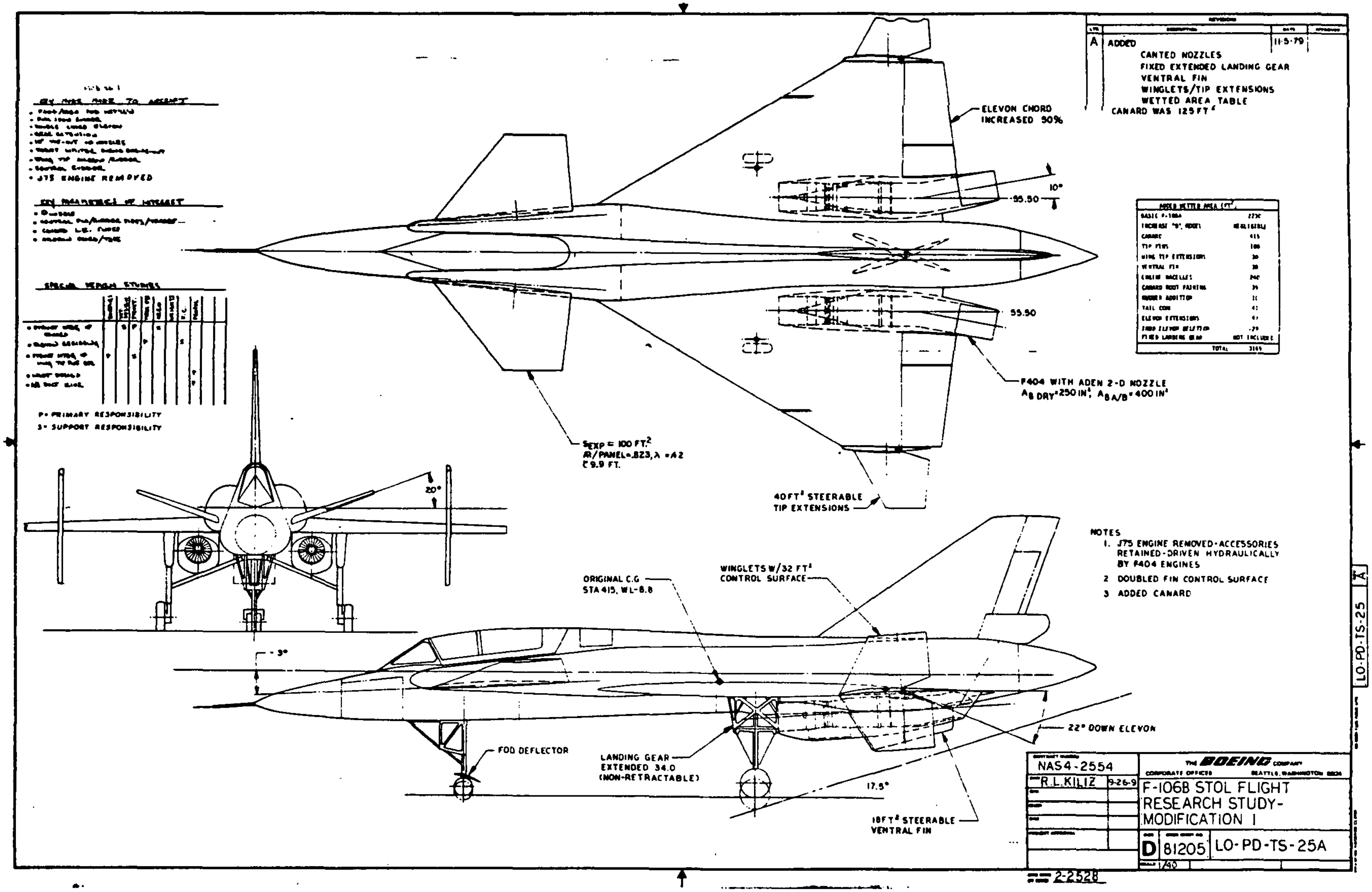


Figure 3.1.4-2. F-106B STOL Flight Research Study Modification #1

the gear. The low speed restriction also opens up the opportunity to add additional flight control surfaces to provide improved pitch, yaw and roll capability. The incorporation of these surfaces for low speed only minimizes structural considerations and hence should help keep modification costs in rein. Specifically, an auxiliary rudder, and all-moveable wing tip extension were added to the wing tip. The intent was to provide additional yaw control which does not aggravate the roll control requirements. Additionally, the nozzles were canted outboard by 10^{0} to minimize yawing moments imposed during engine out. The basic J-75 powerplant was removed and hydraulic and pneumatic services are assumed to be provided by the F-404 engines. A structural extension was provided to the landing gear to improve ground clearance for the nozzles when vectored at high ground aircraft attitude angles. Other changes are noted in the figure.

MODIFICATION #3: (figure 3.1.4-3) was intended to try to provide nozzle vectoring forces close to the aircraft center-of-gravity to minimize trim requirements. This was achieved by providing for removal of the F-106 bolt-on wings and introducing a wing root insert to provide for structural reattachment of the original wing as well as house the F-404 powerplant installation. In addition, using an idea provided by a previous study, the F-106 empennage was replaced with an existing empennage from an F-101 aircraft. The intent is to provide additional pitch control, thus enabling complete use of the existing F-106 elevons for roll control. In an attempt to provide a full flight envelope capability for the aircraft, an alternative to the existing landing gear arrangement was sought. One solution was to employ an existing F-15 landing gear which deploys in a chordwise, rather than spanwise motion, thus avoiding interference with the engine placement. Other changes are noted in the figure.

MODIFICATION 5: (figure 3.1.4-4) was structured to explore the use of thrust vectoring as a supplementary pitch control device. This application of the vectorable nozzle is particularly pertinent to the tailless-type aircraft represented by the F-106. For this class of aircraft, high angle-of-attack attitudes are achieved by upward deflection

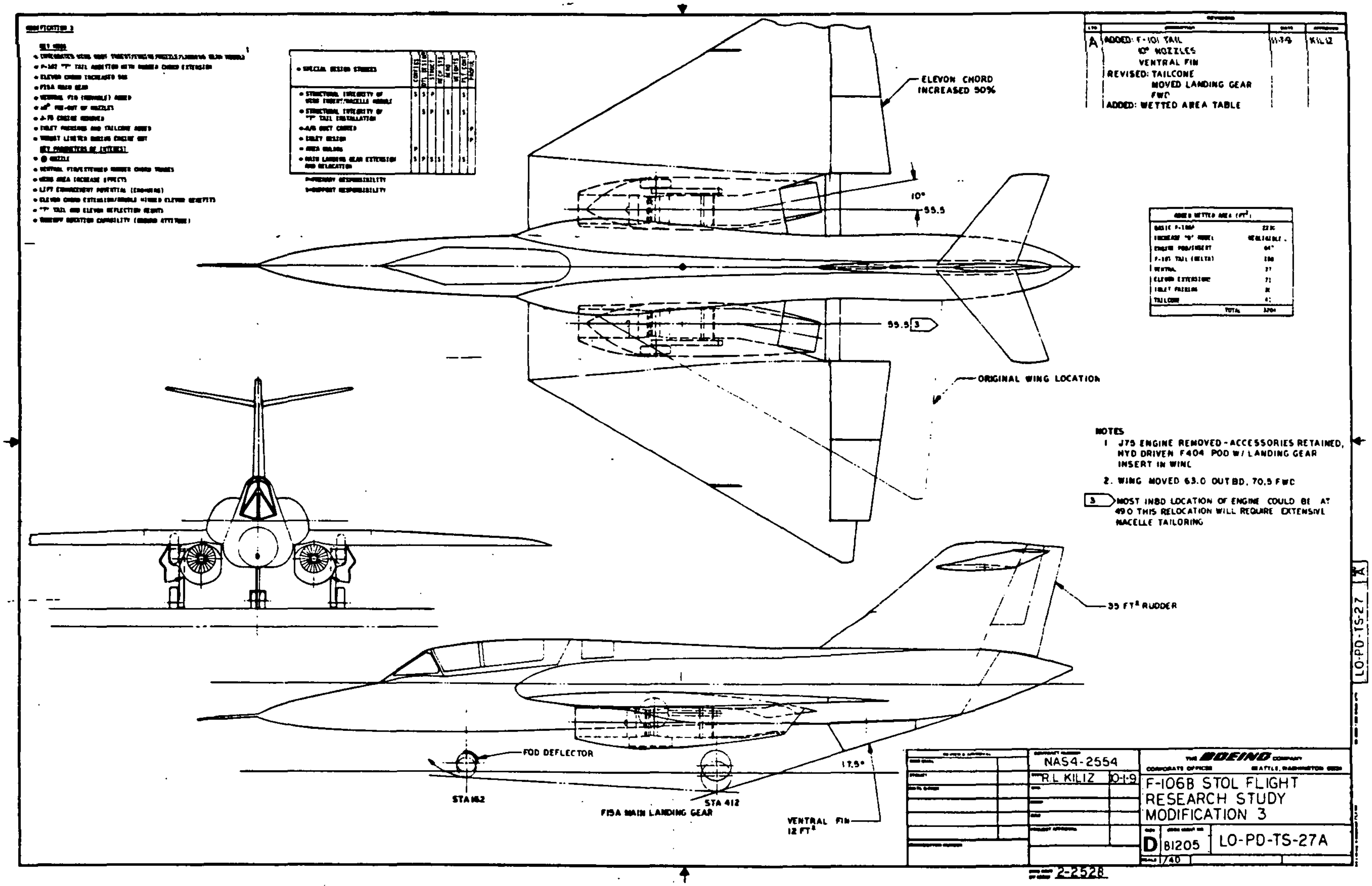


Figure 3.1.4-3. F-106B STOL Flight Research Study Modification #3

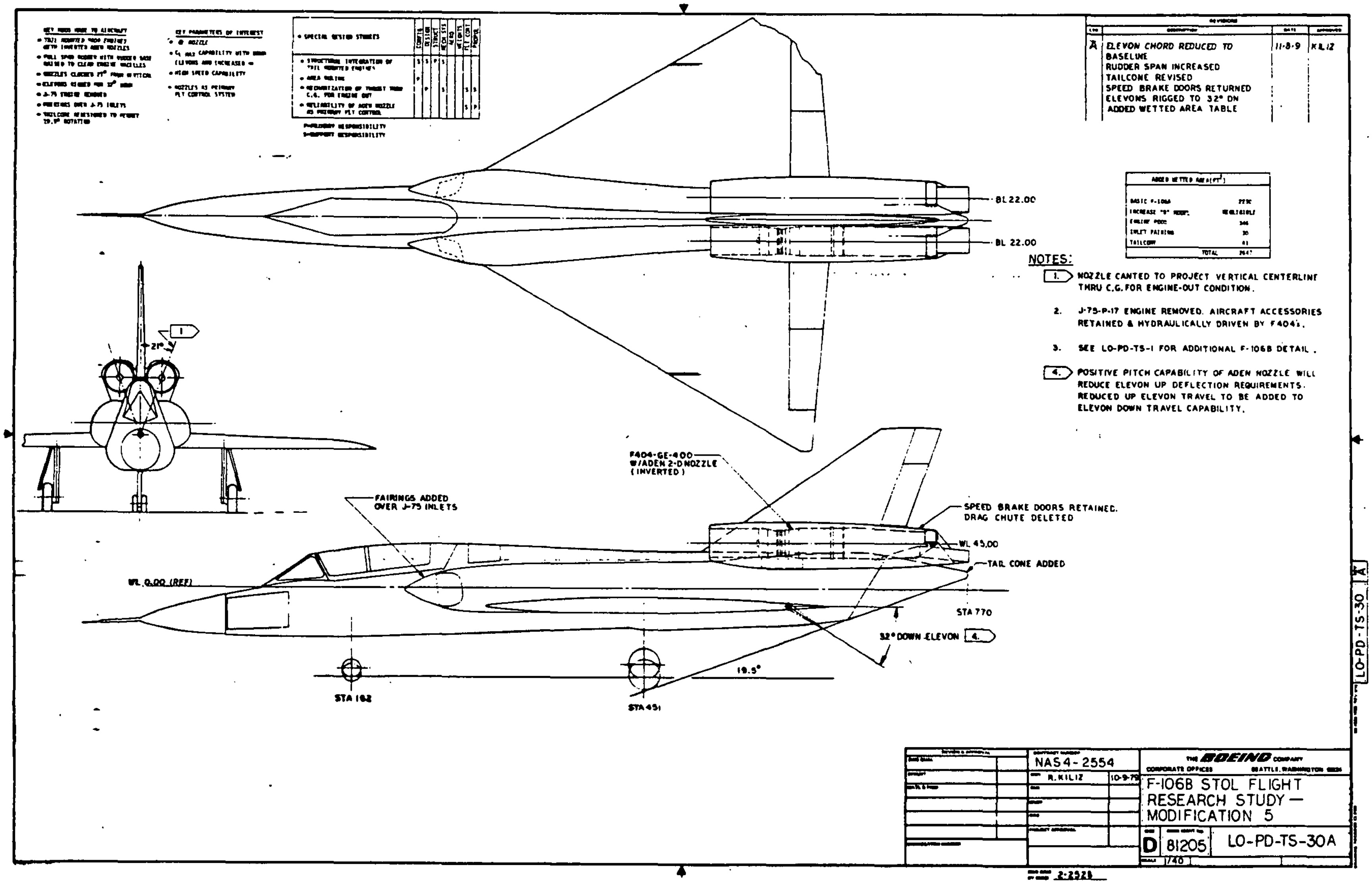


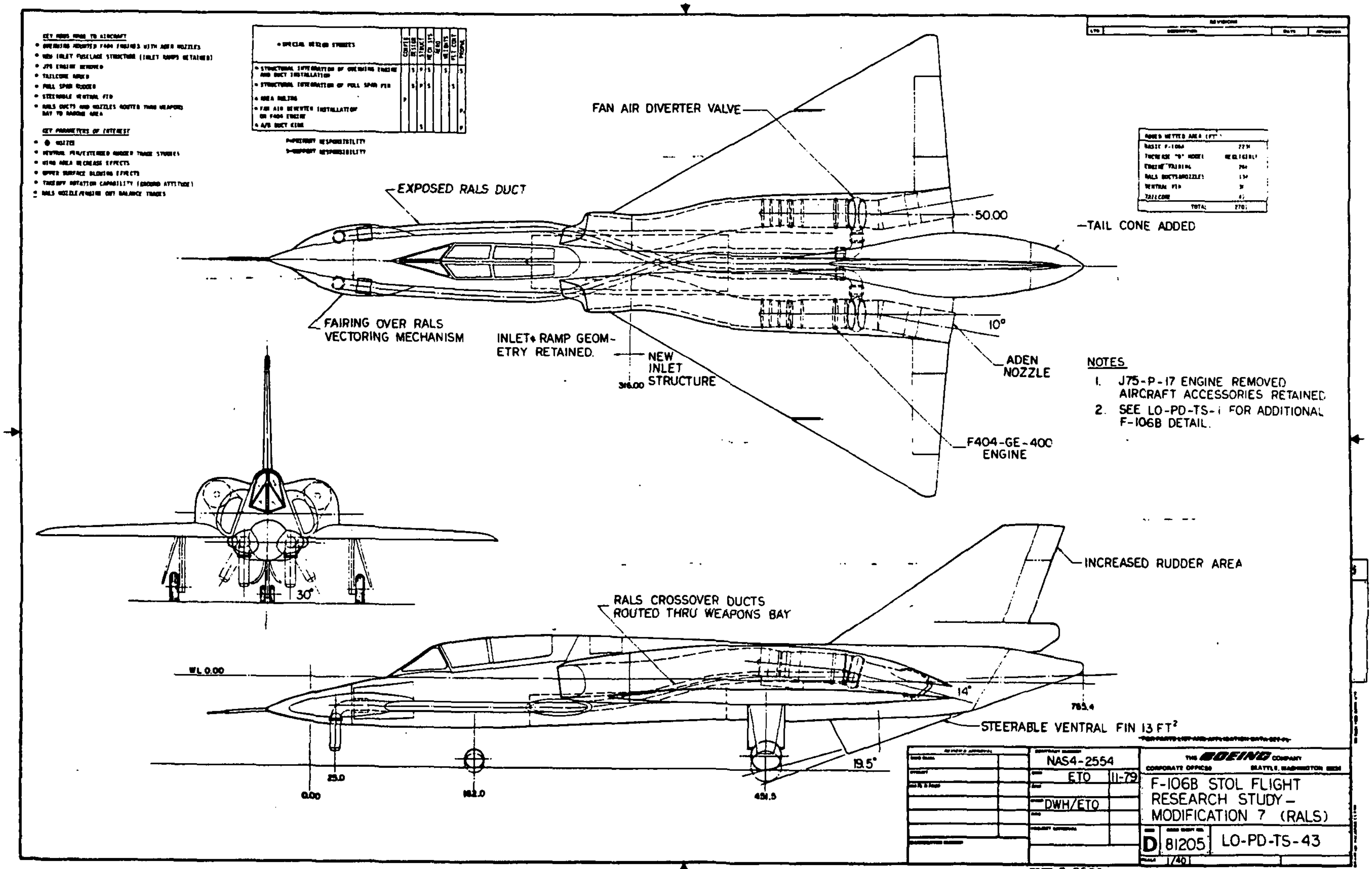
Figure 3.1.4-4. F-106B STOL Flight Research Study Modification #5

of the wing elevons. The negative lift increment developed thus subtracts from the overall wing efficiency. In contrast, an aft-located vectorable nozzle if vectored up can provide the pitch control necessary to put the aircraft at high angle-of-attack. The elevons can then be deflected downward to improve the wing camber for developing higher lift coefficients. This installation would enable research of some key aspects of propulsion/flight controls integration as well as validation of nozzle design considerations. Use of the nozzle as a primary flight control element would also necessitate addressing various nozzle failure modes during the development activities.

Twin pods have been located at the base of the vertical tail to minimize engine-out moments. The configuration should be capable of operation throughout a complete flight placard.

MODIFICATION 7: (figure 3.1.4-5) is similar in some respects to Modification 1 in that the configuration is intended to provide additional lift through thrust vectoring and jet-induced wing lift. Trimming of the vectoring forces, however, is accomplished by the use of a Remote Augmented Lift System (RALS). This system uses F-404 fan air ducted through the aircraft to an auxiliary nozzle located in the forward fuselage. This type of trim system, although complicating the powerplant installation offers some advantages to the aircraft when compared to the canard. Specifically, it avoids airplane balance problems associated with the forward shift of the aerodynamic center imposed by the canard.

Further configuration changes included installation of the F-404 engines above the wing to reduce engine ingestion problems inherent with a RALS jet operating close to the ground. This also leaves the landing gear unaffected.



KEY MODS MADE TO AIRCRAFT

- OVERWING MOUNTED F404 ENGINES WITH ADEN NOZZLES
- NEW INLET FUSELAGE STRUCTURE (INLET RAMPS RETAINED)
- J75 ENGINE REMOVED
- TAILCONE ADDED
- FULL SPAN RUDDER
- STEERABLE VENTRAL FIN
- RALS DUCTS AND NOZZLES ROUTED THRU WEAPONS BAY TO RADOME AREA

KEY PARAMETERS OF INTEREST

- [illegible] NOZZLES
- VENTRAL FIN/EXTENDED RUDDER TRADE STUDIES
- WING AREA DECREASE EFFECTS
- UPPER SURFACE BLOWING EFFECTS
- TAKEOFF ROTATION CAPABILITY (GROUND ATTITUDE)
- RALS NOZZLE/ENGINE OUT BALANCE TRADES

• SPECIAL DESIGN STUDIES	CONFIG	DESIGN	STRUCT	MECH SYS	AERO	WEIGHTS	FLT CONT	PROPUL
• STRUCTURAL INTEGRATION OF OVERWING ENGINE AND DUCT INSTALLATION		S	P	S		S		S
• STRUCTURAL INTEGRATION OF FULL SPAN FIN		S	P	S			S	
• AREA RULING	P							
• FAN AIR DIVERTER INSTALLATION ON F404 ENGINE								P
• A/B DUCT KINK			S					P

P=PRIMARY RESPONSIBILITY
S=SUPPORT RESPONSIBILITY

ADDED WETTED AREA (FT²)	
BASIC F-106A	2234
INCREASE "B" MODEL	NEGLIGIBLE
ENGINE FAIRING	204
RALS DUCTS & NOZZLES	134
VENTRAL FIN	30
TAILCONE	47
TOTAL	2701

NOTES

1. J75-P-17 ENGINE REMOVED AIRCRAFT ACCESSORIES RETAINED.
2. SEE LO-PD-TS-1 FOR ADDITIONAL F-106B DETAIL.

F-106B STOL FLIGHT RESEARCH STUDY – MODIFICATION 7 (RALS)

LO-PD-TS-43

Figure 3.1.4-5. F-106B STOL Fight Research Study Modification #7

3.2A TASK 2 - CONFIGURATION ANALYSES

3.2A.1 Weights and Balance

Data were generated first for a baseline, unmodified aircraft. Baseline F-106B weight and balance for the design condition is shown in the Figure 3.2A.1-1 group level weight and balance statement. Weight data was extracted from Reference 3.2A.1-1 and balance from Reference 3.2A.1-2. 780 lb of liquid ballast is included with non-expendable useful load. The ballast is unusable fuel stored in the integral fuselage tank and pumped to and from the transfer tank for c.g. control (see Figure 3.2A.1-2). Design mission takeoff fuel loading is shown in the following table.

TANK NO.	GALLONS	WEIGHT - LB.
1 Full	299	1944
2 Full	311	2021
3 Full	424	2756
T Full	210	1365
F Partial	6	39
Total Fuel Available	1250	8125

Basic weight and balance for the nozzle feasibility study follow-on F-106B Modification 1 were determined, see figures 3.2A.1-3 and -4. Estimates were based on the reference actual weight and balance of the F-106B modified per drawings developed for this study. Results of this weight and balance estimate compared to the established stability limit (+3% positive stability margin) indicates a requirement for 4525 lb of ballast installed at a composite body station of 71.6 in order to bring the aircraft into acceptable limits throughout the normal flight envelope.

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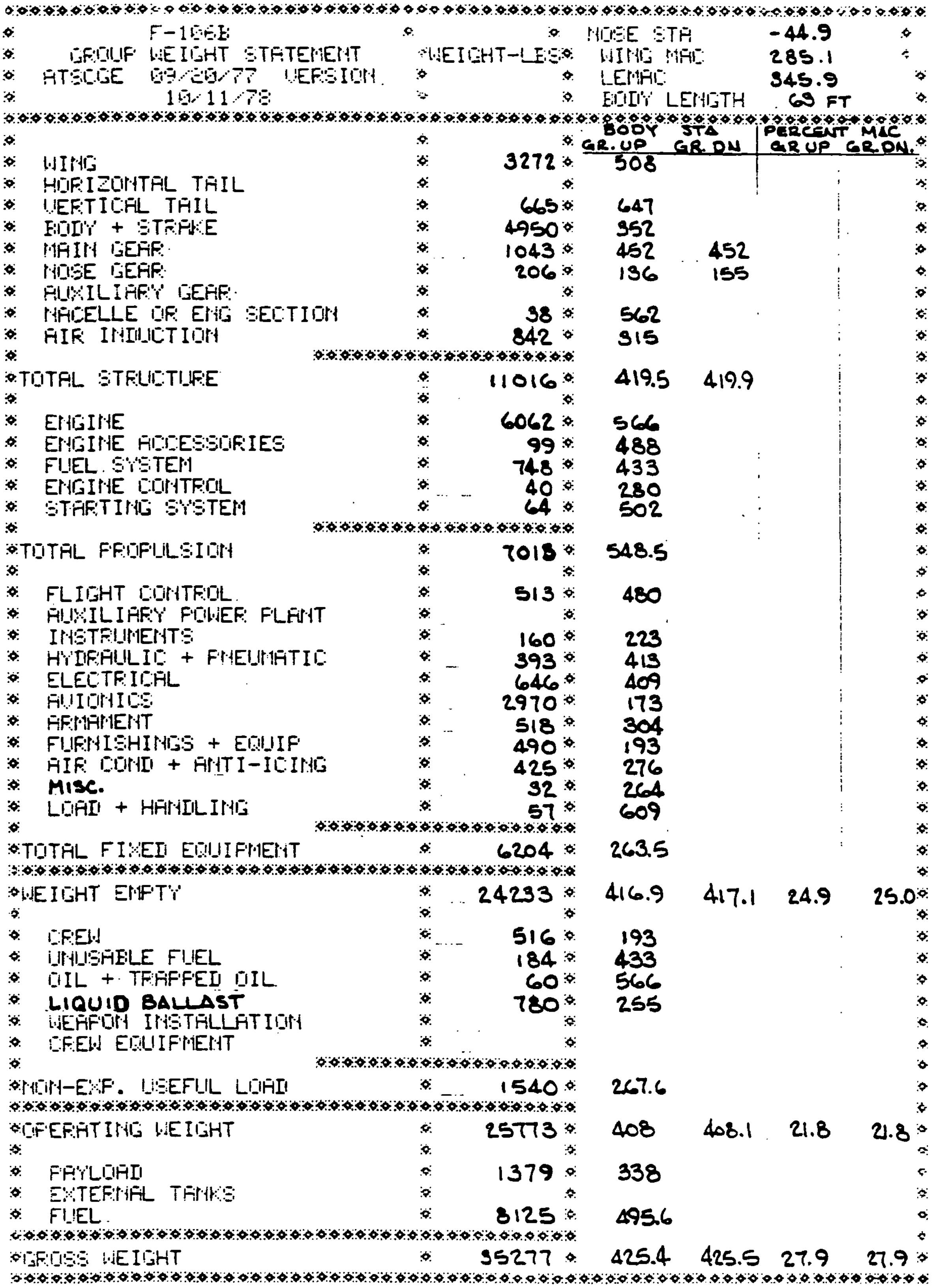


F-106B
GROUP WEIGHT STATEMENT
ATSCGE 09/20/77 VERSION
10/11/78

NOSE STA	-44.9
WING MAC	285.1
LEMAC	345.9
BODY LENGTH	69 FT

	WEIGHT-LBS	BODY STA GR. UP	BODY STA GR. DN	PERCENT MAC GR UP	PERCENT MAC GR. DN.
WING	3272	508			
HORIZONTAL TAIL					
VERTICAL TAIL	665	647			
BODY + STRAKE	4950	352			
MAIN GEAR	1043	462	452		
NOSE GEAR	206	136	155		
AUXILIARY GEAR					
NACELLE OR ENG SECTION	38	562			
AIR INDUCTION	842	315			
TOTAL STRUCTURE	11016	419.5	419.9		
ENGINE	6062	566			
ENGINE ACCESSORIES	99	488			
FUEL SYSTEM	748	433			
ENGINE CONTROL	40	280			
STARTING SYSTEM	64	502			
TOTAL PROPULSION	7018	548.5			
FLIGHT CONTROL	513	480			
AUXILIARY POWER PLANT					
INSTRUMENTS	160	223			
HYDRAULIC + PNEUMATIC	393	413			
ELECTRICAL	646	409			
AVIONICS	2970	173			
ARMAMENT	518	304			
FURNISHINGS + EQUIP	490	193			
AIR COND + ANTI-ICING	425	276			
MISC.	32	264			
LOAD + HANDLING	57	609			
TOTAL FIXED EQUIPMENT	6204	263.5			
WEIGHT EMPTY	24233	416.9	417.1	24.9	25.0
CREW	516	193			
UNUSABLE FUEL	184	433			
OIL + TRAPPED OIL	60	566			
LIQUID BALLAST	780	255			
WEAPON INSTALLATION					
CREW EQUIPMENT					
NON-EXP. USEFUL LOAD	1540	267.6			
OPERATING WEIGHT	25773	408	408.1	21.8	21.8
PAYLOAD	1379	338			
EXTERNAL TANKS					
FUEL	8125	495.6			
GROSS WEIGHT	35277	425.4	425.5	27.9	27.9

Figure 3.2A.1-1. Baseline F-106B Group Level Weight and Balance Statement

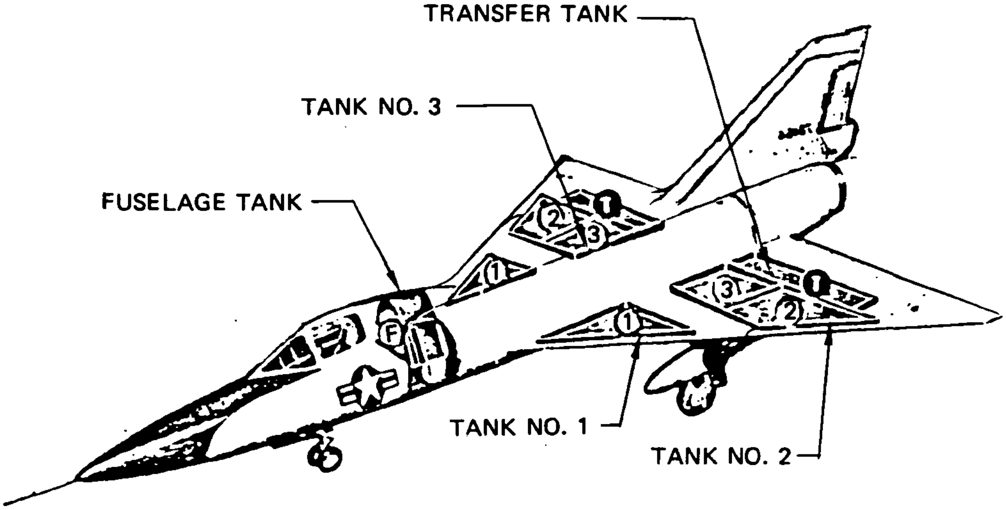


Figure 3.2A.1-2. F-106B Fuel Tank Location

```
***********************************************************************
*         F-106B  MOD1         *           * NOSE STATION      -44.9  *
*    GROUP WEIGHT STATEMENT     *WEIGHT-LBS* WING MAC          285.1  *
*  ATSCGE  09/20/77/  VERSION  *           * LEMAC             345.9  *
*                              *           * BODY LENGTH        63.0  *
***********************************************************************
*                              *           * BODY STA     PERCENT MAC *
*  WING                        *    3342.0 *    508.0                 *
*  CANARD                      *     420.0 *    210.0                 *
*  VERTICAL TAIL               *    1075.0 *    633.3                 *
*  BODY + STRAKE               *    5860.0 *    347.1                 *
*  MAIN GEAR                   *    1320.0 *    452.0                 *
*  NOSE GEAR                   *     300.0 *    162.0                 *
*  AUX GEAR                    *       0.0 *      0.0                 *
*  NACELLE OR ENG SECTION      *     508.0 *    575.0                 *
*  AIR INDUCTION               *     572.0 *    488.0                 *
*                      *********************                          *
*TOTAL STRUCTURE               *   13397.0 *    426.8                 *
*                              *           *                          *
*  ENGINE                      *    5215.0 *    558.9                 *
*  ENGINE ACCESSORIES          *      99.0 *    488.0                 *
*  FUEL SYSTEM                 *    1371.0 *    423.0                 *
*  ENGINE CONTROL              *      80.0 *    280.0                 *
*  STARTING SYSTEM             *      96.0 *    502.0                 *
*                      *********************                          *
*TOTAL PROPULSION              *    6861.0 *    526.7                 *
*                              *           *                          *
*  FLIGHT CONTROL              *    1560.0 *    480.0                 *
*  AUXILIARY POWER PLANT       *       0.0 *      0.0                 *
*  INSTRUMENTS                 *     160.0 *    233.0                 *
*  HYDRAULIC + PNEUMATIC       *    1114.0 *    413.0                 *
*  ELECTRICAL                  *     846.0 *    409.0                 *
*  AVIONICS                    *    2882.0 *    173.0                 *
*  ARMAMENT                    *       0.0 *      0.0                 *
*  FURNISHINGS + EQUIP         *     490.0 *    193.0                 *
*  AIR COND + ANTI ICE         *     425.0 *    276.0                 *
*  MISCELLANEOUS               *      32.0 *    264.0                 *
*  LOAD + HANDLING             *      57.0 *    609.0                 *
*                      *********************                          *
*TOTAL FIXED EQUIPMENT         *    7566.0 *    310.0                 *
********************************************                          *
*WEIGHT EMPTY                  *   27824.0 *    419.7         25.9    *
*                              *           *                          *
*  CREW                        *     516.0 *    193.0                 *
*  UNUSABLE FUEL               *     184.0 *    433.0                 *
*  OIL AND TRAPPED OIL         *      60.0 *    566.0                 *
*  GUN INSTALLATION + PROV     *       0.0 *      0.0                 *
*  BALLAST                     *    4525.0 *     71.6                 *
*  CREW EQUIPMENT              *       0.0 *      0.0                 *
*                      *********************                          *
*NON-EXP USEFUL LOAD           *    5285.0 *    101.6                 *
********************************************                          *
*OPERATING WEIGHT              *   33109.0 *    368.9          8.1    *
*                              *           *                          *
*  PAYLOAD                     *       0.0 *      0.0                 *
*  FUEL - INTEGRAL             *    7936.0 *    446.6                 *
*  FUEL - MISSILE BAY          *    3890.0 *    320.5                 *
********************************************                          *
*GROSS WEIGHT                  *   44935.0 *    378.4         11.4    *
***********************************************************************
```

3.2A.1-3. F-106B STOL Flight Research Study Modification 1 As-Drawn Group Weight and Balance Statement

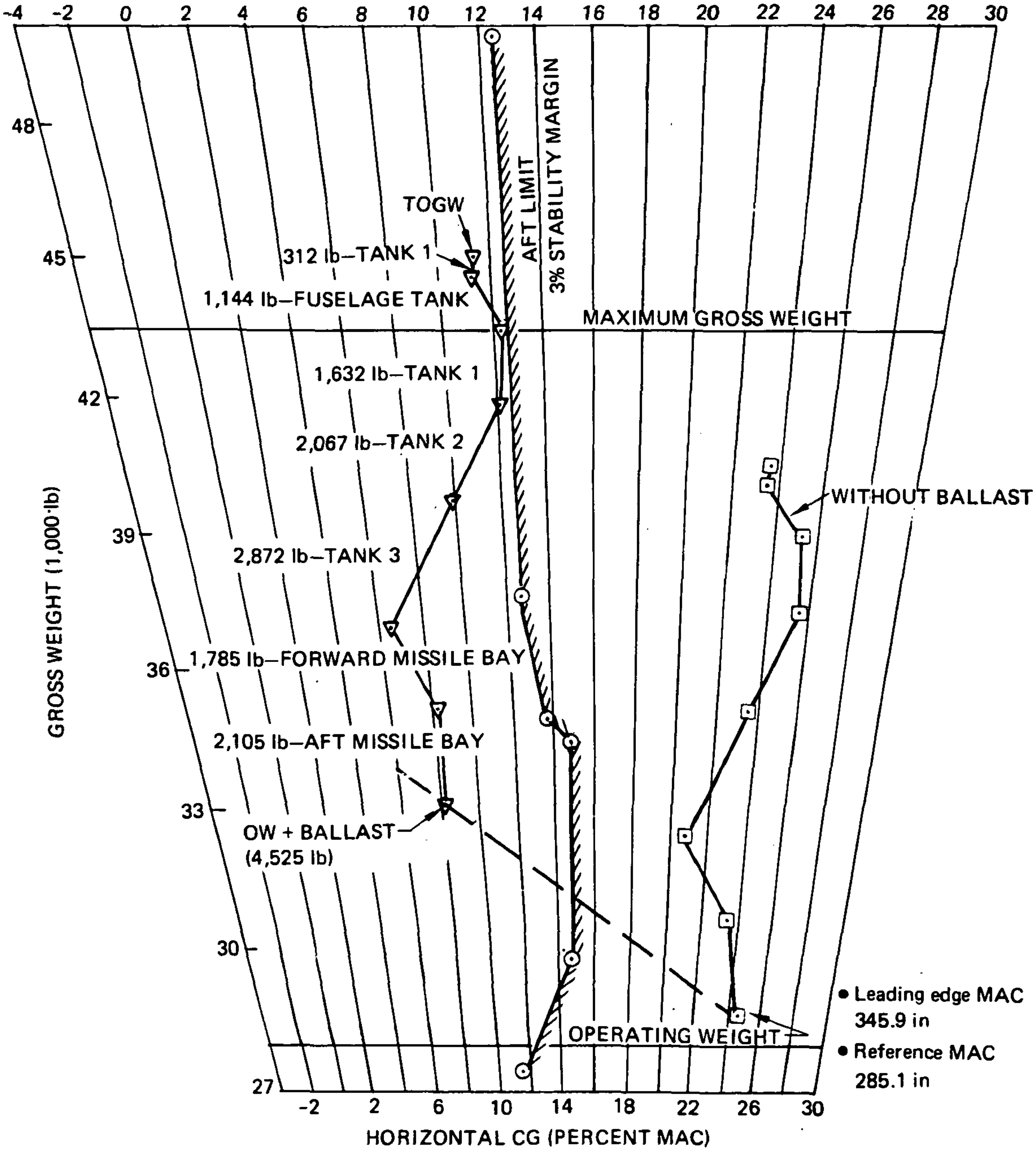


Figure 3.2A.1-4. F-106B STOL Flight Research Study Modification 1 As-Drawn—Weight and Balance Grid

Because of this high requirement for ballast, further modifications were studied. A twenty percent reduction in the canard size shifts the aft stability limit 4% aft allowing a 1645 lb reduction in ballast. These data are given in figures 3.2A.1-5 and -6. Establishing neutral stability combined with reducing the canard shifts the neutral stability point an additional 3% aft allowing a further 1080 lb reduction in ballast. C.g. grids are given in figures 3.2A.1-7 and -8 for each.

It should be noted that during the preceding contract it was established that the maximum structurally allowable ballast would be about 2000 lb.

Weight and balance analysis were developed for F-106B Mod. 3. Weight and balance estimates were based on the actual weight and balance of F-106B and the configuration as shown by Figure 3.1.4-3 develped for this study. The weight and balance investigation for the as-drawn configuration indicated a requirement for 3880 lbs of ballast at body station 71.6 in order to produce a stable aircraft. Weight and balance for the as-drawn configuration are summarized in figure 3.2A.1-9. Figure 3.2A.1-10 summarizes the as-drawn case with the 3880 lb of ballast installed. The weight and c.g. envelope of figure 3.2A.1-11 shows the airplane with and without ballast. The airplane with 3880 lb of ballast installed and a full fuel load exceeded the maximum takeoff gross weight. Therefore, alternative solutions were sought.

Balance sensitivity to relocating the wing was investigated as a means to correct the balance problem. Moving the wing back to the original F-106B longitudinal position produced a considerable improvement to the situation although the airplane did not achieve the desired stability margin throughout the entire flight envelope. Figure 3.2A.1-12 summarizes the weight and balance for this solution and figure 3.2A.1-13 shows the envelope.

```
**********************************************************************
*     F106B MOD1 80% CANRD      *             * NOSE STATION     -44.9 *
*    GROUP WEIGHT STATEMENT     *WEIGHT-LBS*  * WING MAC         285.1 *
*  ATSCGE  09/20/77/  VERSION   *             * LEMAC            345.9 *
*                               *             * BODY LENGTH       63.0 *
**********************************************************************
*                               *             * BODY STA   PERCENT MAC *
*  WING                         *    3342.0 *    508.0                 *
*  CANARD                       *     420.0 *    210.0                 *
*  VERTICAL TAIL                *    1075.0 *    633.3                 *
*  BODY + STRAKE                *    5860.0 *    347.1                 *
*  MAIN GEAR                    *    1320.0 *    452.0                 *
*  NOSE GEAR                    *     300.0 *    162.0                 *
*  AUX GEAR                     *       0.0 *      0.0                 *
*  NACELLE OR ENG SECTION       *     508.0 *    575.0                 *
*  AIR INDUCTION                *     572.0 *    488.0                 *
*                         ********************                        *
*TOTAL STRUCTURE                *   13397.0 *    426.8                 *
*                               *           *                          *
*  ENGINE                       *    5215.0 *    558.9                 *
*  ENGINE ACCESSORIES           *      99.0 *    488.0                 *
*  FUEL SYSTEM                  *    1371.0 *    423.0                 *
*  ENGINE CONTROL               *      80.0 *    280.0                 *
*  STARTING SYSTEM              *      96.0 *    502.0                 *
*                         ********************                        *
*TOTAL PROPULSION               *    6861.0 *    526.7                 *
*                               *           *                          *
*  FLIGHT CONTROL               *    1560.0 *    480.0                 *
*  AUXILIARY POWER PLANT        *       0.0 *      0.0                 *
*  INSTRUMENTS                  *     160.0 *    233.0                 *
*  HYDRAULIC + PNEUMATIC        *    1114.0 *    413.0                 *
*  ELECTRICAL                   *     846.0 *    409.0                 *
*  AVIONICS                     *    2882.0 *    173.0                 *
*  ARMAMENT                     *       0.0 *      0.0                 *
*  FURNISHINGS + EQUIP          *     490.0 *    193.0                 *
*  AIR COND + ANTI ICE          *     425.0 *    276.0                 *
*  MISCELLANEOUS                *      32.0 *    264.0                 *
*  LOAD + HANDLING              *      57.0 *    609.0                 *
*                         ********************                        *
*TOTAL FIXED EQUIPMENT          *    7566.0 *    310.0                 *
*********************************************                         *
*WEIGHT EMPTY                   *   27824.0 *    419.7         25.9    *
*                               *           *                          *
*  CREW                         *     516.0 *    193.0                 *
*  UNUSABLE FUEL                *     184.0 *    433.0                 *
*  OIL AND TRAPPED OIL          *      60.0 *    566.0                 *
*  GUN INSTALLATION + PROV      *       0.0 *      0.0                 *
*  BALLAST                      *    2880.0 *     71.6                 *
*  CREW EQUIPMENT               *       0.0 *      0.0                 *
*                         ********************                        *
*NON-EXP USEFUL LOAD            *    3640.0 *    115.2                 *
*********************************************                         *
*OPERATING WEIGHT               *   31464.0 *    384.4         13.5    *
*                               *           *                          *
*  PAYLOAD                      *       0.0 *      0.0                 *
*  FUEL - INTEGRAL              *    7936.0 *    446.6                 *
*  FUEL - MISSILE BAY           *    3890.0 *    320.5                 *
*********************************************                         *
*GROSS WEIGHT                   *   43290.0 *    390.1         15.5    *
**********************************************************************
```

3.2A.1-5. F-106B STOL Flight Research Modification 1 Incorporating 20% Reduction in Canard Size, Group Weight and Balance Statement

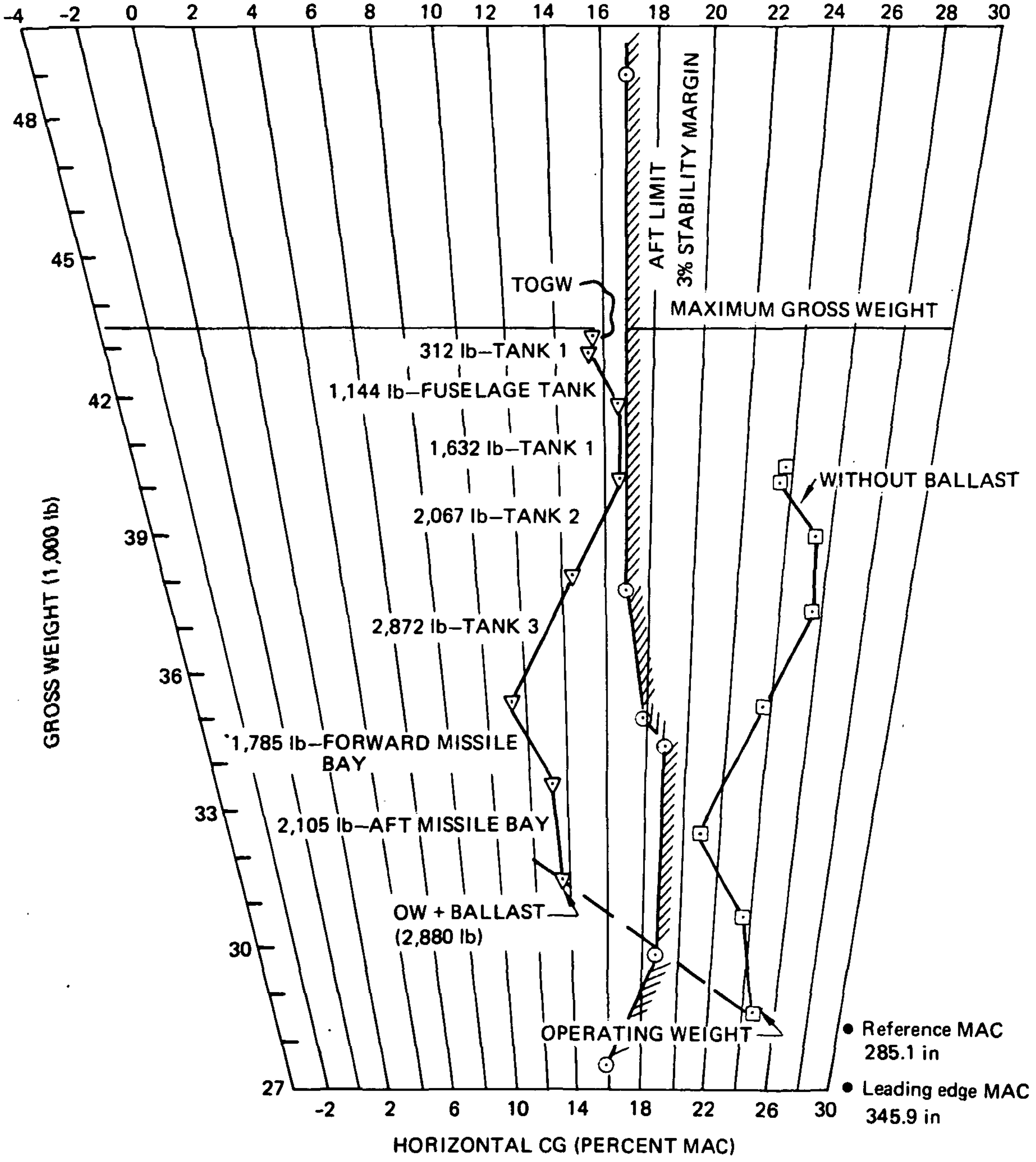


Figure 3.2A.1-6. F-106B STOL Flight Research Study Modification 1 Incorporating 20% Reduction in Canard Size— Weight and Balance Grid

```
***************************************************************************
*F106B MOD1 80% CANRD NEUT STAB*          *  NOSE STATION           -44.9 *
*    GROUP WEIGHT STATEMENT    *WEIGHT-LBS*  WING MAC                285.1 *
*  ATSCGE  09/20/77/  VERSION  *          *  LEMAC                   345.9 *
*                              *          *  BODY LENGTH              63.0 *
***************************************************************************
*                              *          *  BODY STA     PERCENT MAC     *
*  WING                        *   3342.0 *   508.0                       *
*  CANARD                      *    420.0 *   210.0                       *
*  VERTICAL TAIL               *   1075.0 *   633.3                       *
*  BODY + STRAKE               *   5860.0 *   347.1                       *
*  MAIN GEAR                   *   1320.0 *   452.0                       *
*  NOSE GEAR                   *    300.0 *   162.0                       *
*  AUX GEAR                    *      0.0 *     0.0                       *
*  NACELLE OR ENG SECTION      *    508.0 *   575.0                       *
*  AIR INDUCTION               *    572.0 *   488.0                       *
*                    **********************                               *
*TOTAL STRUCTURE               *  13397.0 *   426.8                       *
*                              *          *                               *
*  ENGINE                      *   5215.0 *   558.9                       *
*  ENGINE ACCESSORIES          *     99.0 *   488.0                       *
*  FUEL SYSTEM                 *   1371.0 *   423.0                       *
*  ENGINE CONTROL              *     80.0 *   280.0                       *
*  STARTING SYSTEM             *     96.0 *   502.0                       *
*                    **********************                               *
*TOTAL PROPULSION              *   6861.0 *   526.7                       *
*                              *          *                               *
*  FLIGHT CONTROL              *   1560.0 *   480.0                       *
*  AUXILIARY POWER PLANT       *      0.0 *     0.0                       *
*  INSTRUMENTS                 *    160.0 *   233.0                       *
*  HYDRAULIC + PNEUMATIC       *   1114.0 *   413.0                       *
*  ELECTRICAL                  *    846.0 *   409.0                       *
*  AVIONICS                    *   2882.0 *   173.0                       *
*  ARMAMENT                    *      0.0 *     0.0                       *
*  FURNISHINGS + EQUIP         *    490.0 *   193.0                       *
*  AIR COND + ANTI ICE         *    425.0 *   276.0                       *
*  MISCELLANEOUS               *     32.0 *   264.0                       *
*  LOAD + HANDLING             *     57.0 *   609.0                       *
*                    **********************                               *
*TOTAL FIXED EQUIPMENT         *   7566.0 *   310.0                       *
*******************************************                               *
*WEIGHT EMPTY                  *  27824.0 *   419.7              25.9     *
*                              *          *                               *
*  CREW                        *    516.0 *   193.0                       *
*  UNUSABLE FUEL               *    184.0 *   433.0                       *
*  OIL AND TRAPPED OIL         *     60.0 *   566.0                       *
*  GUN INSTALLATION + PROV     *      0.0 *     0.0                       *
*  BALLAST                     *   1800.0 *    71.6                       *
*  CREW EQUIPMENT              *      0.0 *     0.0                       *
*                    **********************                               *
*NON-EXP USEFUL LOAD           *   2560.0 *   133.6                       *
*******************************************                               *
*OPERATING WEIGHT              *  30384.0 *   395.6              17.4     *
*                              *          *                               *
*  PAYLOAD                     *      0.0 *     0.0                       *
*  FUEL - INTEGRAL             *   7936.0 *   446.6                       *
*  FUEL - MISSILE BAY          *   3890.0 *   320.5                       *
*******************************************                               *
*GROSS WEIGHT                  *  42210.0 *   398.2              18.4     *
***************************************************************************
```

3.2A.1-7. F-106B STOL Flight Research Study Modification 1 Incorporating 20% Reduction in Canard Size Plus Neutral Stability Group Weight and Balance Statement

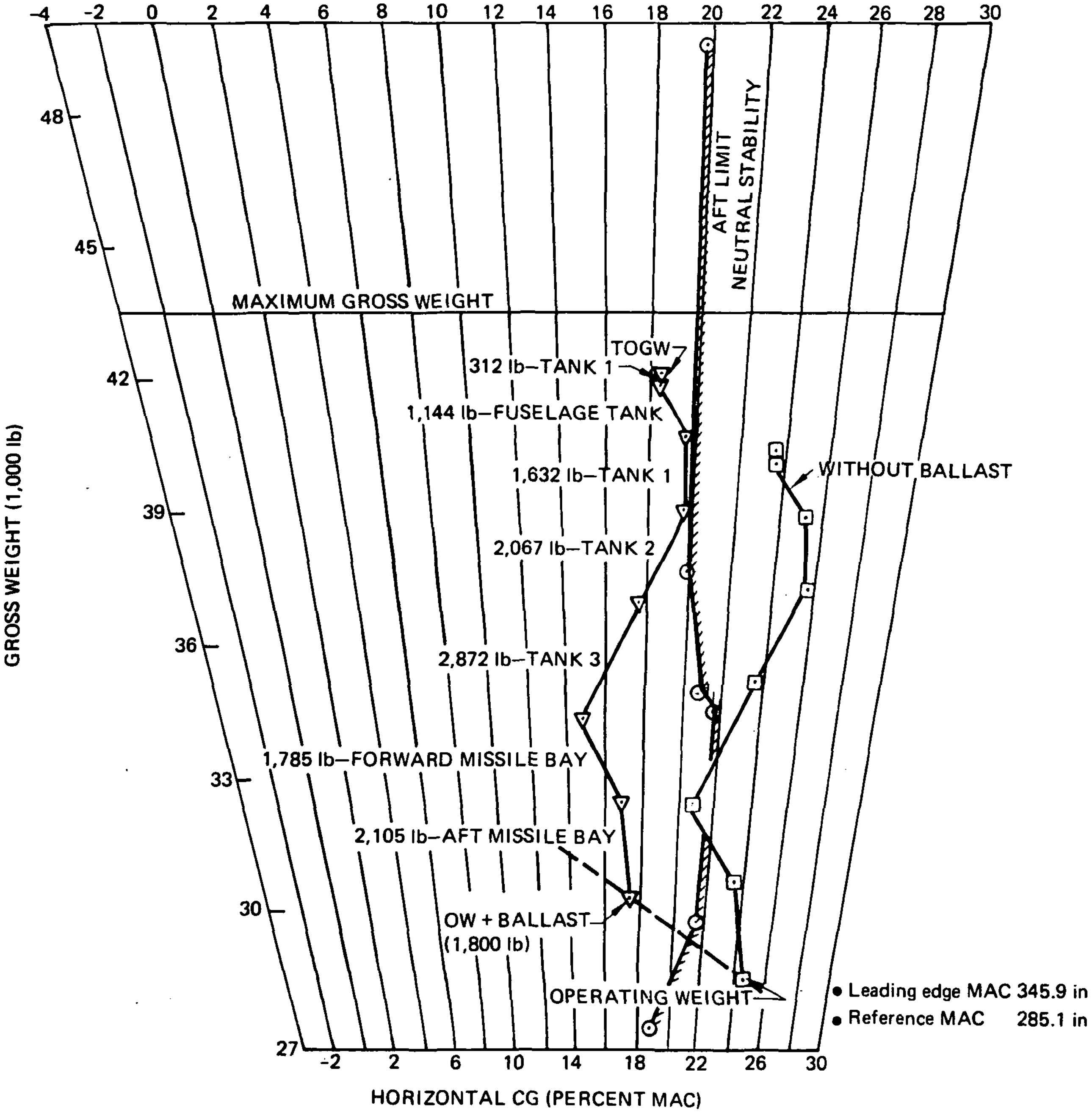


Figure 3.2A.1-8. F-106B STOL Flight Research Study Modification 1 Incorporating 20% Reduction in Canard Size Plus Neutral Stability– Weight and Balance Grid

```
***********************************************************************
*          F106B MOD3           *          * NOSE STATION      -44.9  *
*    GROUP WEIGHT STATEMENT     *WEIGHT-LBS* WING MAC          285.1  *
*  ATSCGE  09/20/77/  VERSION   *          * LEMAC             345.9  *
*                               *          * BODY LENGTH        63.0  *
***********************************************************************
*                               *          * BODY STA     PERCENT MAC *
*  WING                         *   5844.0 *    403.0                 *
*  HORIZONTAL TAIL              *    366.0 *    682.0                 *
*  VERTICAL TAIL                *    588.0 *    644.0                 *
*  BODY + STRAKE                *   5154.0 *    348.0                 *
*  MAIN GEAR                    *   1063.0 *    408.0                 *
*  NOSE GEAR                    *    206.0 *    158.0                 *
*  AUX GEAR                     *      0.0 *      0.0                 *
*  NACELLE OR ENG SECTION       *    504.0 *    384.0                 *
*  AIR INDUCTION                *    572.0 *    342.0                 *
*                      *********************                          *
*TOTAL STRUCTURE                *  14297.0 *    394.0                 *
*                               *          *                          *
*  ENGINE                       *   5215.0 *    377.9                 *
*  ENGINE ACCESSORIES           *     99.0 *    488.0                 *
*  FUEL SYSTEM                  *   1371.0 *    423.0                 *
*  ENGINE CONTROL               *     80.0 *    280.0                 *
*  STARTING SYSTEM              *     96.0 *    502.0                 *
*                      *********************                          *
*TOTAL PROPULSION               *   6861.0 *    389.1                 *
*                               *          *                          *
*  FLIGHT CONTROL               *   1074.0 *    480.0                 *
*  AUXILIARY POWER PLANT        *      0.0 *      0.0                 *
*  INSTRUMENTS                  *    160.0 *    233.0                 *
*  HYDRAULIC + PNEUMATIC        *    900.0 *    413.0                 *
*  ELECTRICAL                   *    796.0 *    409.0                 *
*  AVIONICS                     *   2822.0 *    173.0                 *
*  ARMAMENT                     *      0.0 *      0.0                 *
*  FURNISHINGS + EQUIP          *    490.0 *    193.0                 *
*  AIR COND + ANTI ICE          *    425.0 *    276.0                 *
*  MISCELLANEOUS                *     32.0 *    264.0                 *
*  LOAD + HANDLING              *     57.0 *    609.0                 *
*                      *********************                          *
*TOTAL FIXED EQUIPMENT          *   6816.0 *    294.0                 *
********************************************                          *
*WEIGHT EMPTY                   *  27974.0 *    368.4          7.9    *
*                               *          *                          *
*  CREW                         *    516.0 *    193.0                 *
*  UNUSABLE FUEL                *    184.0 *    433.0                 *
*  OIL AND TRAPPED OIL          *     60.0 *    566.0                 *
*  GUN INSTALLATION + PROV      *      0.0 *      0.0                 *
*  BALLAST                      *      0.0 *      0.0                 *
*  CREW EQUIPMENT               *      0.0 *      0.0                 *
*                      *********************                          *
*NON-EXP USEFUL LOAD            *    760.0 *    280.6                 *
********************************************                          *
*OPERATING WEIGHT               *  28734.0 *    366.1          7.1    *
*                               *          *                          *
*  PAYLOAD                      *      0.0 *      0.0                 *
*  FUEL - INTEGRAL              *   7936.0 *    376.1                 *
*  FUEL - MISSILE BAY           *   3890.0 *    320.5                 *
********************************************                          *
*GROSS WEIGHT                   *  40560.0 *    363.7          6.2    *
***********************************************************************
```

3.2A.1-9. F-106B STOL Flight Research Study Modification 3 As-Drawn Group Weight and Balance Statement

```
***********************************************************************
*          F106B MOD3          *          *  NOSE STATION      -44.9  *
*    GROUP WEIGHT STATEMENT    *WEIGHT-LBS*  WING MAC           285.1  *
*  ATSCGE  09/20/77/  VERSION  *          *  LEMAC              345.9  *
*                              *          *  BODY LENGTH         63.0  *
***********************************************************************
*                              *          *  BODY STA    PERCENT MAC  *
*  WING                        *   5844.0 *     403.0                 *
*  HORIZONTAL TAIL             *    366.0 *     682.0                 *
*  VERTICAL TAIL               *    588.0 *     644.0                 *
*  BODY + STRAKE               *   5154.0 *     348.0                 *
*  MAIN GEAR                   *   1063.0 *     408.0                 *
*  NOSE GEAR                   *    206.0 *     158.0                 *
*  AUX GEAR                    *      0.0 *       0.0                 *
*  NACELLE OR ENG SECTION      *    504.0 *     384.0                 *
*  AIR INDUCTION               *    572.0 *     342.0                 *
*                      *********************                          *
*TOTAL STRUCTURE               *  14297.0 *     394.0                 *
*                              *          *                           *
*  ENGINE                      *   5215.0 *     377.9                 *
*  ENGINE ACCESSORIES          *     99.0 *     488.0                 *
*  FUEL SYSTEM                 *   1371.0 *     423.0                 *
*  ENGINE CONTROL              *     80.0 *     280.0                 *
*  STARTING SYSTEM             *     96.0 *     502.0                 *
*                      *********************                          *
*TOTAL PROPULSION              *   6861.0 *     389.1                 *
*                              *          *                           *
*  FLIGHT CONTROL              *   1074.0 *     480.0                 *
*  AUXILIARY POWER PLANT       *      0.0 *       0.0                 *
*  INSTRUMENTS                 *    160.0 *     233.0                 *
*  HYDRAULIC + PNEUMATIC       *    900.0 *     413.0                 *
*  ELECTRICAL                  *    796.0 *     409.0                 *
*  AVIONICS                    *   2882.0 *     173.0                 *
*  ARMAMENT                    *      0.0 *       0.0                 *
*  FURNISHINGS + EQUIP         *    490.0 *     193.0                 *
*  AIR COND + ANTI ICE         *    425.0 *     276.0                 *
*  MISCELLANEOUS               *     32.0 *     264.0                 *
*  LOAD + HANDLING             *     57.0 *     609.0                 *
*                      *********************                          *
*TOTAL FIXED EQUIPMENT         *   6816.0 *     294.0                 *
********************************************                          *
*WEIGHT EMPTY                  *  27974.0 *     368.4          7.9    *
*                              *          *                           *
*  CREW                        *    516.0 *     193.0                 *
*  UNUSABLE FUEL               *    184.0 *     433.0                 *
*  OIL AND TRAPPED OIL         *     60.0 *     566.0                 *
*  GUN INSTALLATION + PROV     *      0.0 *       0.0                 *
*  BALLAST                     *   3880.0 *      71.6                 *
*  CREW EQUIPMENT              *      0.0 *       0.0                 *
*                      *********************                          *
*NON-EXP USEFUL LOAD           *   4640.0 *     105.8                 *
********************************************                          *
*OPERATING WEIGHT              *  32614.0 *     331.0         -5.2    *
*                              *          *                           *
*  PAYLOAD                     *      0.0 *       0.0                 *
*  FUEL - INTEGRAL             *   7936.0 *     376.1                 *
*  FUEL - MISSILE BAY          *   3890.0 *     321.5                 *
********************************************                          *
*GROSS WEIGHT                  *  44440.0 *     338.2         -2.7    *
***********************************************************************
```

3.2A.1-10. F-106B STOL Flight Research Study Modification 3 As-Drawn Plus 3880 lbs. Ballast Installed Group Weight and Balance Statement

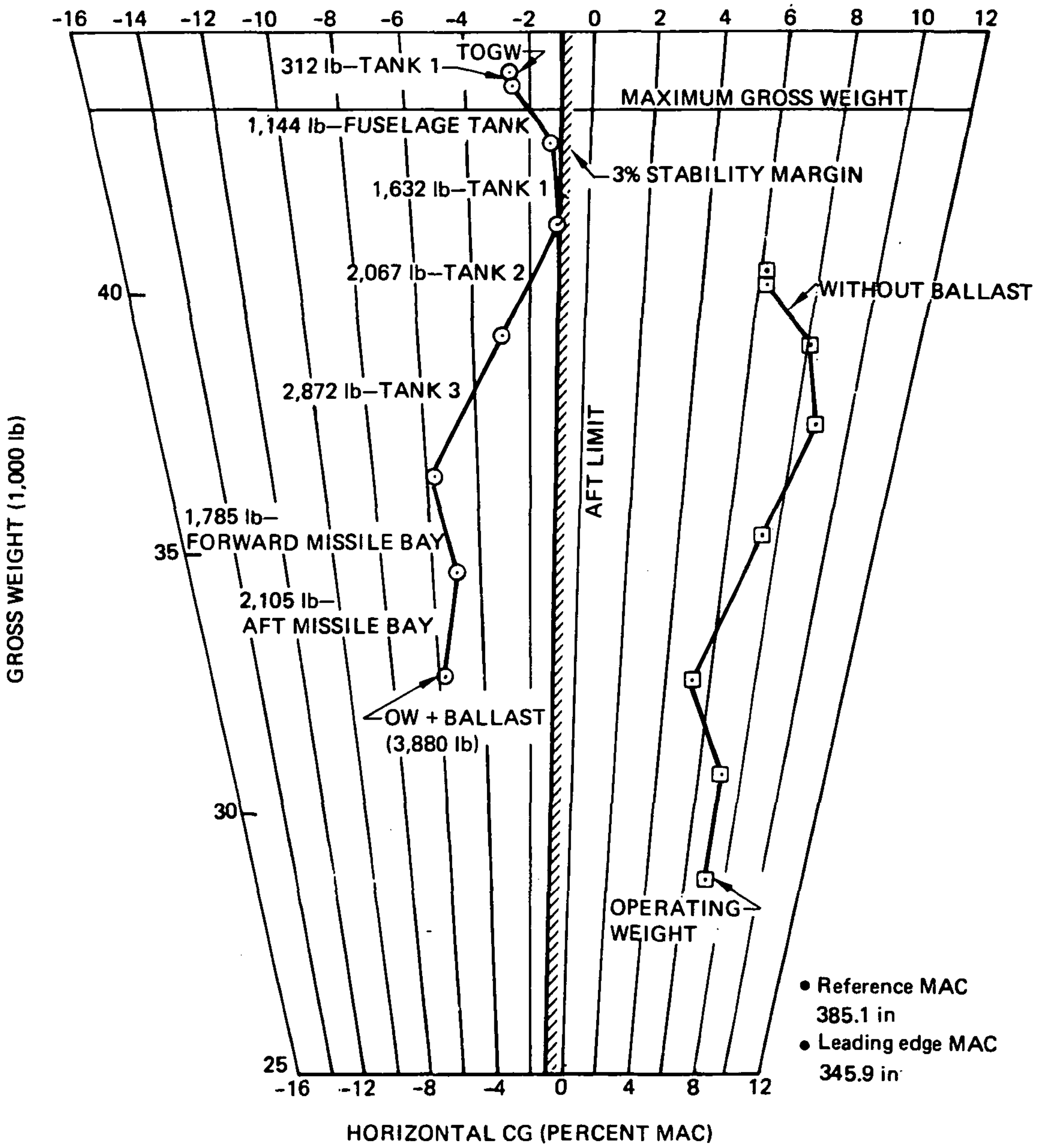


Figure 3.2A.1-11. F-106B Modification 3, As-Drawn Plus 3,880 lb Ballast—Weight and Balance Grid

```
***********************************************************************
*          F106B MOD3          *          *  NOSE STATION      -44.9  *
*    GROUP WEIGHT STATEMENT    *WEIGHT-LBS*  WING MAC          285.1  *
*  ATSCGE  09/20/77/  VERSION  *          *  LEMAC             345.9  *
*                              *          *  BODY LENGTH        63.0  *
***********************************************************************
*                              *          *  BODY STA     PERCENT MAC *
*  WING                        *   5844.0 *     473.0                 *
*  HORIZONTAL TAIL             *    366.0 *     682.0                 *
*  VERTICAL TAIL               *    588.0 *     644.0                 *
*  BODY + STRAKE               *   5154.0 *     348.0                 *
*  MAIN GEAR                   *   1063.0 *     478.0                 *
*  NOSE GEAR                   *    206.0 *     158.0                 *
*  AUX GEAR                    *      0.0 *       0.0                 *
*  NACELLE OR ENG SECTION      *    504.0 *     454.0                 *
*  AIR INDUCTION               *    572.0 *     412.0                 *
*                      ********************                           *
*TOTAL STRUCTURE               *  14297.0 *     433.0                 *
*                              *          *                           *
*  ENGINE                      *   5215.0 *     448.0                 *
*  ENGINE ACCESSORIES          *     99.0 *     558.0                 *
*  FUEL SYSTEM                 *   1371.0 *     493.0                 *
*  ENGINE CONTROL              *     80.0 *     280.0                 *
*  STARTING SYSTEM             *     96.0 *     572.0                 *
*                      ********************                           *
*TOTAL PROPULSION              *   6861.0 *     458.4                 *
*                              *          *                           *
*  FLIGHT CONTROL              *   1074.0 *     550.0                 *
*  AUXILIARY POWER PLANT       *      0.0 *       0.0                 *
*  INSTRUMENTS                 *    160.0 *     233.0                 *
*  HYDRAULIC + PNEUMATIC       *    900.0 *     413.0                 *
*  ELECTRICAL                  *    796.0 *     409.0                 *
*  AVIONICS                    *   2882.0 *     173.0                 *
*  ARMAMENT                    *      0.0 *       0.0                 *
*  FURNISHINGS + EQUIP         *    490.0 *     193.0                 *
*  AIR COND + ANTI ICE         *    425.0 *     276.0                 *
*  MISCELLANEOUS               *     32.0 *     264.0                 *
*  LOAD + HANDLING             *     57.0 *     609.0                 *
*                      ********************                           *
*TOTAL FIXED EQUIPMENT         *   6816.0 *     305.0                 *
*******************************************                           *
*WEIGHT EMPTY                  *  27974.0 *     408.1         21.8    *
*                              *          *                           *
*  CREW                        *    516.0 *     193.0                 *
*  UNUSABLE FUEL               *    184.0 *     513.0                 *
*  OIL AND TRAPPED OIL         *     60.0 *     636.0                 *
*  GUN INSTALLATION + PROV.    *      0.0 *       0.0                 *
*  BALLAST                     *      0.0 *       0.0                 *
*  CREW EQUIPMENT              *      0.0 *       0.0                 *
*                      ********************                           *
*NON-EXP USEFUL LOAD           *    760.0 *     305.4                 *
*******************************************                           *
*OPERATING WEIGHT              *  28734.0 *     405.3         20.8    *
*                              *          *                           *
*  PAYLOAD                     *      0.0 *       0.0                 *
*  FUEL - INTEGRAL             *   7936.0 *     446.0                 *
*  FUEL - MISSILE BAY          *   3890.0 *     320.5                 *
*******************************************                           *
*GROSS WEIGHT                  *  40560.0 *     405.2         20.8    *
***********************************************************************
```

3.2A.1-12. F-106B STOL Flight Research Study Modification 3 With Wing Relocated at Original F-106B Position Group Weight and Balance Statement

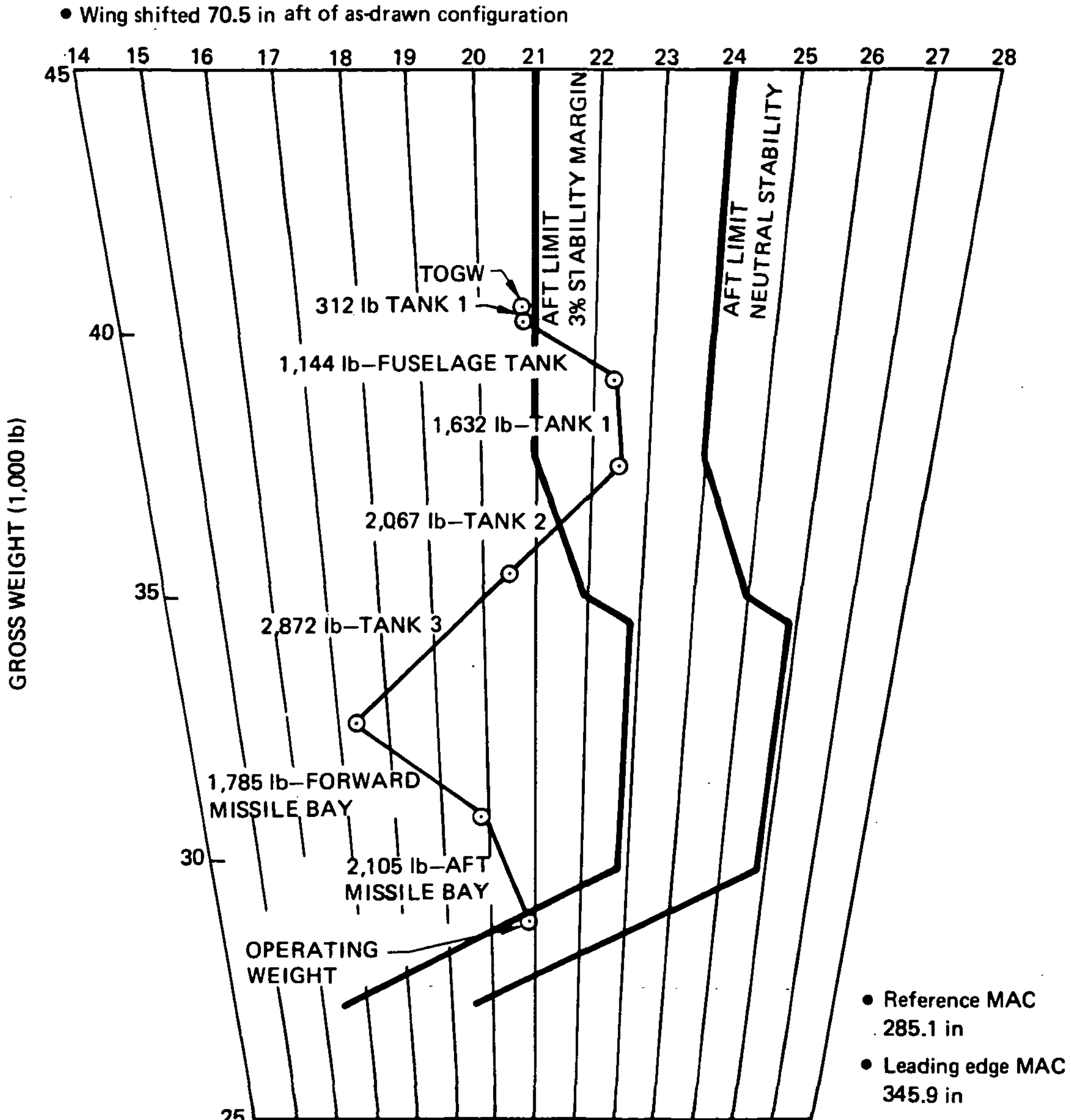


Figure 3.2A.1-13. F-106B STOL Flight Research Study Modification 3, Wing Relocated at Original F-106B Position—Weight and Balance Grid

Moving the wing an additional 10 inches aft produced a configuration which was close to achieving the stability margin required. The results of the analysis of this configuration are shown by figures 3.2A.1-14 and -15.

Another possible solution for this modification would be a combination of ballast in the nose with aft movement of the wing. Analysis has not been done for this option.

Work was accomplished to determine the weight and balance characteristics of F-106B Modification 5. Estimates are based on the actual weight and balance of the F-106B and modified per Figure 3.1.4-4 developed for this study.

Results of this weight and balance study are presented in figures 3.2A.1-16 and -17. The c.g. and gross weight of this modified configuration fall within the prescribed forward and aft limits and maximum gross weight established for the F-106B when ballasted with 1500 lb installed at a composite body station of 71.6.

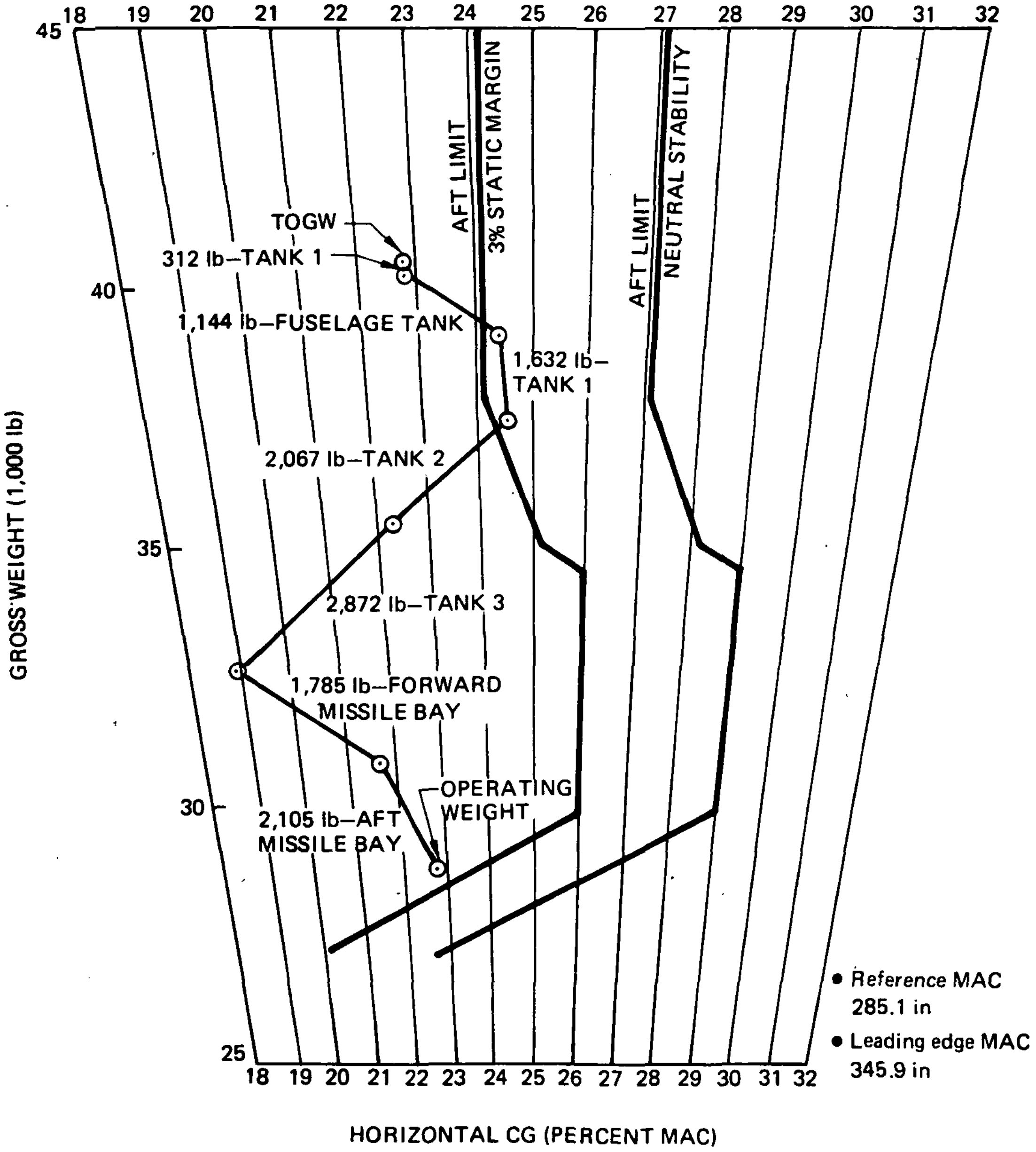
Basic weight and balance characteristics for F-106B Modification 7 have been developed. Estimates were based on the reference actual weight and balance of the F-106B and modified per Figure 3.1.4-5 - "Modification 7" developed for this study.

Results of this weight and balance study are presented in figures 3.2A.1-18 and -19. The c.g. and gross weight of this modified configuration do not fall within the prescribed forward and aft limits and maximum gross weight established for the F-106B even though ballasted with 4480 lb installed at the previous engine location. There are two possibilities for getting the c.g. and gross weight of this modified configuration within the prescribed limits. One possibility would be to re-sequence the forward missile bay fuel burn and the tank no. 3 fuel burn. The other possibility would be to add approximately 2000 lb more ballast and eliminate the fuselage tank and part of the no. 1 fuel tank. It should be noted that since this configuration, unlike the others, requires

```
************************************************************************
*         F106B MOD3           *            *  NOSE STATION    -44.9   *
*    GROUP WEIGHT STATEMENT    *WEIGHT-LBS  *  WING MAC        285.1   *
*  ATSCGE  09/20/77/  VERSION  *            *  LEMAC           345.9   *
*                              *            *  BODY LENGTH      63.0   *
************************************************************************
*                              *            *  BODY STA    PERCENT MAC *
*  WING                        *     5844.0 *    483.0                 *
*  HORIZONTAL TAIL             *      366.0 *    682.0                 *
*  VERTICAL TAIL               *      588.0 *    644.0                 *
*  BODY + STRAKE               *     5154.0 *    348.0                 *
*  MAIN GEAR                   *     1063.0 *    488.0                 *
*  NOSE GEAR                   *      206.0 *    158.0                 *
*  AUX GEAR                    *        0.0 *      0.0                 *
*  NACELLE OR ENG SECTION      *      504.0 *    464.0                 *
*  AIR INDUCTION               *      572.0 *    422.0                 *
*                     ***********************                          *
*TOTAL STRUCTURE               *    14297.0 *    438.6                 *
*                              *            *                          *
*  ENGINE                      *     5215.0 *    458.0                 *
*  ENGINE ACCESSORIES          *       99.0 *    568.0                 *
*  FUEL SYSTEM                 *     1371.0 *    503.0                 *
*  ENGINE CONTROL              *       80.0 *    280.0                 *
*  STARTING SYSTEM             *       96.0 *    582.0                 *
*                     ***********************                          *
*TOTAL PROPULSION              *     6861.0 *    468.2                 *
*                              *            *                          *
*  FLIGHT CONTROL              *     1074.0 *    560.0                 *
*  AUXILIARY POWER PLANT       *        0.0 *      0.0                 *
*  INSTRUMENTS                 *      160.0 *    233.0                 *
*  HYDRAULIC + PNEUMATIC       *      900.0 *    413.0                 *
*  ELECTRICAL                  *      796.0 *    409.0                 *
*  AVIONICS                    *     2882.0 *    173.0                 *
*  ARMAMENT                    *        0.0 *      0.0                 *
*  FURNISHINGS + EQUIP         *      490.0 *    193.0                 *
*  AIR COND + ANTI ICE         *      425.0 *    276.0                 *
*  MISCELLANEOUS               *       32.0 *    264.0                 *
*  LOAD + HANDLING             *       57.0 *    609.0                 *
*                     ***********************                          *
*TOTAL FIXED EQUIPMENT         *     6816.0 *    306.6                 *
*********************************************                          *
*WEIGHT EMPTY                  *    27974.0 *    413.7          23.8   *
*                              *            *                          *
*  CREW                        *      516.0 *    193.0                 *
*  UNUSABLE FUEL               *      184.0 *    513.0                 *
*  OIL AND TRAPPED OIL         *       60.0 *    646.0                 *
*  GUN INSTALLATION + PROV     *        0.0 *      0.0                 *
*  BALLAST                     *        0.0 *      0.0                 *
*  CREW EQUIPMENT              *        0.0 *      0.0                 *
*                     ***********************                          *
*NON-EXP USEFUL LOAD           *      760.0 *    306.2                 *
*********************************************                          *
*OPERATING WEIGHT              *    28734.0 *    410.9          22.8   *
*                              *            *                          *
*  PAYLOAD                     *        0.0 *      0.0                 *
*  FUEL - INTEGRAL             *     7936.0 *    455.2                 *
*  FUEL - MISSILE BAY          *     3890.0 *    320.5                 *
*********************************************                          *
*GROSS WEIGHT                  *    40560.0 *    410.9          22.8   *
************************************************************************
```

3.2A.1-14. F-106B STOL Flight Research Study Modification 3 With Wing Moved Aft of Original Location, Weight and Balance Statement

- Wing shifted 80.5 in. aft of as-drawn configuration



- Reference MAC 285.1 in
- Leading edge MAC 345.9 in

Figure 3.2A.1-15. F-106B STOL Flight Research Study Modification 3, Wing Moved Aft of Original F-106B Position—Weight and Balance Grid

```
**********************************************************************
*        F106B MOD3            *          * NOSE STATION      -44.9 *
*   GROUP WEIGHT STATEMENT     *WEIGHT-LBS* WING MAC          285.1 *
*  ATSCGE  09/20/77/  VERSION  *          * LEMAC             345.9 *
*                              *          * BODY LENGTH        63.0 *
**********************************************************************
*                              *          * BODY STA    PERCENT MAC *
*  WING                        *   3272.0 *    508.0                *
*  HORIZONTAL TAIL             *      0.0 *      0.0                *
*  VERTICAL TAIL               *    665.0 *    647.0                *
*  BODY + STRAKE               *   5196.0 *    354.0                *
*  MAIN GEAR                   *   1043.0 *    452.0                *
*  NOSE GEAR                   *    206.0 *    136.0                *
*  AUX GEAR                    *      0.0 *      0.0                *
*  NACELLE OR ENG SECTION      *   1716.0 *    653.0                *
*  AIR INDUCTION               *    742.0 *    464.0                *
*                      *********************                        *
*TOTAL STRUCTURE               *  12840.0 *    459.2                *
*                              *                                    *
*  ENGINE                      *   5519.0 *    650.0                *
*  ENGINE ACCESSORIES          *     99.0 *    488.0                *
*  FUEL SYSTEM                 *   1371.0 *    423.0                *
*  ENGINE CONTROL              *     80.0 *    280.0                *
*  STARTING SYSTEM             *     96.0 *    502.0                *
*                      *********************                        *
*TOTAL PROPULSION              *   7165.0 *    598.2                *
*                              *          *                         *
*  FLIGHT CONTROL              *    513.0 *    480.0                *
*  AUXILIARY POWER PLANT       *      0.0 *      0.0                *
*  INSTRUMENTS                 *    160.0 *    233.0                *
*  HYDRAULIC + PNEUMATIC       *    393.0 *    413.0                *
*  ELECTRICAL                  *    646.0 *    409.0                *
*  AVIONICS                    *   2970.0 *    173.0                *
*  ARMAMENT                    *      0.0 *      0.0                *
*  FURNISHINGS + EQUIP         *    490.0 *    193.0                *
*  AIR COND + ANTI ICE         *    425.0 *    276.0                *
*  MISCELLANEOUS               *     32.0 *    264.0                *
*  LOAD + HANDLING             *     57.0 *    609.0                *
*                      *********************                        *
*TOTAL FIXED EQUIPMENT         *   5686.0 *    260.1                *
********************************************                        *
*WEIGHT EMPTY                  *  25691.0 *    453.9         37.9   *
*                              *          *                         *
*  CREW                        *    516.0 *    193.0                *
*  UNUSABLE FUEL               *    184.0 *    433.0                *
*  OIL AND TRAPPED OIL         *     60.0 *    640.0                *
*  GUN INSTALLATION + PROV     *      0.0 *      0.0                *
*  BALLAST                     *   1500.0 *     71.6                *
*  CREW EQUIPMENT              *      0.0 *      0.0                *
*                      *********************                        *
*NON-EXP USEFUL LOAD           *   2260.0 *    143.8                *
********************************************                        *
*OPERATING WEIGHT              *  27951.0 *    428.8         29.1   *
*                              *          *                         *
*  PAYLOAD                     *      0.0 *      0.0                *
*  FUEL - INTEGRAL             *   7936.0 *    446.6                *
*  FUEL - MISSILE BAY          *   3890.0 *    320.5                *
********************************************                        *
*GROSS WEIGHT                  *  39777.0 *    421.8         26.6   *
**********************************************************************
```

3.2A.1-16. F-106B STOL Flight Research Study Modification 5 As-Drawn Plus 1500 lbs. Ballast Weight and Balance Statement

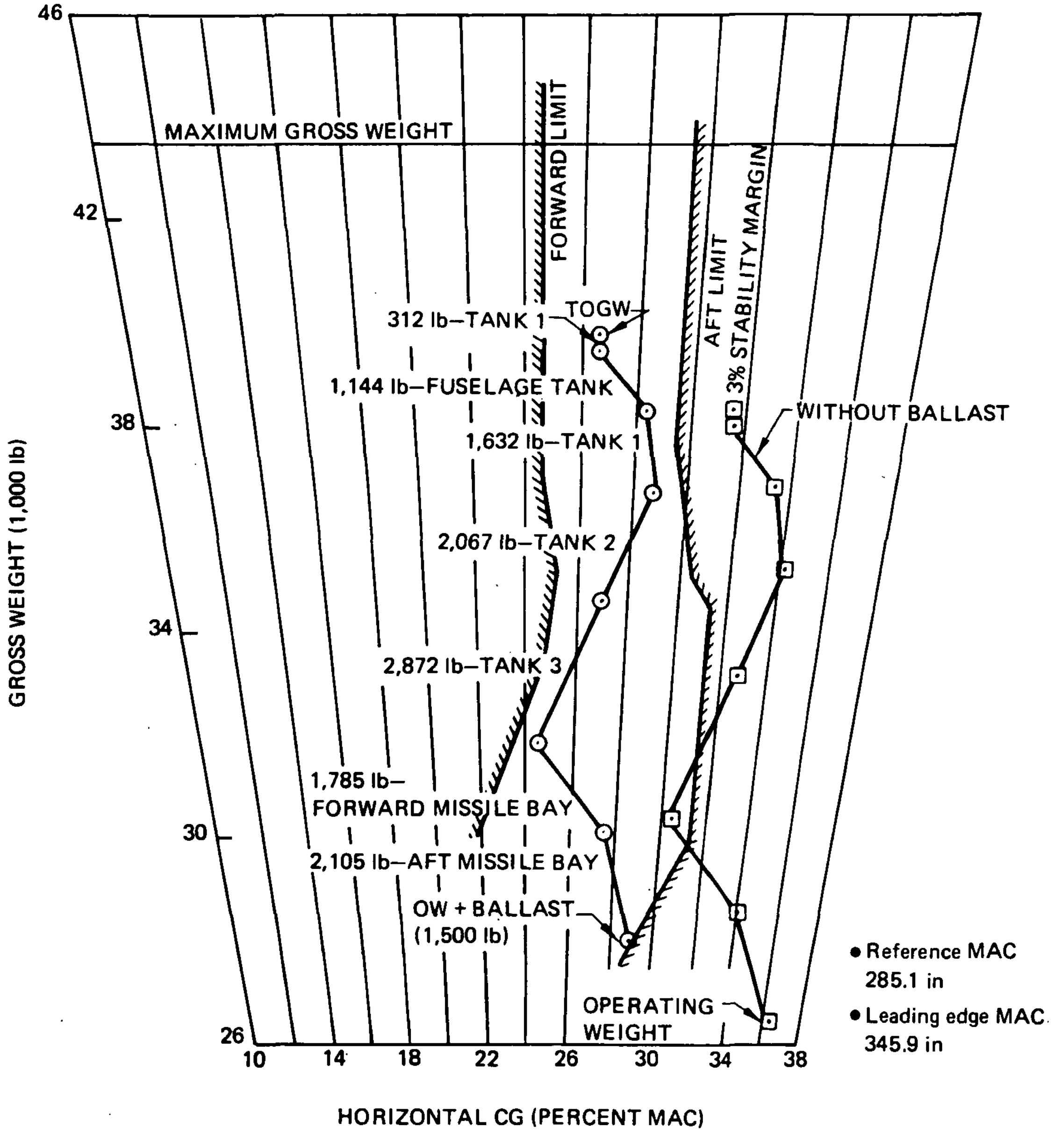


Figure 3.2A.1-17. F-106B STOL Flight Research Study Modification 5, As-Drawn Plus 1,500 lb Ballast–Weight and Balance Grid

```
**********************************************************************
*          F106B MOD7          *          *  NOSE STATION     -44.9  *
    GROUP WEIGHT STATEMENT    *WEIGHT-LBS*  WING MAC         285.1  *
*  ATSCGE  09/20/77/  VERSION  *          *  LEMAC            345.9  *
*                              *          *  BODY LENGTH       63.0  *
**********************************************************************
*                              *          *  BODY STA   PERCENT MAC  *
*  WING                        *   3272.0 *    508.0                 *
*  HORIZONTAL TAIL             *      0.0 *      0.0                 *
*  VERTICAL TAIL               *    665.0 *    647.0                 *
*  BODY + STRAKE               *   6475.0 *    349.5                 *
*  MAIN GEAR                   *   1043.0 *    452.0                 *
*  NOSE GEAR                   *    206.0 *    136.0                 *
*  AUX GEAR                    *      0.0 *      0.0                 *
*  NACELLE OR ENG SECTION      *     38.0 *    562.0                 *
*  AIR INDUCTION               *    871.0 *    366.0                 *
*                      *********************                         *
*TOTAL STRUCTURE               *  12570.0 *    413.3                 *
*                              *          *                          *
*  ENGINE                      *   6531.0 *    475.4                 *
*  ENGINE ACCESSORIES          *     99.0 *    488.0                 *
*  FUEL SYSTEM                 *   1371.0 *    423.0                 *
*  ENGINE CONTROL              *     80.0 *    280.0                 *
*  STARTING SYSTEM             *     96.0 *    512.0                 *
*                      *********************                         *
*TOTAL PROPULSION              *   8177.0 *    465.3                 *
*                              *          *                          *
*  FLIGHT CONTROL              *    513.0 *    480.0                 *
*  AUXILIARY POWER PLANT       *      0.0 *      0.0                 *
*  INSTRUMENTS                 *    160.0 *    233.0                 *
*  HYDRAULIC + PNEUMATIC       *    393.0 *    413.0                 *
*  ELECTRICAL                  *    646.0 *    409.0                 *
*  AVIONICS                    *   2970.0 *    173.0                 *
*  ARMAMENT                    *      0.0 *      0.0                 *
*  FURNISHINGS + EQUIP         *    490.0 *    193.0                 *
*  AIR COND + ANTI ICE         *    425.0 *    276.0                 *
*  MISCELLANEOUS               *     32.0 *    264.0                 *
*  LOAD + HANDLING             *     57.0 *    609.0                 *
*                      *********************                         *
*TOTAL FIXED EQUIPMENT         *   5686.0 *    260.1                 *
*******************************************                          *
*WEIGHT EMPTY                  *  26433.0 *    396.4         17.7    *
*                              *          *                          *
*  CREW                        *    516.0 *    193.0                 *
*  UNUSABLE FUEL               *    184.0 *    433.0                 *
*  OIL AND TRAPPED OIL         *     60.0 *    566.0                 *
*  GUN INSTALLATION + PROV     *      0.0 *      0.0                 *
*  BALLAST                     *   4480.0 *    566.0                 *
*  CREW EQUIPMENT              *      0.0 *      0.0                 *
*                      *********************                         *
*NON-EXP USEFUL LOAD           *   5240.0 *    524.6                 *
*******************************************                          *
*OPERATING WEIGHT              *  31673.0 *    417.6         25.2    *
*                              *          *                          *
*  PAYLOAD                     *      0.0 *      0.0                 *
*  FUEL - INTEGRAL             *   7936.0 *    446.6                 *
*  FUEL - MISSILE BAY          *   3890.0 *    320.5                 *
*******************************************                          *
*GROSS WEIGHT                  *  43499.0 *    414.2         24.0    *
**********************************************************************
```

3.2A:1-18. F-106B STOL Flight Research Study Modification 7 As-Drawn Plus 4480 lbs. Ballast Weight and Balance Statement

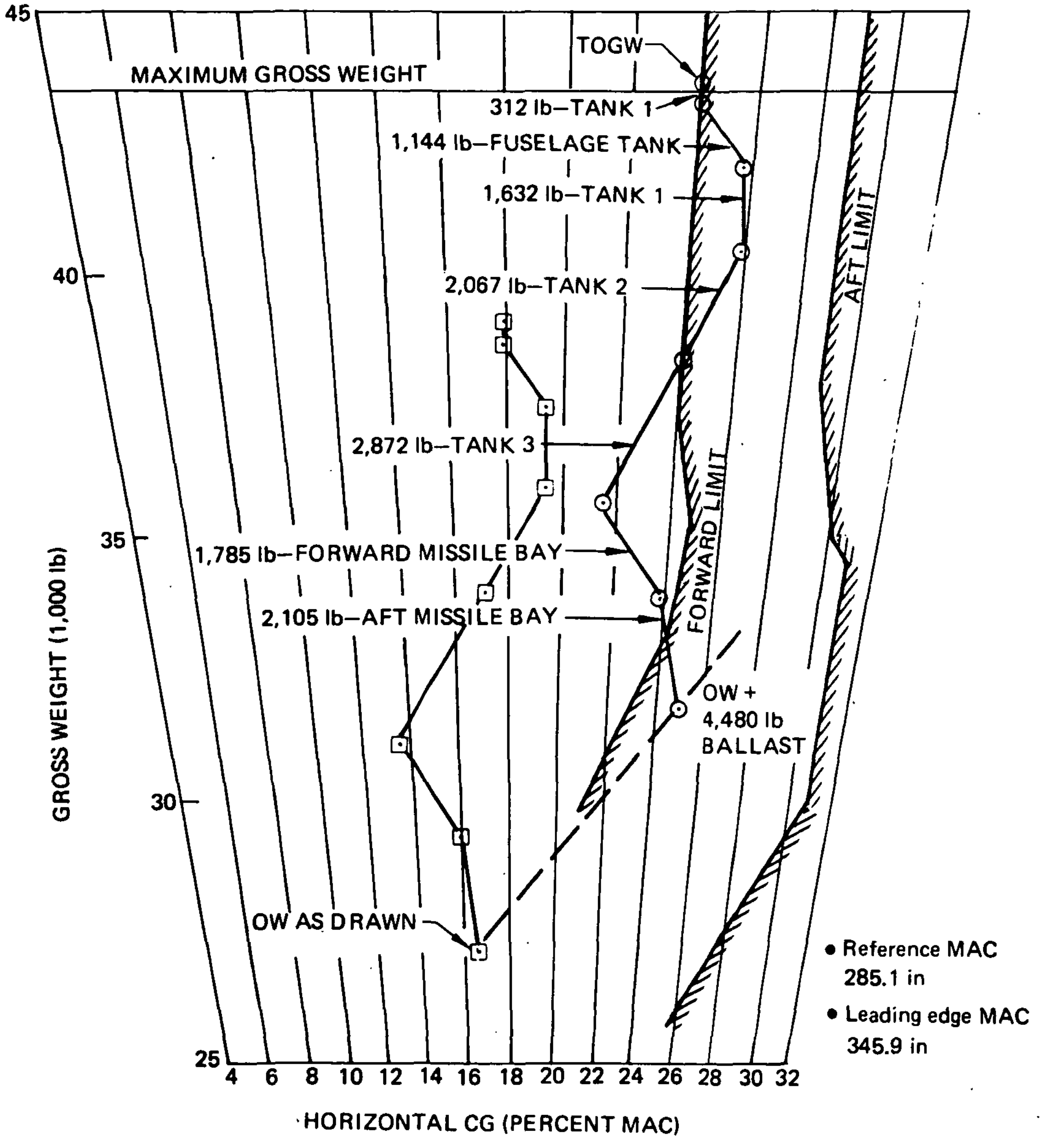


Figure 3.2A.1-19. F-106B STOL Flight Research Study Modification 7, As-Drawn Plus 4,480 lb Ballast—Weight and Balance Grid

aft-located ballast, the structural requirements of the forward fuselage limiting ballast to 2000 lbs does not apply. The 4480 lbs of ballast assumed here is the maximum amount of ballast that can be added without exceeding the maximum gross weight for the given fuel sequence.

3.2A.2 PROPULSION

3.2A.2.1 General

The propulsion analysis of the four candidate F-106B nozzle research configurations consisted of calculation of installed engine performance and the assessment of potential propulsion related problem areas. All four configurations utilized two F-404-GE-400 engines equipped with either the original or new normal shock inlets and ADEN nozzles (see Figure 3.2A.2-1). Since these same inlet/nozzle combinations were analyzed under the original contract, the previously developed installed performance was felt to be satisfactory for the purposes of this study. Figure 3.2A.2-2 presents the SFC - net thrust relationship for these configurations. Because of security considerations, the data has been normalized by performance for max power at takeoff.

Study configuration #7 is equipped with RALS (Remote Augmented Lift System) nozzles which are powered by fan bleed air from the two F-404 engines. Calculations were performed to determine the RALS nozzle performance and the impact of its operation on the F-404 engines. Performance calculations were limited to Mach .2 and static conditions since the anticipated use of the RALS will be for STOL operation. The ambient conditions used were 110°F and 2400 ft. pressure altitude. It should be noted that the p.d. calculations assumed zero losses due to RALS nozzle cooling, diverter valve losses, etc. As such, the present estimates represent an upper bound to the RALS performance. Figure 3.2A.2-3 illustrates the projected available thrust from the RALS nozzle and its subsequent impact on the ADEN nozzle thrust.

3.2A.2.2 Potential Problem Areas

Each of the configurations were examined to identify potential propulsion related design problems. The identified areas of concern are discussed in the following paragraphs.

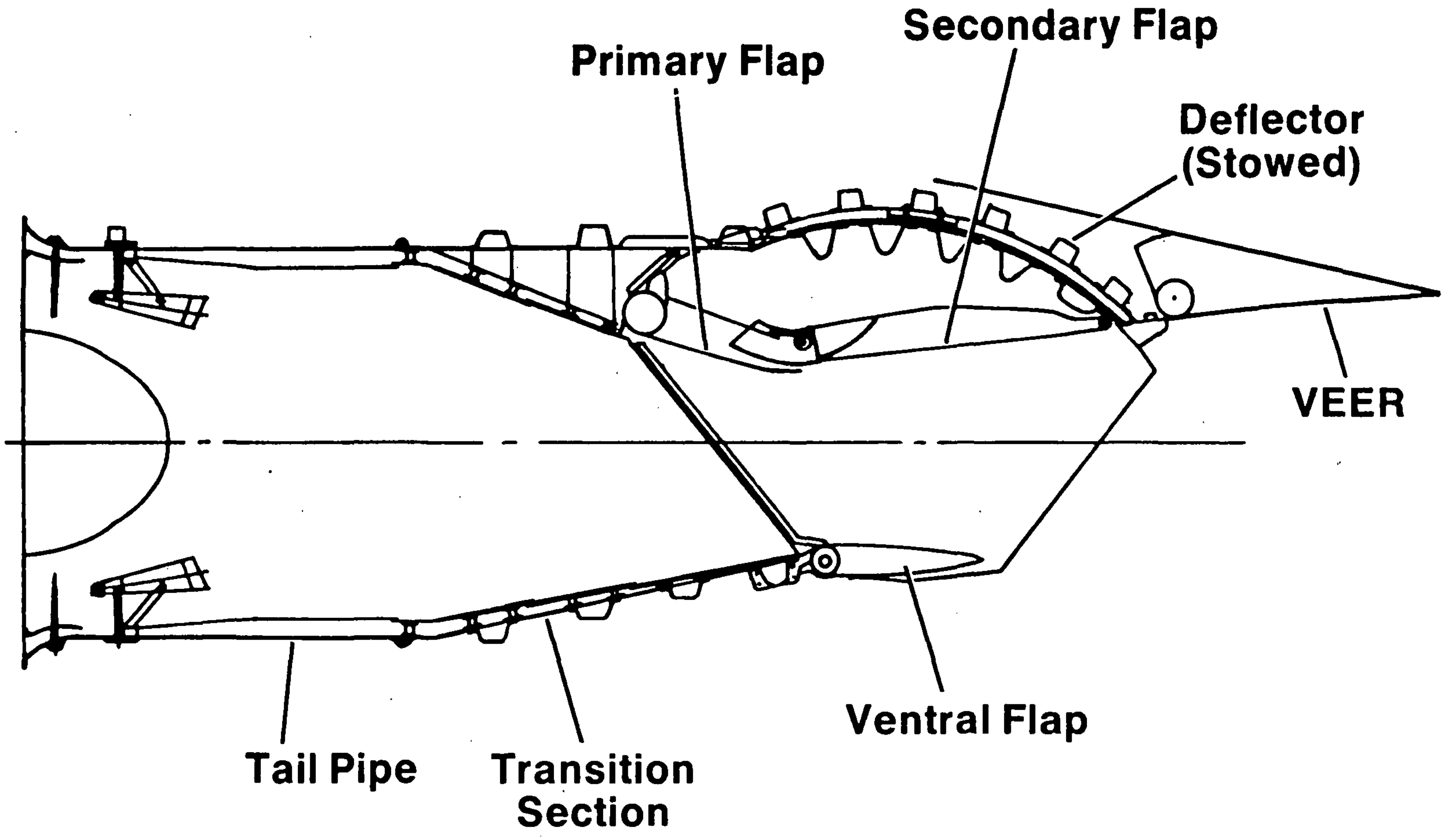


Figure 3.2A.2-1 ADEN Nozzle Flowpath

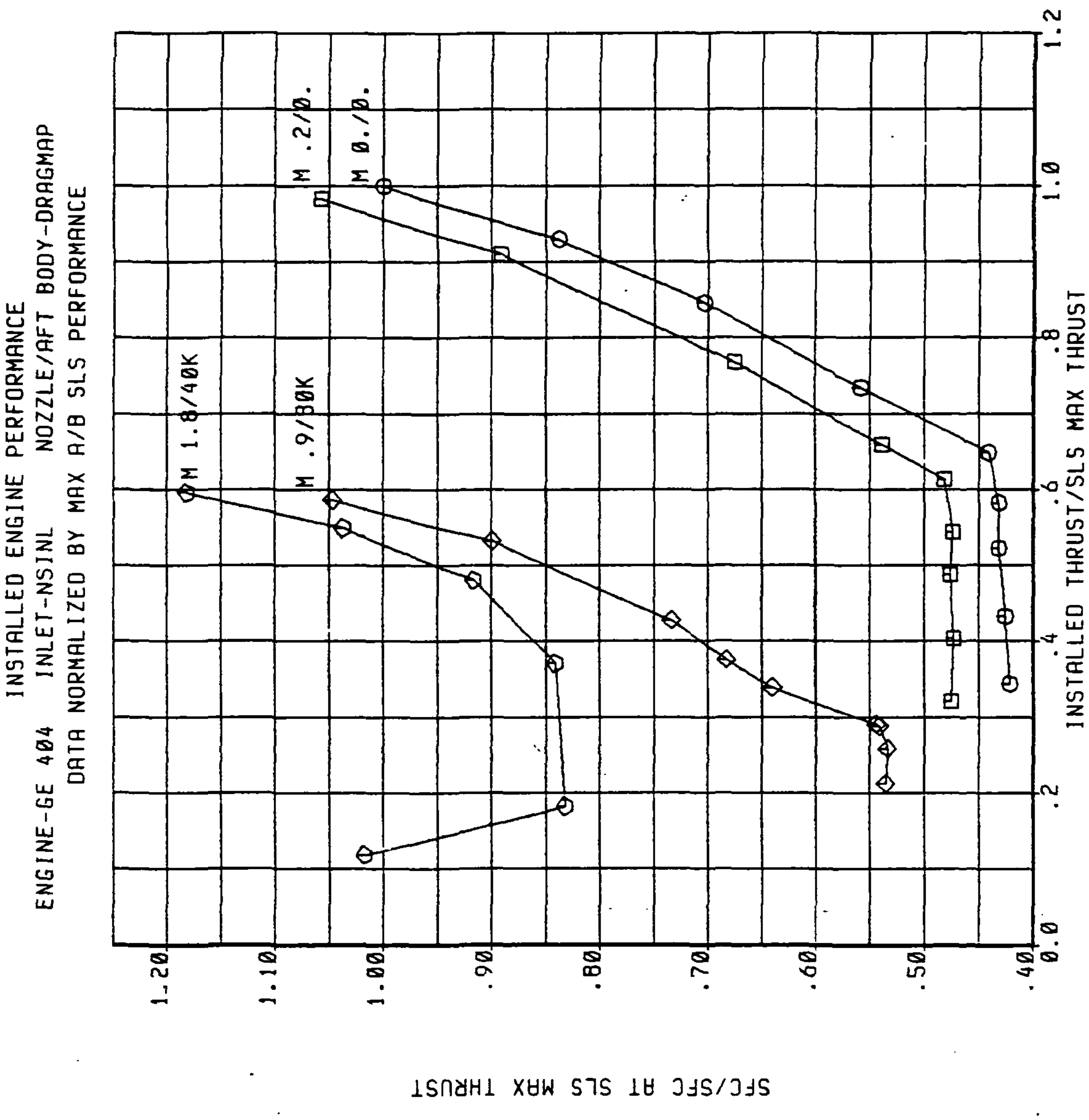


Figure 3.2A.2-2. Installed Engine Performance

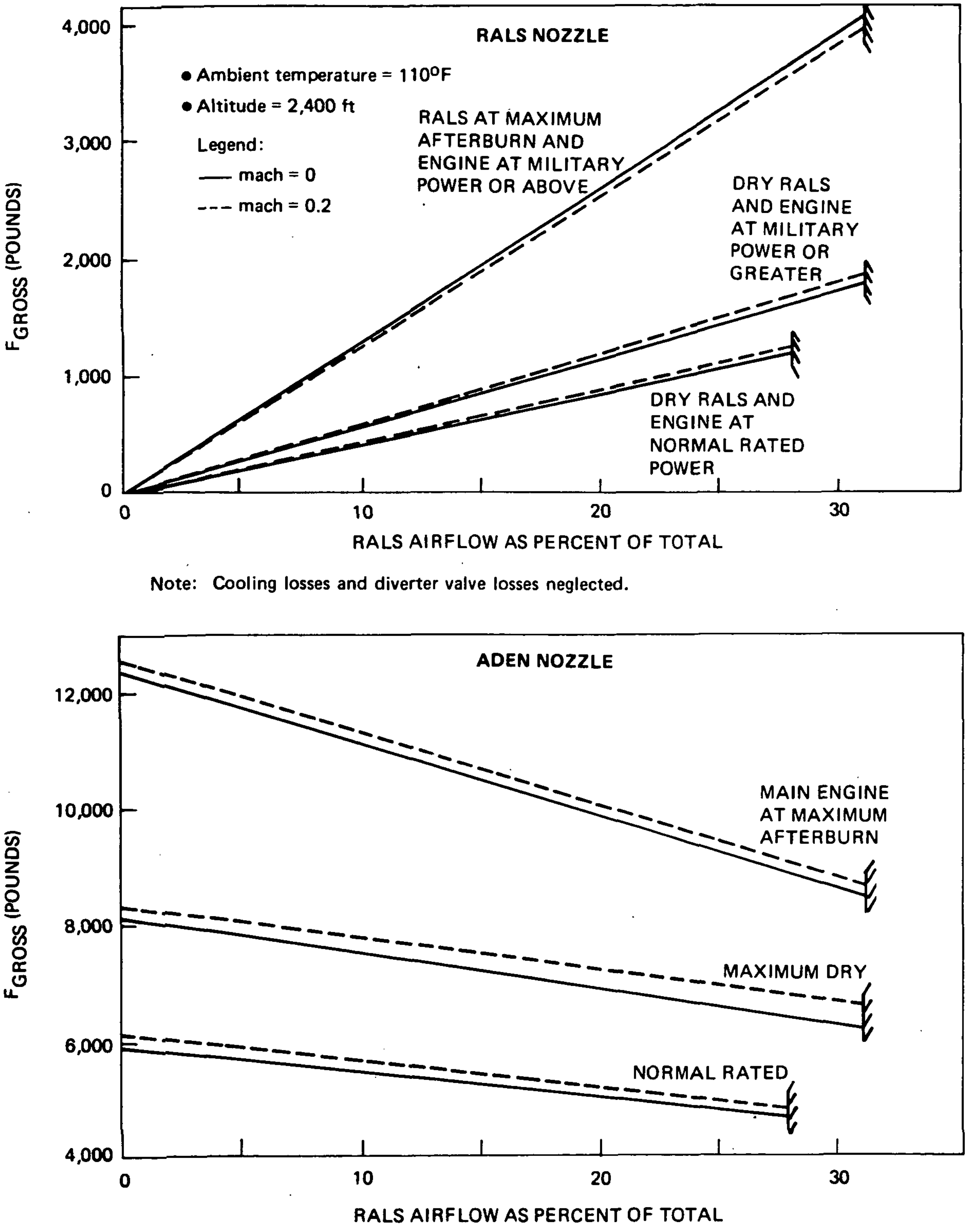


Figure 3.2A.2-3. Projected Available Thrust From RALS Nozzle and Effect on ADEN Nozzle Thrust

Modification 1

The primary area of concern for this configuration was the adverse effect of the landing gear structure on the inlet airflow quality. The inlet ducts should be extended beyond the landing gear structure and a splitter plane added to divert the lower wing boundary layer air.

The nozzle installation has been canted to reduce engine-out moments. Care should be exercised during the detail design to reduce the high nacelle drag this type of installation is likely to incur.

Modification 3

No real design concerns were noted for this configuration. As in Modification 1, provisions should be made to divert boundary layer air from the inlet, and to reduce the nacelle drag which is likely to be high.

Modification 5

This configuration presents the cleanest overall propulsion installation. However, there may be a problem providing high quality inlet airflow, especially at high angles of attack, due to the position of the inlets. Model tests may be needed to clarify this issue.

Modification 7

This configuration is the most ambitious propulsion installation of the four examined, due to the use of RALS nozzles for flight control. Since the RALS nozzles are to be powered by engine fan air, a major engine modification will be needed to install the diverter valve in the fan air duct. The operation of the diverter valve will have to be closely tied in with the throat area control on the ADEN nozzle to insure proper engine match and prevent an engine surge.

To be effective as a flight control device, the RALS nozzles will have to be capable of providing a constantly modulated thrust level. This should not be accomplished by varying the diverter valve position, due to the adverse effect on engine operation and the increased possibilities of surge. One potential alternative would be to leave the diverter valve in a fixed position and modulate the RALS thrust by providing an overboard dump for the excess RALS nozzle air. This area will need a high level of attention during the detail design phase.

3.2A.3 Mechanical Systems

3.2A.3.1 General

A number of considerations relating to the mechanical systems modifications are common among the 4 study configurations. Accordingly, these are discussed first. In subsequent sections, modifications relating specifically to the individual study configurations are described separately. General modifications affecting the Mechanical/Electrical/ Pneumatic Systems are as follows:

- Secondary Power Generation
  - Hydraulic
  - Electric

- Hydraulically Actuated Aerodynamic Control Surface
  - Elevons (revised)
  - Rudder (revised)
  - Canard (new)
  - Wing Tip Fins (new)
  - Winglets (new)
  - Ventral Fins (new)

- 2D Nozzle Actuation

- Hydraulic System Evaluation

Preliminary details of the effects to these areas are described below.

Secondary Power Generation

For modification #1, it has been suggested the J-75 engine be removed from the aircraft, but retain the engine, N_2 , accessory drive gearbox (ADG). This ADG drives the generation elements of the F-106's secondary power system (generator, hydraulic pumps, etc.). Power to drive the retained ADG would be drawn from the F-404 engines and delivered to the J75 ADG via separate hydraulic systems as shown in figure 3.2A.3-1.

Using the hydraulic power transfer system concept, the peak horsepower required from the F-404 engines total 579 hp (289 hp each). The continuous overload power extraction capabilities of the F-404 engine PTO (power take-off) shaft is 150 hp, per Reference 3.2A.3-1. The peak hp demand of the hydraulic and electrical systems is 285 hp. The difference between peak and extraction hp is in the inefficiency of the hydraulic power transfer system.

For the concept where each F-404 engine supplies one-half of secondary power requirements, hydraulic pump and motor sizes for each system shown in figure 3.2A.3-1 are 121 gal/min each. Hydraulic pumps or motors of this size do not exist for aircraft service. The configuration shown in figure 3.2A.3-2 uses 2 pumps and motors per system of 61 gal/min for each pump and motor. Pumps of this capability (B-1) are available and motors of approximately this capability (F15) are available. The hydraulic reservoirs and heat exchangers shown in the figures are new components designed for this application.

However, concept 2 becomes a relatively large, heavy and complex system of transferring power to the F-106 secondary power system. Also, as shown above, the PTO mechanical limits are exceeded by 93% at peak extraction requirements.

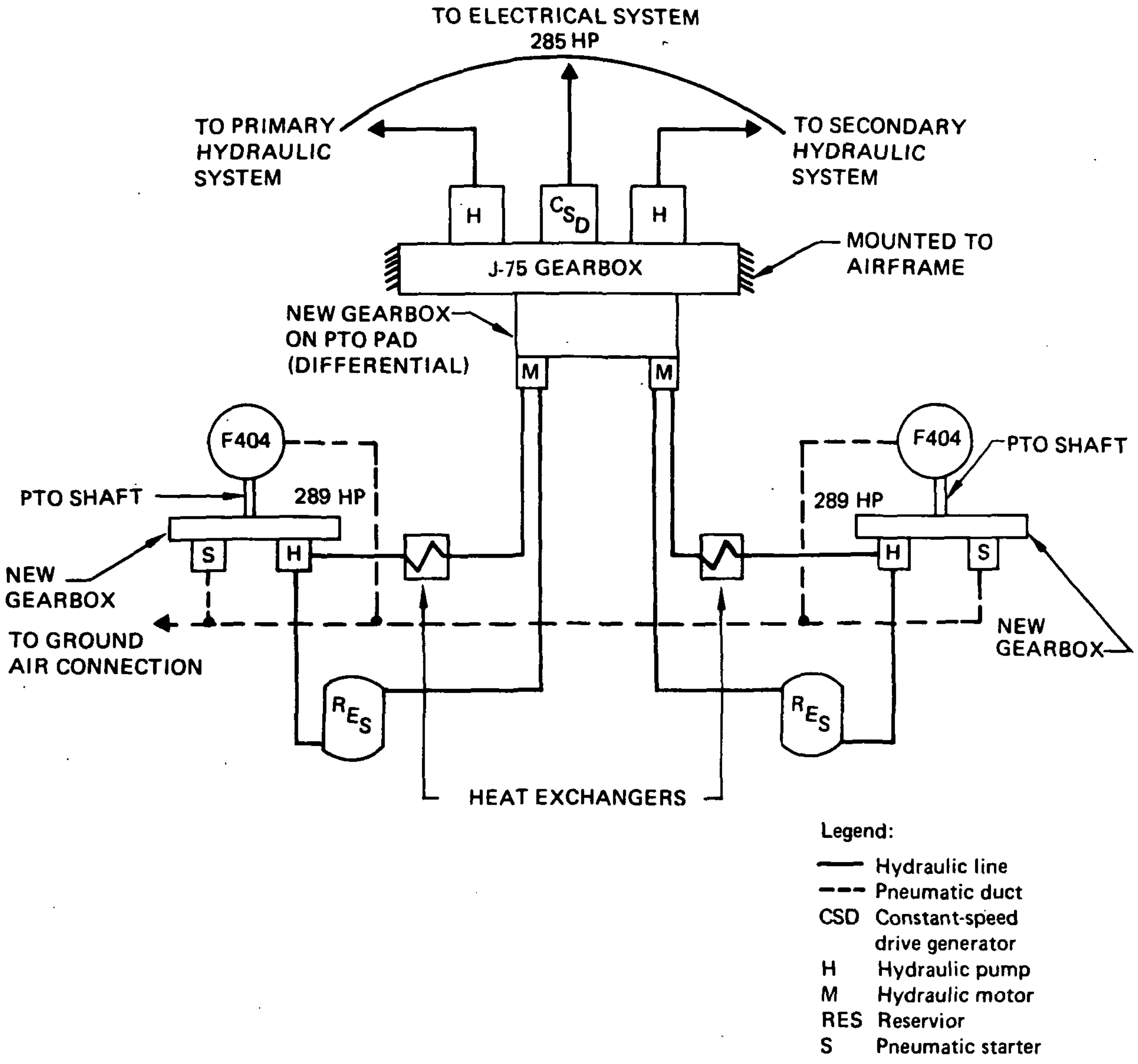


Figure 3.2A.3-1 . F-106B Power Transfer System Concept 1, Modification 1

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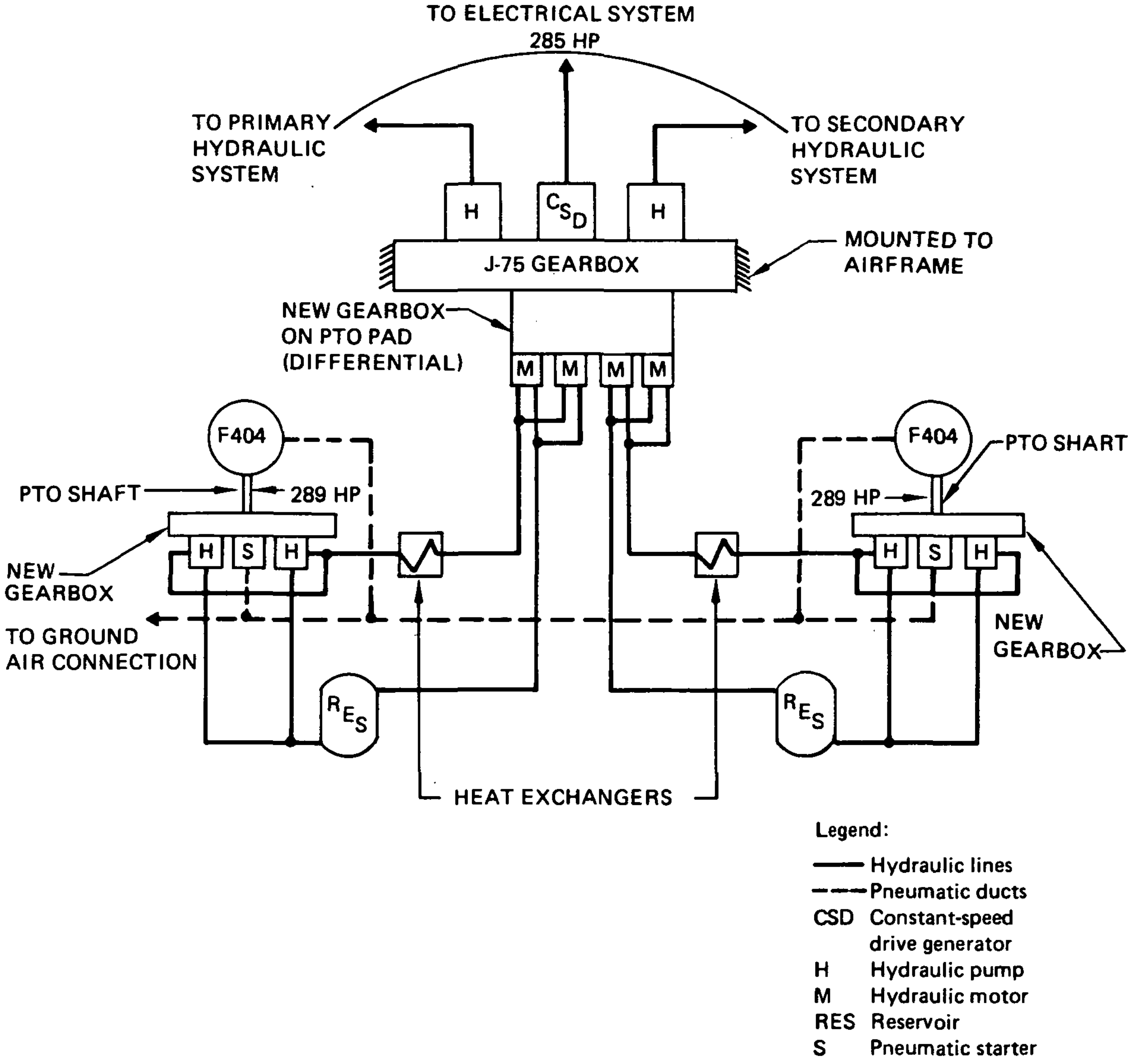


Figure 3.2A.3-2.. F-106B Power Transfer System Concept 2, Modification 1

It is clear that a more efficient power transfer system is required.

A pneumatic power transfer system is possible, but the bleed air is not available from the F-404 engines.

The remaining possibilities are the use of shafts, an auxiliary gas turbine power unit (APU) or the extraction of secondary power directly from the F-404 engines.

A shaft transfer system is more efficient than the hydraulic transfer. At 100% hydraulic and electric power requirements, the hp required is 300 hp, not including shafting gearbox losses, from the F-404 engines. This is also greater than the 150 hp overload power rating for each F-404 PTO shaft, but a reduced life rating of the PTO drive may be acceptable.

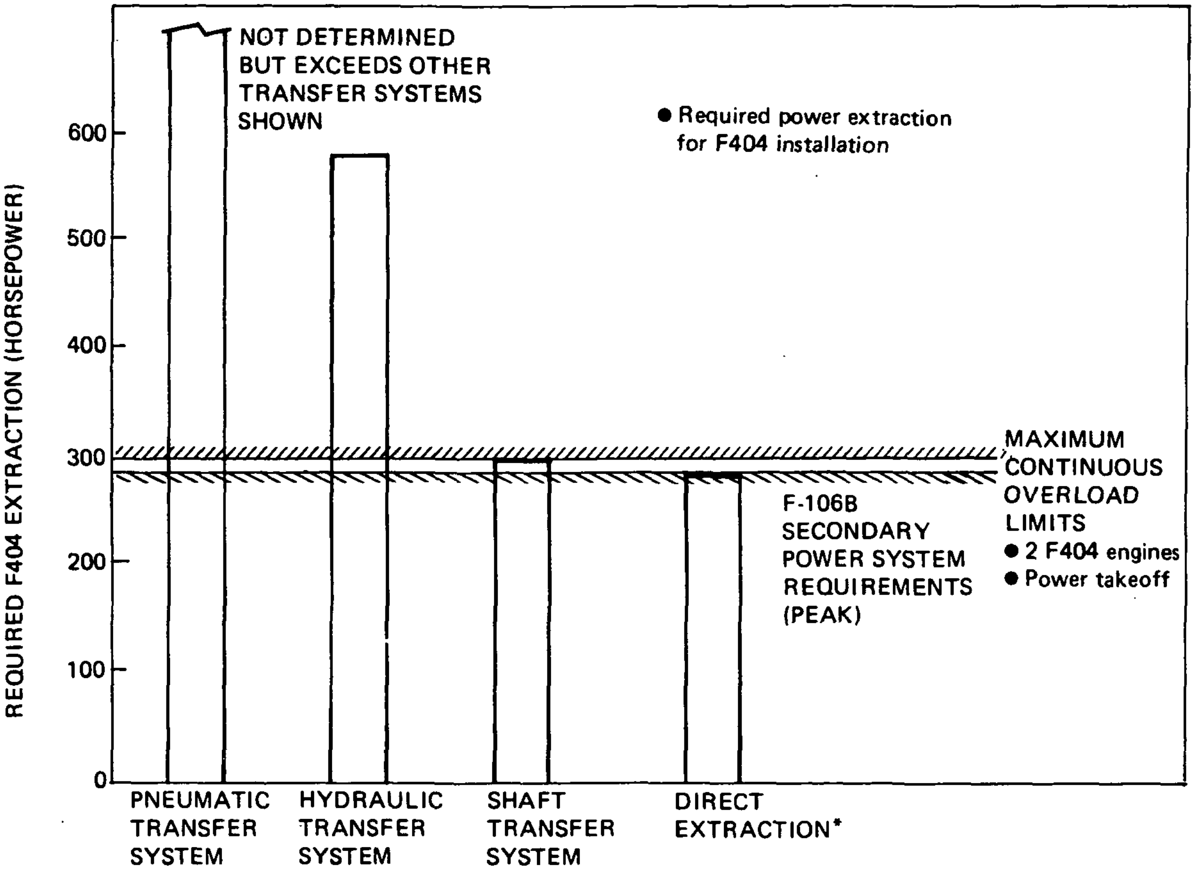
The use of an APU to continuously supply secondary power is a possibility, but has yet to be accomplished in practice.

Using the F-404 test engines directly as the secondary power system source of power is the last possibility.

The maximum power extraction requirement of 283 hp for secondary power is within the overload rating of the PTO shaft. This concept seems to be the best alternative. A comparison of the various methods of transferring power from the F-404 engines to the F-106 secondary power system is shown in figure 3.2A.3-3.

The power extraction requirements mentioned above are the 100% peak, simultaneous power required by the hydraulic and electrical systems. Analysis may indicate that these loads do not occur. If so, the power extraction requirements will be reduced accordingly.

The electrical system evaluation for the modified F-106 will be accomplished for modification 3. The evaluation performed should be applicable to the four modifications of this study. F-106B electrical services are shown in Table 3.2A.3-1.



*Hydraulic pumps and electric generators installed on new F404 accessory drive gear box.

Figure 3.2A.3-3. Comparison of Various Methods of Transferring Power From F404 Engines to F-106 Secondary Power System

Table 3.2A.3-1
EXISTING F-106B SECONDARY SERVICES

EXISTING F-106B HYDRAULIC SERVICES

- o Elevons
- o Rudder
- * o Speed Brakes
- * o Aerial Refueling
- * o Main Landing Gear Actuation and Brakes
- * o Nose Landing Gear Actuation
- o Nose Gear Steering
- o Variable Ramps (Engine Inlet)
- o Emergency AC Generator
- * o Gun System

EXISTING F-106B PNEUMATIC SERVICES

High Pressure

- o Combustion Starter (engine)
- o Main Landing Gear Brakes
- o Ram Air Turbine Extension
- o Rudder Feel System
- * o Infrared Receiver Extension
- * o Armament System
- o Hydraulic Reservoir Pressurization
- * o Drag Chute Release
- o Emergency
  - Engine and CSD Air-Oil Cooler Valve
  - Cockpit Pressurization System
  - * - Landing Gear Extension
  - * - Aerial Refueling Slipway Door
  - * - Speed Brake Extension
  - Variable Ramp Retraction (Engine Inlet)

*These services may not be operating on the test aircraft

EXISTING F-106B PNEUMATIC SERVICES (cont)

Low Pressure

- o Anti-Ice System
- o Windshield Rain Clearing System
- o Elevator Feel System
- o Engine and Accessory Cooling System
- o Canopy Seal Pressurization
- o Pilot Anti-G Suit Pressurization
- o Inlet Dual Variable Ramp Seal Pressurization
- o Fuel System Pressurization
- o Radom Anti-Ice Fluid Tank Pressurization

EXISTING F-106 ELECTRICAL SERVICES

- o Communications
- o Navigation
- o Landing Aids
- o Radar
- * o Infrared Receiver
- o Flight Control and Measurement
- o Computers
- * o Armament
- o Cockpit Controls and Displays
- o Lights

*These services may not be operating on the test aircraft.

The evaluation will include the effects on the existing system and the concept where secondary power is generated directly by the F-404 test engines.

Elevon Actuation

The elevon flight control surfaces will be modified by increasing the aerodynamic chord of the outboard panel, by increasing the chord while decreasing the span of the inboard panel, per reference 3.2A.3-2 and increasing elevon authority from (-32°, +15°) to (±30°) per references 3.2A.3-2 and -3. In addition to the above modifications, the outboard elevon panels will be mechanically linked to the steerable tip extensions per reference 3.2A.3-4. This modification will be designed for low speed flight only ($<$ 200 kn).

An outboard elevon installation diagram is shown in figure 3.2A.3-4. This figure shows the relationships among the actuator (3), elevon horn (2), elevon panel (10) and the structural grounding (1) of the actuator. The feedback control linkages for both elevon panels on one side of the aircraft is installed on the inboard elevon actuator installation.

Figure 3.2A.3-5 shows the modifications required to the outboard elevon actuation concept to achieve ±30 elevon authority, while retaining the existing hydraulic actuator. As shown, the horn is shortened to obtain the increased elevon authority. An extension of the actuator rod would be necessary for connection to the elevon horn.

The effects of the previously described elevon panel and elevon actuation concept modifications on the ability of its actuator to develop the required hinge moment throughout the elevon authority limit has been roughly evaluated, using data from reference 3.2A.3-6. Taking into acount the increased elevon authority (δ), elevon exposed area, aerodynamic chord, reduced flight speed (200 kn) and horn length, it has been determined the outboard elevon actuator should be able to develop the required hinge moment for full elevon authority.

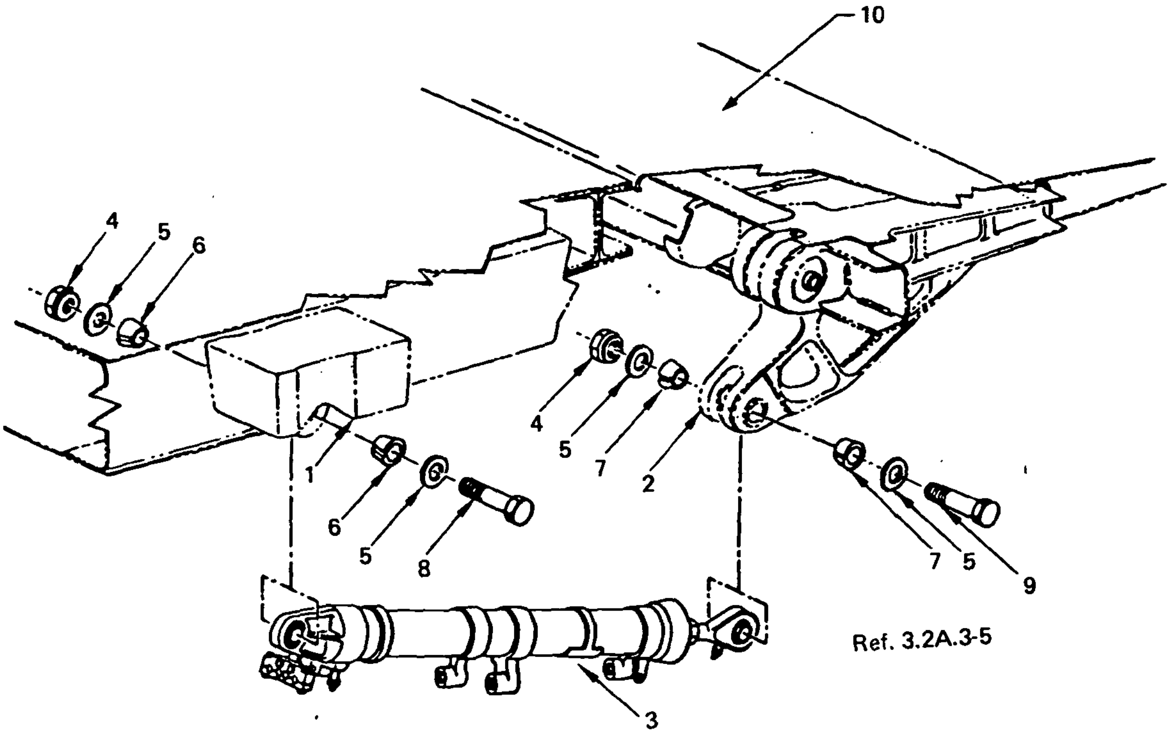


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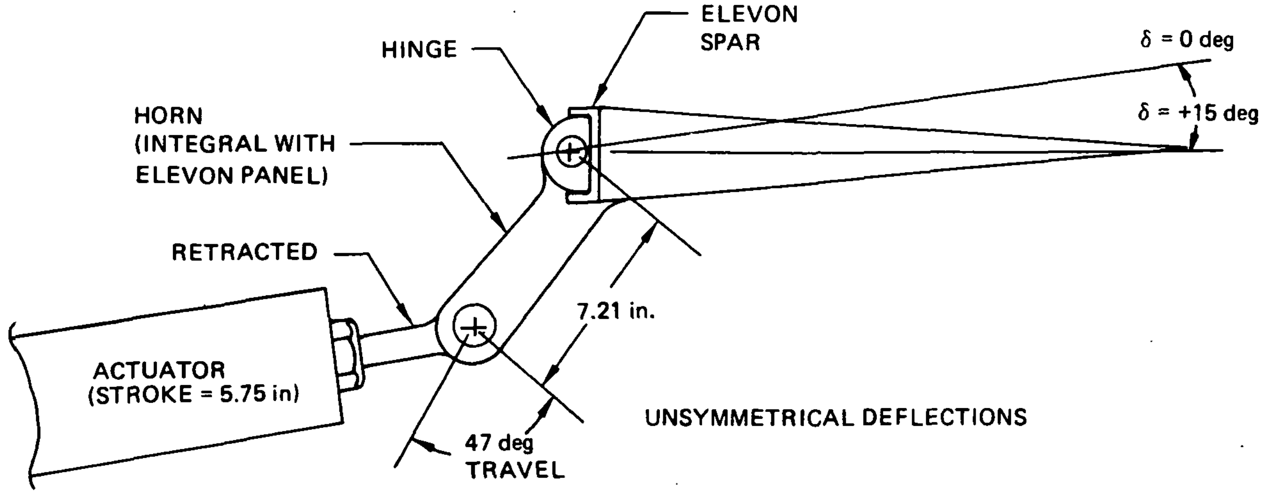
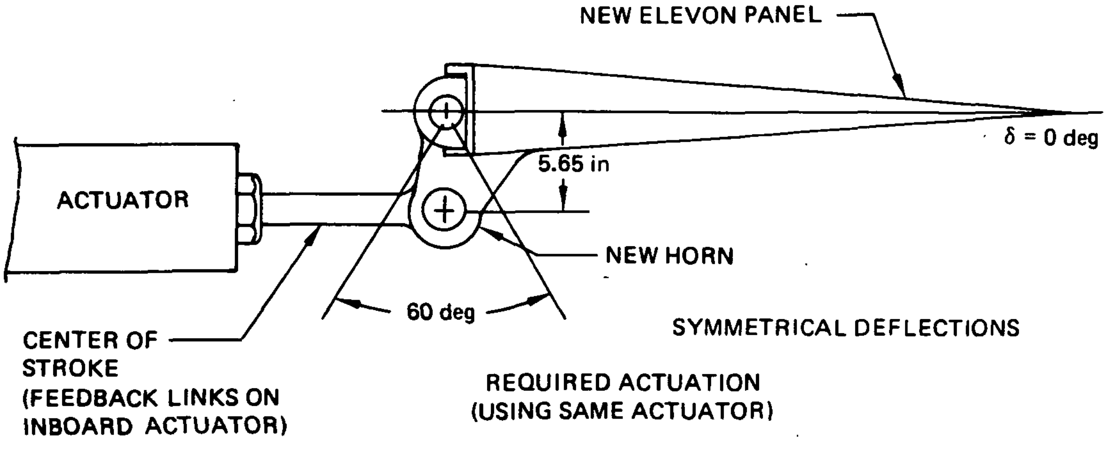
Figure 3.2A.3-4. Outboard Elevon Actuation Installation



EXISTING OUTBOARD ELEVON ACTUATION



REQUIRED ACTUATION
(USING SAME ACTUATOR)

Figure 3.2A.3-5. Outboard Elevon Actuator Installation Modification

Rather than redesign the elevon horn, a new actuator with a larger stroke could be installed. The stroke would be increased from 5.75" to 7.21". The actuator length increase due to the increased stroke is 2.91" since the actuator is a dual tandem type actuator. Also, the actuator has to be moved forward 3.61" for the actuator to be nulled at center stroke for symmetrical elevon deflections. Total length increase of 6.53" is required for a new actuator installation. An area increase of the actuator pistons is required to produce the required hinge moment at full deflection. A new structural tie would be required for the forward end of the actuator since it is being moved forward, if room in the fairing is available for the larger actuator and sufficient structural strength is available at the new actuator location.

The above data is the result of a preliminary study. To determine the full effects of the modified flight control surface on actuation requires a detailed study of the aircrafts stability and control characteristics.

The tip extension actuation concept, reference 3.2A.3-4 is shown in figure 3.2A.3-6. A four bar mechanism, consisting of the outboard elevon horn, a slave link, a bellcrank and aircraft structure, transmits force from the outboard elevon actuator to a torque tube to rotate the tip extension. The forces in the linkages should be low since the hinge point of the tip extension is located at the quarter chord, which is the approximate center of pressure of this low speed surface.

The four bar mechanism can be designed to articulate the tip extension to a ratio differing from unity, and/or bias the trailing edge up or down with respect to the elevon surface, in order to reduce the chance of stalling the tip extension.

The inboard elevon actuation installation is shown in figure 3.2A.3-7. This figure shows the relationship among the actuator (23), elevon crank (10), pilot input link (24), hydraulic elevon control (HEP) valve, feedback link (2), elevon horn (22) and the structural frames in the immediate area.

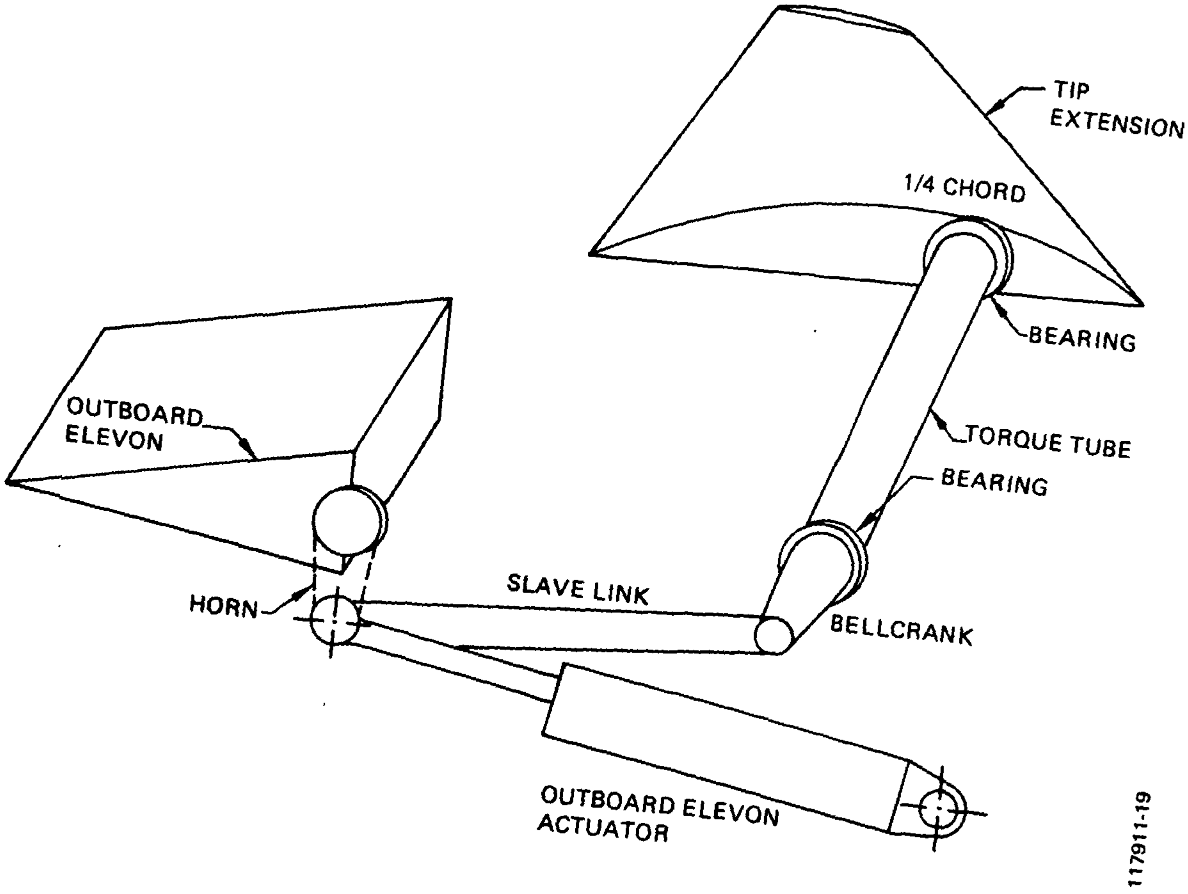


Figure 3.2A.3-6. Tip Extension Actuation Concept

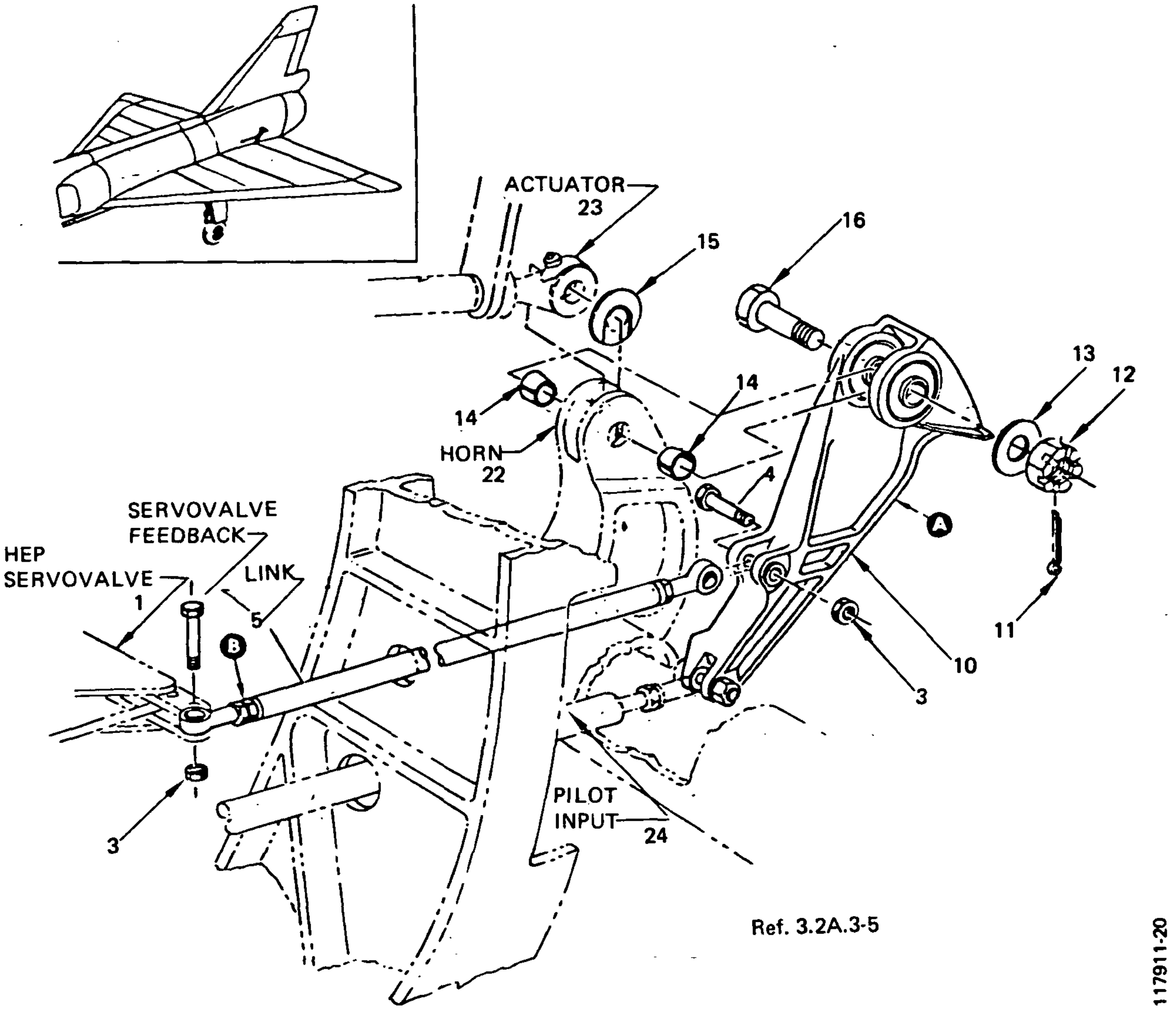


Figure 3.2A.3-7. Inboard Elevon Actuation Installation

Modifications to increase the elevon authority to ±30 would require a redesigned elevon crank (10) to allow a shorter horn (22) for increased authority using the same hydraulic actuator. The horn length reduction is approximately 22%.

The null position of the inboard horn will probably be changed very slightly if at all. However, the pilot input links and HEP valve feedback links would be redesigned to take into account the greater authority of the elevon panels.

Figure 3.2A.3-8 shows the inboard elevon panel installation. A new torque tube would be installed between the horn (47) and the remaining section of the inboard elevon panel to transfer the torque from the horn to the elevon panel.

The inboard elevon actuator could be replaced with one of a larger stroke. The installation problems of a longer actuator exists, as for the outboard actuator. The linkages for pilot input and servovalve feedback will still need to be redesigned, as for the case where the horn is redesigned.

The rudder for this modification is increased in area chord product by 258%. Rudder authority is unchanged. Using the same ratio of q as for elevon actuator evaluation, the rudder actuator should be able to provide sufficient hinge moment for full rudder authority, at the low speeds for which this modification is designed.

The winglet actuation concept is shown in reference 3.2A.3-4. The canard and ventral fin control surfaces are actuated hydraulically.

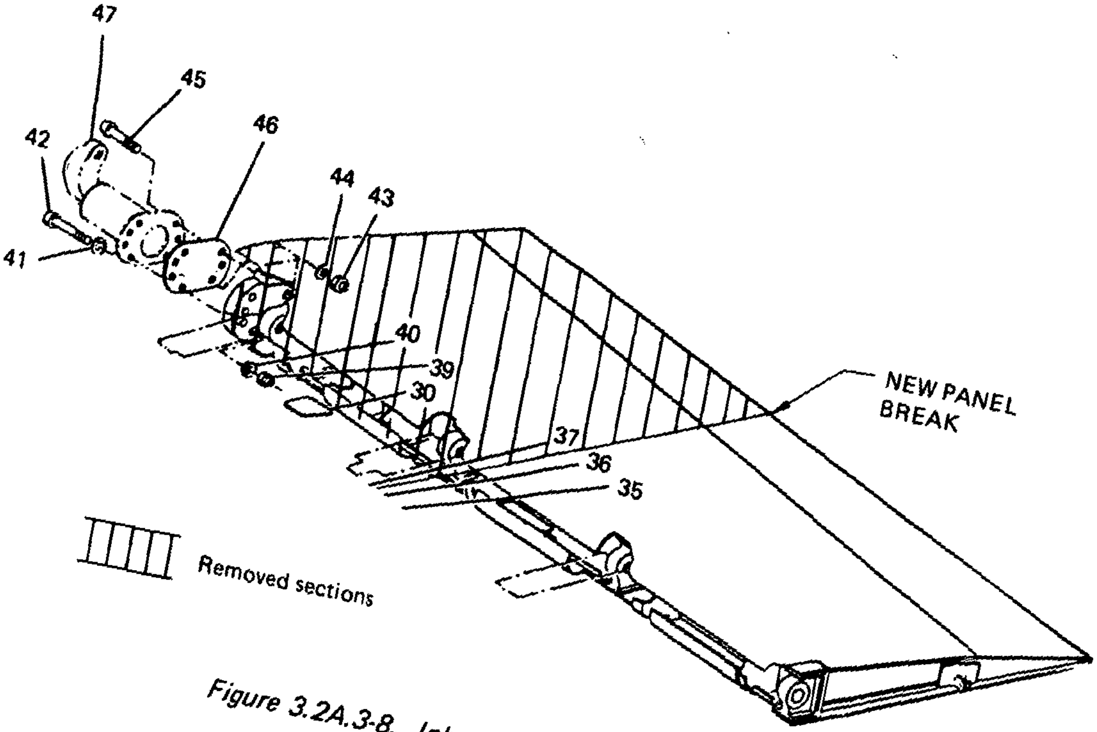


Figure 3.2A.3-8. Inboard Elevon Installation

Ref. 3.2A.3-5

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Hydraulic System Evaluation

The addition of canard, winglet, and ventral fin aerodynamic control surfaces to the existing F-106 hydraulic services shown in Table 3.2A.3-1 put additional loads on the hydraulic systems. Additional rudder, elevon and tip extension aerodynamic control surfaces uses existing actuation and does not cause additional loads on the hydraulic systems.

Since it was recommended that the hydraulic generation system be mounted on the F-404 test engines in lieu of the retained J75 gearbox, sufficient hydraulic power will be available for actuation.

For the concepts retaining the J75 gearbox, service demand profiles will need to be evaluated to determine if sufficient hydraulic power is available to meet the demand.

3.2A.3.2 Modification 1

Landing Gear

The tricycle landing gear, consisting of two main gear assemblies and one steerable nose gear assembly, have each been extended 34" to provide sufficient rotation angle. The rotation angle became inadequate because the F-404 engines were installed beneath the aft portion of the wings. The gear cannot be retracted with the 34" extension due to lack of stowage space. Because the nose and main gear are fixed in the extended position, the following landing gear subsystems are not needed:

- o retraction/extension system (hydraulically actuated)
- o emergency extension system (pneumatically actuated)
- o door system (hydraulically actuated)
- o retraction/extension control system (electrical)
- o position and warning system (electrical)

Additional structural bracing is required to extend and support the gear. Insufficient stiffness of the gear and its supports may cause a "gear walk" problem and thus degrade braking system performance.

Landing gear induced engine foreign object and water ingestion was evaluated. Engine inlets should preferably be located outside the flow patterns from the nose and main gears to eliminate the need for deflectors. Results of the analysis indicate that the F-404 engine inlets, located beneath the wings and adjacent to the fuselage, are within the spray patterns (see figure 3.2A.3-9).

Specifically, the following problem areas are indicated:

- o Side spray from the nose gear will be deflected into the engines. Chine tires will not divert the water sufficiently outboard to solve the problem.

- o Ingestion of thrown tire treads is not a problem.

- o At a speed range of 20 to 50 knots, part of the bow wave from the main gear will enter the engines (see figure 3.2A.3-9). However the spray density is likely low enough to avoid engine surging.

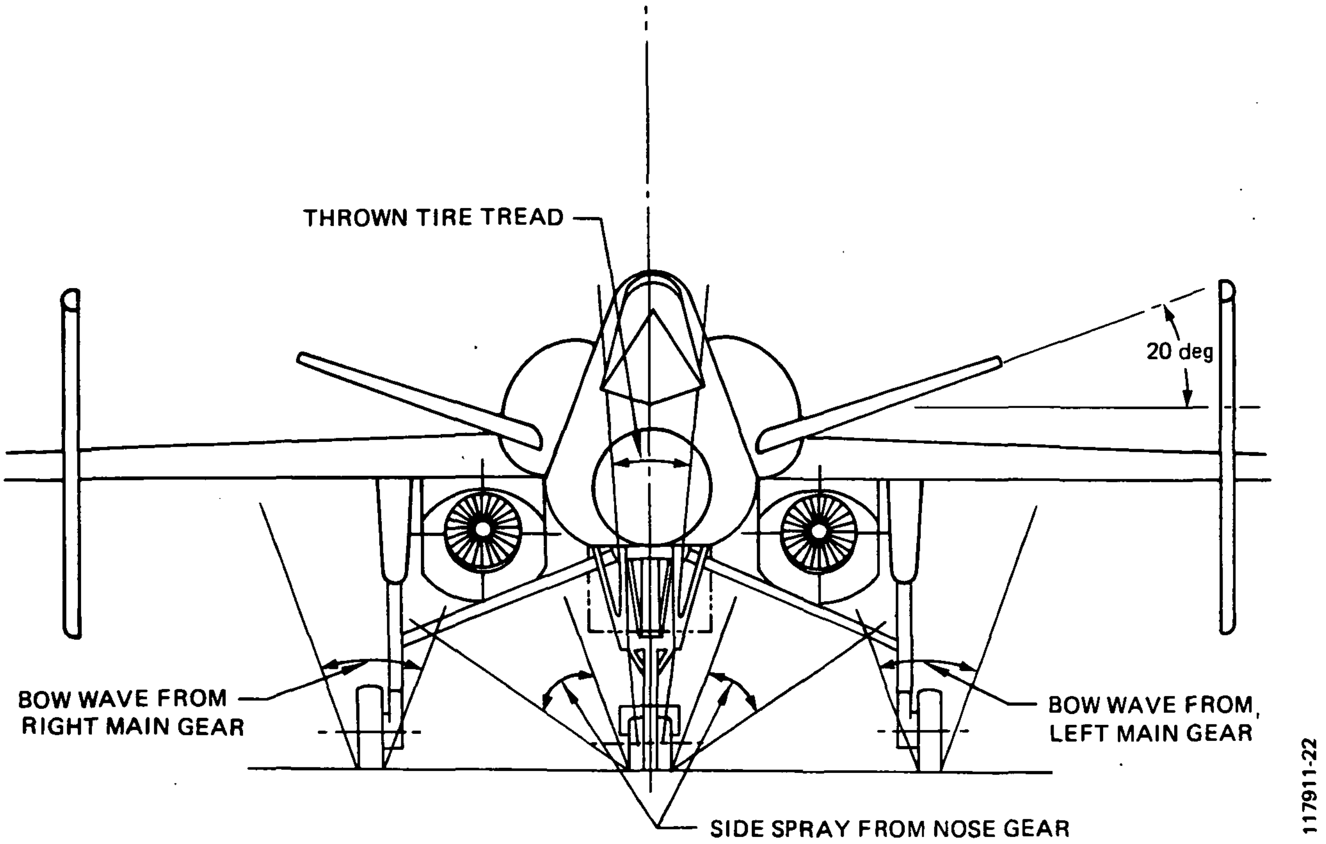


Figure 3.2A.3-9. Spray Patterns and Thrown Tire Tread Envelope for Landing Gear Induced Engine Foreign Object and Water Ingestion

- The nose gear deflector shown is not adequate to prevent water or foreign object ingestion. Based on previous deflector design efforts, an in-depth study will be required to develop a satisfactory deflector. For example, the Boeing SST program performed an extensive investigation to develop an adequate slush deflector. Figure 3.2A.3-10 shows a "fender-type" deflector which was tested.

A solution to the landing gear induced slush ingestion may be to restrict operation to dry runways.

The aircraft is equipped with pneumatically operated, hydraulically controlled, multiple disc-type brakes. The lengthening of the landing gear 34" will raise the airplane vertical center-of-gravity. This degrades braking performance because of the greater dynamic load shift to the nose gear during braking. Fore-aft stiffness of the landing gear also affects braking system performance. System efficiency is degraded by induced "gear walk". Therefore an analysis of the braking system performance and compatibility of the brake control system and lengthened main gear will be required.

An analysis of the brake energy will be required when the flight test plan is determined. The brake energy capacity may become a limiting factor during flight test operation. Engine idle thrust level can also have a significant effect on brake heat sink requirements.

The performance of the F-106B braking system is poor (i.e. braking coefficient of 0.15). This adversely impacts its STOL capability. The discussion below gives the reasons for poor braking performance, and suggests methods to improve it.

Reasons for Poor Braking Performance

The braking performance of the F-106B is poor for mainly two reasons: it has pneumatically actuated brakes, and it does not have an antiskid

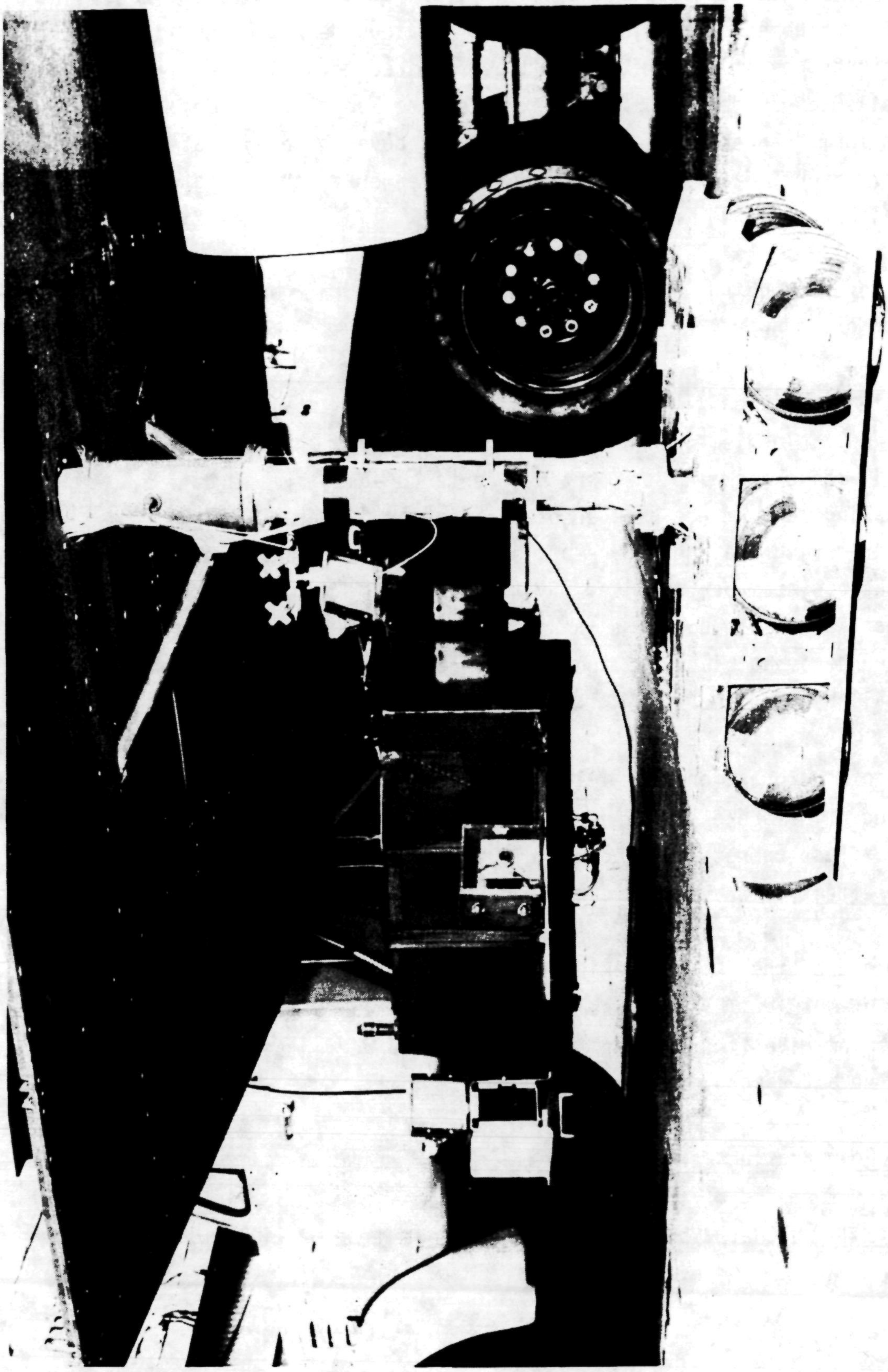


Figure 3.2A.3-10. Boeing SST Slush Deflector

system. The performance of pneumatic brakes, in general, is inferior to hydraulic brakes, due to the compressibility of air leading to poor brake response. This is the reason that most modern braking systems are hydraulically actuated.

A modern antiskid system considerably improves braking performance. For example, a hydraulic braking system without antiskid would have a braking coefficient of approximately 0.2. The addition of a good antiskid system, like the advanced 737 system, would improve it to greater than 0.4. Installation of an existing antiskid system without fine tuning for optimum performance would improve the braking coefficient to approximately 0.3. Braking coefficients for some Boeing aircraft are shown below.

Braking Coefficients

	ANTISKID ON		ANTISKID OFF
AIRPLANE	DRY RUNWAY	WET RUNWAY	DRY RUNWAY
707	.36		
727-100	.345		.206
727-200	.372		.247
737 Original	.352	.20	
737 Advanced	.415	.24	

There are many factors affecting the performance of an antiskid system. A sensitivity study was performed on F-4 braking system performance, which is very poor, particularly on wet runways. The F-4 has a hydraulic braking system with antiskid. The results of the study revealed factors (listed below) that contributed to the poor braking performance, some of which may also apply to F-106B.

- Remote antiskid valves (long lines to brakes) causing slow response
- Low fore-aft strut stiffness
- High tire pressure
- Short coupling (large dynamic load transfer to nose)
- Poor lateral control

Improvement of Braking Performance

The least cost improvement would be to install pneumatic antiskid valves and an existing antiskid system into the F-106B without changing the actuation system. Boeing made a similar improvement on the NASA "Buffalo" augmentor wing aircraft for about $50K in 1971-72. However, very little testing and instrumentation were required for that case since improved stopping performance was not an objective, i.e., the system was installed to prevent tire blowout during stopping. We estimate approximately $150K would be required to install a similar system today, assuming lab simulation for performance evaluation and compatibility check only on the airplane. The braking coefficient may be improved to approximately 0.3 with this change, if the system does not have to be severely detuned to eliminate gear walk.

A higher cost improvement would be to install a hydraulically actuated brake system with antiskid. Interface problems are potentially more severe with this improvement. The cost would be substantially higher than the other, dependent upon how extensive the changes are. The braking coefficient may be improved to 0.35, again depending on system compatibility. Figure 3.2A.3-11 shows the estimated braking coefficients of the F-106B, along with braking coefficients of some Boeing aircraft.

Pneumatic System

The aircraft has both high pressure and low pressure pneumatic supply systems. The high pressure pneumatic system has 3000 psi air stored in the aircraft as a source of power for the normal and emergency operation of various aircraft systems. The high pressure system was not impacted by the modifications. F-106B pneumatic services are shown in Table 3.2A.3-1.

The low pressure pneumatic supply system conducts engine bleed air to various subsystems. Most of the air passes through a refrigeration unit where it is cooled for use in the cockpit and electronics compartment.

The substitution of the two F-404 engines for the J75 engine impacts the low pressure pneumatic system. Bleed air data for the J75 and F-404 engines is shown in Table 3.2A.3-2. Table 3.2A.3-2 shows the available bleed air from two F-404 engines is generally at higher temperature and pressure, but lower flow rate than the J75 engine.

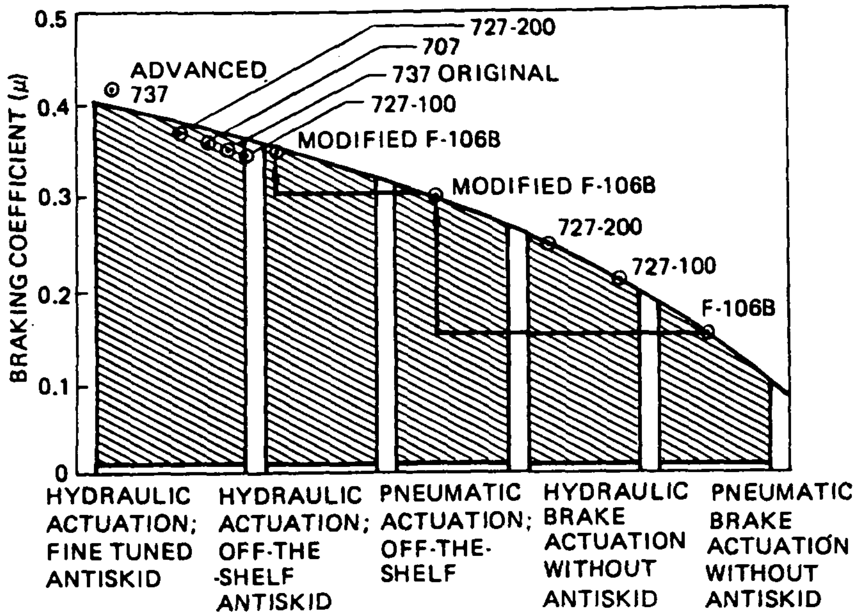


Figure 3.2A.3-11. Braking Coefficients of F-106B and Boeing Aircraft

Table 3.2A.3-2. Bleed Air Data

Engine	Mach	Altitude (ft)	Condition	Flow rate (lbm/s)	Pressure (lb/in^2)	Temperature (°R)
J75-P-17	0	Sea level	Maximum afterburn	2.52	174	1,160
			Maximum dry	13.86	174	1,160
			Idle	4.4	35.3	674
	0.8	30,000	Maximum afterburn	1.03	85	1,106
			Maximum dry	5.68	85	1,106
			Idle	3.3	28.3	743
F404	0	Sea level	Maximum afterburn	2 x 2.63	353	1,440
			Maximum dry	2 x 2.63	353	1,440
			Idle	2 x 1.35	58	846
	0.8	30,000	90% military	2 x 2.8	125	1,270

The low pressure pneumatic system was designed for the bleed air temperatures, pressures, and flow rates available from the J75 engine. Therefore, the higher temperature of the F-404 bleed air will degrade the performance of the refrigerator unit. More critically, the materials in the system may not tolerate the higher temperature. Degraded refrigeration performance may be acceptable, and the material specifications may be adequate for the higher temperature, however further analysis is required to make this assessment.

If higher temperature bleed air is not acceptable, then a precooler must be added to the system.

The higher pressure of the F-404 bleed air is not a problem. If the pressure is too high for the system, a regulator valve can be added.

The lower bleed air flow rate with the two F-404 engines may degrade the cooling performance of the system. The engine idle at Mach zero and sea level condition requires the maximum amount of bleed air, because a bleed air ejector system is required to provide ambient cooling airflow across the heat exchanger during static operation of the airplane. The flow available from the J75 at that condition is 4.4 lbm/sec, and 2.7 lbm/sec from the two F-404 engines. The maximum amount of bleed air the cockpit requires is 0.27 lbm/sec, however the maximum mount required to cool the electronics compartment is unknown. Therefore, we could not assess whether the bleed flow available is adequate.

The conclusions of the low pressure pneumatic system evaluation are:

- Substitution of the two F-404 engines for the J75 engine may degrade system performance.

- Further analysis is required to assess the impact of higher temperatures and pressures, and lower flow rates of the F-404 bleed air on the low pressure system.

3.2A.3.2 Modification 3

The proposed changes required by Modification 3, Reference 3.2A.3-7, affect the following areas of the mechanical systems of the baseline F-106B aircraft.

- Secondary power generation
  - o hydraulic
  - o electric
- Hydraulically powered aerodynamic flight control surfaces
  - o steerable ventral fin (new)
  - o elevons (revised)
  - o F101 rudder (new & revised)
  - o F101 stabilator (new)
- 2-D nozzle actuation
- Hydraulic system evaluation.

The problem of generation of secondary power exist with this configuration as well as Modification 1. The problem is to transfer secondary power from the F-404 test engines to the F-106B's secondary power system, since the J75 main engine will be removed from the aircraft. As for Modification 1, a new secondary power system mounted on the F-404 test engines and connected to the existing distribution system is the recommended method of secondary power generation.

Hydraulic pump size determination is accomplished with the aid of a hydraulic system load profile. The load profile is calculated with the aid of a stability and control analysis of the aircraft. When the stability and control analysis is available the hydraulic pump sizes can be selected.

The recommended electrical generators are variable speed constant frequency generators (VSCF). Existing VSCF systems, installed on the F-18 aircraft, have sufficient capacity (30/60 KVA) and be of a small volume for installation on each F-404 gearbox.

The ventral fin control surface effects on the F-106B include hydraulic actuator installation and connection to the flight control system.

The effects of the revised elevon flight control surfaces on the F-106B aircraft are the same as in Modification 1.

An F-101 "T" tail is to be installed in the place of the F-106 vertical tail for this modification. The installation and system effects of the stabilator flight control surface was explained in Reference 3.2A.3-8. These effects are: the stabilator actuator is a long actuator and space for it must be available for installation; hydraulic flow requirements are low since this service is a pitch trimming device; and the control linkages for the rudder (connect to existing rudder control linkages) and stabilator actuators (new control linkages) need to be designed.

As shown in Reference 3.2A.3-7 the rudder area and chord is increased to 35 ft^2 from approximately 14 ft^2. To predict the effects of this area and chord increase on the ability of the rudder actuator to provide adequate actuation, hinge moment data must be available. Determination of actuator sizing for a flight control device requires data on hinge moment for the surface at different points in the flight envelope.

The actuation requirements for the 2-D nozzles are the same as in modification 1.

The hydraulic system evaluation should be made when the duty cycle for the utilization components (rudder, etc.) are known from stability and control calculations.

3.2A.3.3 Modification 5

The proposed changes required by Modification 5, Ref. 3.2A.3-9, affect the following areas of the mechanical systems of the baseline F-106B aircraft:

Secondary power generation
- hydraulic
- electric

Hydraulically powered aerodynamic flight control surfaces
  - o elevons
  - o rudder

2-D nozzle actuation
Hydraulic system evaluation.

The secondary power generation system is affected in the same way as the Modifications 1 and 3.

The existing rudder and elevon actuators will need to be evaluated for various flight conditions to determine the adequacy of the actuators to provide the required authority. Hinge moment calculations provide the necessary data to evaluate the required hydraulic actuator performance.

The modification to rerig the elevons to +32° authority, would require extensive modifications to the mechanical linkages of the elevon actuation systems, as for Modification 1.

The rudder modification would be to install a larger actuator, if required, since this modification is a higher Mach airplane than the previous modifications.

The 2-D nozzles are used as flight control devices for this modification. In this case, the reliability of the actuation system would have to conform to Mil-Spec MIL-F-9490.

The hydraulic system capacity evaluation is similar to Modifications 1 and 3.

3.2A.3.4 Modification 7

The proposed changes required by Modification 7 affect the following areas of the mechanical systems of the baseline F-106B aircraft:

Secondary power
  - o hydraulic
  - o electric

Hydraulically powered flight control devices
  o rudder
  o RALS
  o ventral fin
2-D nozzle actuation
Hydraulic system evaluation

The secondary power generation system is affected in the same way as Modifications 1, 3, and 5, described above.

The revised rudder surface may require a revised actuation system, as discussed for Modification 5.

The RALS (remote augmented lift system) and ventral fin actuation system are additions to the flight control and hydraulic system of the baseline F-106B aircraft. Detailed evaluation of the effect of these additional services was not undertaken during this study.

The 2-D nozzle actuation system is the same as in Modifications 1 and 3.

Hydraulic system evaluation is the same as for Modifications 1 and 3.

3.2A.4 Structures

This section provides discussion of general structural requirements for flight test vehicles, available strength in the NASA-modified F-106B, and structural aspects of the four proposed modifications under study.

Structural Requirements for Flight Test

Standard practice which has been used for both the Augmentor Wing Buffalo and QSRA STOL aircraft requires that flight maneuvers are limited to those which do not result in loads greater than 80% limit load. Ultimate loads are obtained by multiplying limit loads by 1.5. In addition, parts which have not been proof tested to limit load must maintain a minimum margin of safety of .25.

Flutter clearance would be obtained in the same manner as previous programs whereby freedom from flutter is demonstrated at .2 Mach greater than the required flight profile.

Strength of the F-106B Test Bed

The basic F-106B is designed to limit load factors of 6.0 and -2.4 at Combat Gross Weight (60% fuel or less). Anticipated usage of the existing test bed reduces these to 4.5 and -1.0 for design of the nacelle and its attachment. However, when large amounts of ballast are required the strength of the fuselage may not permit maneuvers to 4.5g.

Flutter clearance was previously obtained by NASA for smaller, J-85 size nacelles by demonstrating no flutter at .2 Mach above the required flight profile. The result for the two heaviest nacelles evaluated are shown in Figure 3.2A.4-1. Note that this is not the flutter boundary but it can be seen that there is ample space inside the flight envelope for STOL flight research.

Engine Installation Considerations

The F-404 engines are intended for buried fighter-type installation rather than pod mounting where the inlet loads are carried by the compressor

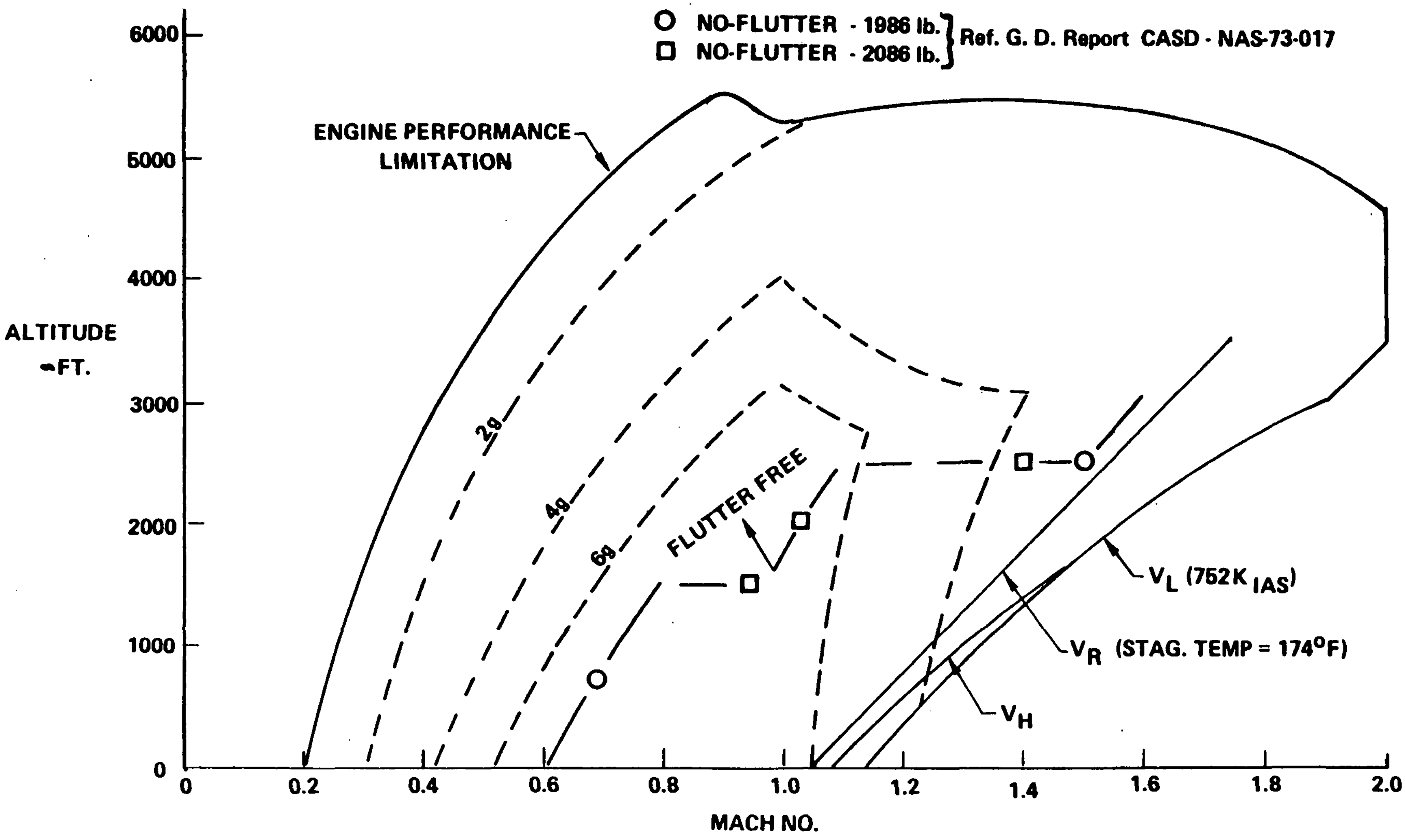


Figure 3.2A.4-1. Load Factor Capability F-106B W = 34780 lb. and J-85 Flight Flutter Results.

casing. The nacelle must therefore be designed to carry inlet and nozzle loads with the engine suspended inside. The nacelle assembly must then be integrated with the wing. This arrangement will be heavier than a conventional pod where inlet and nozzle loads are carried by the engine and the nacelle structure is essentially a fairing.

Modification #1 (Per LO-PD-TS-25A)

A review was conducted to determine the feasibility of designs for canard, wing-tip extension, and winglet installations on the F-106B. The canard design load was a uniform pressure of 1.471 psi which results from a normal force coefficient of 1.0 at 250 knots. The wingtip extension and winglet assumed design loads were based on a load distribution resulting from a 4g symmetrical pullout.

The only area that presents a risk in carrying the design loads is the wing just outboard of the engine. Although this wing was originally designed for 6g's, the internal load distribution from the extended wing tips, winglets, and increased elevon at 4g's may exceed the design allowables. There was insufficient information in the available F-106B stress analysis to accurately determine the new internal loads in this complex structure. An external loads comparison indicates that a 3.5g limitation will keep the internal loads within the original design values. Further analysis based on the F-106A stress analysis will be needed to verify the capability of this structure before flight.

Both the 4 in. diameter tube carrying the canard and the 2 in. diameter tube carrying the wingtip are capable of withstanding design loads when made of 160 KSI steel with wall thickness of .375 in. and .32 in. respectively. In both cases stiffness could be increased and possibly weight saved by using larger diameter thinner wall tubes.

The canard installation will require a full depth (below cockpit floor) bulkhead and attachment fittings to distribute their loads into the fuselage. Since the nose landing gear shears and moments exceed the canard loads, the fuselage requires no further modification. The present design results in limit bearing loads of 52,000 lb inboard and 63,000 lb outboard. These could be reduced by increasing the bearing spacing or installing the canard on a single shaft.

The rest of the F-106B structure was designed to higher loads than those imposed by these modifications.

Modification #3 (Per LO-PD-TS-27A)

Loads - The critical design load for the wing was an assumed 4g symmetrical pull up with a 40,000 lb gross weight. This resulted in a 1.135 psi pressure equally distributed over the wing area.

Wing Modifications - These have been kept to a minimum because the original design was based on a 6g load with a smaller total wing area. Since there is no path for spar 6 loads and spar 5 is much deeper than spar 7, the load in spar 6 will be transferred to spar 5. This will require skin doublers between spars 5 and 6 and possible beef-up of spar 5 web and the root rib. It was assumed that although the elevon was increased in area, the actuators remain the same. Therefore, the maximum elevon loads would not increase.

Fuselage Modifications - The basic fuselage does not have the capacity to carry the bending loads from wing spars 1, 2, 3 and 5 with the wing located 70.5 in forward. At wing spar 1 the minimum change would be frame beef up or it could be designed similar to the modification for spars 2, 3 and 5. At wing spars 2, 3 and 5 frame beef up would be so extensive it appears impractical. However, there is room to run these spars through the fuselage. This method will still require some frame modification to transfer shear loads into the fuselage. The through fuselage spars will carry all spar bending loads.

Wing Extension (Between Fuselage and Old Wing) - In order to keep modifications to the existing F-106B to a minimum, this section will be designed to carry much of the redistribution. Consequently it will be heavier than normal for the loads it carries. The main spars of this section will be a stub wing spar 1, through fuselage wing spars 2, 3 and 5, stub wing spar 3, stub spar at old spar 3 on fuselage, stub diagonal spar from old spar 4 on fuselage to wing spar 5, and a separate spar from wing spar 7 to old spar 5 on fuselage. Heavy ribs will be required to distribute engine, gear, wing spar 6, and stub spar loads.

"T" Tail Installation (F-101 Tail) - The D180-25418-1 feasibility study showed that the loads from the F-101 tail were compatible with the F-106B. Since required loads are expected to be no greater, no further work was done.

Modification # 5 (Per LO-PD-TS-30A)

Loads - The critical condition for the F-106B aft fuselage is 6g pull up. It is assumed that this airplane will be limited to 4g's and that the engine installation experiences 4g's. Engine thrust is 13,000 lb per engine and the nozzle can be vectored up at 30°.

Stations 510 to 585 - The new bending loads are less than 10% greater than the F-106B. Since no critical margins of safety are listed in the F-106B analysis for this area, it is probable that no changes will be required except for local structure to attach the engines.

Aft of Station 585 - The thrust vectoring results in a considerable increase in loads for this area. Even with this load increase, the stress levels remain relatively low (-38KSI for critical longeron). Since our present study provided neither detail drawings or analysis of this area it should be assumed that some beef-up will be required to add stability to the longerons and shear capability to the skin.

Forward of Station 510 - Here the new loads are being reacted by wing spars and the forward fuselage. With the airplane restricted to 4g's these loads will be less than the F-106B. Therefore no changes are expected.

Modification #7 (Per LO-PD-TS-43)

This installation places the new, lighter engines forward of the old engine. Thus, the only fuselage changes for engine installation are local brackets to get the loads into the fuselage.

The vertical thrust load of 4000 lb per engine at Station 25 will require beef-up of the fuselage structure forward of Station 147. Based on the limited amount of stress analysis available there is low risk in assuming the structure aft of Station 147 is adequate.

The full span rudder will significantly increase the bending loads at the base of the fin. Therefore speed-deflection placards will be required to keep from exceeding the original design loads.

Summary

There are no structural reasons to eliminate any of the four proposed modifications at this time. They will all have to operate under some limitations which may affect the extent of demonstrations of thrust vectoring at high speed. Use of thrust reversers may, depending on the design, require changing some of the F-106 primary structures from aluminum to titanium or steel.

3.2A.5 Flight Controls

Summary:

Four modifications of the F-106B were evaluated as possible F-106B STOL demonstrators using thrust vectoring. Each configuration was initially analyzed "as-drawn," see section 3.1.4. Then, based on the initial analysis, further modifications were hypothesized as required and analyzed, although the configurations were not redrawn. All configurations are extensively modified externally except number 5. Modification 1, with a canard, had nose wheel lift-off restraints which required a canard flap and forward movement of the gear. The final configuration, at very light weights and aft c.g.s can perform at STOL speeds (about 120 kn) with about 20 degrees of thrust vectoring. Modification 3, with a wing root insert and horizontal tail, is controllable only down to about 125 knots and could be operated at only light weights. Modification 5, the least modified configuration, which has engines mounted on each side of the vertical tail, is operable at light weights to 120 knots. Modification 7, inclusion of RALS in the fuselage nose, is operable with about 20 degrees of vectoring down to 120 knots. Controllable thrust vectoring is limited to 15 degrees for engine-out conditions at low speeds. All configurations will require extensive modification to the flight control systems, since each is significantly altered from the basic F-106B.

In conclusion, all modified configurations, with certain weight and c.g. limitations, appear to be feasible for STOL demonstrations using thrust vectoring. Since the present analysis was limited to evaluating potential feasibility, it should be noted that substantial further analysis is required to validate some of the critical assumptions.

Discussion

Preliminary design level analyses were performed for each of four F-106 modifications, References 3.2A.5-2 through -5, to determine their feasibility and controllability for operation at STOL speeds. Ground rules used during the analyses were as follows: (1) goal for minimum flying or operating speed is 120 knots, (2) static stability margins would be the same as basic F-106 margins (approximately 3% at low speed), (3) elevons will be rerigged to provide ± 30 degrees of deflection, (4) elevons would be reapportioned between pitch and roll control for STOL (low speed) operation. To simplify and assist comparisons of each modification, F-106B reference dimensions and stations are used. Aerodynamic data from Reference 3.2A.5-6 are the basis for the estimated stability and control characteristics. Adjustments were made to this base data as required, for each configuration, using methods of Reference 3.2A.5-7.

Figure 3.2A.5-1 presents the effect of exposed canard area on low speed aerodynamic center for Modification 1. The revised 88 sq. ft. canard results in an aft c.g. limit of $0.1675\bar{c}$. The forward c.g. limit will be determined by nose wheel lift-off (NWLO) speeds and ballast requirements. Nose wheel lift-off speeds below 108 knots are required for a minimum flying speed of 120 knots. Initial estimates of nose wheel lift-off speed were above 108 knots for all reasonable operating weights and c.g.'s obtainable with the 88 sq. ft. canard configuration, Figure 3.2A.5-2. Two means analyzed to reduce nose wheel lift off speeds to acceptable levels were: (1) use of canard deflection for takeoff rotation instead of only a canard flap and (2) movement of the main gear forward. Movement of the gear was chosen because it would take a canard deflection of 14 degrees to provide the same NWLO speeds as a 24-inch movement of the gear. Movement of the main gear is possible since the gear has been assumed to be modified for the configuration and is non-retractable. The gear is fixed in the down position since the configuration is intended to operate only at low speeds. A 24 inch forward movement of the gear with the 88 sq. ft canard provides acceptable NWLO speed for mid-c.g.s and light weights, Figure 3.2A.5-2.

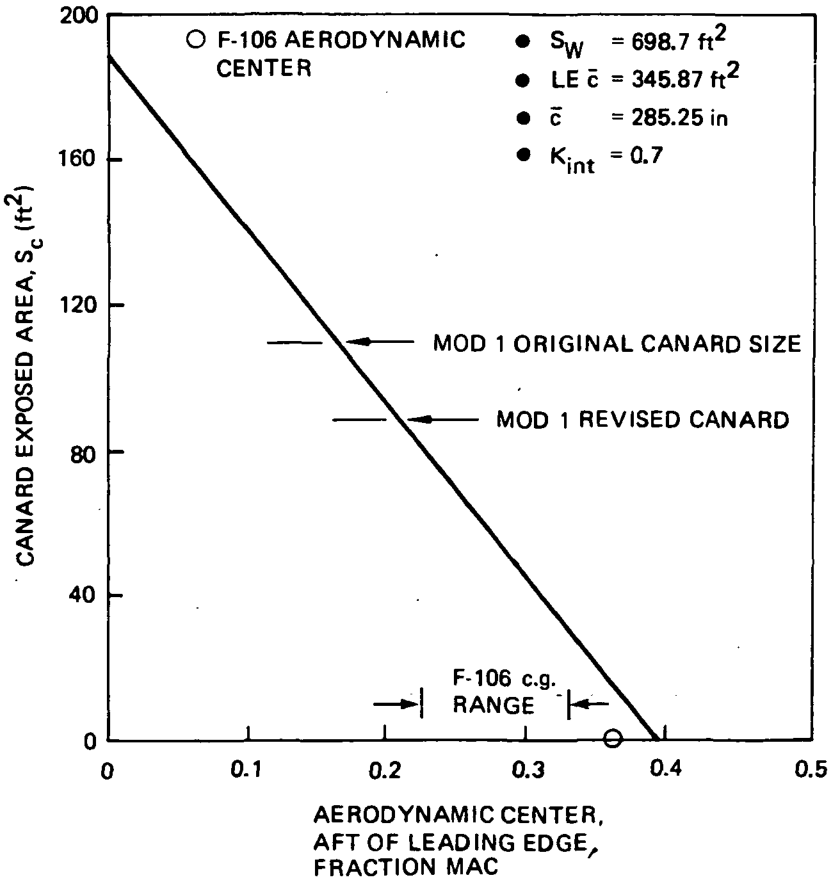


Figure 3.2A.5-1. F-106 Modification 1—Airplane Aerodynamic Center Versus Exposed Canard Area

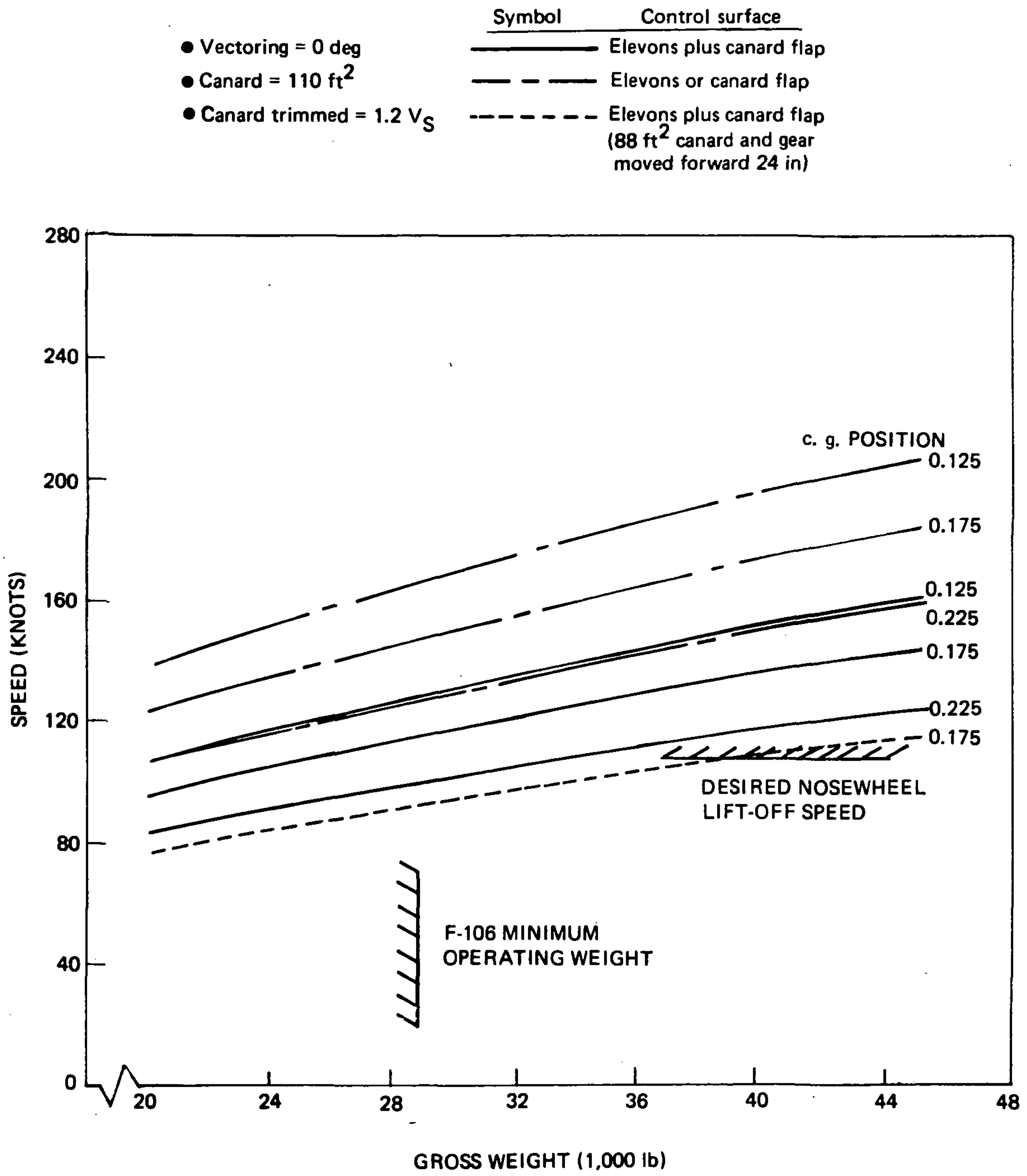


Figure 3.2A.5-2. F-106 Modification 1—Nosewheel Lift-Off Speed

Figures 3.2A.5-3 and -4 present forward and aft c.g. trim requirements for heavy and light weights for the 88 sq. ft canard. Elevons are 0 degrees in Figure 3.2A.5-3 and +10 degrees in Figure 3.2A.5-4. Canard total angle-of-attack (wing angle-of-attack plus canard deflection) should be limited to approximately 25°. Beyond 25° total angle-of-attack, the canard will tend to be stalled and not provide additional trimming moments. The solid curve data show that light weight, aft c.g. configurations are trimmable to 120 knots with the canard (no canard flap) for elevons 0° or 10°. Thrust vectoring will induce additional moments that must be trimmed. The data points show that the configuration is trimmable with 20° of thrust vectoring for light weights and aft c.g.'s if a flapped canard is used. At these speeds, the canard is near stall, and additional moments due to more forward c.g. location, heavy weights, or additional vectoring must be trimmed by methods other than the canard. Ground scrape attitude (17.5°) is exceeded at 120 knots by all but the lightest weights without vectoring. Twenty degrees of thrust vectoring eliminates ground attitude restraints.

Figure 3.2A.5-5 presents engine out ground minimum control speed. Full rudder deflection, 24 degrees, (tip fin rudders in addition to main fin rudder) provides an acceptable minimum control speed of 98 knots at the original gear location and 90 knots at the revised gear position.

Figure 3.2A.5-6 presents engine out lateral-directional control requirements. Available aileron roll control enables thrust vectoring angles up to 30 degrees at 120 knots to be trimmed, assuming no induced lift due to vectoring. The ailerons are limited to ±15 degrees of deflection in order to provide pitch control and/or lift (flaps). Sideslip angle and rudder deflection are within acceptable bounds. If a significant amount of induced lift (one pound of induced lift for each pound of deflected thrust) is assumed, instead of no induced lift as in Figure 3.2A.5-6, available roll control will limit trimmable thrust vectoring to 17 degrees at 120 knots. Note that the wing tip extensions have been assumed used to supplement elevon roll authority. The wing tips have been assumed to be fully effective to ± 15 degrees of deflection at all angles-of-attack. This assumption may be optimistic

- Elevons = 0 deg
- Vectoring = 0 deg
- Static margin, aft cg = 3%
- $K_{int} = 0.7$
- Canard = 88 ft^2

Symbol		Weight (lb)	CG
⊙	———	43,500	0.17
▽	— —	43,500	0.1275
■	—·—	30,000	0.17
▲	- - - -	30,000	0.1275

Note: Symbols are for 20 deg thrust vectoring, with induced lift at maximum power trimmed with flapped canard, canard flap at 25 deg.

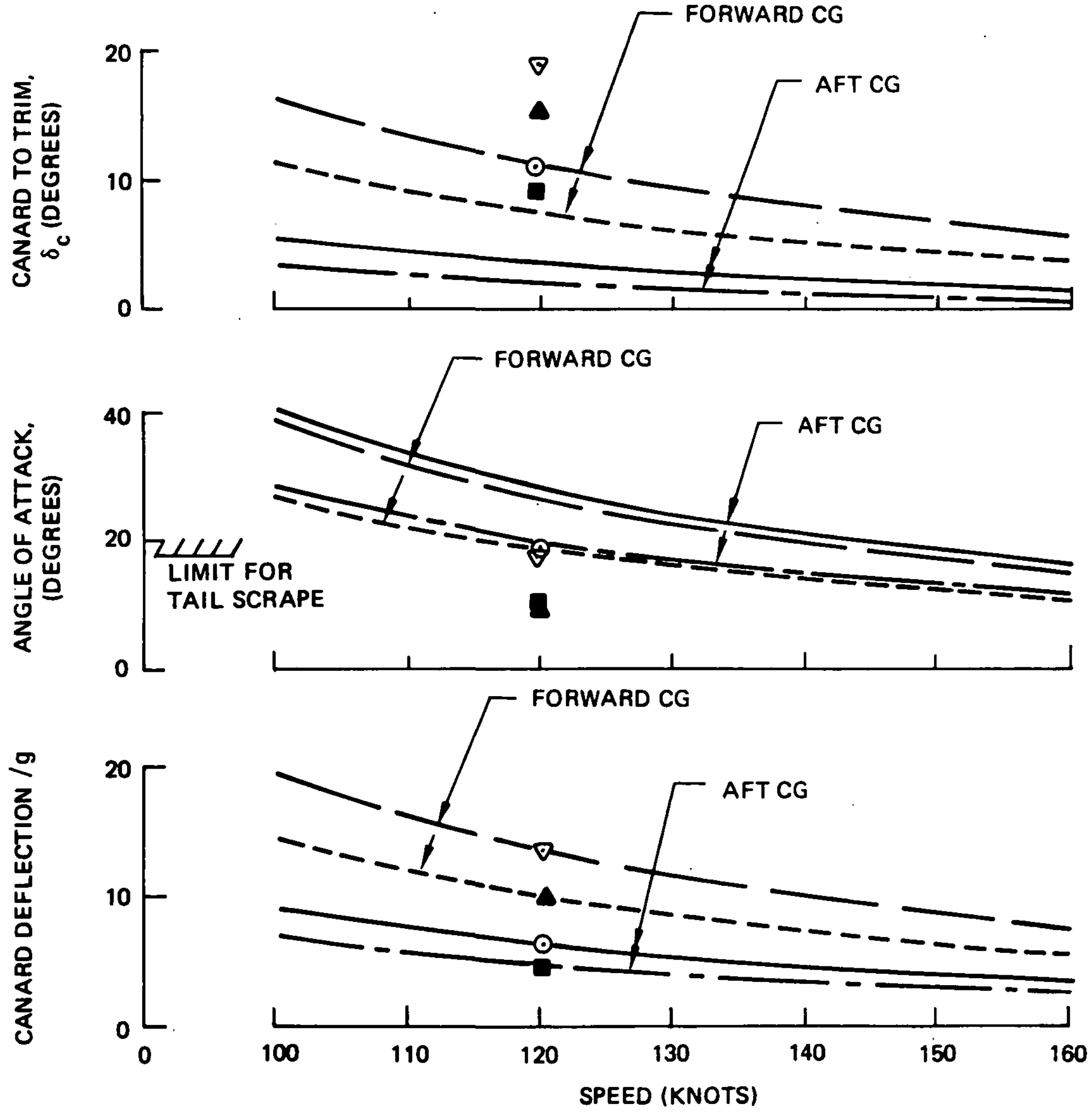


Figure 3.2A.5-3. F-106 Modification 1—Trim Conditions, Elevon at 0 deg

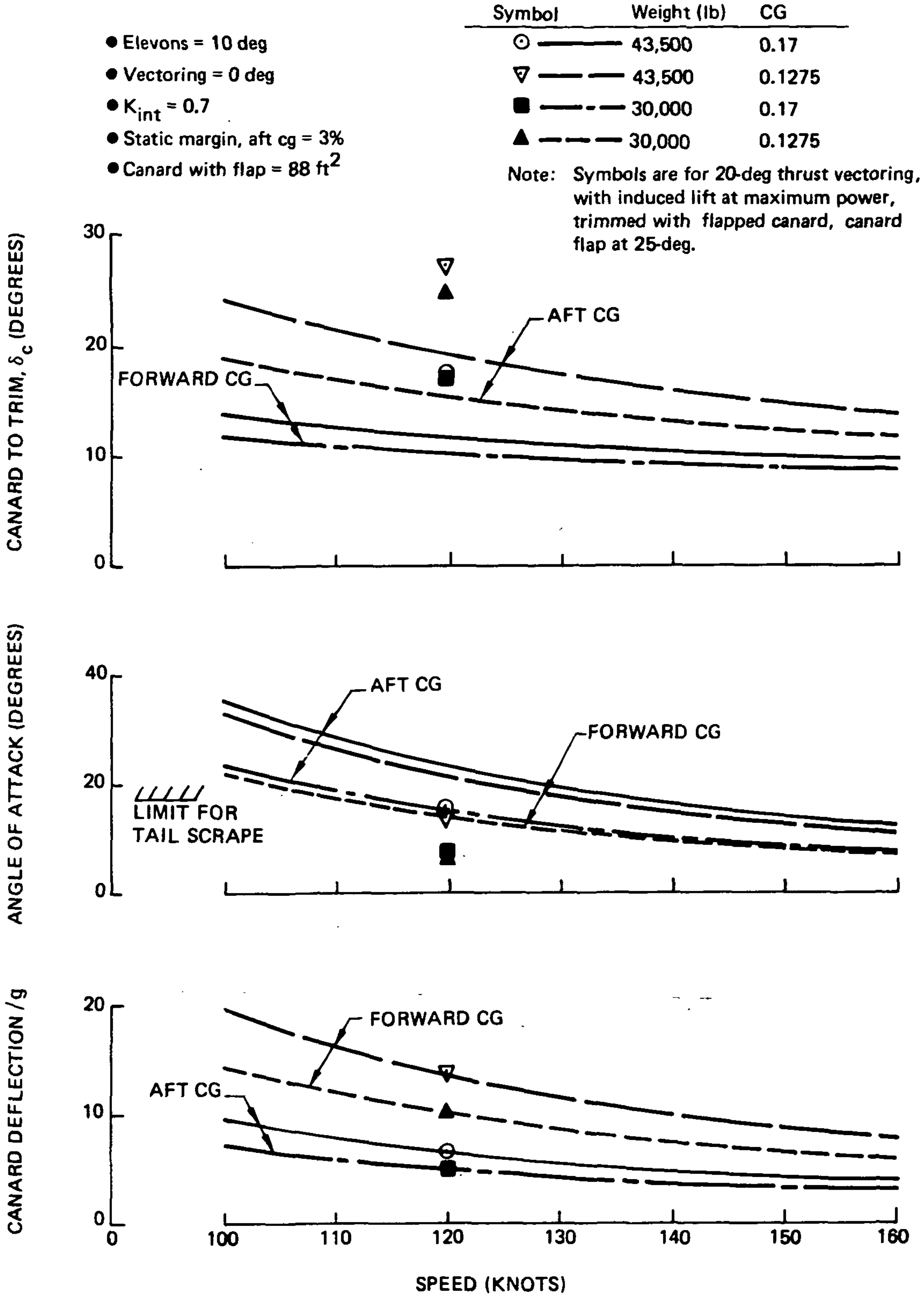


Figure 3.2A.5-4. F-106 Modification 1–Trim Conditions, Elevon at +10 deg

- Thrust = 13,000 lb
- Vectoring = 0 deg
- Altitude = 3,000 ft
- β = 0 deg
- δ_A = 0 deg
- ϕ = 0 deg
- F-106 gear location
- Engines canted 10 deg
- One engine out

Symbol	Configuration
———	Main fin rudder only—extended chord and span
— — —	Main fin rudder plus tip fin rudders (main fin rudder has extended chord and span)
—— - ——	Gear moved forward 24 in (main fin rudder plus tip fin rudders)

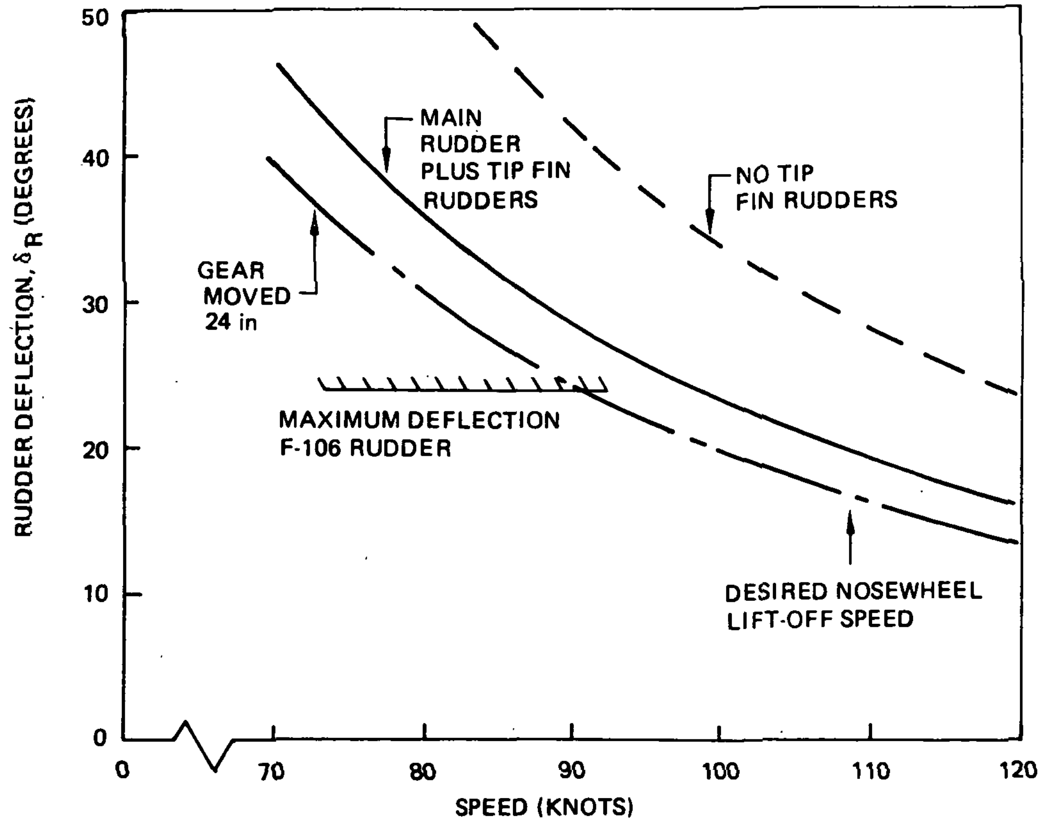


Figure 3.2A.5-5. F-106 Modification 1—Ground Minimum Control Speed

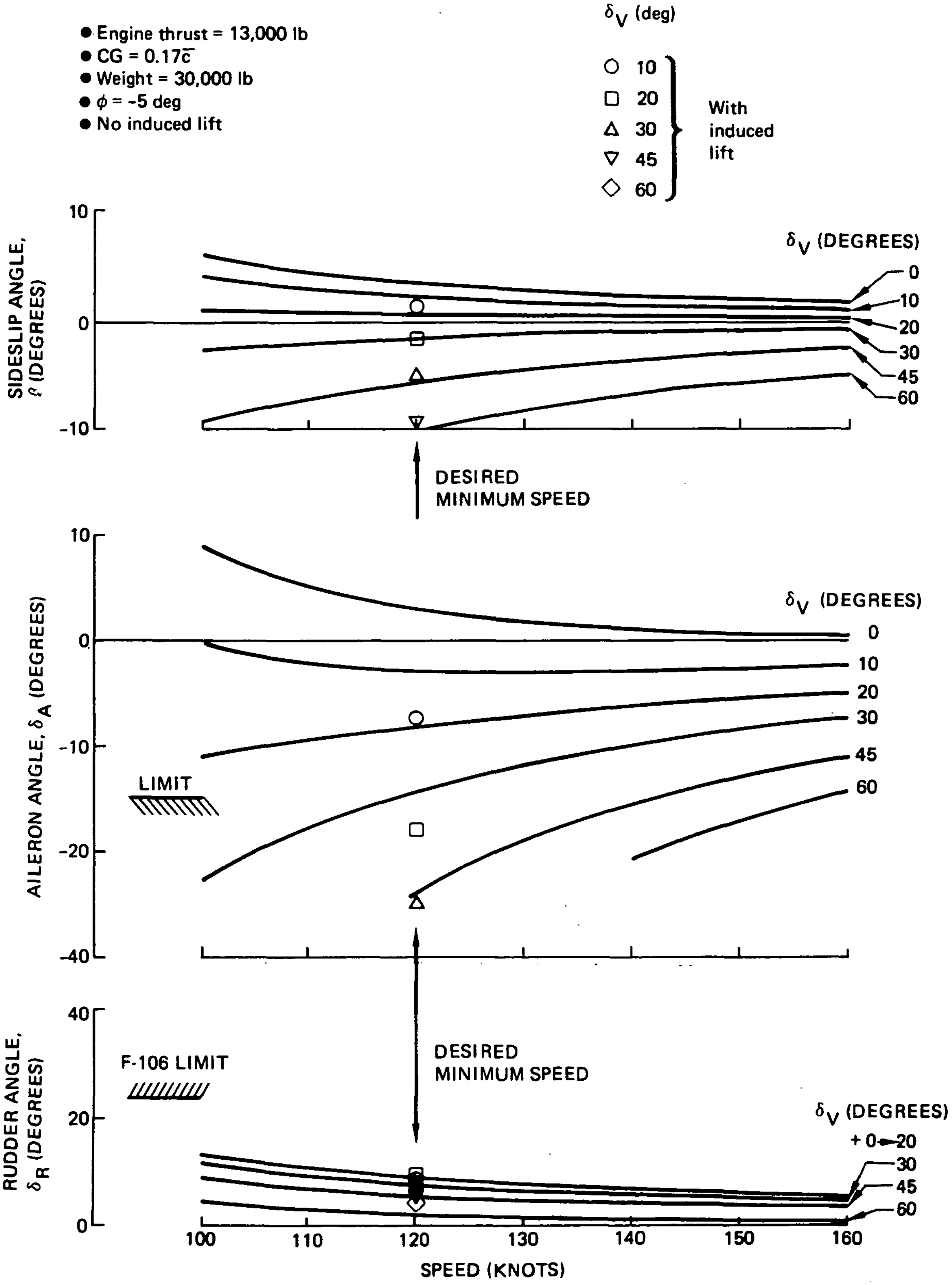


Figure 3.2A.5-6. F-106 Modification 1—Air Minimum Control Speed

since one wing tip would be at 32 degrees angle-of-attack at maximum deflection while the other wing tip would be at zero at low speeds. At 32 degrees angle-of-attack the wing tip could be stalled and ineffective as a roll producing device.

In summary, the flight controls aspects of Modification 1 have been evaluated with respect to the aircraft's ability to perform in a STOL mode at 120 knots. Results are:

(1) The allowable c.g. envelope is dependent upon ballast reqirements as discussed in section 3.2A.1. These requirements limit the exposed canard area to approximately 88 sq. ft.

(2) Nosewheel lift-off speeds of 108 knots are obtainable for some weights and mid c.g.s with a 24 inch forward relocation of the gear, provided a canard flap is used with the 88 sq. ft. canard.

(3) A flapped canard is required to provide trim capability for 20° of thrust vectoring at maximum power for low speed operation.

(4) Engine out control requirements (roll) limit sustained thrust vectoring to 17 degrees of deflection with maximum thrust. If engine failure were to occur at higher deflection angles, the pilot would have to reduce the vectoring and/or thrust and seek a stable equilibrium configuration. The dynamics of such transient operation have not been studied.

(5) A new flight control system probably will be required, since the configuration has been extensively modified relative to the basic F-106B.

Modification #3 replaces the F-106B fin with an F-101 empennage. It was originally analyzed as drawn (see Figure 3.1.4-3), but the airplane was not balanceable in this configuration. Accordingly, the configuration was reanalyzed with the wing moved 10 inches aft. Figure 3.2A.5-7 presents aerodynamic center versus Mach number for this revision to Modification 3. The combined effect of the wing movement and large wing root insert resulted in an aerodynamic center forward of the F-106 aerodynamic center.

Figure 3.2A.5-8 presents nose wheel lift-off speeds for the configuration. The speeds are too high for the desired STOL speed of 120 knots. The more forward location of the a.c. (with F-106 static margins) results in a gear-c.g. relationship that results in unacceptable nose wheel lift-off speeds. Since the gear is a new item to the configuration and is part of the engine nacelle, a 30 inch forward movement is possible, and will provide acceptable nose wheel lift off speeds at light gross weights. Further forward gear positions are possible if required.

Figures 3.2A.5-9 and -10 present forward and aft c.g. trim requirements for heavy and light weights. Elevons are 0 degrees in Figure 3.2A.5-9 and + 10 degrees in Figure 3.2A.5-10. With 0 degrees elevon, all weights and c.g.'s are trimmable. Ground attitude constraints (17.5°) limit the configuration to mid-weights. With 10 degrees of elevons, the configuration is trimmable only for aft c.g.'s. Ground attitude constraints further limit the configuration to mid-weights and aft C. G.s. Thrust vectoring angles of 20° at maximum power are trimmable for all conditions with 0 degrees elevon but limited to aft c.g.'s with 10 degrees elevon. Ground attitude constraints are relieved and are acceptable with thrust vectoring.

Figure 3.2A.5-11 presents ground minimum control speed. Maximum rudder deflection with the gear in the original position resulted in an unacceptable 121 knot control speed. The 30 inch forward movement of the gear gave an acceptable ground control speed of 108 knots.

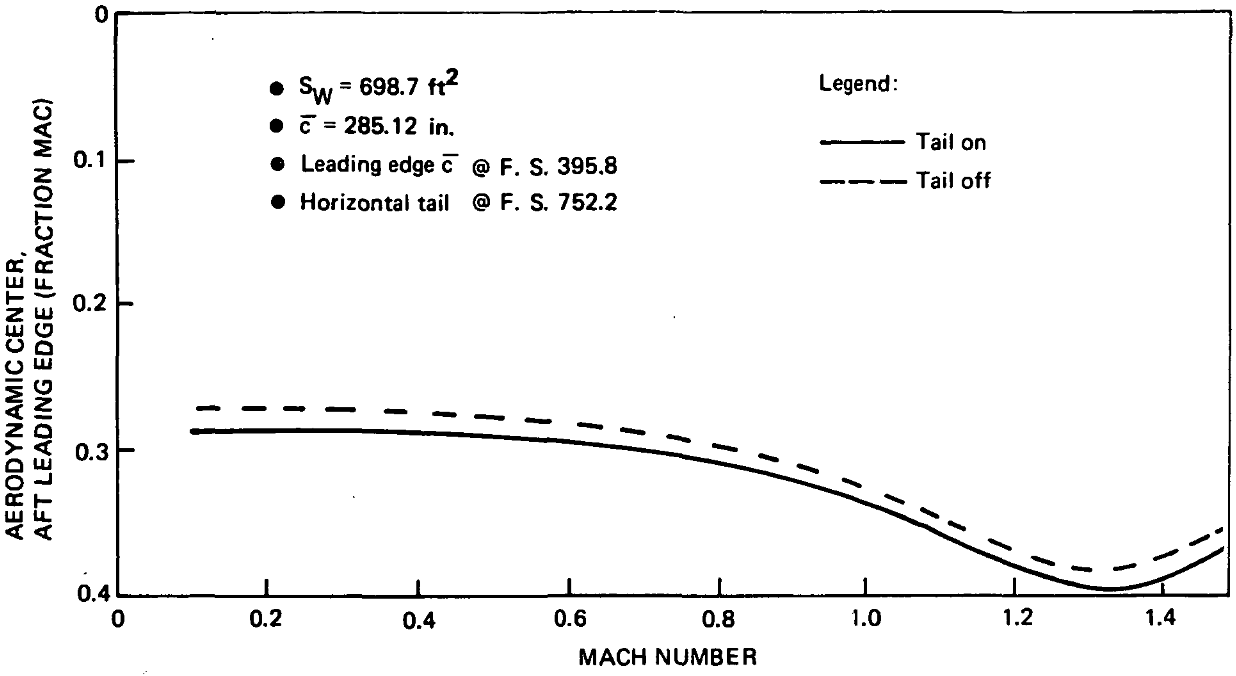


Figure 3.2A.5-7. F-106 Modification 3—Aerodynamic Center Versus Mach Number

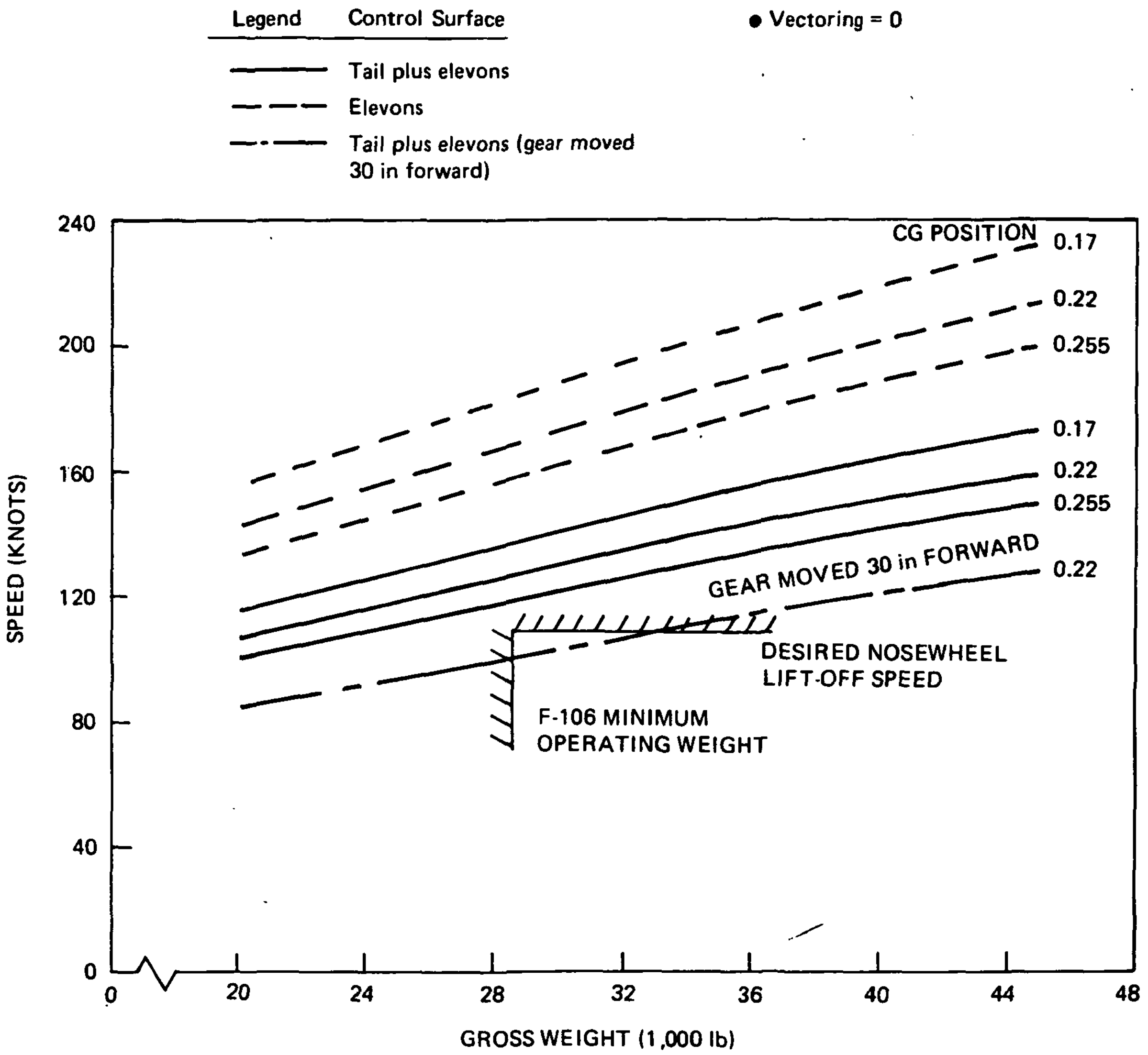


Figure 3.2A.5-8. F-106 Modification 3—Nosewheel Lift-off Speed

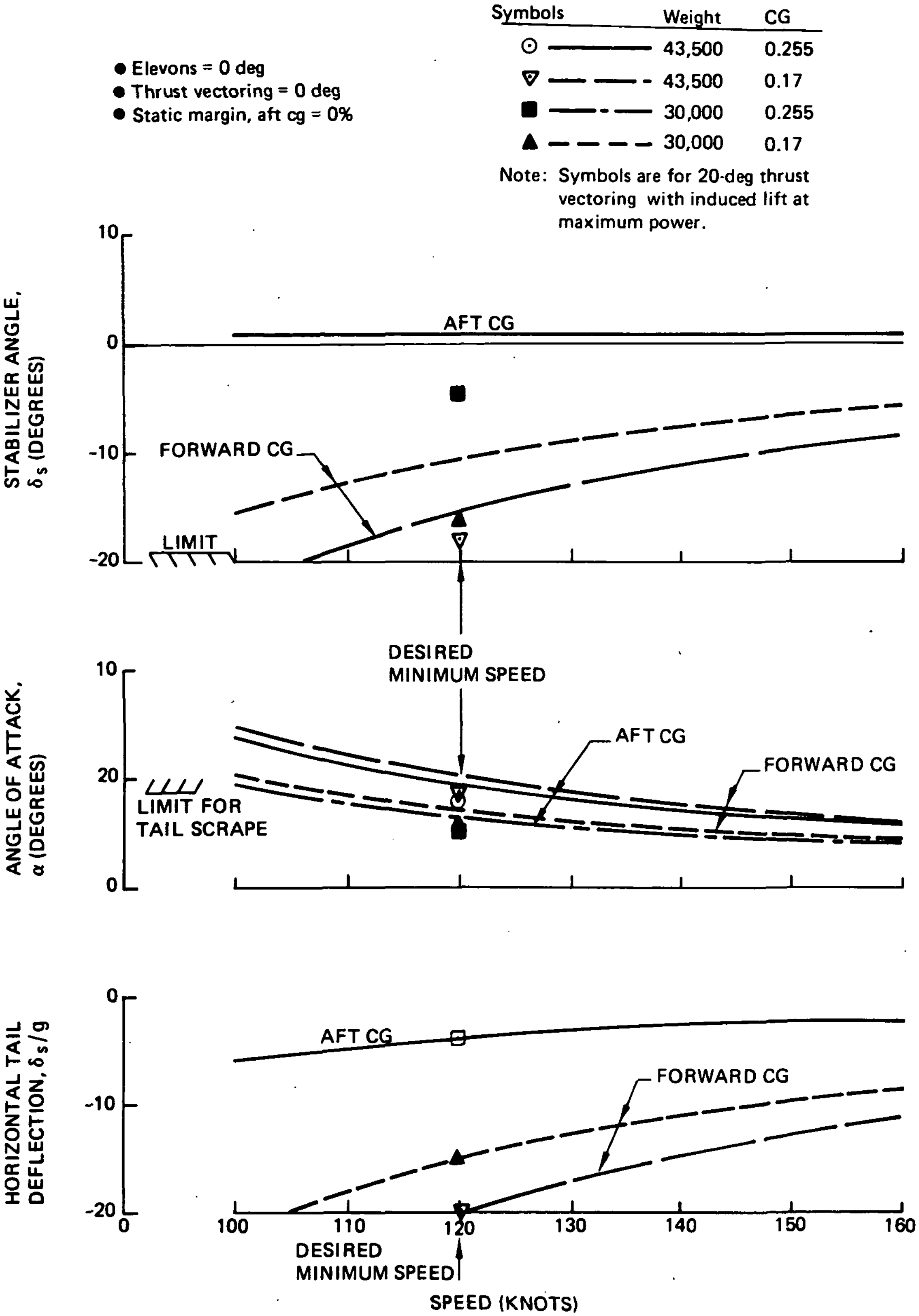
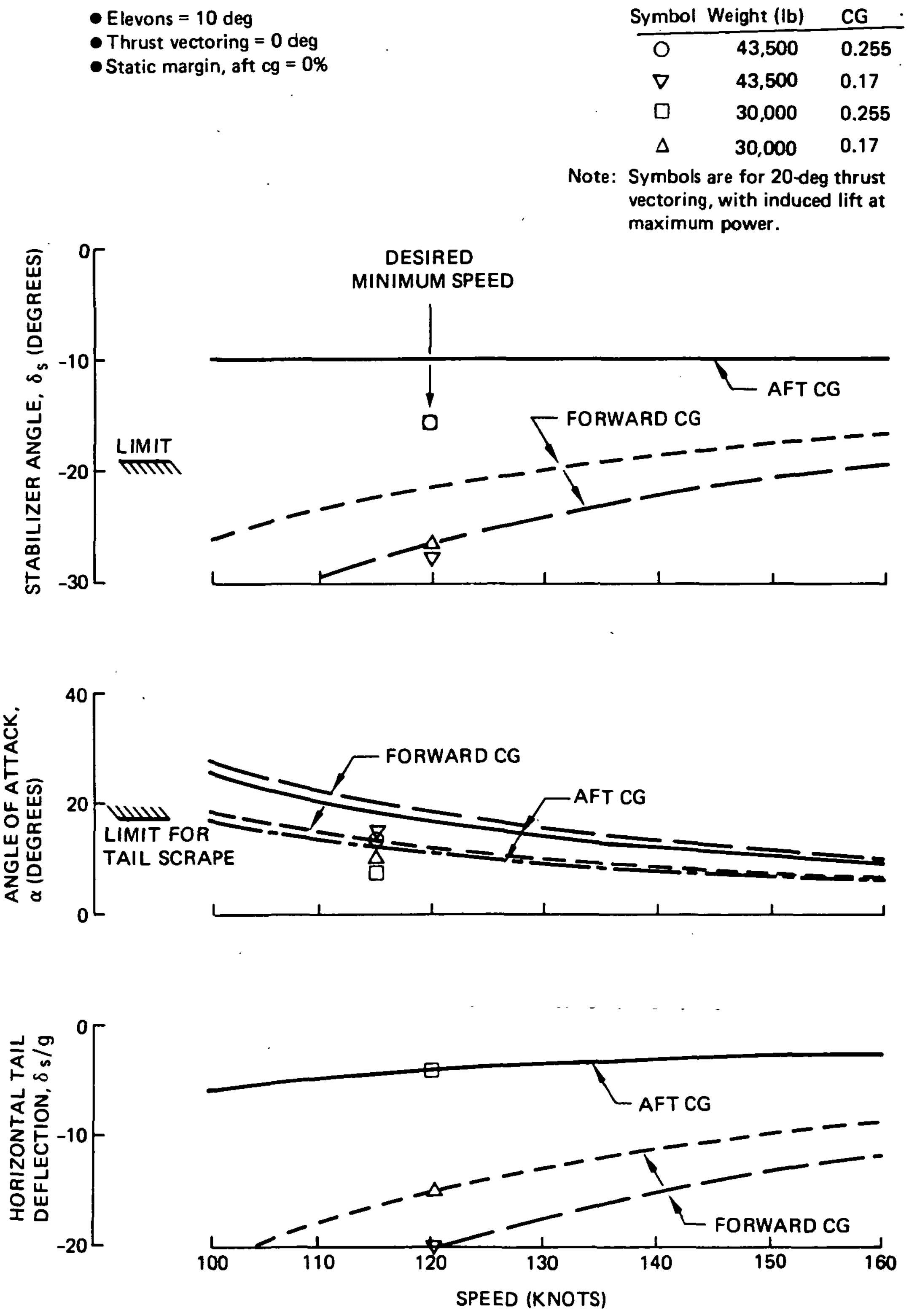


Figure 3.2A.5-9. F-106 Modification 3—Trim Conditions, Elevon at 0 deg



- Elevons = 10 deg
- Thrust vectoring = 0 deg
- Static margin, aft cg = 0%

Symbol	Weight (lb)	CG
○	43,500	0.255
▽	43,500	0.17
□	30,000	0.255
△	30,000	0.17

Note: Symbols are for 20-deg thrust vectoring, with induced lift at maximum power.

Figure 3.2A.5-10. F-106 Modification 3—Trim Conditions, Elevon at +10 deg

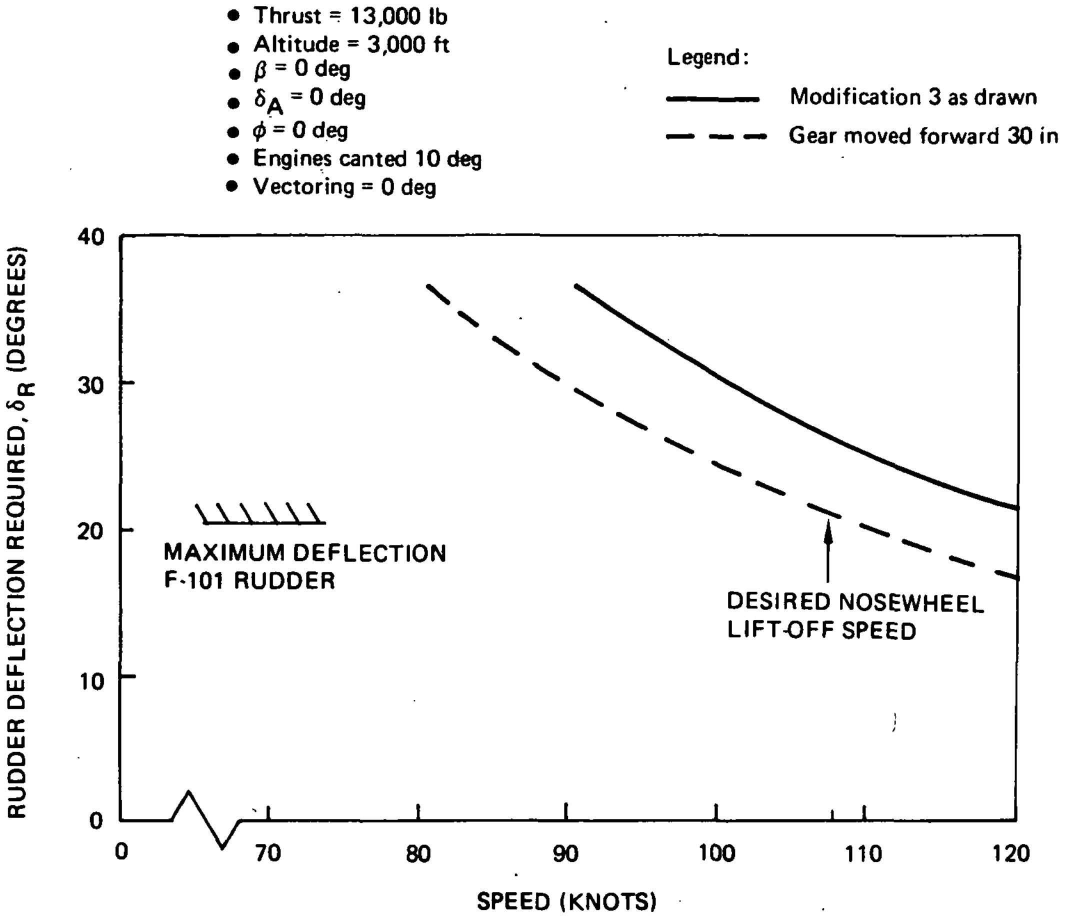


Figure 3.2A.5-11. F-106 Modification 3—Ground Minimum Control Speed

Figure 3.2A.5-12 presents engine-out control characteristics with maximum power developed on the remaining engine. Two sets of data are shown. First, assume no induced lift due to thrust vectoring. Then, at 120 knots, directional control limits vector angles to approximately 30 degrees or less, while lateral control limitations require thrust vector angles between 20 and 45 degrees.

Second, assume one pound of induced lift per pound of vectored thrust. In this instance, directional control limits vector angles to 20 degrees or less, and lateral control limitations require vector angles between 12 and 30 degrees.

In either case, sideslip angles are large (between 10 and 20 degrees), which would require unusual pilot skill for takeoffs or landing.

In summary, the flight controls aspects of Modification #3, with revised wing and gear location, have been evaluated with respect to the aircraft's ability to perform in a STOL mode at 120 knots. Results are:

(1) Acceptable nose wheel lift off speeds are achievable with a 30-inch forward movement of the gear.

(2) Trim can be maintained for all weights and c.g.s for zero degrees elevons, but only aft c.g.'s can be trimmed with + 10 degrees of elevons. Thrust vectoring imposes only small additional restrictions.

(3) At 120 knots, engine out roll control requires a thrust vector angle between 12 degrees and 30 degrees, while directional control requires between 0^o and 20^o of thrust vectoring. The engine-out-control requirement for a narrow range of vector angles is undesirable. If an engine failure were to occur at other vector angles, the pilot would be required to seek an equilibrium configuration by changing the vector angle or reducing thrust. The dynamics of such transient operation have not been studied.

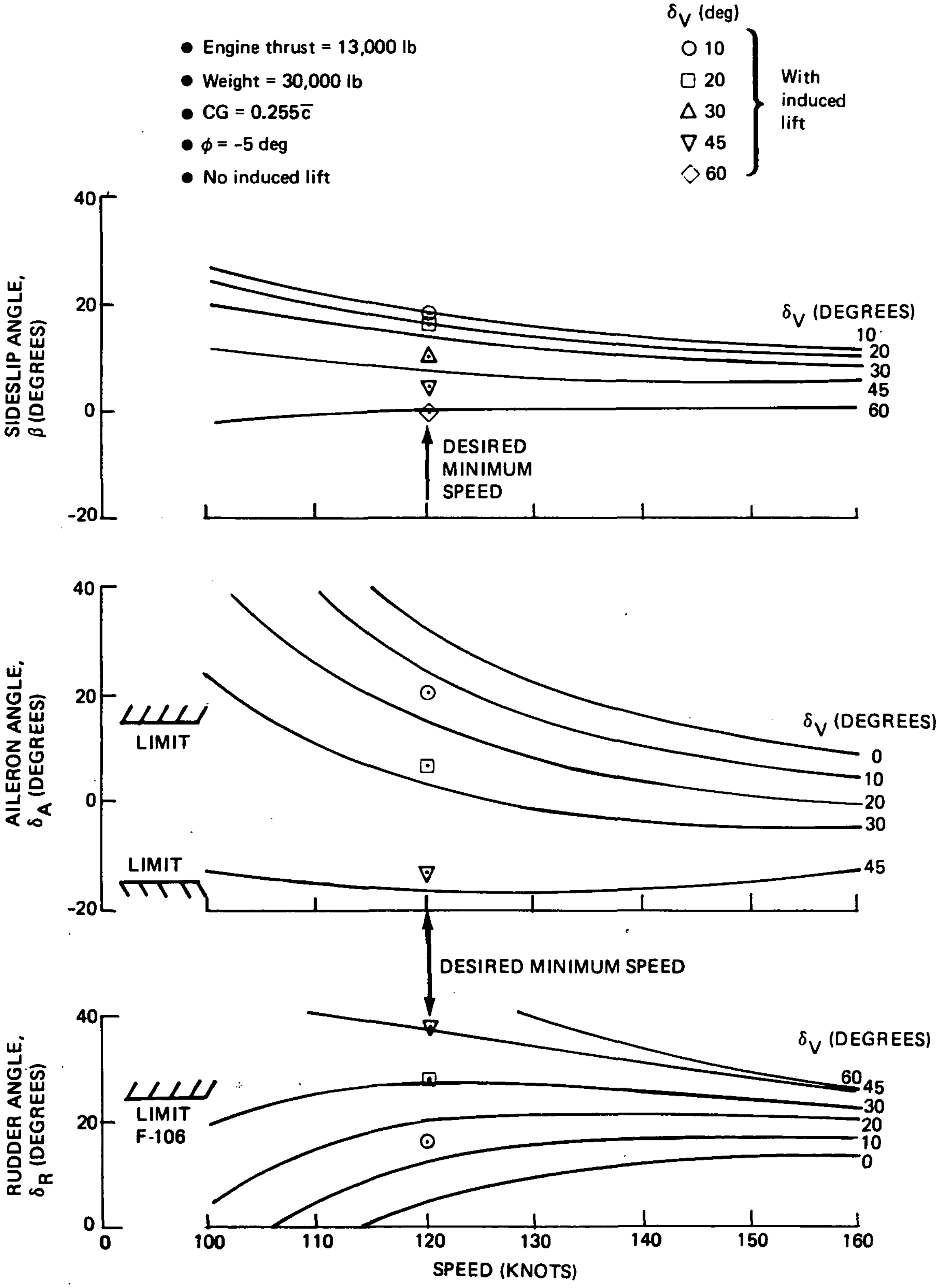


Figure 3.2A.5-12. F-106 Modification 3—Air Minimum Control Speed

(4) Due to the magnitude of the modifications relative to the basic F-106, a substantial change to the existing flight control system will be required.

Modification 5 envisions using elevons as flaps with thrust vectoring as the balancing pitch control. Since the elevons are also used as flaps, their deflection is limited to a maximum of ± 15 degrees for roll control. For the forward c.g., Figure 3.2A.5-13 shows -22 to -28 degrees of thrust vectoring is required for 15 degrees positive elevon deflection at 120 knots. Ground attitude limitations require more than -15 degrees of thrust vectoring for light weights and more than -40° for the heavy weights. For aft c.g.'s, Figure 3.2A.5-14, thrust vectoring angles of about -14 degrees are required for +15 degrees of elevons. Ground attitude limitations at 120 knots can be met only at the light gross weights with more than 5° negative vector angles. The narrow range of thrust vector angles available between trim and attitude constraints limits the gross weights for which takeoff or landing could be performed while using vectored thrust.

Acceptable nose wheel lift-off speeds are obtainable, Figure 3.2A.5-15, for all weights and c.g.s.

Figure 3.2A.5-16 presents engine-out ground minimum control speeds. Directional control can be maintained below all nose wheel lift-off speeds.

Figure 3.2A.5-17 presents air minimum control speed and associated lateral-directional control requirements. Control trim requirements and sideslip angle are within acceptable limits for all thrust vector angles at maximum power.

In summary, Modification 5 has no major flight control limitations that prevent the configuration from operating in a STOL mode at 120 knots at light weights. One configuration concern for further study is:

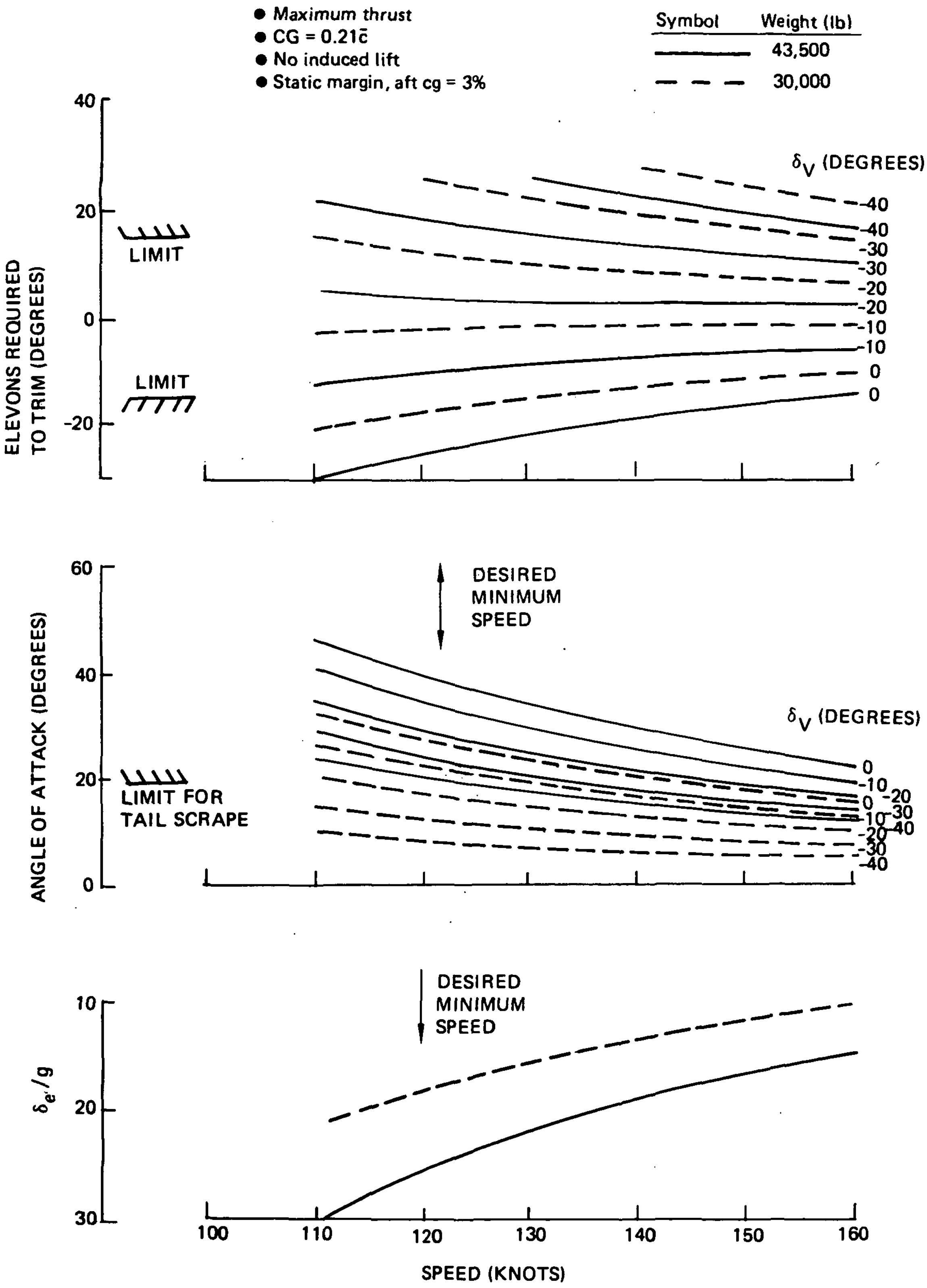


Figure 3.2A.5-13. F-106 Modification 5—Trim Conditions, Forward Center of Gravity

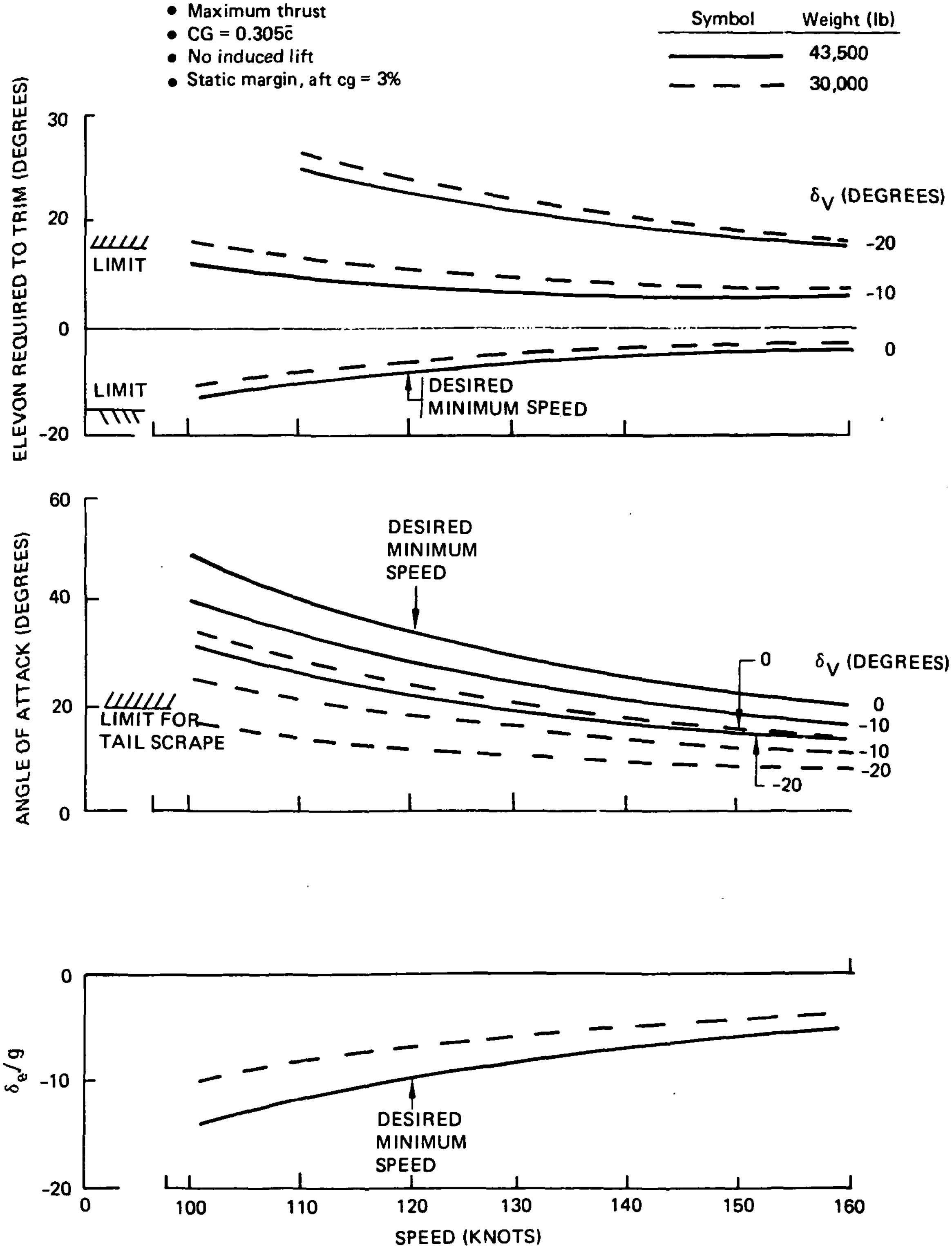


Figure 3.2A.5-14. F-106 Modification 5—Trim Conditions, Aft Center of Gravity

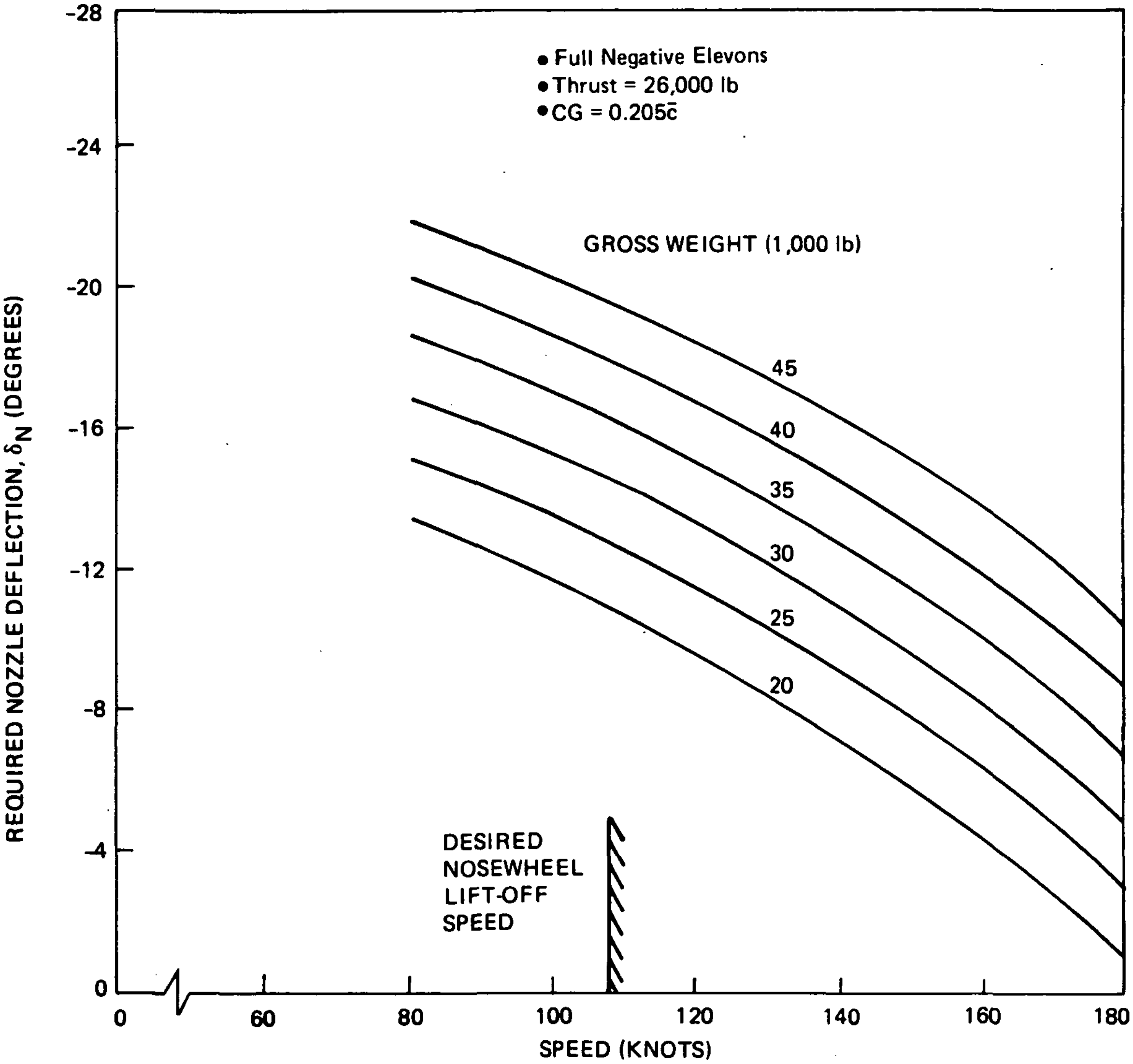


Figure 3.2A.5-15. F-106 Modification 5—Nosewheel Lift-off Speed

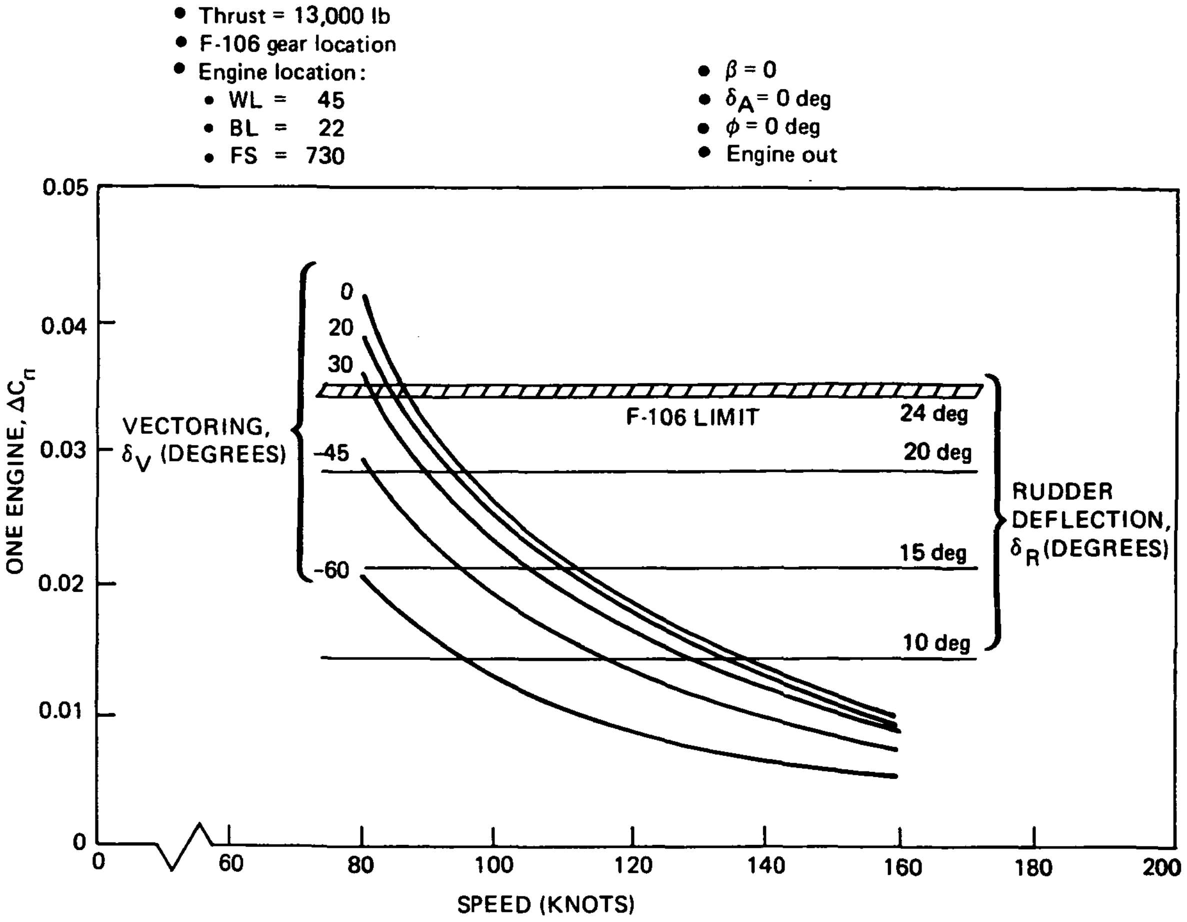


Figure 3.2A.5-16. F-106 Modification 5—Ground Minimum Control Speed

- Engine thrust = 13,000 lb
- Weight = 30,000 lb
- CG = 0.305$\bar{c}$
- ϕ = -0.7 deg
- Engine out

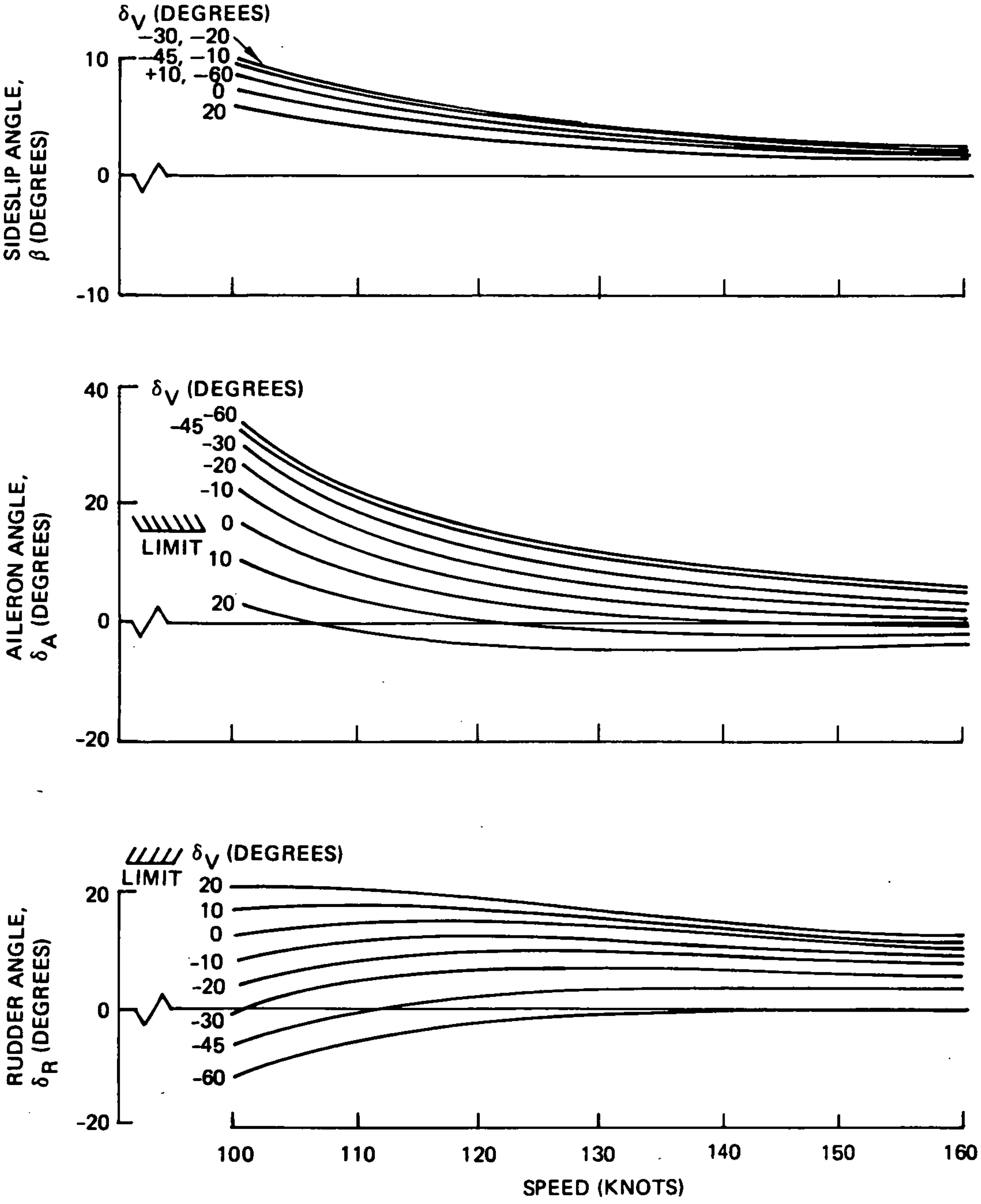


Figure 3.2A.5-17. F-106 Modification 5–Air Minimum Control Speed

(1) Use of engine thrust vectoring as the primary pitch control may require a sophisticated flight control system to provide acceptable handling qualities. Failure modes and effects are also of concern.

Modification Number 7 uses Remote Augmented Lift System (RALS) for low speed pitch control. It is envisioned that elevons would be used as flaps in a fixed position and pitch control provided by the RALS. Figure 3.2A.5-18 presents elevon deflection required to control an afterburning or non-afterburning RALS versus speed. A dry RALS is sufficient to balance 20 degrees elevons or 10° of thrust vectoring at 120 knots, Figure 3.2A.5-18. An afterburning RALS will balance 20° elevon and 27° of thrust vectoring.

Nose wheel lift-off speeds are acceptable for all weights and c.g.'s if full negative elevons and dry RALS are used, Figure 3.2A.5-19. If full afterburning RALS is used, acceptable nose wheel lift off speed can be obtained with zero elevons.

Engine-out ground minimum control speeds are satisfactory, Figure 3.2A.5-20.

At 120 knots, air minimum control speed limits thrust vectoring (with one failed engine and the good engine at maximum power) to 15 degrees, Figure 3.2A.5-21. Both rudder and aileron are limiting control surfaces. If an engine failure were to occur at other vector angles, the pilot would be required to seek an equilibrium configuration by changing the vector angle or reducing thrust. The dynamics of such a transient operation have not been studied.

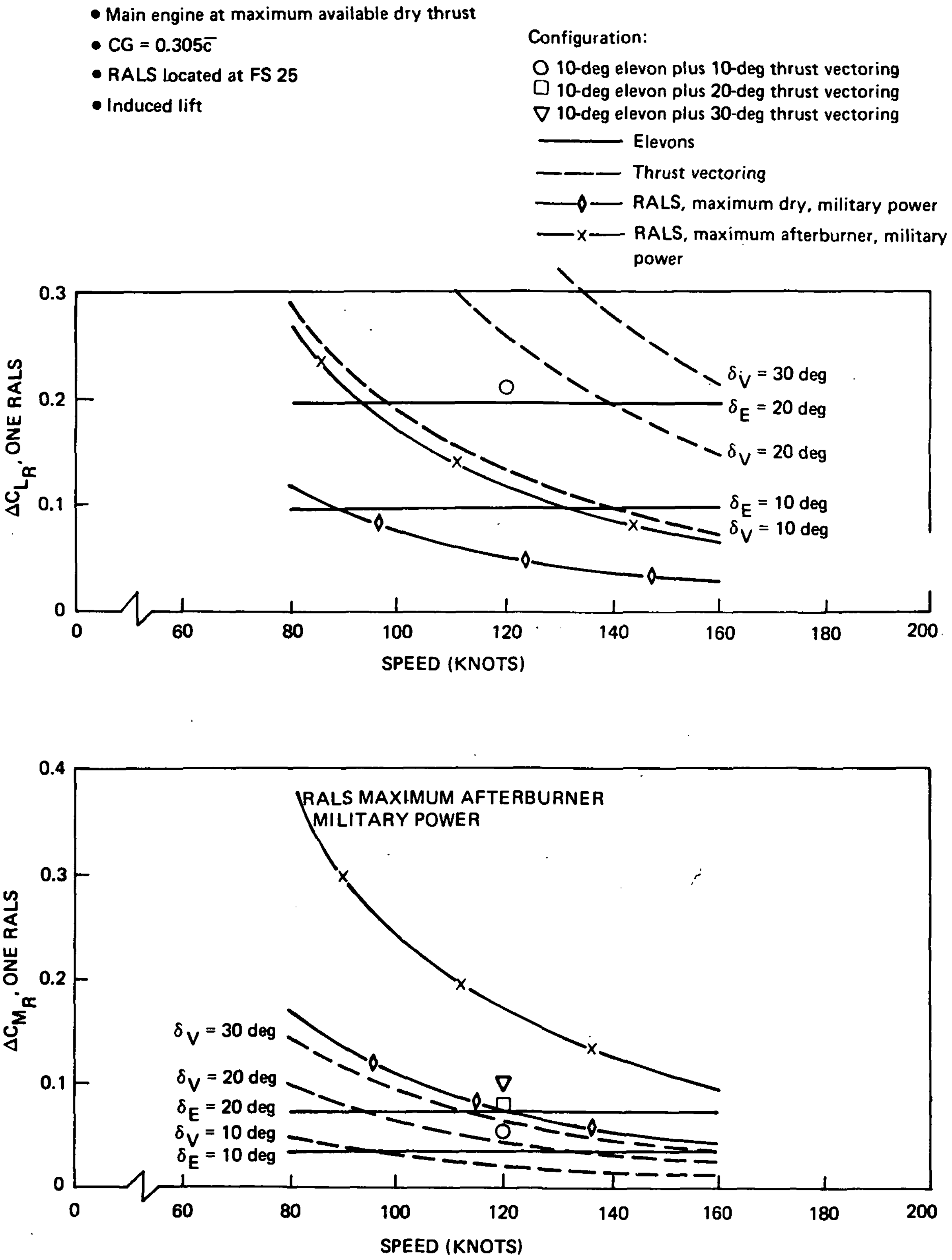


Figure 3.2A.5-18. F-106 Modification 7—RALS Effectiveness Versus Speed

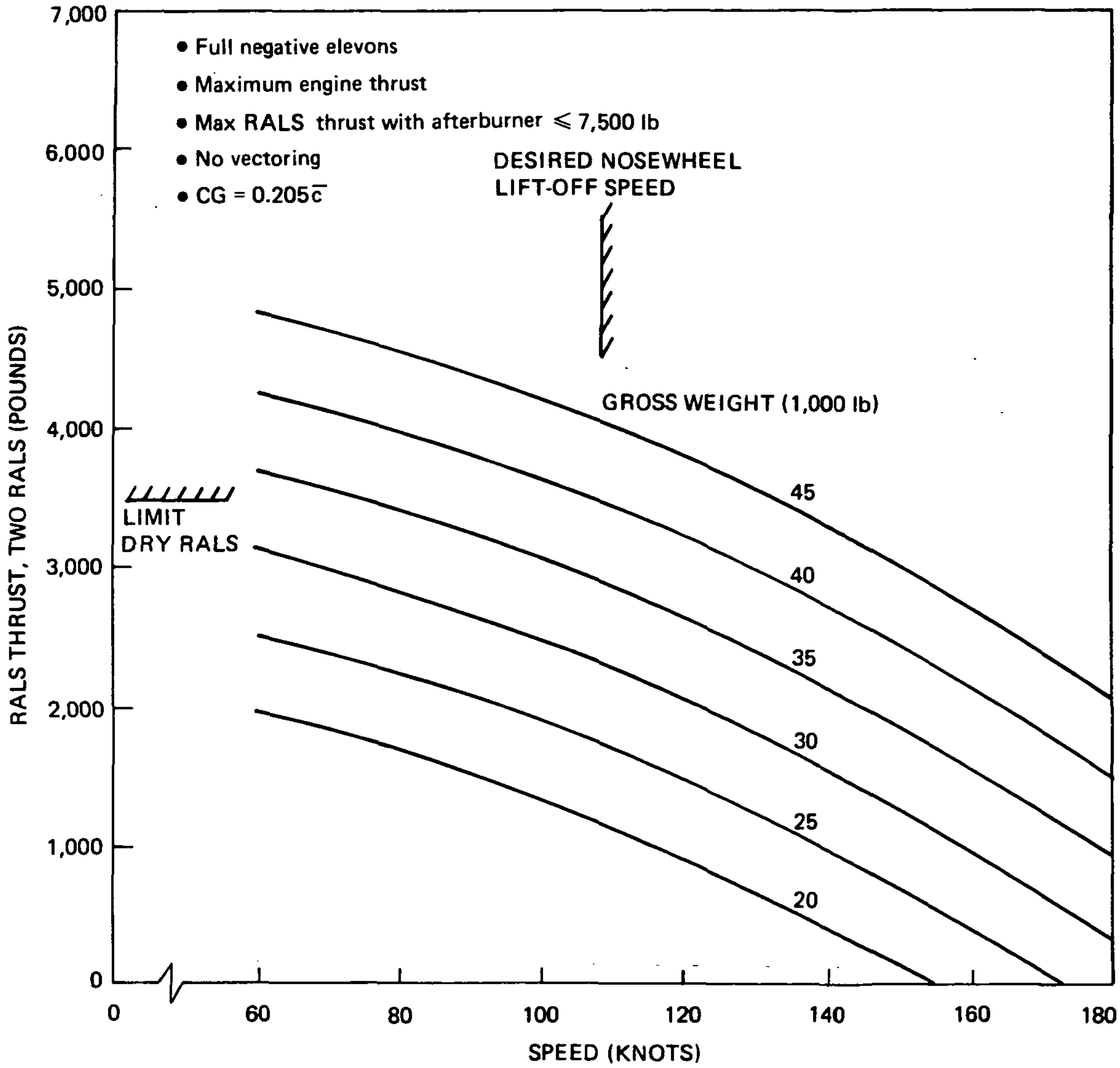


Figure 2A.5-19. F-106 Modification 7—Nosewheel Lift-Off Speed

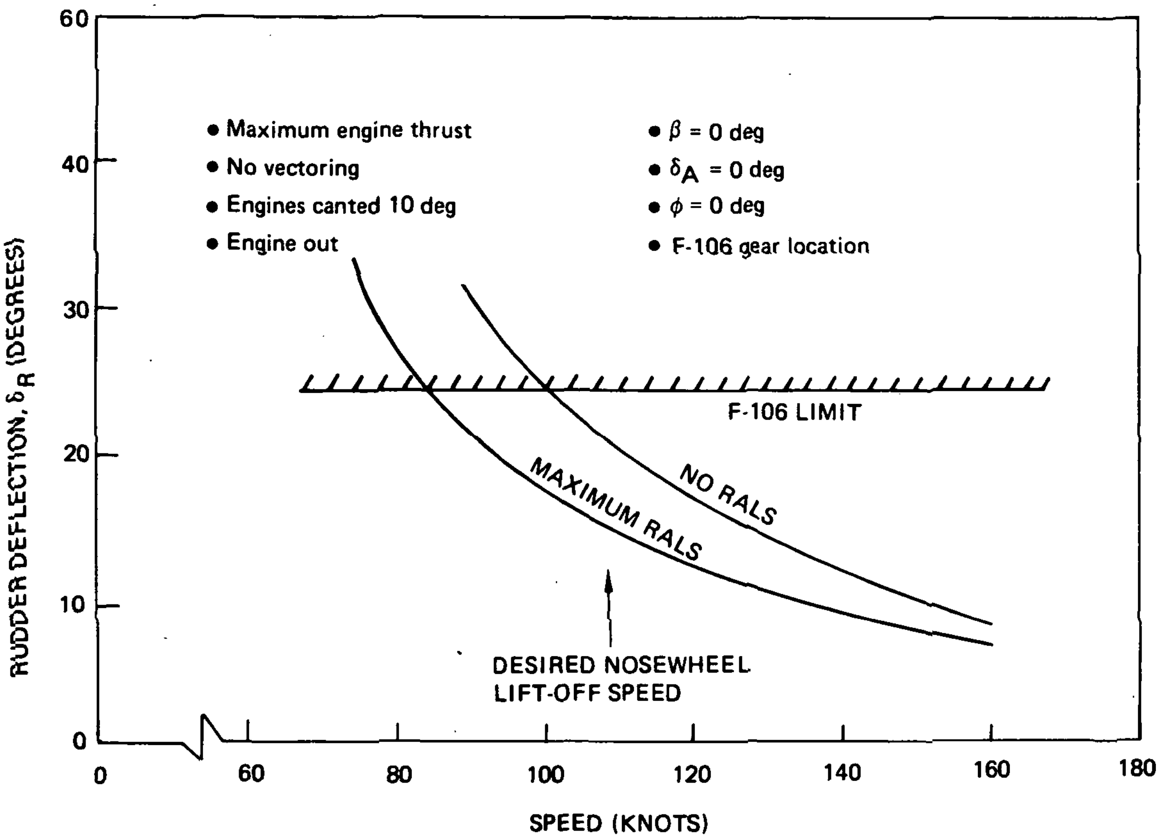


Figure 3.2A.5-20. F-106 Modification 7—Ground Minimum Control Speed

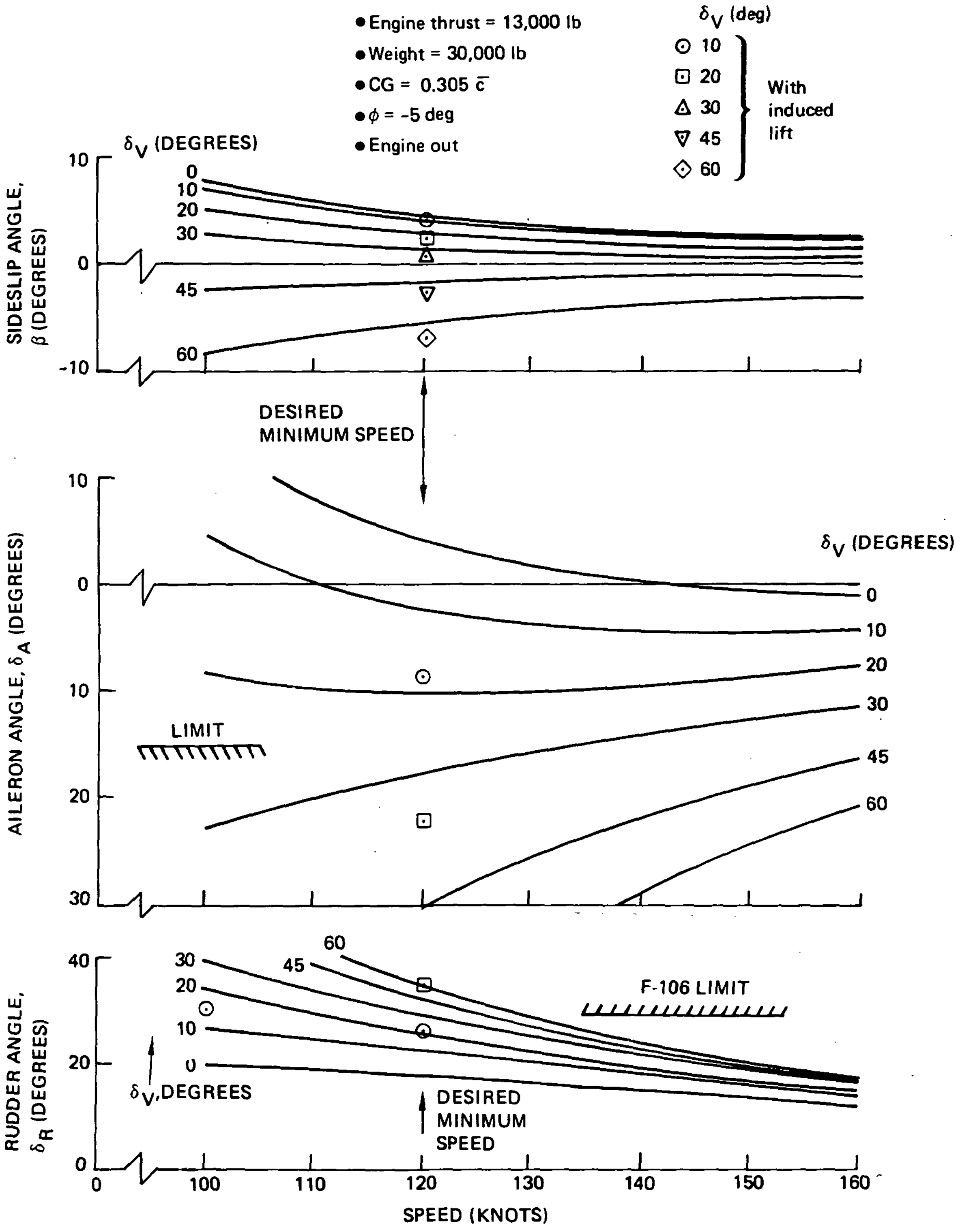


Figure 3.2A.5-21. F-106 Modification 7—Air Minimum Control Speed

In summary, the flight controls limitations of Modification 7 with respect to the aircraft's ability to perform in the STOL mode at 120 knots are:

(1) Rudder and ailerons limit thrust vectoring for one engine failed and the good engine at maximum thrust to 15°.

(2) The flight control system will require a significant modification to incorporate the RALS.

A final tabulation, summarizing the flight controls analysis of all four F-106B STOL modifications is given in Figure 3.2A.5-22.

Flight control requirement / Configuration	Adequate nose wheel lift-off speed $\leqslant$ 108 kn	Adequate all-engines-operating low-speed control (120 kn)		Adequate engine-out control (120 kn, maximum power)		Flight Control System
		Longitudinal trim	Ground attitude	Ground minimum control	Air minimum control	
Modification 1	Yes—but limited to forward cg at light weights	Yes—at light weights $\delta_V = 20$ deg $\delta_e = 0, 10$ deg	OK	Yes	Yes—at light weights, δ_N limited to about 17 deg	New (Full time flight safety critical augmentation may be required)
Modification 3	Yes—limited to light weights	No—adequate pitch control limited to above 125 kn and aft cg's $\delta_V = 20$ deg $\delta_e = 0, 10$ deg	OK	Yes	Yes—at light weights, δ_N limited to 12 to 20 deg for sustained operation	New
Modification 5	Yes	Yes—limited to light weights $\delta_V = -10$ deg	Limited to light weights	Yes	Yes	New (Incorporate TV as pitch control)
Modification 7	Yes	Yes— $\delta_V = 20$ deg $\delta_e = 10$ deg	OK	Yes	Yes—δ_N limited to about 15 deg	New (Incorporate RALS as pitch control)

Figure 3.2A.5-22. Flight Control Analysis Summary

3.2A.6 Aerodynamics

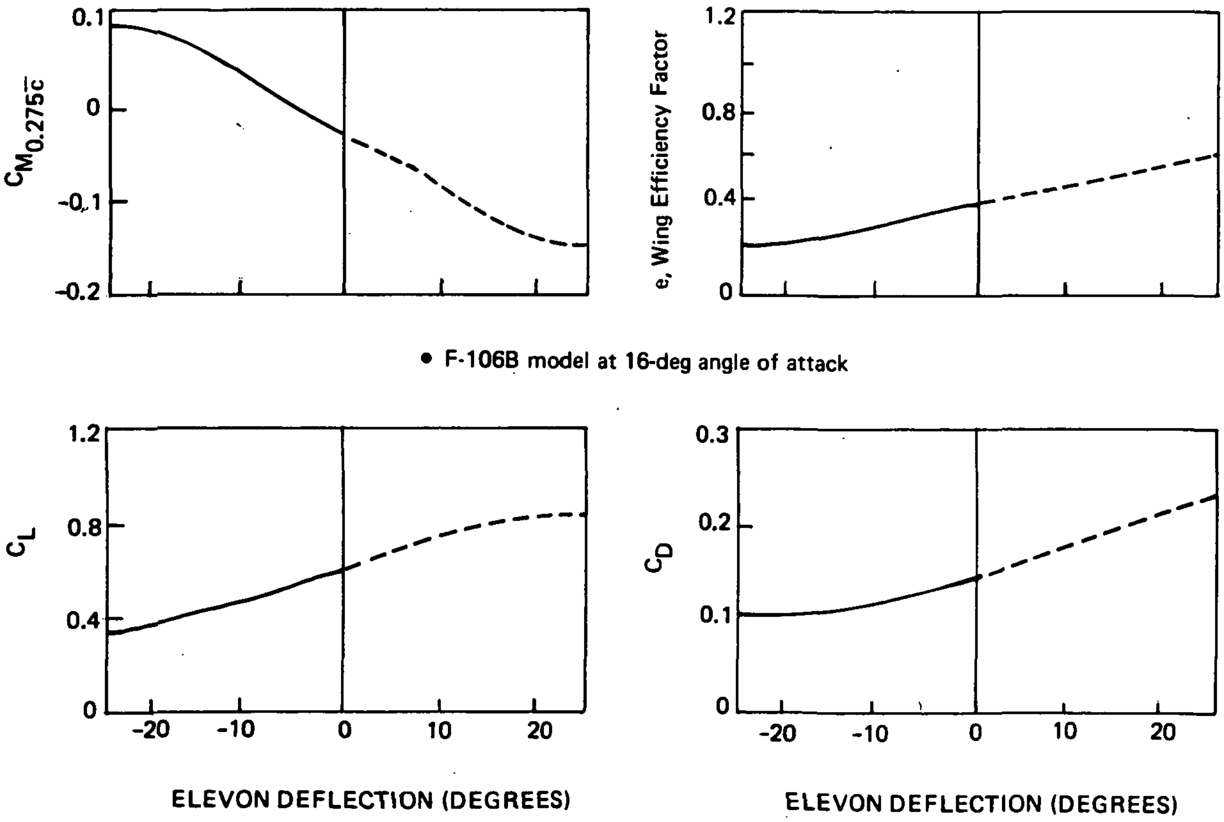
Aerodynamic characteristics of the four F-106B STOL modifications were based on the low speed characteristics of the unmodified airplane as reported in Reference 3.2A.6-1. The reference contains data for elevon deflections ranging from +5 degrees to -25 degrees. Since some of the modifications exploit the lift advantage of larger positive elevon deflections, the first adjustment to the referenced data was to project the aerodynamic characteristics of the unmodified airplane with positive elevon deflections up to +25 degrees. Referenced and projected data for 16 degrees angle-of-attack are presented in Figure 3.2A.6-1. Moment and lift characteristics are approximately symmetrical about 0 degrees elevon deflection. Similar projections were developed for 12 degrees angle-of-attack for Modification #3.

These data were then adjusted for configuration differences of each individual modification. Zero lift drag levels were adjusted for scale effects, gear drag was added as appropriate, and friction and pressure drag changes due to modifications were applied. Drag-due-to-lift, lift and moment characteristics were adjusted to reflect changes in lifting surface configuration such as elevon area and wing area differences and addition of surfaces such as the canard (Mod. #1) and horizontal tail (Mod. #3). Individual adjustments are described in succeeding paragraphs.

Induced lift effects were derived for Modifications #1 and #3. The derivation was based on the theories of Spence with empirical adjustments as described in Reference 3.2A.6-2.

<u>Modification #1</u>

The zero lift drag of Modification #1 was adjusted as follows (all incremental drag coefficients for all modifications use the unmodified wing area of the F-106 as a reference):



- F-106B model at 16-deg angle of attack

Figure 3.2A.6-1. F-106B Aerodynamic Characteristics

ΔC_D for gear	+0.0564
ΔC_D for other modifications	+0.0034
ΔC_D for scale	-0.0054
Total for ΔC_D	+0.0544

Pitching moment, lift and drag-due-to-lift contributions due to elevon deflection were adjusted for a change in elevon area from 67 ft^2, unmodified, to 112 ft^2, modified.

Full credit for the canard's pitching moment contribution was assumed but no net lift from the canard/wing combination was credited. Canard capability was based on wind tunnel test data.

<u>Modification #3</u>

Zero lift drag of Modification #3 was adjusted as follows:

ΔC_D for gear	+0.0240
ΔC_D for other modifications	+0.0032
ΔC_D for scale	-0.0054
Total ΔC_D	+0.0218

Pitching moment, lift and drag-due-to-lift contributions due to elevon deflection were adjusted for the change in elevon area from 67 ft^2, unmodified, to 109 ft^2, modified. Additionally, pitching moment, lift and drag-due-to-lift characteristics were adjusted for a 52% change in wing area largely due to a wing root insert which was assumed to be 75% effective as a lifting surface. Classical methods were used to derive the aerodynamic characteristics of the F-101 horizontal tail used on this modification.

<u>Modification #5</u>

Zero lift drag of Modification #5 was adjusted as follows:

ΔC_D for gear	+0.0240
ΔC_D for modifications	+0.0015
ΔC_D for scale	-0.0054
Total ΔC_D	+0.0201

A 50% elevon chord extension was assumed for this configuration although it was not drawn that way. Therefore, pitching moment, lift and drag-due-to-lift contributions from the elevons were adjusted for a change in area from 67 ft^2, unmodified, to 134 ft^2, modified.

Modification #7

The zero lift drag of Modification #7 was adjusted as follows:

ΔC_D for gear	+0.0240
ΔC_D for modifications	+0.0014
ΔC_D for scale	-0.0054
Total ΔC_D	+0.0200

Since the propulsion system of this modification is located on top of the wing, it is expected that wing lift and elevon contributions (no change in chord) will be degraded. Therefore, pitching moments, lifts and drags-due-to-lift were adjusted for an effective wing area reduction of 21% and elevon area reduction of 27%.

3.2B TASK 2 - CONFIGURATION EVALUATION

The configuration and conditions for low speed equilibrium (moment balance and no normal or longitudinal acceleration) flight with all engines operating (2-F-404) for four F-106B STOL modifications are described in the following paragraphs. All four modifications use twin F-404 engines (J75 removed) and vectoring nozzles (ADEN). Various trimming schemes have been provided to balance vectoring and induced lift moments as well as, allowing positive deflection of elevons to a greater degree than is possible on the current F-106.

Modification #1

Modification #1 features a close-coupled canard. A flapped canard 20% smaller than the as-drawn surface was assumed after preliminary weight and balance analysis indicated difficulty in balancing the as-drawn configuration. A canard lift coefficient of 2.5 was assumed. Center-of-gravity for a minimum stability margin of 3% (2880 lb of ballast forward) was applied for most of the analyses although some data are presented for neutral stability center-of-gravity (1800 lb of ballast forward). Equilibrium flight conditions for this modification are presented in Figure 3.2B-1.

Modification #1 has difficulty attaining speeds much below 130 KEAS at usable weights. Nozzle deflections are generally low (less than 20°) and, therefore, induced lift effects would be proportionately small. STOL operation with this modification is effectively constrained between the airplanes lower weight boundary and zero vectoring (not necessarily a hard constraint), for positive elevon deflection. An equivalent speed of 125 kn appears possible at a weight of about 2000 lb above operating weight with 5° of elevon, 8° of vectoring, 12,000 lb of total gross thrust and a positive stability margin. With a lesser stability margin, an equivalent speed of 120 kn appears possible at a weight of 2000 lb above operating weight with 3° of elevon, 15° of vectoring and 12,000 lb of total gross thrust.

Modification 1:

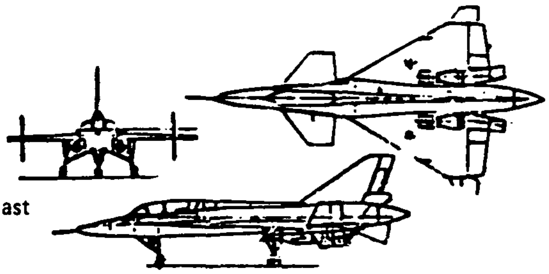
- C_{L} CANARD = 2.5
- 16-deg angle of attack
- All engines operating

- 87.5 ft^2 canard
- CG per Figure 3.2A.1-6, -8

Legend:

--- 120 kcas with neutral stability and 1800-lb ballast

▬ 3% stability with 2,880-lb ballast



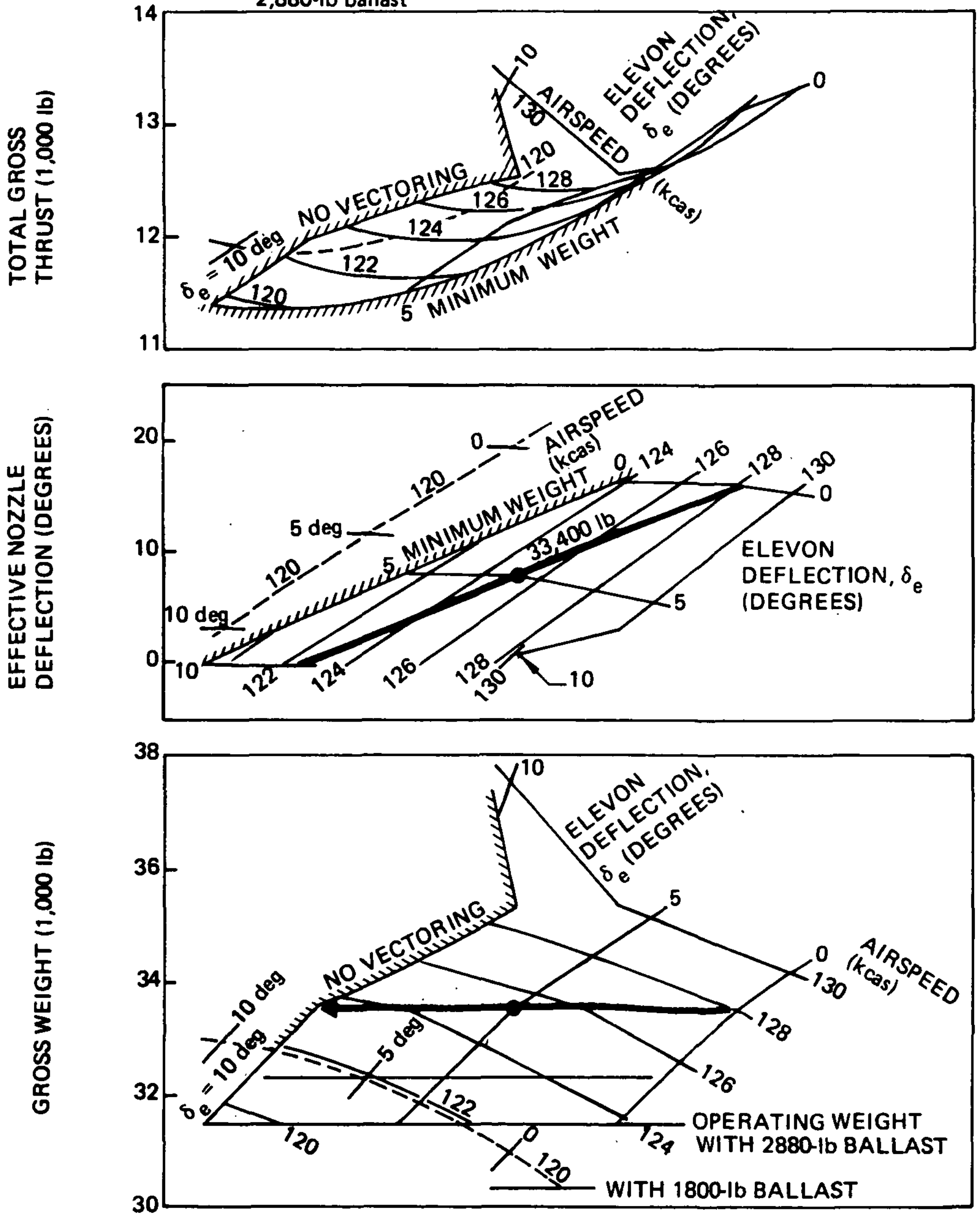


Figure 3.2B-1. Modification 1—Equilibrium Flight Conditions

These analyses were performed for 16° angle-of-attack. Preliminary computations have indicated that higher vector angles can be achieved at lesser angles-of-attack.

Modification #3

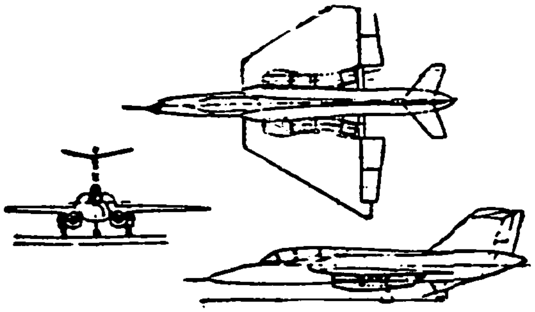
This modification features a horizontal tail (F-101 T-tail) and engines located well forward under a wing root insert. Analyses were performed for airspeeds of 120 and 130 KEAS, 12° angle-of-attack and 0° of elevon deflection. The wing insert was assumed to be 75% effective as a lifting surface. Initial analysis of this configuration, as drawn, showed difficult weight and balance problems. Thus, the configuration was reanalyzed, although not redrawn, for the wing relocated further aft. For the data presented, center-of-gravity correspond to those for the wing located 80.5 in. aft of the as-drawn position. Adjusted in this way, no ballast is required by the modification and stability margins in excess of 3% are possible for weights under 37,000 lb. Equilibrium flight conditions for Modification #3 are presented in Figure 3.2B-2.

Operation of Modification #3 at speeds of 130 KEAS and below and the other assumed conditions appears to be limited by tail lift capability in the negative direction. At weights above operating weight plus about 2000 lb, too much tail lift (a maximum tail lift coefficient of -.75 is a reasonable assumption) is required to balance moments and equilibrium is extremely sensitive to nozzle deflection. At the lower weights, required nozzle deflections are around 20° and total gross thrust is about 10,000 lb. Induced lift provides about 10% of the total required.

The angle-of-attack and elevon deflection for which Modification #3 was analyzed are low and were not optimized. Hopefully, a better combination could be identified. However, it is doubtful that the tail lift problem can be much improved with the wing at the aft position analyzed. A more forward location should be more favorable even though the airplane would require some ballasting.

Modification 3:
- 12-deg angle of attack
- 0-deg elevon deflection
- All engines operating
- Wing moved 80.5 in aft of "as drawn"
- CG per Figure 3.2A.1-15

Legend:
- ——— 130 kcas
- – – – 120 kcas



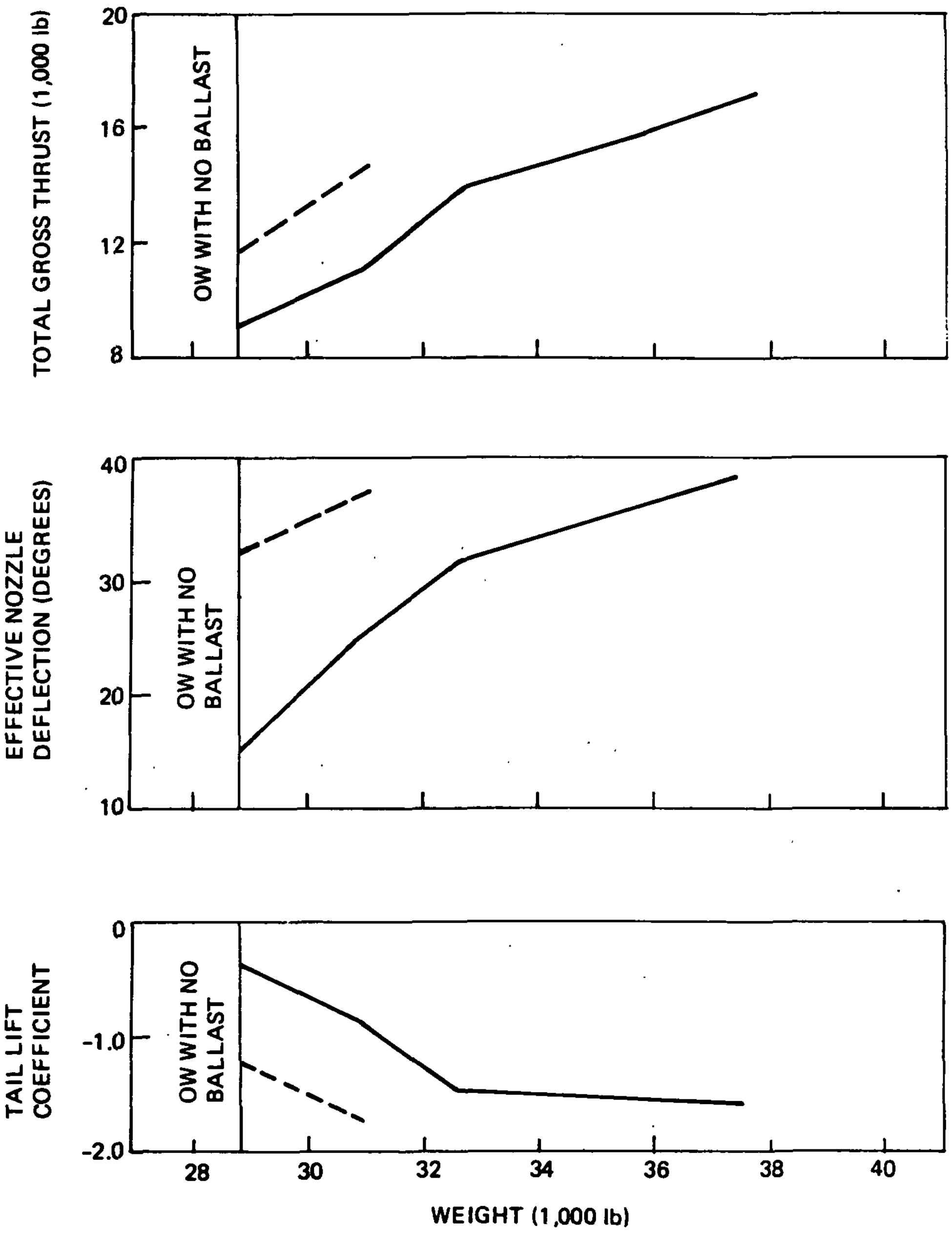


Figure 3.2B-2. Modification 3--Equilibrium Flight Conditions

Modification #5

Modification #5 is unique in that it employs ADEN nozzles located well aft and vectored in the negative (i.e., upwards) direction. It was analyzed for 16° angle-of-attack and 15° of elevon deflection. It was assumed that the elevons on this modification "as drawn" would be increased in size via a 50% chord extension. Additionally, a double hinged elevon with 15°/15° deflection was examined. Centers-of-gravity corresponded with 1500 lb of forward ballast and stability margins in excess of 3%. Performance for Modification #5 is presented in Figure 3.2B-3.

An equivalent speed of 125 kn is about as low as this modification (as drawn) can be expected to attain at usable weights with single hinged elevons. Speed may be decreased another 3 kn using double hinged elevons. Effective nozzle deflections in the neighborhood of negative 30°-35° are required with single hinged elevons. No induced lift is assumed for this concept. Total gross thrust varies around 13,000 lb. About 2000 lb more thrust and 8° more negative nozzle deflection are required for the double hinged elevon configuration.

Modification #7

Modification #7 uses a remote augmented lift system (RALS) for trim. RALS air is provided by main engine bleed and main engine performance is degraded accordingly. The configuration was analyzed for an airspeed of 120 KEAS, 16° angle-of-attack and 10° of elevon. The airplane is ballasted with 4480 lb aft. Resultant centers-of-gravity somewhat exceed the forward limit at some weights with current F-106B fuel sequencing. However, this situation was assumed to be improvable with further work. Results are presented in Figure 3.2B-4.

Equivalent speeds of 110-120 KEAS are attainable at weights between 32,000 lb (near operating weight) and 40,000 lb (near maximum). Low speed flight at the heavier weights will ultimately become limited by available thrust from the ADEN nozzles and/or the RALS (augmented). Effective nozzle deflections vary from 14° at the lighter airplane weights (120 kn) to 32°, heavy (110 kn). No induced lift was assumed for this configuration due to probable pressure field degradation caused by the presence of the propulsion system on the wing upper surface.

Modification 5:

- With 50% elevon chord extension
- 16-deg angle of attack
- 15-deg elevon deflection
- All engines operating
- CG per Figure 3.2A.1-17

Legend:

⊙ With double-hinged elevons

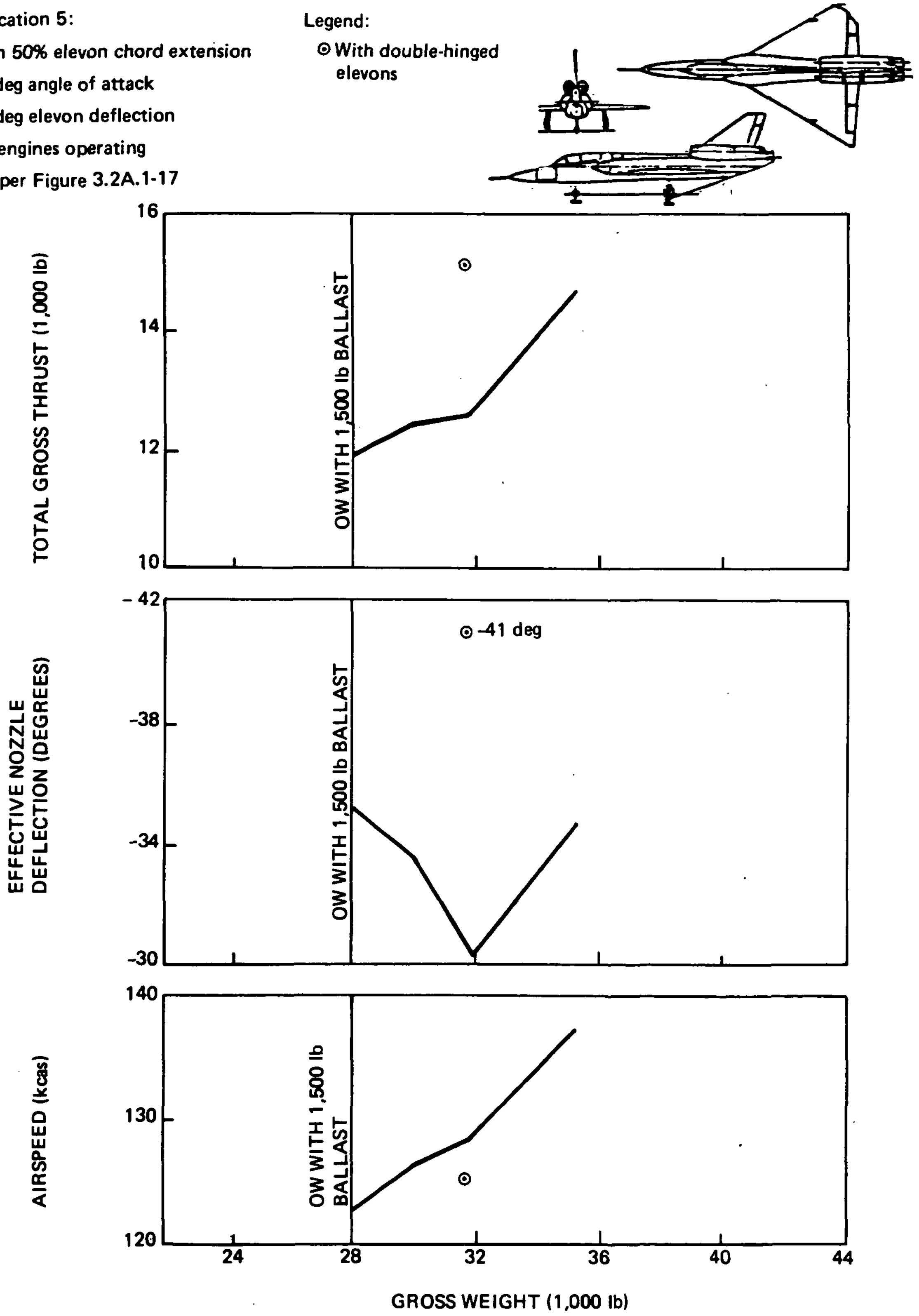


Figure 3.2B-3. Modification 5—Equilibrium Flight Conditions

Modification 7:
- 16-deg angle of attack
- 10-deg elevon deflection
- All engines operating
- No induced lift assumed
- CG per Figure 3.2A.1-19

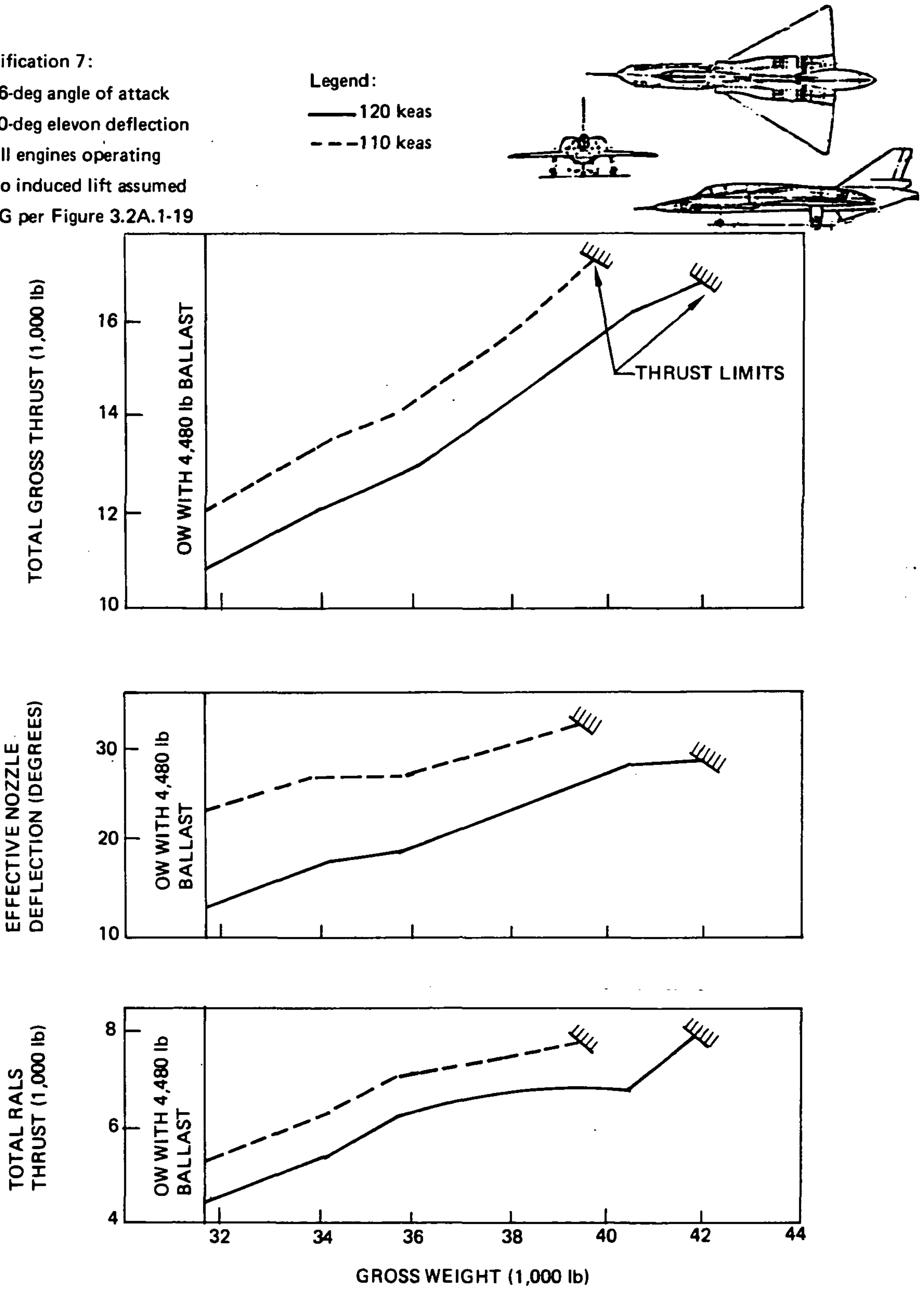


Figure 3.2B-4. Modification 7—Equilibrium Flight Conditions

Conclusions

A summary of the low speed equilibrium flight analysis is given in figure 3.2B-5. Of the four modifications, #7 appears to be most feasible for a low speed demonstrator based on attaining low equilibrium flight speeds combined with large values of thrust deflection angles. The other modifications can demonstrate somewhat higher speeds for a somewhat narrow range of weights. Nozzle deflections are low for Modification #1. Finally, Modification #3 appears to be the least feasible low speed demonstrator, being in the 130 kn class even at lower airplane weights, for reasonable levels of tail lift.

	Estimated equilibrium conditions at operating weight plus 3,000 lb			
	Airspeed (kn)	Thrust deflection (deg)	Elevon setting (deg)	Remarks
Modification 1	125 to 130	5 to 15	0 to 5	● 2,880-lb nose ballast ● 1,800-lb nose ballast
	120 to 125 with neutral stability	15 to 20	5 to 10	
Modification 3	130 to 135	20 to 25	0	● Limiting tail pitch control ● Wing longitudinal relocation probably not optimal ● Wing α reduced to offset lift of wing insert
Modification 5	125 to 130	30 to 40 (upward nozzle)	15	● 1,500-lb nose ballast ● Possible double-hinged elevon
Modification 7	110 to 120	15 to 25	10	● 4,480-lb aft body ballast

Figure 3.2B-5. Summary of Low-Speed-Equilibrium Flight Conditions

3.3 TASK 3 - RESEARCH PROGRAM DEFINITION

In the prior phase of the study, 4 schedules were developed for flight research programs to develop 2-D nozzle technology. One of those schedules specifically encompassed development of a GE F-404/ADEN nozzle integrated with the F-106B aircraft. That schedule was reviewed for application to the present STOL modifications. Since that schedule was paced by the nozzle development activities, the general time frame was found to be still compatible with the STOL modifications envisioned for the present study.

Moreover, the general program objectives identified for 2-D nozzle research remain similar to those of interest for STOL research, namely:

- Nozzle/Airframe integration including exploration of propulsive lift and trimming techniques, reverser effectiveness evaluation and validation of aeropropulsive model data
- Engine/Nozzle Integration including engine stability and nozzle design validation
- Systems Integration including propulsive/flight controls coupling
- Operational Applications

In view of the above, the schedule given in figure 3.3-1 was used as the basis for the budgetary cost estimates described in Section 3.4. The same schedule was judged applicable to the 4 study modifications. It should be noted that no extensive attempt was made to establish a minimum-schedule-length program and it is judged likely that, if studied in more detail, significant compression of the schedule could be achieved.

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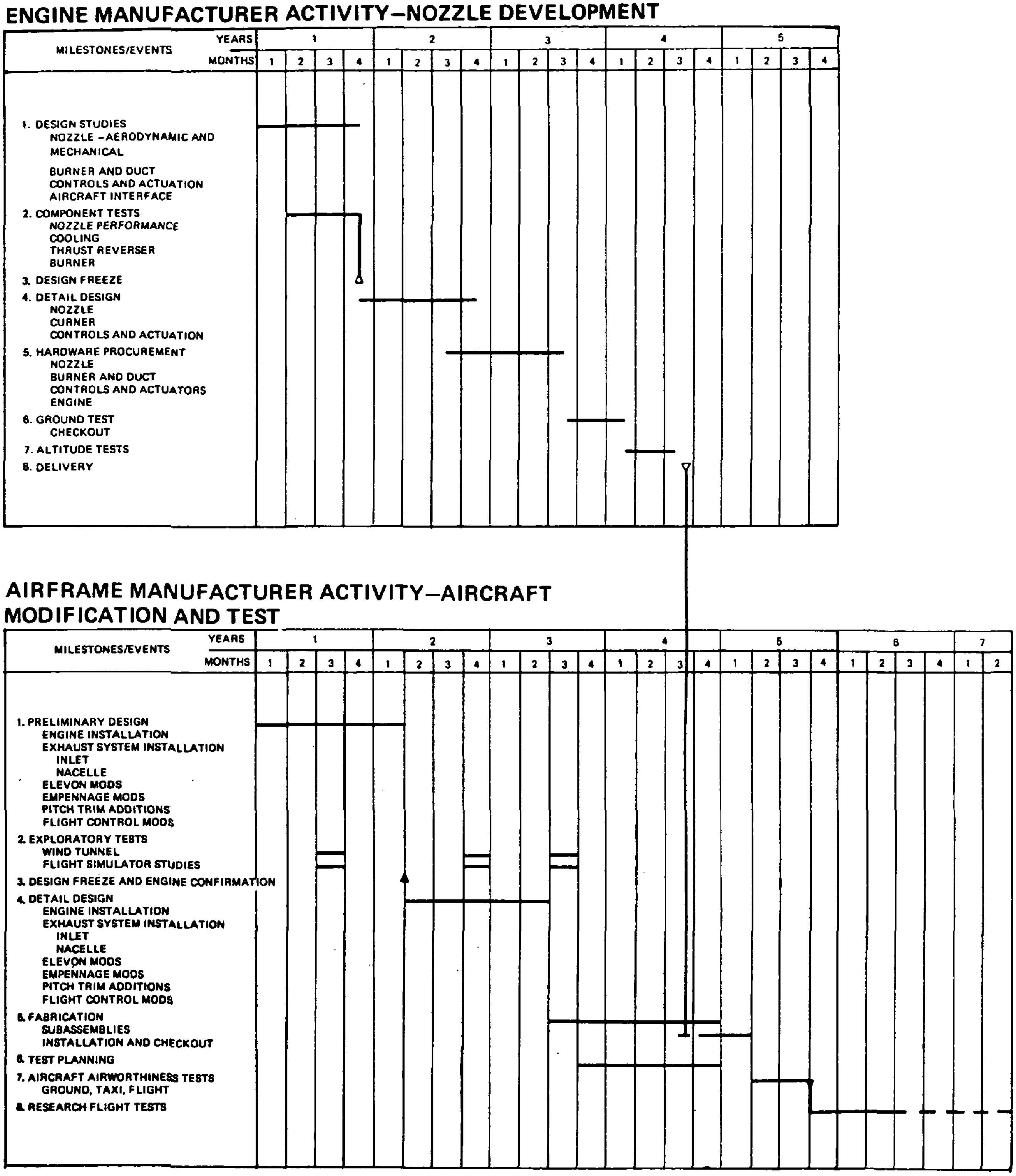

Figure 3.3-1. F-106B STOL Flight Research Program

3.4 TASK 4 -- PROGRAM COST PROJECTIONS

Based on the program tasks and schedules described in Section 3.3, budgetary cost estimates were developed for both the engine manufacturer and airframe manufacturer activities. The costs developed are for planning purposes only and do not constitute a commitment by either Boeing or the General Electric Company. Additionally, although efforts were made during the study phase to develop and achieve a low cost program, no direct attempt was made to review the initial budgetary estimates in light of the minimum possible program cost.

The cost estimating ground rules and summary figures are given separately below for first, the engine manufacturer costs and second, the total program costs including both engine manufacturer and airframe manufacturer requirements.

3.4.1 Engine Manufacturer Costs

A single engine manufacturer cost, based on studies conducted for the prior phase of this contract, has been used for all four study modifications, since all involved fabrication of a pair of ADEN nozzles adapted to the GE F-404 engine. In addition to the basic configuration, several optional programs were considered. The basic assumption was that the existing ADEN would be refurbished and a Variable Exit Expansion Ramp (VEER) and control would be added. In addition, a new duplicate ADEN would be fabricated. Other assumptions included:

1) Two GFE F-404 engines in flight-ready operating condition will be delivered with engine control systems at least 5 quarters before delivery of engine/nozzle to Boeing for flight test. No cost has been included for engine refurbishment.
2) Inlet/nacelle design and fabrication costs are not included.

3) The engine will be operated under augmented conditions.
4) The tail pipe will be modified/extended to fit the aircraft installation.
5) The engine/nozzle mounting will be modified to assure bending moments on the engine remain within limits. This may require relocation of engine rear mount or the nozzle mounted to the aircraft with an isolation joint to prevent carrying bending moments to the engine.
6) The existing F-404 afterburner will require modification and relocation in conjunction with the extended tailpipe.
7) An internal blocker/cascade thrust reverser will be designed to fit in the tailpipe upstream of the ADEN.
8) One new ADEN will be fabricated according to the current design with no modifications. The existing ADEN will be furnished at no charge by NAPC and will be refurbished as required.
9) Modifications will be made to the forward tailpipe to match the F-404 rear flange diameter (originally designed to fit YJ101).
10) a) The ADEN A8 will be controlled and driven by the engine.
    b) The thrust reverser and VEER will be aircraft controlled with actuators supplied by General Electric and hydraulic power supplied by the aircraft.
11) A 50 hour Safety of Flight test will be conducted by General Electric on an F-404/ADEN using the existing ADEN with an extended tailpipe and modified A/B at the General Electric Peebles outdoor test site.
12) An altitude test is recommended to be conducted in a GFE facility. No support or test costs for such a test has been included.
13) Costs are estimated through delivery of engines and nozzles to Boeing for flight test. Flight test support is <u>not</u> included.

Option A

For Option A, it was assumed that the engine would be operated in the dry mode only and no A/B work would be required.

Option B

For Option B, it was assumed that the thrust reverser would be deleted.

Option C

For Option C, both dry operation and no thrust reverser was assumed.

Schedules

A three-year program, through ground testing, was assumed.

Estimated Budgetary Costs

The estimated budgetary costs of the basic configuration and options discussed above are presented in this section. These estimated costs are consistent with the assumptions discussed above and the schedules previously submitted. All cost estimates represent cost-plus-fixed-fee (CPFF) in millions of dollars and assumed a program start date of January 1, 1981.

ENGINE MANUFACTURER'S ESTIMATED BUDGETARY COSTS
(CPFF in $1,000,000)

	EST. COST
BASIC CONFIGURATION	10.8
OPTION A	9.6
OPTION B	7.4
OPTION C	6.2

3.4.2 Total Program Costs

General ground rules and assumptions that apply to all four F-106B modifications studied are described below. Ground rules that apply to a specific configuration are described separately.

1. Simulators and wind tunnels will be government furnished and manned. Boeing will supply personnel to these efforts only as consultants.

2. Wind tunnel models will be fabricated by Boeing and supplied to the testing agency. Modifications to the models during the wind tunnel tests will be done by government personnel under the direction of Boeing Engineering.

3. Boeing personnel in conjunction with Government simulation personnel will develop flight simulation test plans and will act in support in the conduct of the simulator tests.

4. Modifications to the aircraft will be accomplished at a Boeing facility. Ferry allowances have been included in the estimates.

5. Airworthiness flight tests will be conducted at Boeing. Subsequent research flight tests will be conducted at a NASA facility by NASA personnel.

6. No automatic flight control system equipments have been considered.

7. Costs shown are in constant year 1980 dollars.

The costs shown below have been estimated by the following means. Engineering efforts were manloaded by the functional organizations. Aircraft modifications were priced by use of weight statements which were analyzed to calculate the weight of structure removed, weight of structure modified, and weight of new structure required. A dollar per pound factor was then applied to arrive at the modification costs. Developmental shop and program management and control (PMO) costs were generated throught the use of historical factors applied to engineering and fabrication.

Wind tunnel models were priced by historical data obtained from the Boeing wind tunnel organization. Support people required for wind tunnel and simulator tests were calculated through manloads.

Flight test support was estimated through manloads.

GROUND RULES FOR MOD #1

1. Landing gear is nonretractable.
2. Aircraft is to be used for low speed flight tests only as defined elsewhere.
3. Control system in aircraft has extensive modifications as many of the components are required to move in concert.
4. Wind tunnel tests for this modification are limited to low speed investigations as compared to other configurations.
5. Engine installation will be accomplished by Boeing, however, the engine build up including nozzles will be done by the engine contractor.

MODIFICATION #1

COST SUMMARY

(Dollars in Millions)

General Electric Efforts (F-404 Engines)	$10.8
Engineering	
Project	3.6
Staff	6.6
Other	.4
Sub Total Engineering	10.6
Simulation & Wind Tunnel Support	1.2
Developmental Shop Support	3.2
Production (Aircraft Mod)	
Tooling	2.4
Production Material & Purchase Equipment	.2
Production Labor	5.7
Flight Test Support (Technicians)	.4
P.M.O., Travel, etc.	3.2
Total Effort	$37.7

GROUND RULES FOR MOD #3

1. F15 landing gear will be government furnished.
2. F101 tail assembly will be government furnished.
3. Aircraft is capable of high speed tests.
4. Structural mods to this configuration are extensive, due to inserts, wing relocation and adaption of the T-tail.
5. Boeing will install the engines, however, the engine contractor will do the engine build up and nozzle adaptation.

MODIFICATION #3

COST SUMMARY

(Dollars in Millions)

General Electric Efforts (F-404 Engines)	$10.8
Engineering	
Project	5.8
Staff	10.3
Other	.4
Sub Total Engineering	$16.5
Simulation & Wind Tunnel Support	1.5
Developmental Shop Support	5.1
Production (Aircraft Mod)	
Tooling	1.7
Production Material & Purchase Equipment	.3
Production Labor	3.9
Flight Test Support (Technicians)	.4
P.M.O., Travel, etc.	4.9
Total Effort	$45.1

GROUND RULES FOR MOD #5

1. Engines are located above the wing.
2. This configuration has the least number of structural changes of all the configurations which is reflected in the cost.
3. Aircraft is configured for high speed tests.
4. Control system modifications are minimal.
5. Boeing will install the engines, however, engine and nozzle build up will be done by the engine contractor.

MODIFICATION #5

COST SUMMARY

(Dollars in Millions)

General Electric Efforts (F-404 Engines)	$10.8
Engineering	
Project	2.6
Staff	4.8
Other	.4
Sub Total Engineering	$ 7.8
Simulation & Wind Tunnel Support	1.5
Developmental Shop Support	2.3
Production (Aircraft Mod)	
Tooling	1.4
Production Material & Purchase Equipment	.2
Production Labor	3.4
Flight Test Support (Technicians)	.4
P.M.O., Travel, etc.	2.4
Total Effort	$30.2

GROUND RULES FOR MOD #7

1. Aircraft has the RALS system incorporated. RALS nozzles and burners will be fabricated at Boeing.

2. Engines are overwing incorporating extensive air inlet redesign and rework.

3. Engine bleed air extraction system has been priced as Boeing built, however may be accomplished by engine contractor.

4. Aircraft has been configured for high speed tests.

5. Boeing will do the engine installation, however, the engine contractor will do the engine and nozzle build up.

MODIFICATION #5

COST SUMMARY

(Dollars in Millions)

General Electric Efforts (F-404 Engines)	$10.8
Engineering	
Project	4.7
Staff	8.5
Other	.4
Sub Total Engineering	$13.6
Simulation & Wind Tunnel Support	1.5
Developmental Shop Support	4.2
Production (Aircraft Mod)	
Tooling	1.5
Production Material & Purchase Equipment	.2
Production Labor	3.9
Flight Test Support (Technicians)	.4
P.M.O., Travel, etc.	4.1
Total Effort	$40.2

A cross breakdown of the previous total program costs is given below more in accordance with the key research program tasks described previously in Section 3.4.

PROGRAM COST BREAKDOWN BY TASK
(DOLLARS IN MILLIONS)

	MOD #1	MOD #3	MOD #5	MOD #7
PRELIMINARY DESIGN	$ 1.3	$ 2.1	$ 1.0	$ 1.7
EXPLORATORY TESTS	1.0	1.5	.7	1.2
DETAIL DESIGN	7.3	11.8	5.1	9.6
TEST PLANNING & P.M.O.	3.6	5.4	2.8	4.6
DEVELOPMENTAL SUPPORT	3.2	5.1	2.3	4.2
SIMULATION & WIND TUNNEL	1.2	1.5	1.5	1.5
RESEARCH FLIGHT TESTS	1.0	1.0	1.0	1.0
TEST ARTICLE FABRICATION	8.3	5.9	5.0	5.6
ENGINE MANUFACTURING COSTS	10.8	10.8	10.8	10.8
TOTAL	$37.7	$45.1	$30.2	$40.2

4.0 CONCLUSIONS AND RECOMMENDATIONS

Four modifications of an F-106B aircraft were studied to evaluate the feasibility for STOL flight research applicable to advanced tactical military aircraft. Each modification used 2 F-404 engines integrated with 2-dimensional, vectorable ADEN nozzles. Preliminary design layouts, analysis of the modified aircraft, and formulation of representative flight programs and budgetary cost estimates were established to support the study.

The major study conclusions are as follows:

(1) A modified F-106B, with thrust reverse, reasonably improved braking capability and some automation to effect short braking and thrust reverse actuation times was shown to be capable of achieving a 1000 foot landing roll if approach speeds could be reduced to the range of 120 to 130 knots. Achievement of this speed was selected as a design goal for the configuration modifications. Additionally, aircraft controllability for landing and taking off with one engine failed was taken as a design objective.

(2) Configuration modifications to enhance low speed capability and controllability were developed and analyzed to a preliminary design level to ensure the feasibility of: configuration operational compatibility; structural load paths; actuation and other mechanical systems; and weight and balance. The controllability in flight and the equilibrium airspeeds sustainable were then analyzed. The resulting capabilities and limiting factors for each of the configurations were determined to be:

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Modification #1

Equilibrium flight speeds in the range 125-130 knots should be sustainable with 10 to 15 degrees of thrust vectoring at light gross weights with 3% static margin. If the aircraft could be satisfactorily operated at neutral stability, then airspeed could be reduced to about 120 knots with 15 to 20 degrees of thrust vectoring. Risk areas requiring further design and analysis to corroborate estimates made for the current study include: canard lift capability (with flap) and interference with the wing; ability to structurally integrate the 2880 lbs of nose ballast.

Modification #3

Equilibrium flight speeds in the range 130-135 knots should be sustainable with 20 to 25 degrees of thrust vectoring at 3% static margin. Risk areas requiring further design and analysis to corroborate estimates made for the current study include: horizontal tail lift capability which is limiting in pitch control; improved capability to reconcile the narrow range of configuration opportunities which satisfy engine-out lateral and directional control. In addition, this modification was analyzed for two quite different longitudinal wing locations with neither being completely satisfactory. It is likely that an intermediate location could yield better results.

Modification #5

Equilibrium flight speeds in the range 125-130 knots should be sustainable with 30 to 40 degrees of upwards deflected nozzle in combination with 15 degrees of down elevon. This configuration proved to be the simplest design approach and introduced the fewest uncertainties. One risk area requiring further design and analysis is evaluation of failure modes and redundancy requirements on the nozzle actuation system which, for this concept, is functioning as a primary aircraft control.

Modification #7

Equilibrium flight speeds in the range 110-120 knots should be sustainable with 15 to 25 degrees of thrust deflection. Risk areas requiring further design and analysis to corroborate estimates made for the current study include: location and operability of the RALS system at ground level without interference to adjacent structure or systems; detail design and implementation of the RALS assembly including the interface with the F-404 system. An attractive implementation concept for demonstration would be to leave the main F-404 engines intact and to power the RALS nozzle with a separate, dedicated engine housed in the fuselage. This approach is likely to be less expensive as well.

(3) Configuration modifications #1, 3, and 7 are each suited to evaluating the development and operation of two dimensional thrust vectoring nozzles and integration with their respective pitch trimming techniques, i.e. canard, aft horizontal tail and auxiliary nose jet (RALS). Thrust-induced lift would be best researched on modification #1, although some lesser levels of induced lift would be anticipated for the other modifications. All three configurations would establish the effects of vectoring on lateral and directional control as well. Configuration modification #5, in contrast, would enable research of the nozzle and its use as a primary aircraft control (pitch).

(4) A flight test program for any of the study configurations will be paced by the nonaxisymmetric nozzle development and engine integration. A moderately paced program including static and altitude cell testing of the engine/nozzle, and taxi and initial flightworthiness tests of the modified aircraft would require a maximum of 4-1/2 to 5-1/2 years prior to the first research flight depending on the study configuration. Probably this schedule could be improved upon since no effort was made to develop a minimum-flow-time schedule.

(5) Budgetary contractor costs for the total development program (engine and airframe manufacturer) were estimated parametrically. Costs varied between $30 million to $45 million depending on the study configuration. No effort was made in this preliminary evaluation to establish a minimum cost program. It is judged, however, that further evaluation could identify means to reduce the estimates given.

The limited scope of the present study precluded several investigations of interest. These are the subject of the following recommendations for future work:

- Refined analysis of each of the study configurations to remove limitations to achieving lower speeds. Since the limitations have now been isolated through the present initial analysis, a focussed effort to remove them should be pursued.
- Wind tunnel studies focussing on the canard/wing aerodynamics and on the RALS system/aircraft interaction should be undertaken to enhance confidence in these aspects of the analytical projections.
- The penalty of designing for full engine-out control and safe return of the aircraft is considerable both in performance limitations and cost. An alternative approach is to design for safe pilot ejection only. The benefits and penalties of these separate design approaches should be investigated.
- The parametric cost estimates developed are higher than desired. Additional design definition particularly concerning implementation of the required flight control system modifications is desirable. This together with a more detailed cost breakdown should be pursued to identify cost reduction opportunities.

REFERENCES:

3.2A.3-1 CP45K0006, F-404 Engine, General Electric Company, November 15, 1975.

3.2A.3-2 Drawing LO-PD-TS-25A; F-106B STOL Flight Research Study - Modification 1

3.2A.3-3 Memo Sheet 2-8050-MBS-79-239-6633A; Ground Rules for Design and Planned Operational Use of the F-106B Aircraft as a STOL Demonstrator

3.2A.3-4 Drawing LO-PD-TS-46, Winglet/Tip Extension Layout, Modification 1

3.2A.3-5 To 1F-106B-4; F-106B Illustrated Parts Breakdown

3.2A.3-6 To 1F-106B-1; F-106B Flight Manual

3.2A.3-7 Drawing LO-PD-TS-27A, F-106B STOL Flight Research Study, Modification 3.

3.2A.3-8 D180-25418-1, Feasibility Study of an F-106 Aircraft for Non-Axisymmetric Nozzle Flight Research (NASA Contract NAS4-2554)

3.2A.3-9 Drawing LO-PD-TS-30A, F-106B STOL Flight Research Study, Modification 5

3.2A.3-10 Drawing LO-PD-TS-43, F-106B STOL Flight Research Study, Modification 7 (RALS)

3.2A.5-1 Drawing LO-PD-TS-1A - General Arrangement F-106B

3.2A.5-2 Drawing LO-PD-TS-25A - F-106B STOL Flight Research Study Modification 1.

3.2A.5-3 Drawing LO-PD-TS-27A - F-106B STOL Flight Research Study-Modification 3

3.2A.5-4 Drawing LO-PD-TS-30A - F106B STOL Flight Research Study Modification 5

3.2A.5-5 Drawing LO-PD-TS-43 - F-106B STOL Flight Research Study Modification 7 (RALS).

3.2A.5-6 Morgan, W. R. C/S BMAD-FC-130, F-106B Baseline Aerodynamic Data for F-106 2D Nozzle Study, October 28, 1978

3.2A.5-7 USAF STABILITY AND CONTROL DATCOM, Air Force Flight Dynamic Laboratory, October, 1960 (Revised, April 1978)

3.2A.6-1 Substantiating Data Report for F-106A Standard Aircraft Characteristics Charts, 1 September 1956, (Contract AF33(600)-30169), Convair.

3.2A.6-2 C.S. BMAD-AERO-256, M987-350 Takeoff and Landing Performance Incorporating Wind Tunnel Data and Estimates of the Effect of a Nose Mounted Remotely Augmented Lift System (RALS) for Trimming, 6 October 1979, E. G. Sevigny.

APPENDIX A

STATEMENT OF WORK
NAS4-2554

STATEMENT OF WORK
NAS4-2554

STOL FLIGHT RESEARCH FEASIBILITY STUDY USING A F-106 AIRCRAFT
April 27, 1979

1.0 OBJECTIVE

The objective of this task is to explore the utility of the F-106 aircraft as a vehicle on which to conduct nonaxisymmetric nozzle research applicable to advanced STOL combat aircraft.

2.0 SCOPE

This feasibility study will investigate three different configurational arrangements of the F-106B aircraft. For these configurations, the contractor will define the feasibility, identify problem areas, determine potential research tasks, and develop budgetary cost information upon which a meaningful STOL research program can be planned. The selected approaches will assume use of the F-404 engine and ADEN-type 2D nozzle with deflector.

3.0 DESCRIPTION OF TASKS

3.1 Configuration Identification (Task 1)

The contractor shall study three configurations of a F-106B aircraft modified for STOL flight research. The study configurations will be based upon ability to improve the low speed/STOL characteristics of the F-106 in combination with the F-404/ADEN. The objective shall be to minimize the asymmetric moments due to engine out or nozzle hardover failure and to maximize the vectoring angle capability during normal flight operation. The contractor shall propose for NASAS approval, preliminary layouts of the configurations to be studied within 30 days of authorization to proceed with this task.

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3.2 Evaluation and Design Studies (Task 2)

3.2.1 The contractor shall make a preliminary evaluation of the feasibility, identify problem areas, and determine the research potential of each of the approved study configurations. The contractor shall develop a set of layout drawings for each configuration. Each set shall include the modifications appropriate to the powerplant, nozzle, and aircraft installation concept. These drawings shall be kept up-to-date throughout the study and included as part of the final report.

The contractor shall study and analyze the selected configurations to enhance their capabilities to provide relevant STOL research.

3.2.2 Additionally, major design impact areas will be selected for preliminary design details to be incorporated into the basic layouts. These layouts will be used to support preliminary engineering evaluations of weight changes, structural load paths, aircraft stability, control and balance requirements, canard and T-tail installation, special cooling reqirements, flutter considerations, and others. These layouts will be accomplished only to such level of detail as required to support the engineering evaluation. Detail design is not part of this task.

3.2.3 The contractor shall make a preliminary design evaluation of the impact of the potential modifications on aircraft performance and operating envelope. Requirements for ballast, if any, shall be identified, and the resulting aircraft range and endurance shall be developed from a computer evaluation of the F-106 aircraft based on contractor developed and/or any available government aerodynamic, propulsion, weight and balance, and structural design data.

3.3 Research Program Projection (Task 3)

3.3.1 The contractor shall project typical expected output from a STOL flight research program for each of the study configurations. Following government approval, the selected plans will be developed in more detail. Additionally, the contractor shall delineate key program research objectives and analysis, design, fabrication and test milestones. The contractor shall identify required NASA support when and where needed.

3.3.2 At the completion of this task, the contractor shall review the configuration and program plans and responsibilities required of the principal expected participants (airframe manufacturer, engine manufacturer, government). With government approval, these data will be used to develop budgetary program costs in Task 4.

3.4 Program Cost and Schedule (Task 4)

Budgetary cost information shall be developed for the study configurations defined in Task 1. These shall include engineering analysis and design; instrumentation; required hardware fabrication an installation; systems checkout requirements; flight test support; and data analysis and documentation. Costs for any area where NASA might be able to assume responsibilities shall be delineated by the contractor. Contractor/governent responsibilities developed in Task 3. will be used for cost breakdown elsewhere. For costing purposes, the engines and nozzle shall be assumed to be GFE.

4.0 REVIEW AND REPORTING

4.1 The contractor shall make two (2) trips to NASA Dryden Flight Research Center for the purpose of program reviews as follows:

1. Review of the configuration identification task (Paragraph 3.1)
2. Approval of flight research projections (Paragraph 3.3.1)