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FINAL REPORT

FEASIBILITY STUDY OF AN F-106 AIRCRAFT FOR NONAXISYMMETRIC NOZZLE FLIGHT RESEARCH

Prepared under Contract NAS 4-2554
By
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A/B	Afterburner
ADEN	Advanced Deflector Engine Nozzle
ALT	Altitude
AOA	Angle of attack
AR	Nozzle aspect ratio
B.L.	Buttock line
C_D	Drag coefficient
C_{f_g}	Thrust coefficent
c.g.	Center of gravity
C_L	Lift coefficient
C_N	Side force coefficient
C_V	Nozzle velocity coefficient
EFCS	Electronic Flight Controls System
F_G	Gross thrust
F_N	Net thrust
F_{RAM}	Ram drag
g	Acceleration due to gravity
GE	General Electric Company
GPM	Gallons per minute
h	Aircraft altitude
h/c	Height-to-chord ratio
IMS	Integrated Mean Slope
KTS	Knots
M	Mach number
MAC	Mean Aerodynamic Chord
M/B	Missile bay
n	Load factor
NASA	National Aeronautics and Space Administration
NM	Nautical miles
NPR	Nozzle pressure ratio
PS	Engine power setting

P_{T3}/P_{T2}	Compressor pressure ratio
S_C	Canard area
SFC	Specific fuel consumption
SLS	Sea level static
S_W	Wing area
T-D	Thrust-minus-drag
T.E.	Trailing edge
TOGW	Takeoff gross weight
T_8	Exhaust gas temperature
W	Aircraft weight
β	Sideslip
δ_{ail}	Aileron deflection
δ_c	Canard deflection
δ_e	Elevon deflection
δ_H	Horizontal tail deflection
δ_N	Nozzle deflection
δ_R	Rudder deflection
δ_V	Nozzle deflection
ϕ	Bank angle
α	Angle of attack

1.0 SUMMARY

The objective of this program was to study key aspects of the feasibility of using a NASA F-106 aircraft for non-axisymmetric (i.e. 2-D) exhaust system research. Recent USAF-sponsored weapon system effectiveness studies show requirements for aircraft speed, maneuverability, and stealth to contend with the increasingly sophisticated enemy threat. 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.

Recent industry studies have given differing results concerning the benefits of the 2-D nozzles. These differences can be attributed to evaluation of these nozzles on different types of aircraft, to a relatively weak data base and to inadequate understanding of the complete aircraft systems implication of the various nozzle features. Much of the data base inadequacy can be alleviated by further analysis and design studies. However, Boeing experience with its YC-14 vectored thrust STOL transport 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.

Since supersonic nozzle development has traditionally been a difficult mechanical and aerodynamic task, skeptics of the 2-D nozzle may ask: will practical design considerations such as mechanical layout, actuation systems and cooling and sealing requirements reduce the potential benefits? Can the nozzle vectoring/reversing forces and moments be efficiently integrated into the aircraft flight control system? Are current design approaches and cost estimates 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.

To evaluate the feasibility of an F106 2-D nozzle flight research program, this NASA-sponsored study was undertaken by Boeing supported by The General Electric Company under subcontract. Four candidate F-106 modifications differing in powerplant, aerodynamic, and configurational changes were selected for evaluation of practicality and cost:

o	MODIFICATION #1	incorporated two high aspect ratio 2-D nozzles on auxiliary, wing-pod-mounted J85 engines
o	MODIFICATION #2	was similar to MOD #1 but also incorporated a new horizontal tail for trimming of thrust vectoring
o	MODIFICATION #3	incorporated a single low aspect ratio 2-D nozzle on the basic F-106B J-75 powerplant
o	MODIFICATION #4	incorporated 2 GE ADEN 2-D nozzles on auxiliary wing-pod-mounted F404 engines

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:

- Each of the four study configurations was judged to be technically feasible and capable of providing research data for thirty degrees of thrust vectoring at transonic conditions provided certain operational limitations are observed. These included:
    - operation at low speed and low altitude solely with the basic J-75 powerplant for configurations #2 and #4. This results from auxiliary-engine-out control requirements exceeding available capability at low dynamic pressure conditions; this is consistent with previous, similar use of the aircraft by NASA Lewis Research Center to support SST nozzle research several years ago.

    - operation at transonic conditions, for configuration #4, such that should an F404 engine failure occur, sufficient room is allowed for in the flight envelope to accommodate the transient motion involved in trimming the aircraft to J75 thrust only. Under this failure circumstance, the aircraft would terminate the research test and proceed back to base under J75 power.

- Study configurations #1, 2 and 3 will provide, for research testing, on the order of 1 1/2 to 2 hours of transonic flight time. Configuration #4, without inflight refueling, would be limited to about 30 minutes for the as-drawn modification.

- Configuration #1 is well-suited to research objectives exploring flight-effects associated with design aspects of engine/nozzle integration. Configuration #2 would further enable investigation of nozzle/airframe integration aspects including jet-induced wing lift. Configuration #3 would allow evaluation of the nozzle as a pitch control device (which is especially appropriate to a tailless delta-wing aircraft) as well as evaluation of engine/nozzle integration aspects. Configuration #4 would provide research opportunities similar to Configuration #2 but with a more-to-scale wing/power plant configuration. Configuration #4 further allows exploration of certain design aspects of canards.

- 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.

- Budgetory contractor costs for the total development program (engine and airframe manufacturer) were estimated to be between $15 million to $30 million depending on the configuration selected, the flight regime capability required of the modified aircraft and the level of contractor effort required for preliminary safety of flight testing and for planning and conduct of initial research tests.

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 for non-axisymmetric exhaust system research. The study expanded upon a preliminary Boeing in-house evaluation which showed the F-106 to be a promising configuration for such 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 2-D nozzle studies, conducted as part of the ATS program and supplemented by other technology efforts, have shown: on the order of 3 - 5% improvment in thrust-minus-drag; sustained transonic load factor improvements of .25 to .5 g's; instantaneous transonic load factor improvements of 1 to 1.5 g's; low speed landing field length reductions of 25%; and 1 to 2 order of magnitude reductions in both infrared and radar cross-section signature contributions associated with the exhaust system. Additional opportunities exist in the areas of more optimal control of the aircraft for several specialized tasks, for missile breaklock, and others.

However, other recent industry studies have shown fewer or no such benefits. Part of the reason for these differences can be attributed to evaluation of these nozzles on different types of aircraft. But in addition, the differences can be attributed to a relatively weak data base and inadequate understanding of the complete aircraft systems implications of the various nozzle features.

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 systems integration of these nozzles with the airframe aerodynamics, structure, flight controls, powerplant and electronic warfare elements. Currently, the data base for evaluating these varied implications is weak relative to evaluation of conventional axisymmetric nozzles. Moreover, supersonic nozzle development has traditionally been a difficult mechanical and aerodynamic task. Skeptics ask: will practical design considerations such as mechanical layout, actuation systems and cooling and sealing requirements reduce the potential benefits? Can the nozzle vectoring/reversing forces and moments be efficiently integrated into the aircraft flight control system? Are current design approaches and cost estimates 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 opportunities for such a flight research program using an F106 aircraft to improve current understanding of the benefits and problem areas of such nozzles. An F106 aircraft was selected for evaluation for several reasons:

- the planform and nozzle placement was compatible with possible wing-canard moment balancing schemes developed in preliminary design studies. This 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 J85 engines. Much of this hardware is still available. Moreover, it was believed that utilizing auxiliary engines for the research nozzles rather than the primary aircraft powerplant would be a technique to minimize the research costs.

To evaluate the feasibility of an F106 flight research program, a four-task study was undertaken as shown in Figure 2-1. Boeing efforts were supported by The General Electric Company under subcontract. GE provided nozzle concepts, design data, and flight program planning support related to the exhaust system.

Four candidate powerplant, aerodynamic, and configurational changes to the F-106B aircraft were selected for evaluation of practicality and cost. Propulsion system/nozzle installations, associated aircraft modifications and flight program content were identified and evaluated. Assumptions concerning responsibilities between an airframe manufacturer, engine manufacturer and NASA were defined and coordinated with the NASA program monitor. Potential flight research technology was established and the most promising configuration/program candidates were identified. The output of the study is anticipated to support government planning and decision-making for proposed flight research efforts.

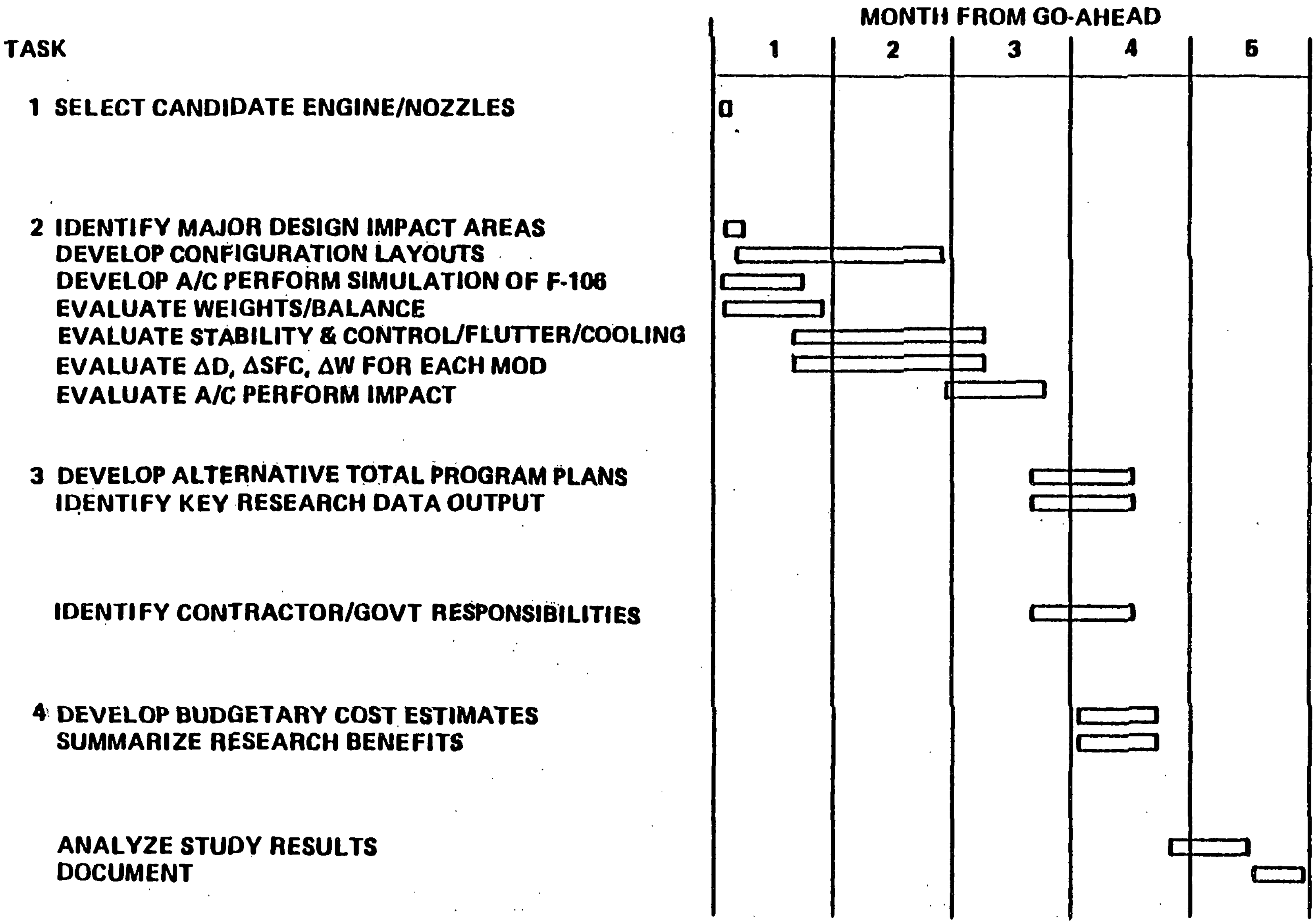

Figure 2-1. F-106 Feasibility Study - Key Tasks

3.0 RESULTS

3.1 TASK I - CONFIGURATION IDENTIFICATION

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 which 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 after-

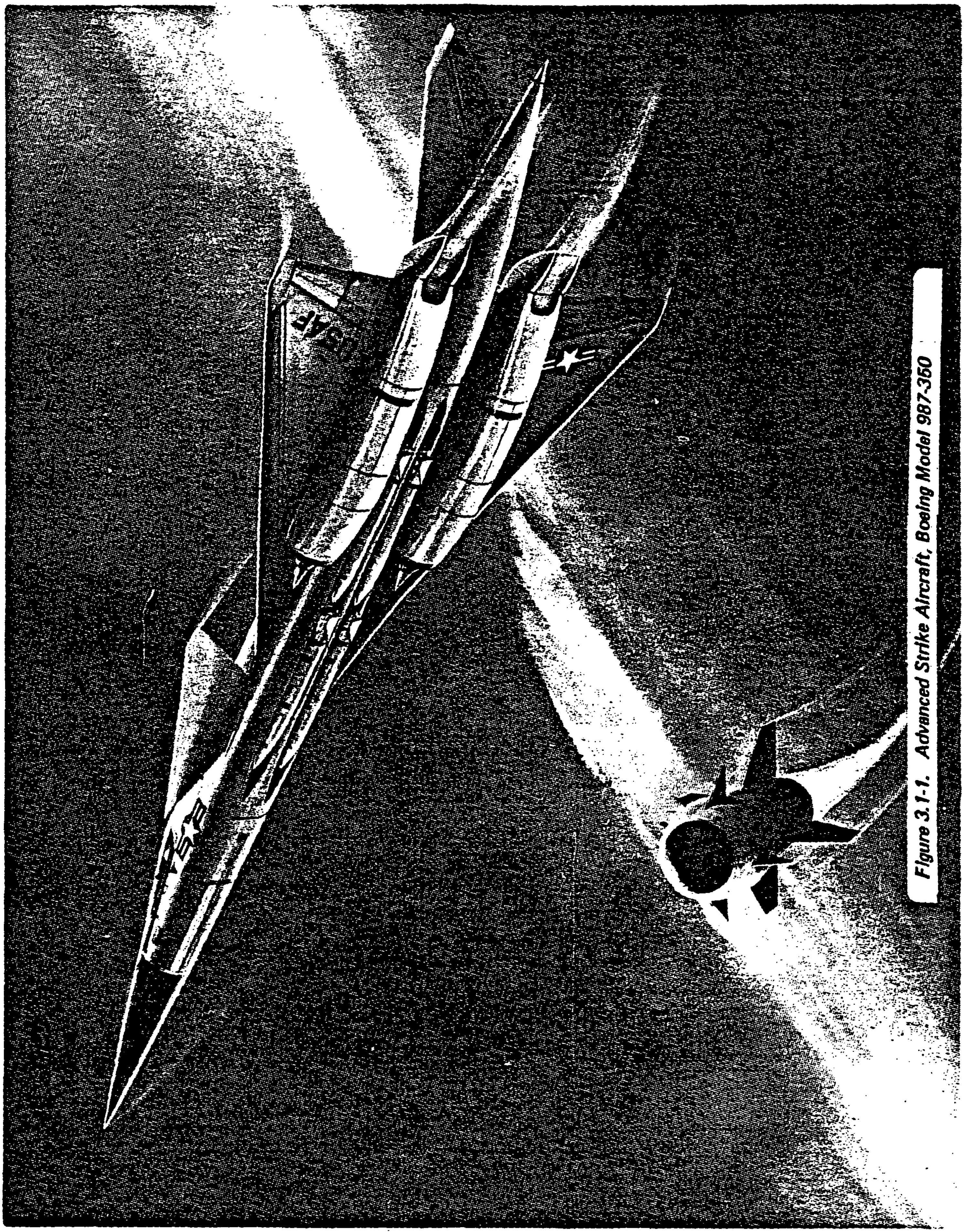

Figure 3.1-1. Advanced Strike Aircraft, Boeing Model 987-350

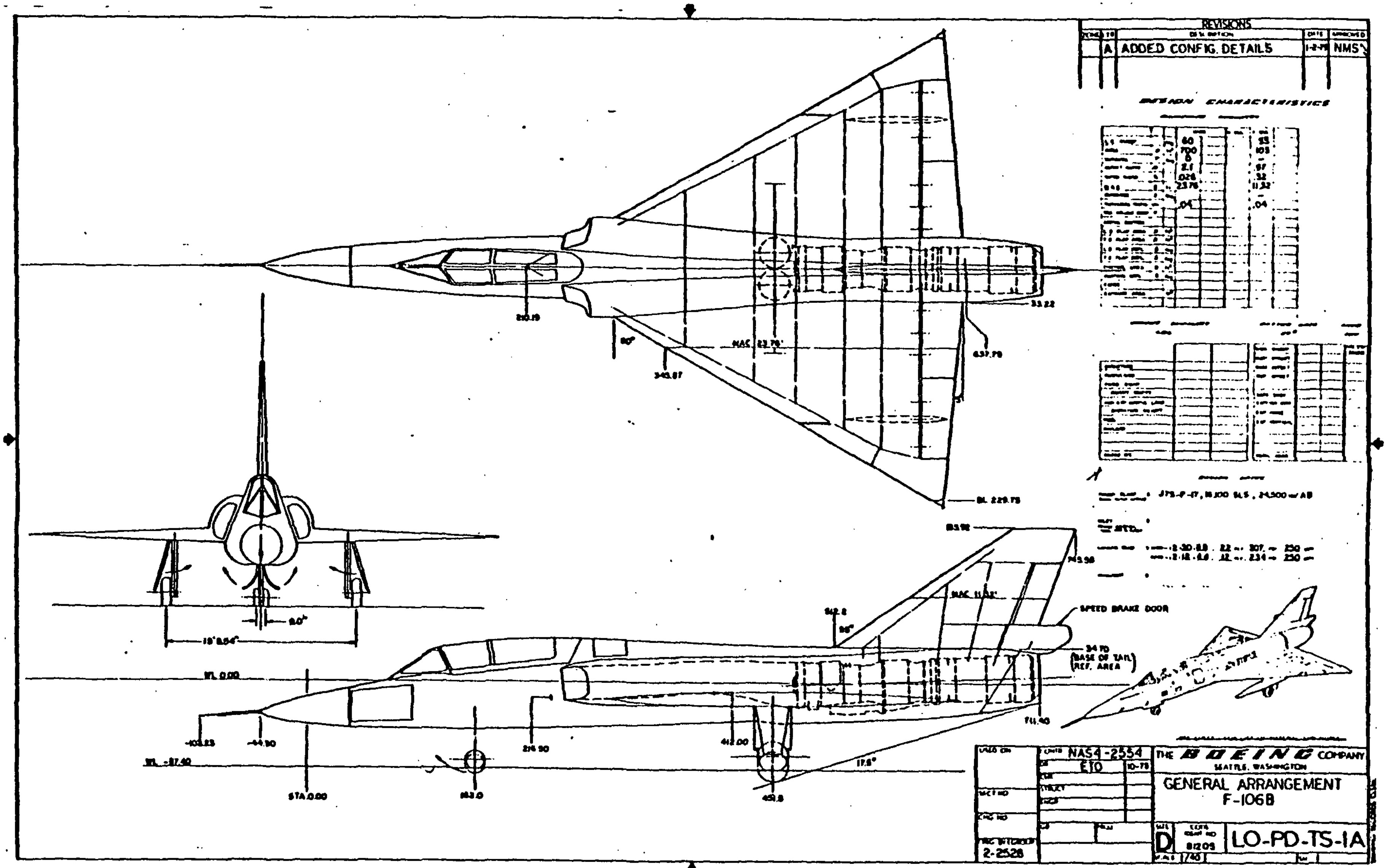

Figure 3.1-2. F-106B General Arrangement

burner. Maximum dry static thrust is 16,100 lb. Twin side-fuselage-mounted inlets are located forward and above the 700 square foot wing.

The configuration modifications selected for the present feasibility study were a compromise between NASA defined research objectives and the need to include low cost program options. Research objectives of interest included:

- Demonstration of nozzle viability and engine/nozzle integration
- Validation of airframe/nozzle installed performance
- Demonstration of propulsion/flight controls integration concepts
- Investigation of vehicle operational characteristics.

Program cost considerations were addressed by restricting two of the four study configurations to minimum modification, low cost approaches. The final four selected configurations are each described briefly below.

Modification #1 was intended as the lowest cost option whereby the aircraft functions only as a "test bed" for flying the nozzle. Research objectives would be focussed almost entirely on demonstrating the viability of the 2-D nozzle design; i.e., mechanical and structural adequacy, cooling scheme viability, actuation dependability, etc. The flight research would be a natural extension to ground-based nozzle developmental and test activity. Aircraft modifications consist of installing a high aspect ratio, 2-D nozzle on 2 J85-21 engines mounted on pods beneath the F-106 wing, see Figure 3.1-3. The high aspect ratio

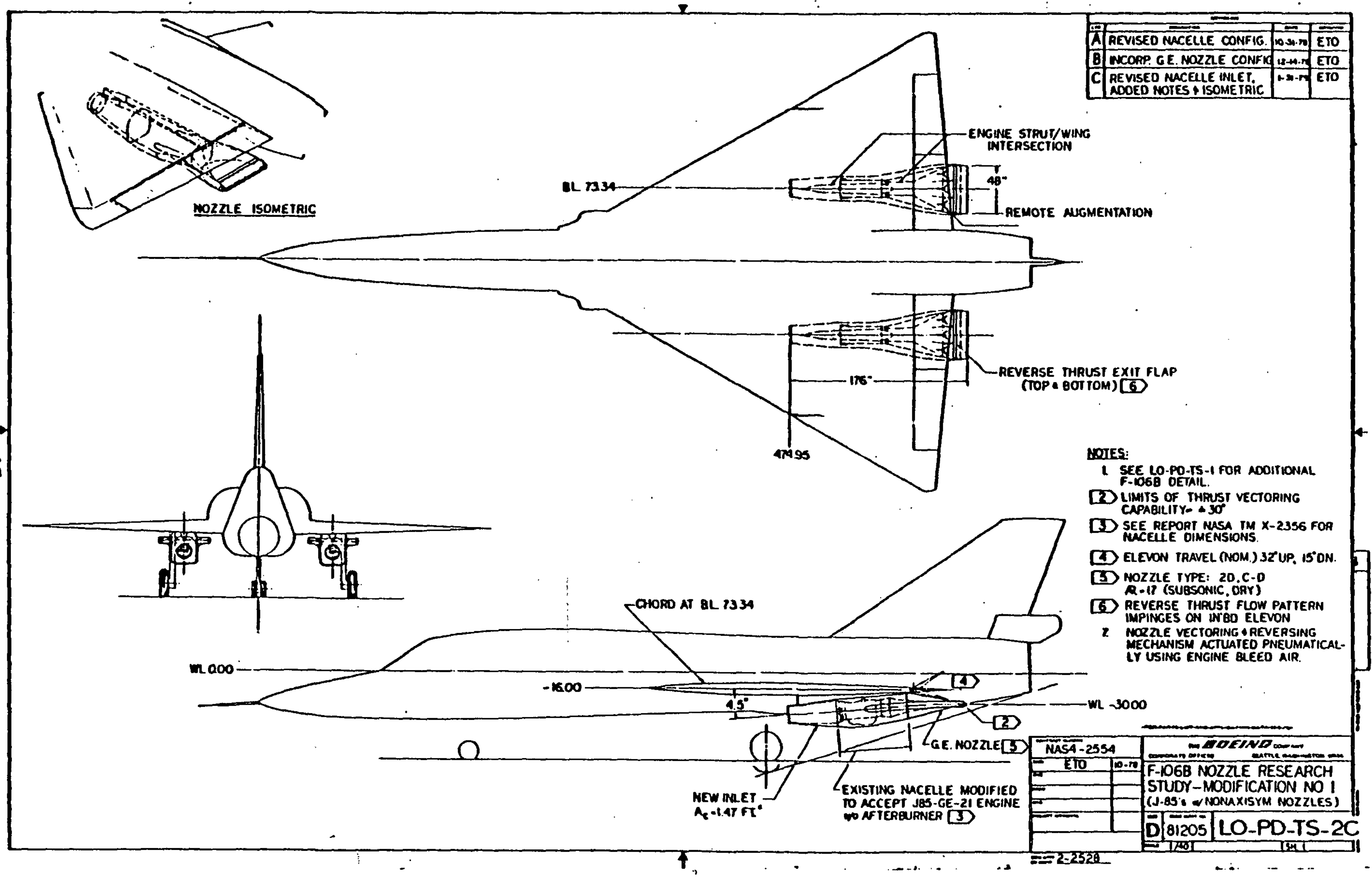

Figure 3.1-3 F-106B General Arrangement Modification No. 1

nozzle was selected to extend previous government and industry studies on low aspect ratio (i.e., "square") nozzle shapes. It is intended to install the pods in the same wing location as previously used by NASA and to use the existing NASA nacelles. No particular effort was made to establish good wing-induced lift. Trimming of the vectored thrust moments was to be accomplished with the existing elevons.

Modification #2 (Figure 3.1-4) again used the J85-21 engines, the high aspect ratio 2-D nozzles and the NASA nacelles. Unlike Modification #1, this configuration was intended to help research wing-induced-lift effects. To this end, (1) the nozzle is more highly integrated with the wing trailing edge, and (2) the empennage is modified to add a horizontal tail for trimming the moments due to thrust vectoring. Use of the horizontal tail will enable fixed elevon settings during thrust vectoring. This is necessary if the induced lift effects on the wing are to be isolatable from the trim effects. To minimize costs, an existing F-101 empennage (with existing horizontal tail) was proposed to replace the F-106 vertical fin.

Modification #3 (see Figure 3.1-5) was structured to explore the use of the 2-D nozzle 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 of the wing elevons. The negative lift increment developed thus subtracts from the overall wing efficiency. In contrast, an aft-located vectorable nozzle

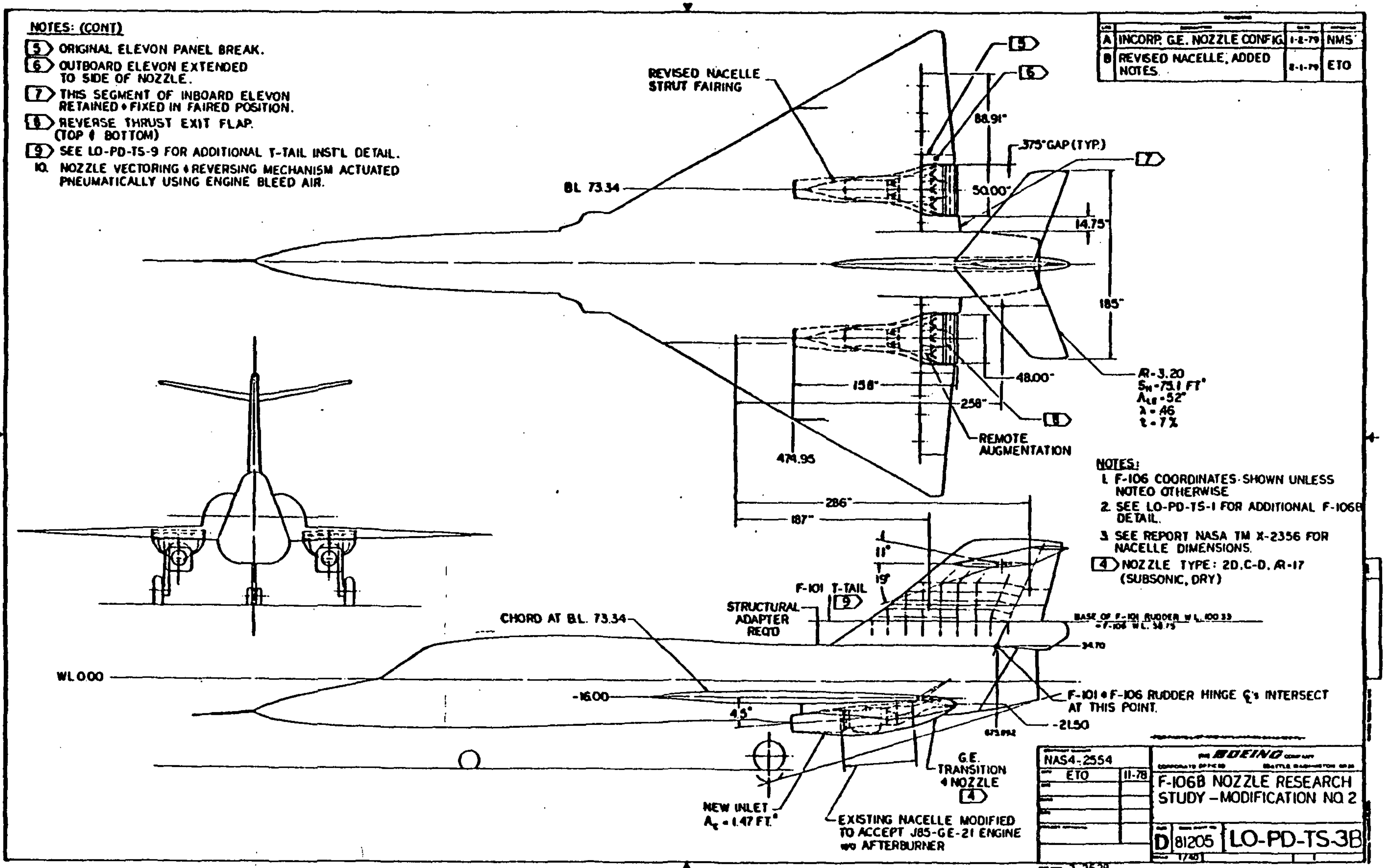

Figure 3.1-4 F-106B General Arrangement Modification No. 2

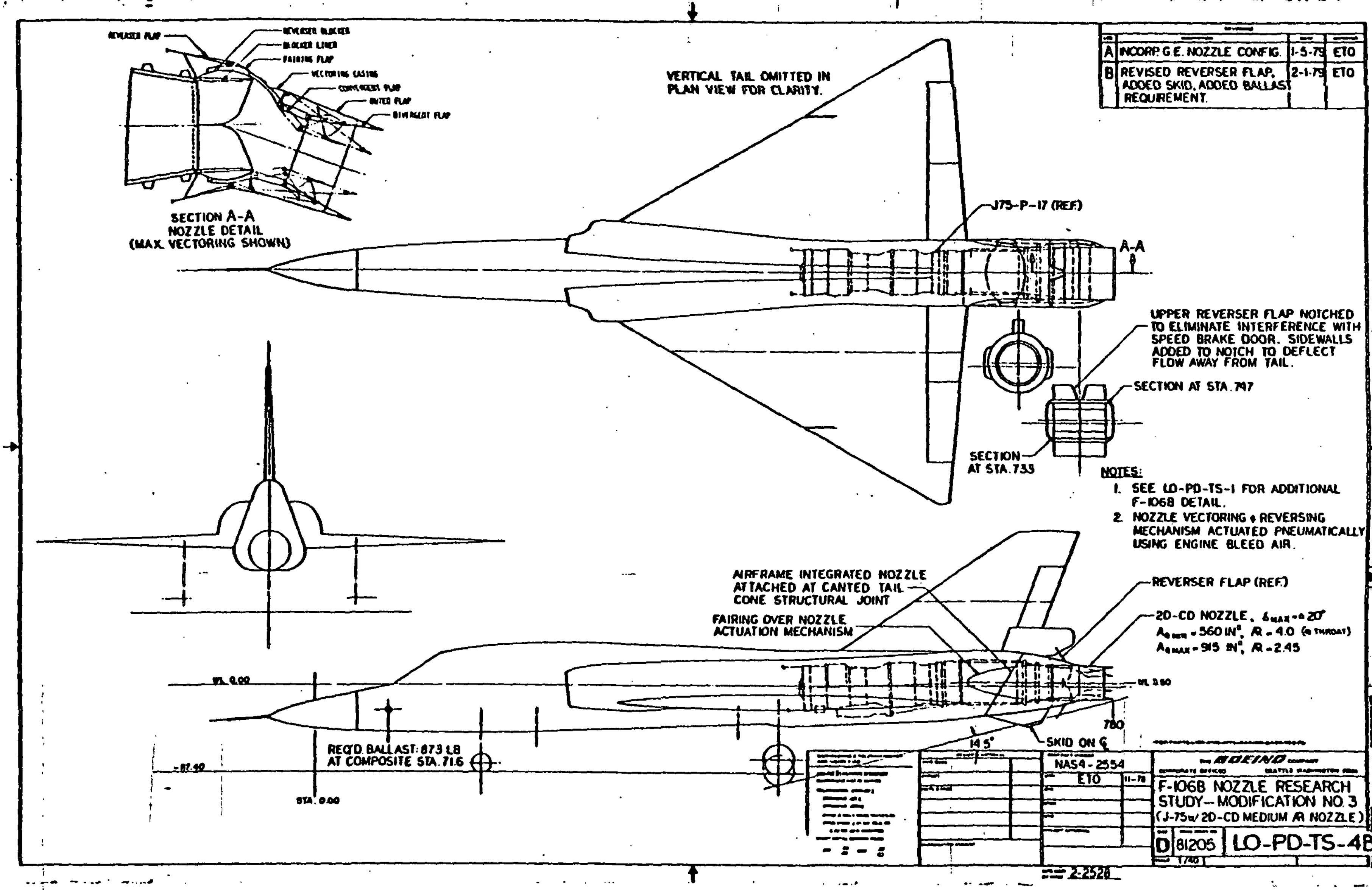

Figure 3.1-5. F-106B General Arrangement Modification No. 3

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. Modification #3 is also distinguished from the others since the (single, low aspect ratio) 2-D nozzle is integrated with the primary, rather than an auxiliary, aircraft powerplant.

Modification #4 (see Figure 3.1-6) is the most ambitious and the most costly of the four study configurations. Research objectives included: evaluation of a "more-to-scale" powerplant than the J85 and installation of a canard to help address propulsion/flight controls coupling and other canard-related aerodynamic issues. GE F-404 low bypass ratio turbofan engines were selected in lieu of the J85 engines. For this reason, the GE-developed ADEN 2-D nozzle was used.

The #4 configuration posed the most challenges to developing a viable arrangement. Since the scope of the study was limited, a comparative evaluation of several candidate arrangements was not undertaken. A basic ground rule adopted was to treat the F-404's as auxiliary engines and not remove the basic J75 powerplant. This was judged to minimize costs by, (1) avoiding re-arrangement of aircraft electrical, hydraulic and

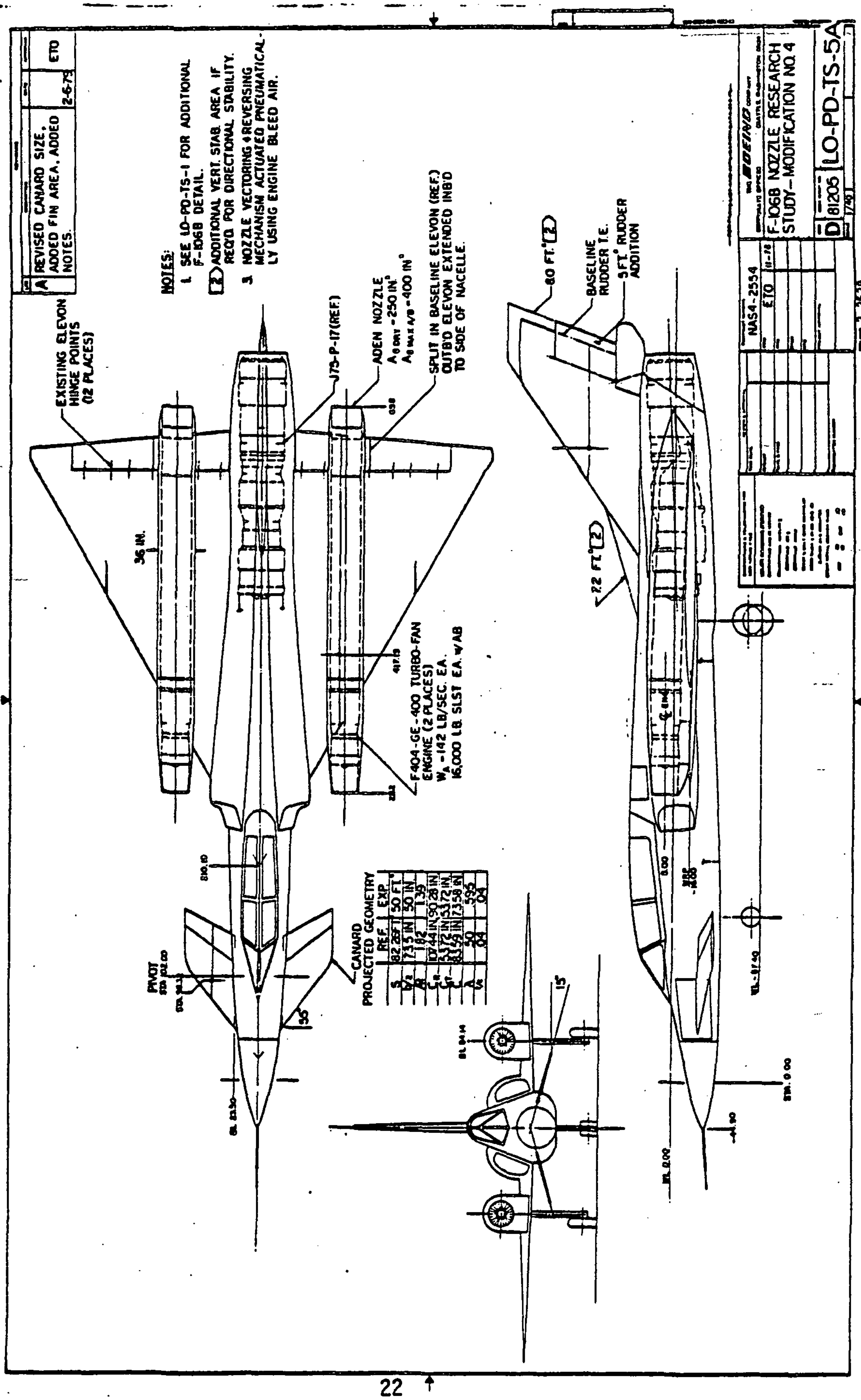

Figure 3.1-6 F-106B General Arrangement Modification No. 4

pneumatic services driven by the J75, and (2) reducing the pre-research testing associated with proving flight safety with the new engine. The overwing pod installation was selected to minimize interference with the landing gear. Canard location was picked based on availability of an existing structural bulkhead. Some changes to the vertical fin were also required as shown in the figure.

It should be noted that configuration choices other than those described above for modification #4 could possibly have led to more optimum research vehicles. However, it is felt that the basic understanding of research capability and program costs for an F404-type installation can be well established with the configuration selected. Figure 3.1-7 summarizes an assessment of each study configuration in terms of anticipated ability to research specific areas of interest identified by NASA.

CONFIGURATION ACHIEVEMENT OF RESEARCH OBJECTIVE

RESEARCH OBJECTIVE	CONFIGURATION #1	#2	#3	#4
AIRFRAME/NOZZLE				
1. ACCURATE T-D PERF (*VECTORING/ REVERSING*)	N_{AD}-S_{MOD} *TO ELEVON* NOTCH	G_{AD}-*INFLIGHT REVER. NEEDS DEVELOP.*	G_{AD}-REVERSER NEEDS TAILORING FOR GOOD FLOW	G_{AD}-NEED A/B DEVELOP.
2. EVALUATION OF INDUCED LIFT	N_{AD}	G_{AD}-NEED TO VALIDATE VECTORING/h.t. INTERFERENCE	N_{AD}	G_{AD}-NEED TO EVALUATE CANARD/WING/VECTORING INTERACTION
3. EVALUATION OF REVERSER ON STRUCTURE/CONTROLS	N_{AD}-S_{MOD} TO ELEVON NOTCH	G_{AD}	G_{AD}	S_{AD}-SUBJECT TO EVALUATION OF A/C S&C INFLIGHT
4. VERIFICATION OF MODEL DATA (ENG./NOZZLE/AIRCRAFT)	N_{AD}-S_{MOD} TO ELEVON NOTCH	G_{AD}	G_{AD}-(NO INDUCED LIFT)	G_{AD}
ENGINE/NOZZLE				
1. ENGINE STABILITY DURING VECTORING/REVERSING	G_{AD}-REVERSER NEEDS TO BE EXAMINED	G_{AD}	G_{AD}	G_{AD}
2. NOZZLE COOLING/PERFORM/WEIGHT TRADES & VALIDATION	G_{AD}	G_{AD}	G_{AD}	G_{AD}
3. RAM AIR COOLING TRADE DATA	G_{AD}	G_{AO}	G_{AS}	G_{AD}
4. HI Æ NOZZLE & REMOTE BURNER DESIGN & VALIDATION	G_{AD}	G_{AD}	N_{AD}-G_{MOD} FOR HI Æ NOZZLE	N_{AD}-G_{MOD} FOR HI Æ NOZZLE
SYSTEMS INTEGRATION & CONTROLS				
1. DIGITAL "ACTIVE" CONTROLS	N_{AD}	N_{AD}-S_{MOD} FOR EFCS	N_{AD}- MOD & INTERPRET "ACTIVE" AS NOZZLE SYSTEM	N_{AD}-S_{MOD} FOR EFCS
2. INTEGRATION OF VECTORING/ *REVERSING INTO FCS*	N_{AD}-S_{MOD} FOR INTEGRATED CONTROLS	N_{AD}-G_{MOD} FOR INTEGRATED CONTROLS	N_{AD}-G_{MOD} FOR INTEGRATED CONTROLS	N_{AD}-G_{MOD} FOR INTEGRATED CONTROL
3. EVALUATION OF S&C DURING VECTORING/REVERSING (NEED TO CLARIFY THIS OBJECTIVE)	N_{AD}	G_{AD}	S_{AD}	G_{AD}
OPERATIONAL APPLICATIONS				
1. EXPLORE TR & TV ON SUSTAINED/ INST. MANEUVER	N_{AD}	S_{AD}	S_{AO}	G_{AD}
2. IDENTIFY STOL CHARACTERISTICS	N_{AD}	S_{AD}-QUESTION ABOUT GEAR DOWN AT LOW SPEED	G_{AD}-EVALUATE NOZZLE REDUNDANCY AS PRIMARY FLIGHT CONTROL	G_{AD}
3. INVESTIGATE MAN/MACHINE INTERFACES (WORK LOAD)	N_{AD}-S_{MOD} FOR DISPLAYS AND INTEGRATED CONTROLS	N_{AD}- MOD FOR DISPLAYS AND INTEGRATED FLIGHT CONTROLS	S_{MOD}-G_{MOD} FOR INTEGRATED FLIGHT CONTROLS AND DISPLAYS	N_{AD}-G_{MOD} FOR INTEGRATED FLIGHT CONTROLS AND DISPLAYS

LEGEND

G - GOOD RESEARCH POTENTIAL
S - SOME RESEARCH POTENTIAL
N - NEGLIGIBLE RESEARCH POTENTIAL

SUBSCRIPTS

AD = AS DRAWN
MOD = WITH OTHER MODS

Figure 3.1-7. Configuration Achievement of Research Objectives

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 condition 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

Preliminary weight and balance estimates for Modification No. 1 and for Modification No. 2 are tabulated and shown in the attached Group Weight Statements (Figures 3.2A.1-3 and -5). Weight and balance as shown are based on: actual weight and balance reports for both the F-106B and

```
****************************************************************************************
*           F-106B                  *              *  NOSE STA     -44.9               *
*   GROUP WEIGHT STATEMENT          *WEIGHT-LBS*   WING MAC     285.1                  *
*  ATSCGE  09/20/77  VERSION.       *              *  LEMAC        345.9               *
*          10/11/78                 *              *  BODY LENGTH  63 FT               *
****************************************************************************************
*                                   *              *   BODY   STA  | PERCENT MAC       *
*                                   *              *  GR.UP  GR.DN | GR.UP  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 *   230                             *
*  STARTING SYSTEM                  *           64 *   502                             *
*                     *******************************                                  *
*TOTAL PROPULSION                   *         7013 *   548.5                           *
*                                   *              *                                   *
*  FLIGHT CONTROL                   *          513 *   480                             *
*  AUXILIARY POWER PLANT            *              *                                   *
*  INSTRUMENTS                      *          160 *   223                             *
*  HYDRAULIC + PNEUMATIC            *          393 *   415                             *
*  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 *   256                             *
*  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     *
****************************************************************************************
R
 EOI ENCOUNTERED.
C>BYE
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Figure 3.2A.1-1. Baseline F-106B Group Level Weight and Balance Statement

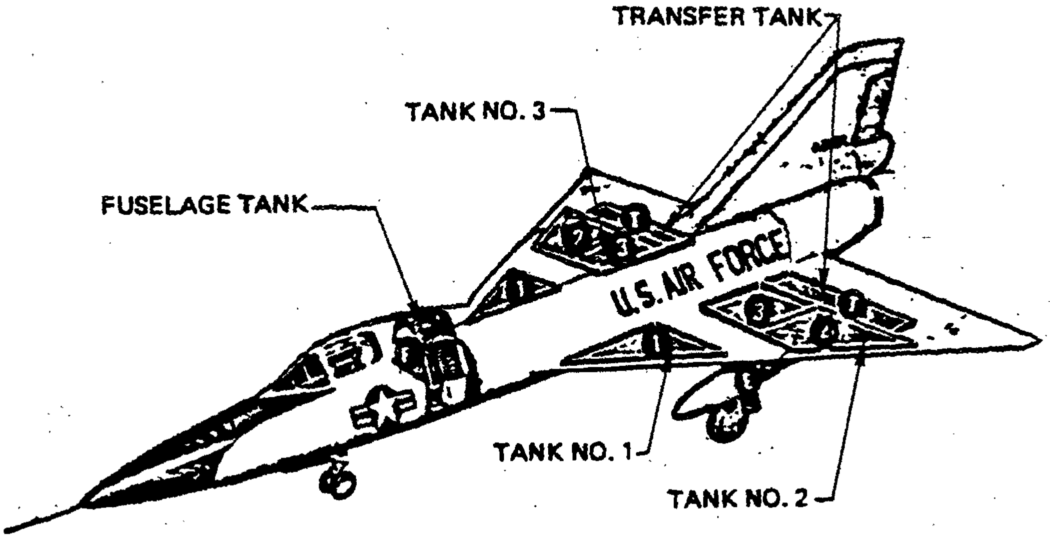
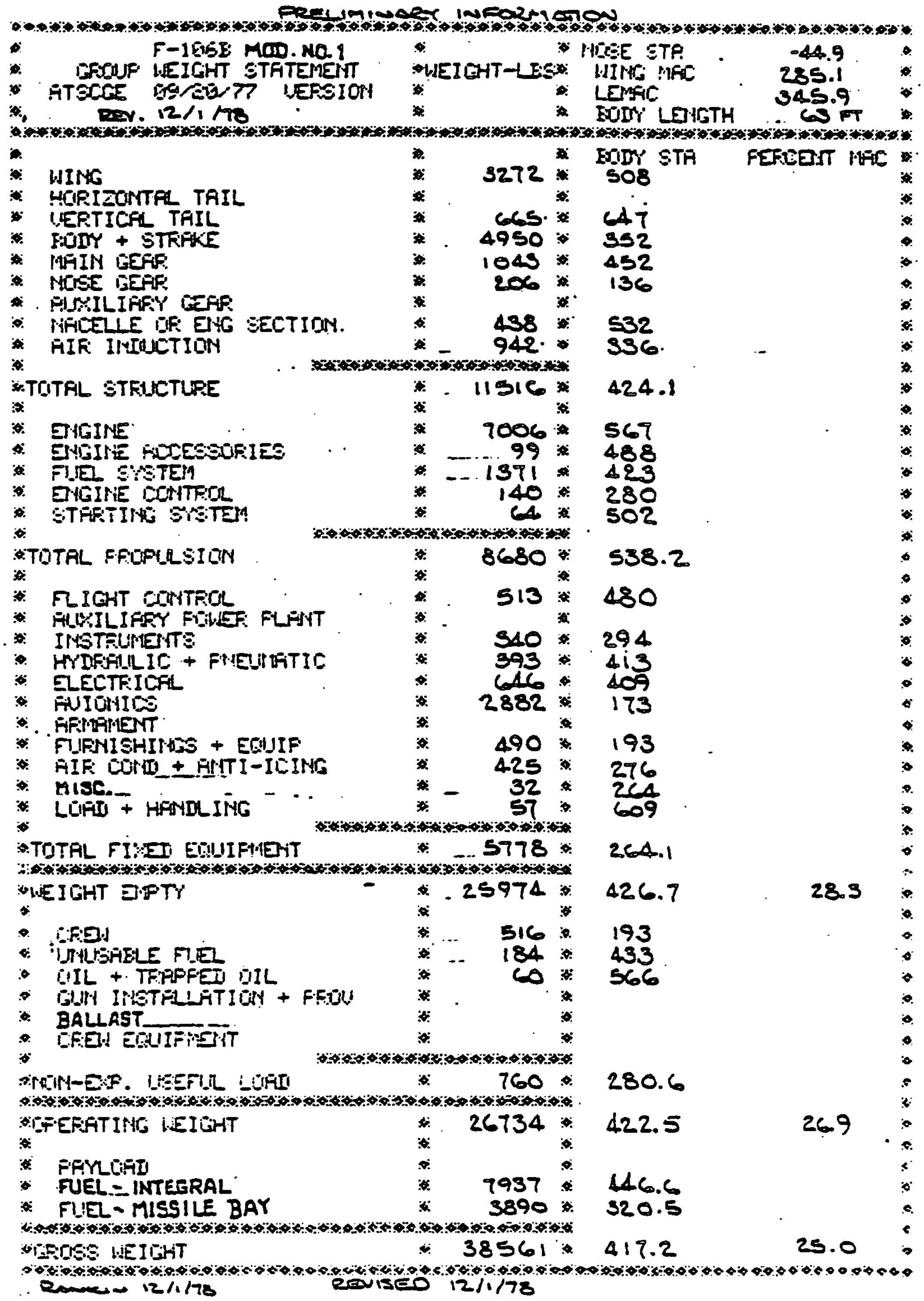


Figure 3.2A.1-2 F-106 Fuel Tank Location



PRELIMINARY INFORMATION

F-106B MOD. NO. 1
GROUP WEIGHT STATEMENT
ATSCGE 09/20/77 VERSION
REV. 12/1/78

	WEIGHT-LBS	
		NOSE STA -44.9
		WING MAC 285.1
		LEMAC 345.9
		BODY LENGTH 63 FT

		BODY STA	PERCENT MAC
WING	3272	508	
HORIZONTAL TAIL			
VERTICAL TAIL	665	647	
BODY + STRAKE	4950	352	
MAIN GEAR	1045	452	
NOSE GEAR	206	136	
AUXILIARY GEAR			
NACELLE OR ENG SECTION.	438	532	
AIR INDUCTION	942	336	
TOTAL STRUCTURE	11516	424.1	
ENGINE	7006	567	
ENGINE ACCESSORIES	99	488	
FUEL SYSTEM	1371	423	
ENGINE CONTROL	140	280	
STARTING SYSTEM	64	502	
TOTAL PROPULSION	8680	538.2	
FLIGHT CONTROL	513	480	
AUXILIARY POWER PLANT			
INSTRUMENTS	340	294	
HYDRAULIC + PNEUMATIC	393	413	
ELECTRICAL	646	409	
AVIONICS	2882	173	
ARMAMENT			
FURNISHINGS + EQUIP	490	193	
AIR COND + ANTI-ICING	425	276	
MISC.	32	264	
LOAD + HANDLING	57	609	
TOTAL FIXED EQUIPMENT	5778	264.1	
WEIGHT EMPTY	25974	426.7	28.3
CREW	516	193	
UNUSABLE FUEL	184	433	
OIL + TRAPPED OIL	60	566	
GUN INSTALLATION + PROV			
BALLAST			
CREW EQUIPMENT			
NON-EXP. USEFUL LOAD	760	280.6	
OPERATING WEIGHT	26734	422.5	26.9
PAYLOAD			
FUEL - INTEGRAL	7937	446.6	
FUEL - MISSILE BAY	3890	320.5	
GROSS WEIGHT	38561	417.2	25.0

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Figure 3.2A.1-3. F-106B Modification No. 1 Weight and Balance Statement

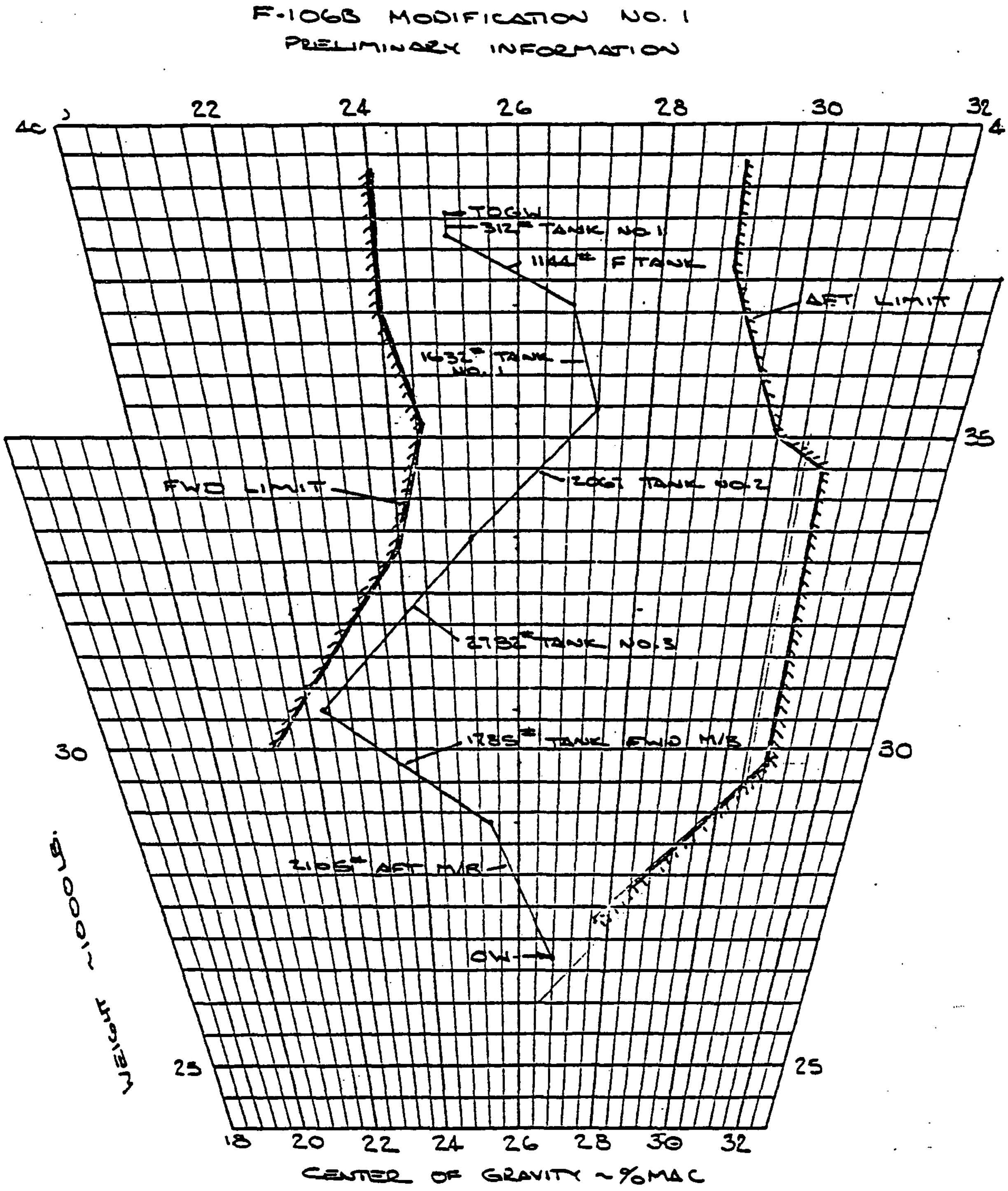
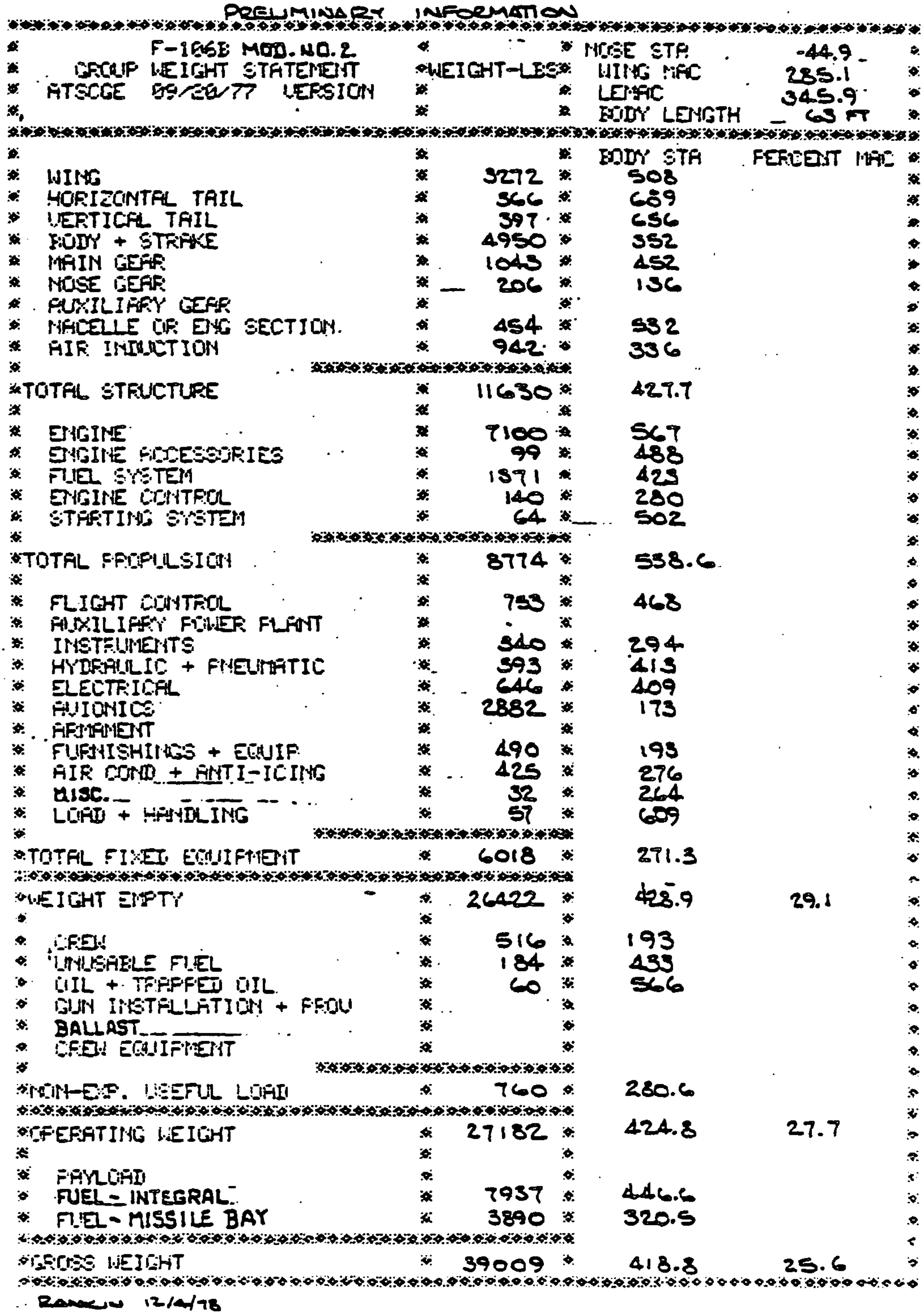


Figure 3.2A.1-4. F-106B Modification No. 1 Weight and cg. Grid



PRELIMINARY INFORMATION

F-106B MOD. NO. 2 GROUP WEIGHT STATEMENT ATSCGE 09/20/77 VERSION	WEIGHT-LBS		
		NOSE STA	-44.9
		WING MAC	285.1
		LEMAC	345.9
		BODY LENGTH	63 FT

	WEIGHT-LBS	BODY STA	PERCENT MAC
WING	3272	508	
HORIZONTAL TAIL	566	689	
VERTICAL TAIL	397	656	
BODY + STRAKE	4950	352	
MAIN GEAR	1043	452	
NOSE GEAR	206	136	
AUXILIARY GEAR			
NACELLE OR ENG SECTION.	454	532	
AIR INDUCTION	942	336	
TOTAL STRUCTURE	11630	427.7	
ENGINE	7100	567	
ENGINE ACCESSORIES	99	488	
FUEL SYSTEM	1371	423	
ENGINE CONTROL	140	280	
STARTING SYSTEM	64	502	
TOTAL PROPULSION	8774	558.6	
FLIGHT CONTROL	753	468	
AUXILIARY POWER PLANT	-		
INSTRUMENTS	340	294	
HYDRAULIC + PNEUMATIC	593	413	
ELECTRICAL	646	409	
AVIONICS	2882	173	
ARMAMENT			
FURNISHINGS + EQUIP	490	193	
AIR COND + ANTI-ICING	425	276	
MISC.	32	264	
LOAD + HANDLING	57	609	
TOTAL FIXED EQUIPMENT	6018	271.3	
WEIGHT EMPTY	26422	428.9	29.1
CREW	516	193	
UNUSABLE FUEL	184	433	
OIL + TRAPPED OIL	60	566	
GUN INSTALLATION + PROV			
BALLAST			
CREW EQUIPMENT			
NON-EXP. USEFUL LOAD	760	280.6	
OPERATING WEIGHT	27182	424.8	27.7
PAYLOAD			
FUEL - INTEGRAL	7937	446.6	
FUEL - MISSILE BAY	3890	320.5	
GROSS WEIGHT	39009	418.8	25.6

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Figure 3.2A.1-5. F-106B Modification No. 2 Weight and Balance Statement

F-106A, engine and nozzle data from G.E., information gained through telephone conversations with Mr. P. Colarusso and Mr. E. Boyer both of NASA-Cleveland, miscellaneous NASA and Convair Reports pertaining to the F-106B for both Mod. 1 and 2, as well as, the F-101C actual weight and balance report for Mod. No. 2.

The center of gravity limits for the modified F-106B are those specified by Chart E of T.O. 1F-106B-5 for the operating weight condition, and 768 lb of ballast required on Mod. 1 to maintain these limits. Further telephone conversation with Mr. Boyer provided information to establish the aerodynamic limits consistent with those shown on c.g. grids as reported in General Dynamics Report GDC-66-062 titled, "F-106B NASA SST TEST BED STUDY PHASE II". Report GDC-66-062 also specified recommended fuel sequencing. The center of gravity versus gross weight grids of Figures 3.2A.1-4 and -6, for Mod. 1 and 2 respectively, show that both models remain within limits throughout the flight envelope without ballasting.

Weight and balance estimates for Modification No. 3 are shown in Figure 3.2A.1-7. The addition of the two-dimensional CD nozzle to the existing J-75 installation increases the weight empty approximately 1570 lb. This weight increase at the extreme aft location shifts the airplane cg sufficiently aft to require 873 lb of ballast in the nose.

The assumption was made that the NASA F-106B was the base and that we would not use the missile bay fuel, even though the fuel volume is available. Figure 3.2A.1-8 shows the weight vs cg throughout the envelope using the recommended fuel sequencing minus the missile bay fuel.

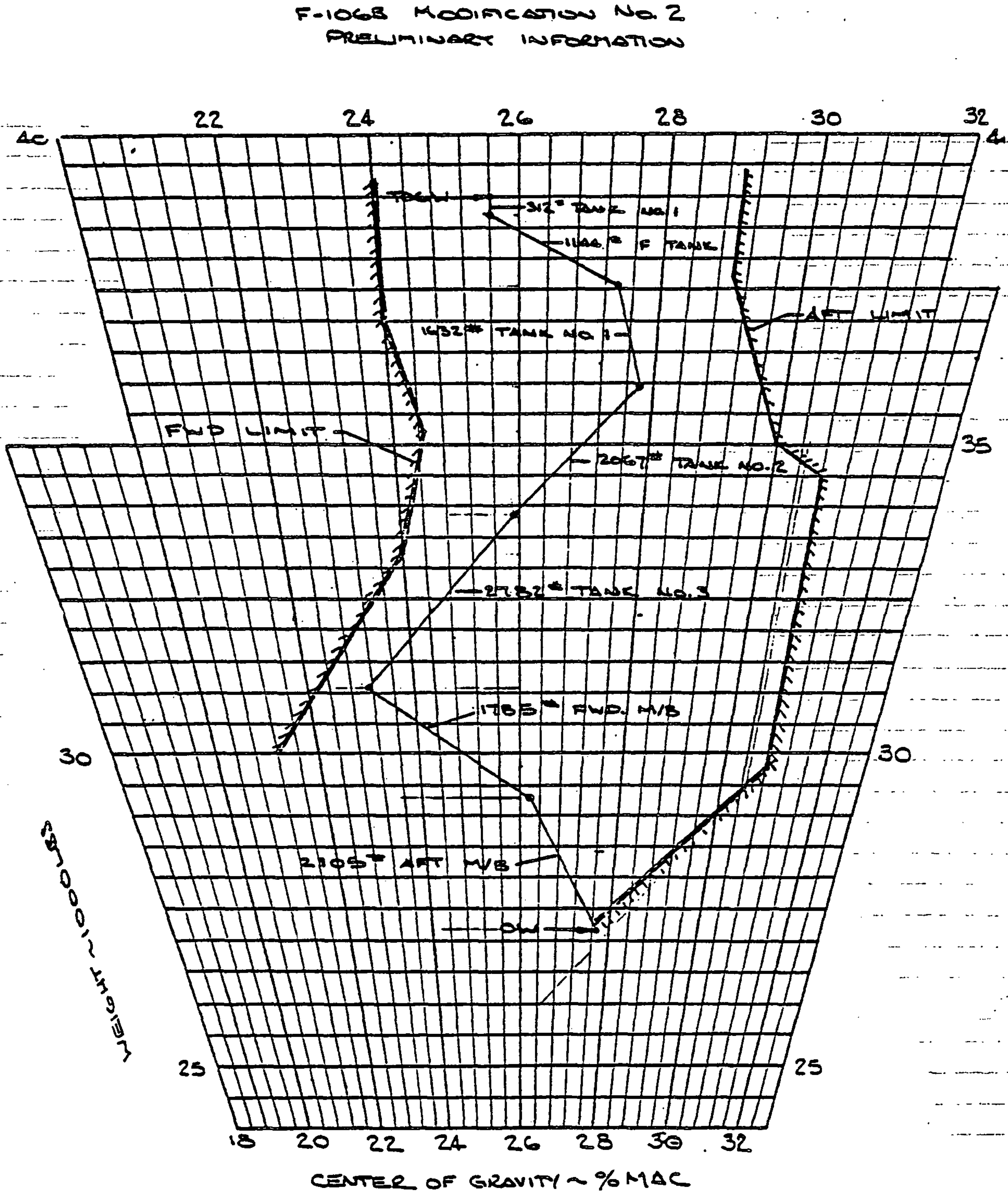
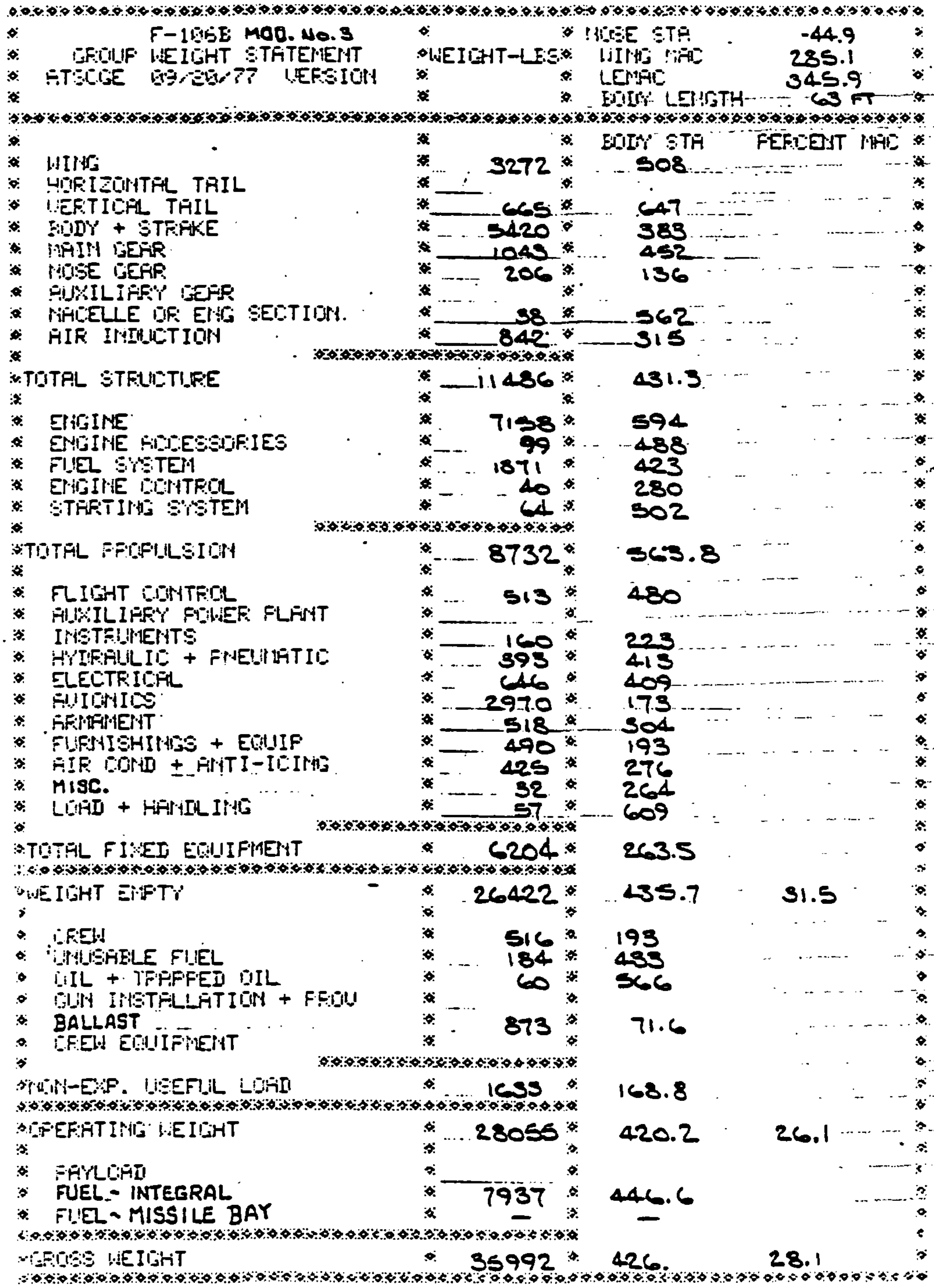


Figure 3.2A.1-6. F-106B Modification No. 2 Weight and cg. Grid



F-106B MOD. No. 3
GROUP WEIGHT STATEMENT
ATSCGE 09/20/77 VERSION

NOSE STA -44.9
WING MAC 285.1
LEMAC 345.9
BODY LENGTH 63 FT

	WEIGHT-LBS	BODY STA	PERCENT MAC
WING	3272	508	
HORIZONTAL TAIL			
VERTICAL TAIL	665	647	
BODY + STRAKE	5420	383	
MAIN GEAR	1043	452	
NOSE GEAR	206	136	
AUXILIARY GEAR			
NACELLE OR ENG SECTION.	38	562	
AIR INDUCTION	842	315	
TOTAL STRUCTURE	11486	431.3	
ENGINE	7158	594	
ENGINE ACCESSORIES	99	488	
FUEL SYSTEM	1871	423	
ENGINE CONTROL	40	280	
STARTING SYSTEM	64	502	
TOTAL PROPULSION	8732	563.8	
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	26422	435.7	31.5
CREW	516	193	
UNUSABLE FUEL	184	433	
OIL + TRAPPED OIL	60	566	
GUN INSTALLATION + PROV			
BALLAST	873	71.6	
CREW EQUIPMENT			
NON-EXP. USEFUL LOAD	1633	168.8	
OPERATING WEIGHT	28055	420.2	26.1
PAYLOAD			
FUEL - INTEGRAL	7937	446.6	
FUEL - MISSILE BAY	—	—	
GROSS WEIGHT	35992	426.	28.1

Figure 3.2A.1-7. F-106B Modification No. 3 Weight and Balance Statement

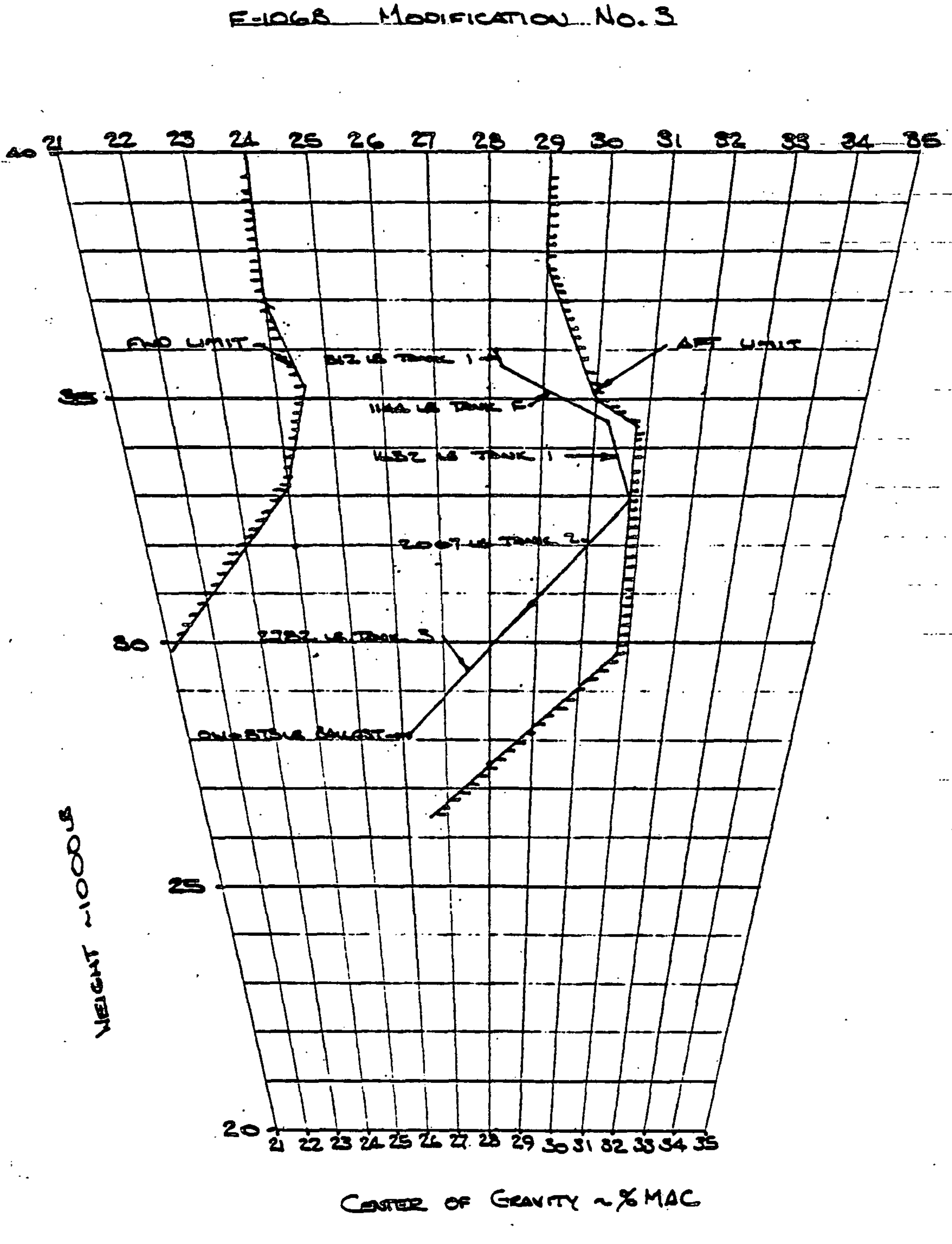
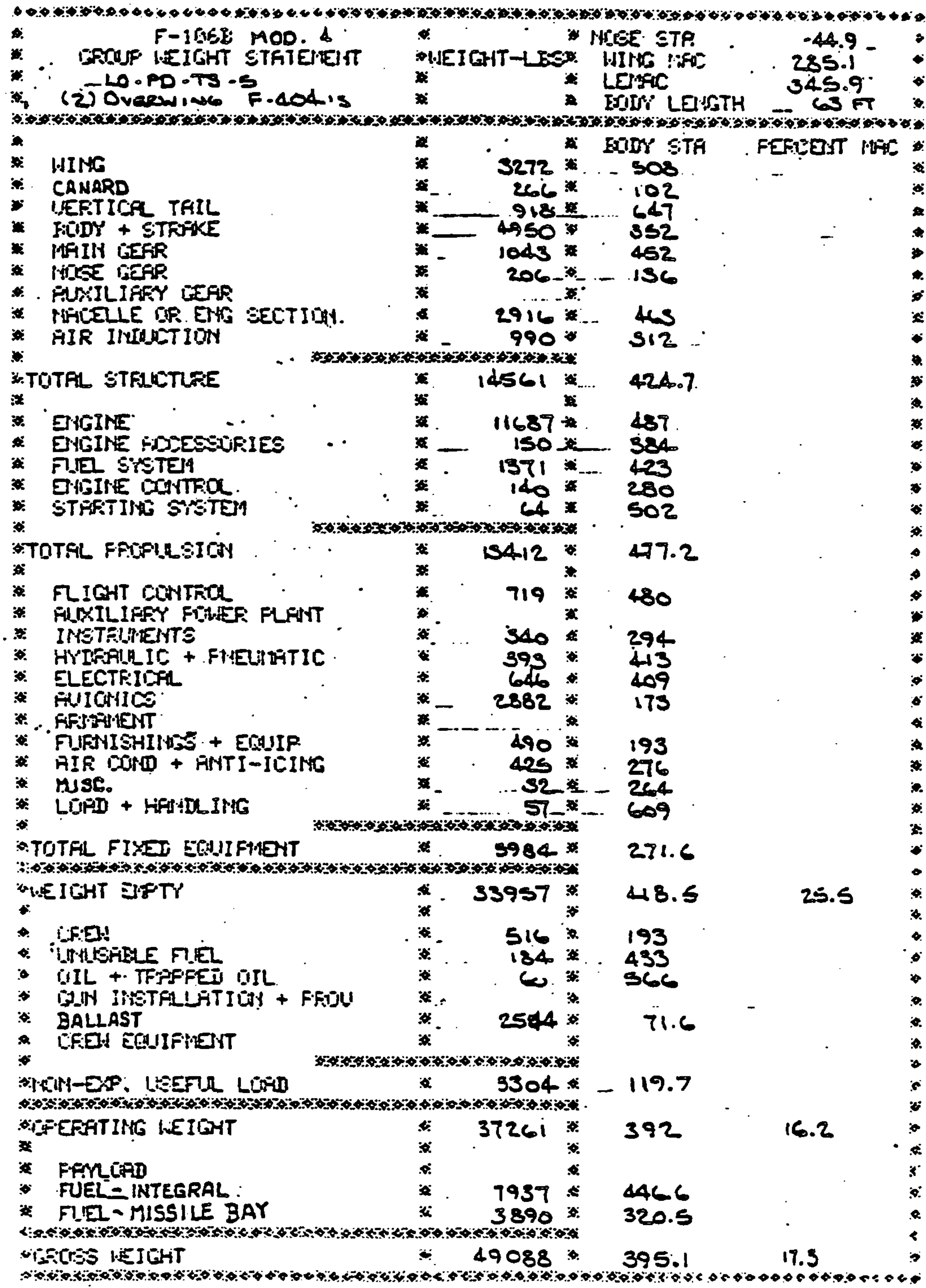


Figure 3.2A.1-8 . F-106B Modification No. 3 Weight and cg. Grid

Weight and balance estimates for Modification No. 4 are shown in Figure 3.2A.1-9. The addition of 2 F-404's, the canard and increased vertical tail size increase the airplane weight empty approximately 9700 lb with an aft cg shift of approximately 1/2% MAC.

The addition of the canard shifts the cg limits forward 10-1/2% MAC. In order to keep the modified aircraft within limits throughout the flight envelope utilizing the recommended fuel sequencing, 2544 lb of ballast must be added at a composite body station of 71.6. The cg vs gross weight grid shown in Figure 3.2A.1-10 indicates that the airplane at maximum gross weight including full fuel and ballast exceeds the allowable maximum gross weight by approximately 5600 lb. Flying with reduced fuel load in order to reduce the maximum gross weight and maintain aircraft balance is assumed.



F-106B MOD. 4
GROUP WEIGHT STATEMENT
LO-PD-T3-5
(2) OVERWING F-404's

NOSE STA -44.9
WING MAC 285.1
LEMAC 345.9
BODY LENGTH 63 FT

	WEIGHT-LBS	BODY STA	PERCENT MAC
WING	3272	508	
CANARD	266	102	
VERTICAL TAIL	918	647	
BODY + STRAKE	4950	352	
MAIN GEAR	1043	462	
NOSE GEAR	206	136	
AUXILIARY GEAR			
NACELLE OR ENG SECTION.	2916	463	
AIR INDUCTION	990	312	
TOTAL STRUCTURE	14561	424.7	
ENGINE	11687	487	
ENGINE ACCESSORIES	150	384	
FUEL SYSTEM	1371	423	
ENGINE CONTROL	140	280	
STARTING SYSTEM	64	502	
TOTAL PROPULSION	13412	477.2	
FLIGHT CONTROL	719	480	
AUXILIARY POWER PLANT			
INSTRUMENTS	340	294	
HYDRAULIC + PNEUMATIC	393	413	
ELECTRICAL	646	409	
AVIONICS	2882	173	
ARMAMENT			
FURNISHINGS + EQUIP	490	193	
AIR COND + ANTI-ICING	425	276	
MISC.	32	264	
LOAD + HANDLING	57	609	
TOTAL FIXED EQUIPMENT	5984	271.6	
WEIGHT EMPTY	33957	418.5	25.5
CREW	516	193	
UNUSABLE FUEL	184	433	
OIL + TRAPPED OIL	6	566	
GUN INSTALLATION + PROV			
BALLAST	2544	71.6	
CREW EQUIPMENT			
NON-EXP. USEFUL LOAD	3304	119.7	
OPERATING WEIGHT	37261	392	16.2
PAYLOAD			
FUEL - INTEGRAL	7937	446.6	
FUEL - MISSILE BAY	3890	320.5	
GROSS WEIGHT	49088	395.1	17.5

Figure 3.2A.1- 9 . F-106B Modification No. 4 Weight and Balance Statement

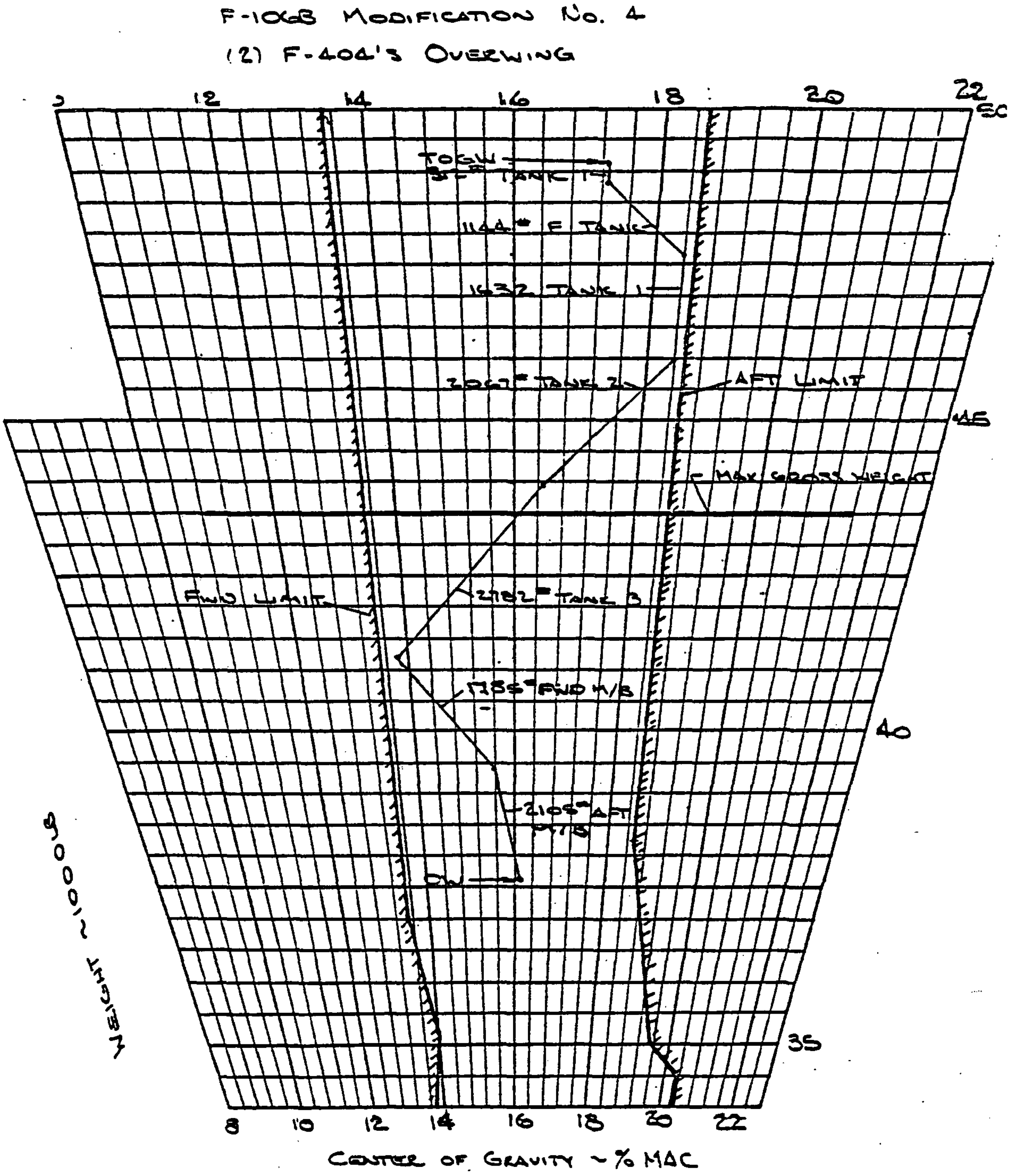


Figure 3.2A.1-10. F-106B Modification No. 4 Weight and cg. Grid

3.2A.2 Propulsion

The propulsion analysis of the four candidate (Reference 3.2A.2-7) F-106B nozzle research configurations consisted of calculation of installed engine performance and the assessment of potential propulsion-related problem areas for each configuration. The Boeing developed "PROP" computer code was used to calculate installed performance utilizing map inputs for inlet/nozzle internal performance and external drag along with uninstalled engine performance. Aftbody external drag increments for each of the configurations were estimated via IMS (Integrated Mean Slope) correlations of the type shown in Figure 3.2A.2-1. Boeing has developed correlations for several installations (e.g., single and twin axisymmetric, single and twin wedge, etc.) and it was felt that this data base was sufficient for the purposes of this study.

In general, all of the configurations examined present workable options, from a propulsion point of view, provided the identified problem areas, discussed below, are addressed during advanced design. Configuration #3 is felt to present the lowest development risk, while Configurations 1 and 2 are viewed as requiring more effort, primarily because of the necessary A/B and design work for the high aspect ratio nozzle. Configuration 4 presents several unique problems due to the installation and large size of the engine (and thus loads placed on the aircraft). These effects are treated in the Flight Controls discussion, section 3.2A.2-5.

The various inputs, assumptions, calculations, and problem areas for each configuration are discussed below.

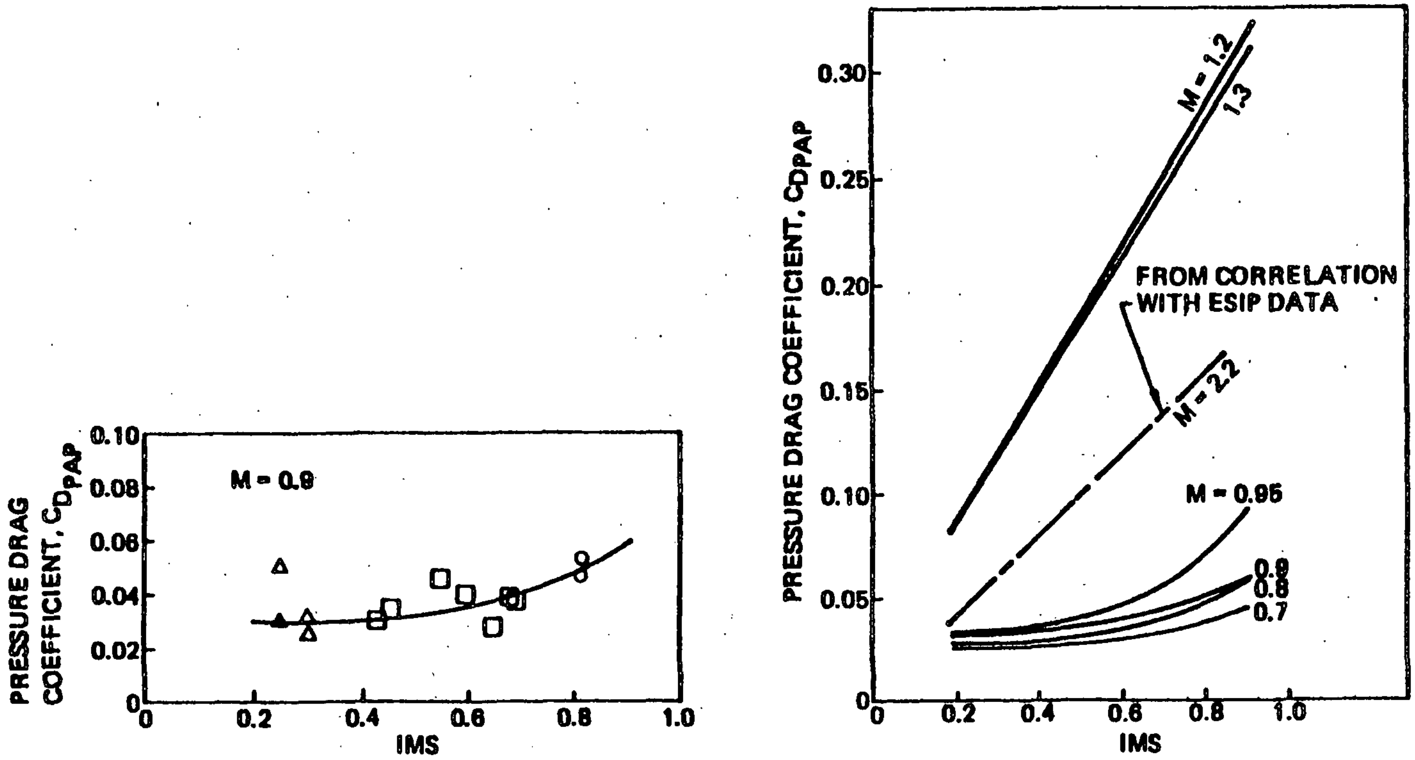


Figure 3.2A.2-1. Aft Body Drag Estimates Based on an IMS Correlation Technique

3.2A.2.1 Configurations 1 and 2

These configurations utilized two pod mounted GE J85-21 turbojet engines in addition to the baseline J75-P17 engine. Uninstalled performance for the J85-21 engine was gathered for the flight conditions of interest from Reference 3.2A.2-1. Since expected horsepower and airbleed requirements had not been defined, no allowance was made for them. This is consistent with the feasibility objectives of the study which is to examine first order effects.

The podded nacelle utilized a normal shock inlet and a 2D-CD nozzle of aspect ratio 17 (Figure 3.2A.2-2). Inlet performance was supplied using inlet Configuration #5 from Reference 3.2A.2-2, while nozzle internal performance was supplied by G.E. via Reference 3.2A.2-4 with the data presented in Table 3.2A.2-1. Nozzle internal performance included penalties for nozzle coolant flow pressure loss and leakage. A 4.5% reduction in max A/B power was used to reflect increased coolant flow requirement of the AR 17 nozzle. Aftbody external drag was estimated using the IMS program and area distributions as determined from the Reference 3.2A.2-7 layouts.

The PROP computer program was used to compute the installed performance utilizing the above inputs. The resulting installed data is presented in Figure 3.2A.2-3 for the four flight conditions of interest.

Potential problems identified for Configurations 1 and 2 centered on the development of remote augmentors for the AR 17 nozzle and thrust reverser

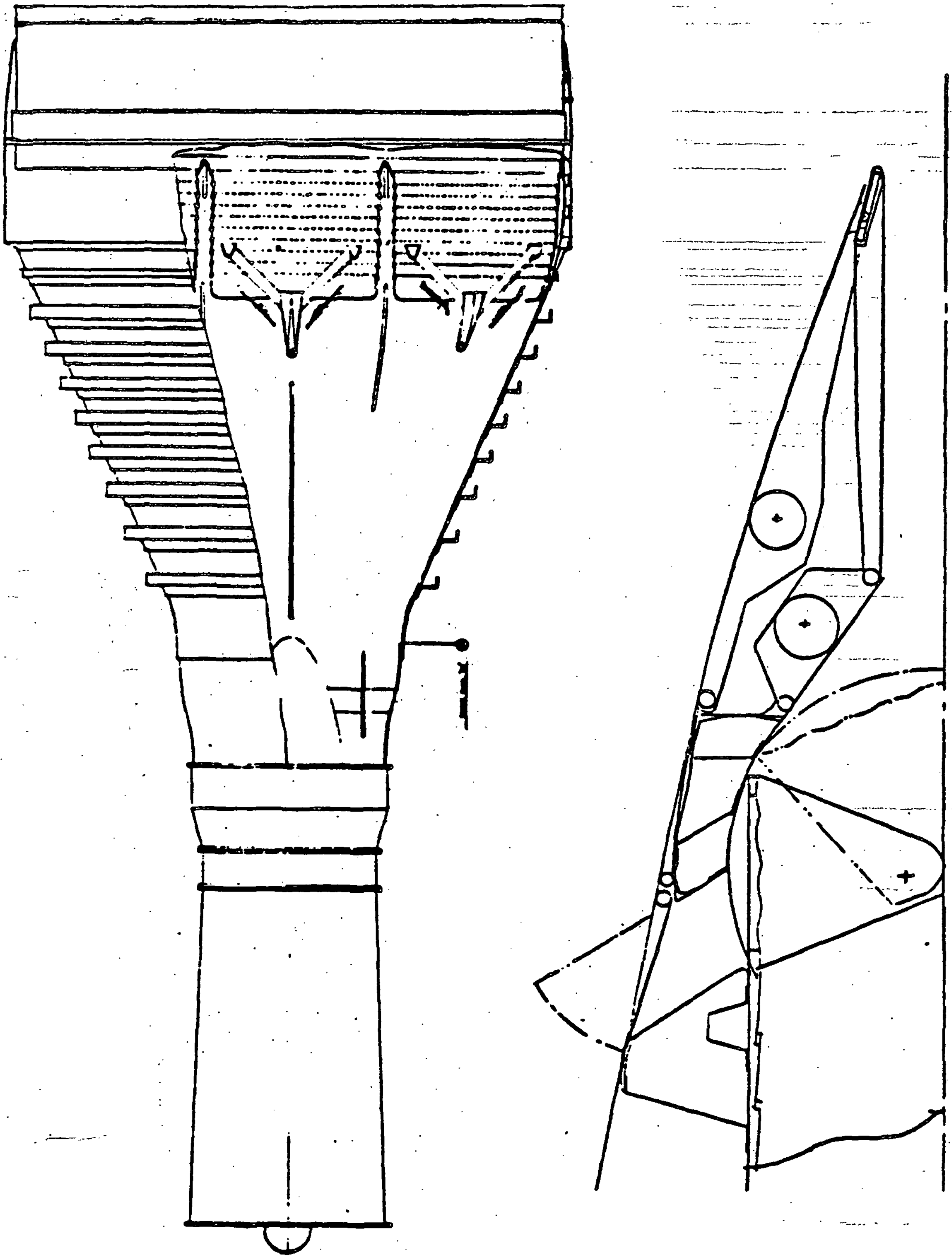


Figure 3.2A.2-2. 2D-CD Nozzle with Aspect Ratio (AR) = 17

Table 3.2A.2-1. Typical Performance and Weight Data for 2D-CD Nozzles

Spot point performance (internal C_{fg}) for 2D CD nozzles

Alt	M_o	Power	NPR	AR17 C_{fg}*	AR 4 C_{fg}*
40K	1.8	Max	7.95	.978	.979
30K	0.9	Cruise	3.60	.975	.977
0	0.2	Mil.	2.52	.973	.975

* Includes cooling ΔP_T & leakage losses.

The weights and performance of the 2D CD nozzles are as follows:

	WEIGHT, LBS.*	MAX T_8	COOLING ΔC_{fg} @ Max A/B**
AR 17	455	3307°R	4.5%
AR 4	317	3556°R	1 %

* Includes Nozzle/reverser/duct/augmentor for J85-21

** Δ from J85-21

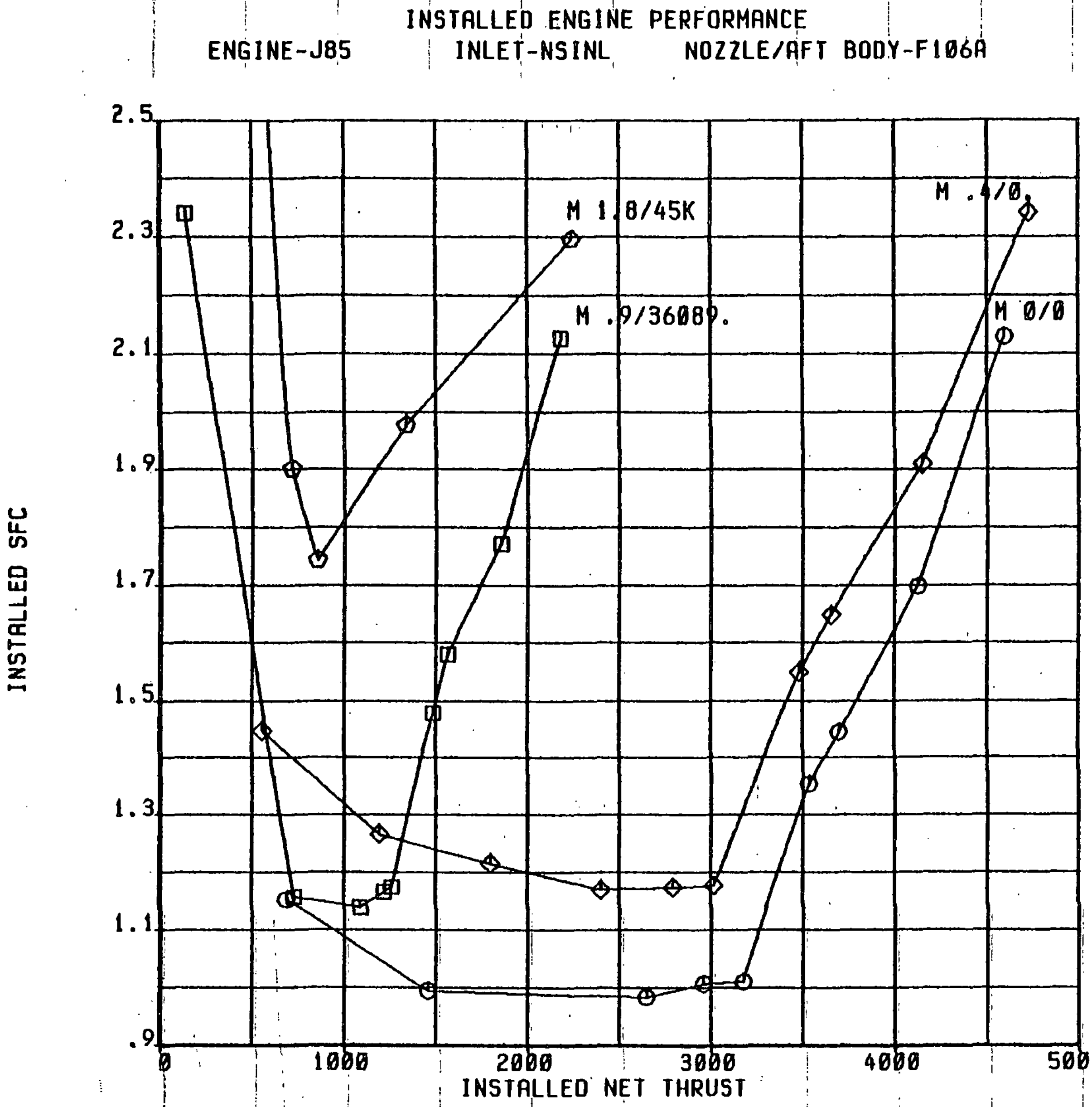


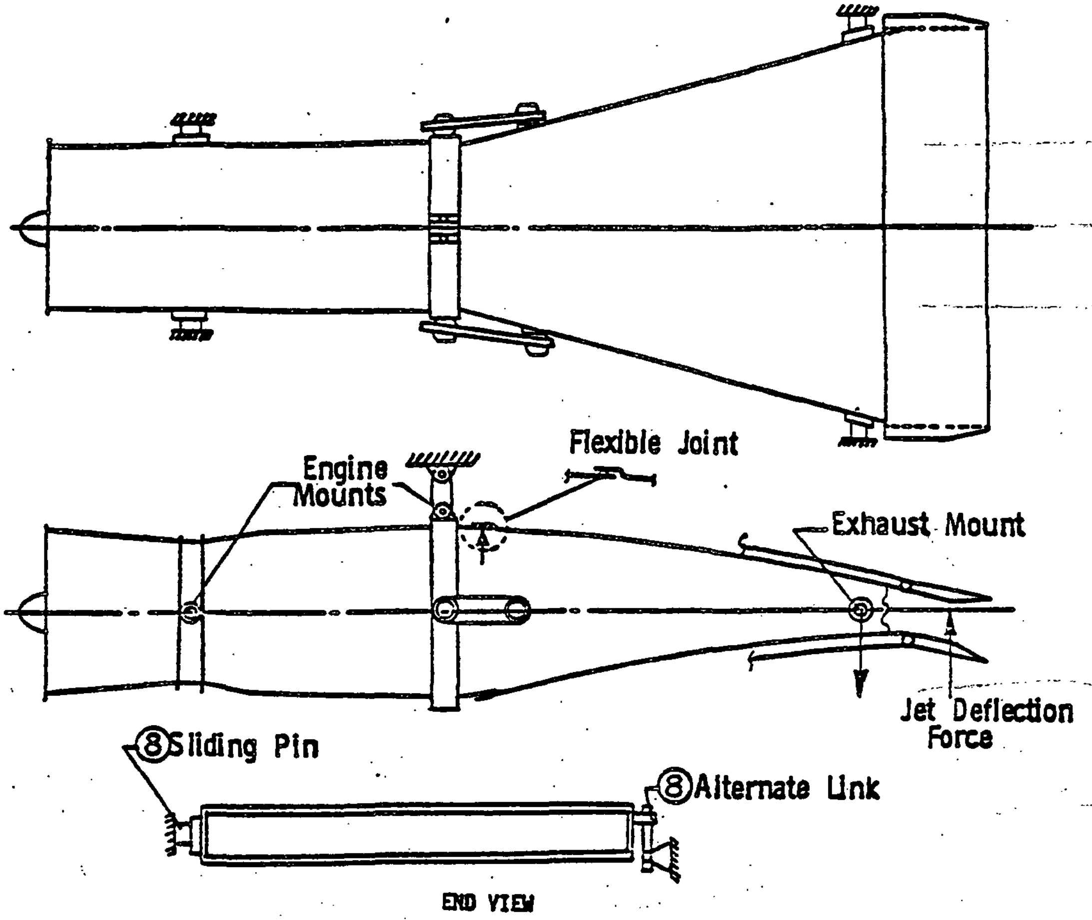
Figure 3.2A.2-3. *Installed Performance for Four Flight Conditions Computed by the PROP Program*

design. As a means of keeping total nacelle length short, remote augmentors with high intensity burners were selected for the high aspect ratio nozzles. This is a high technology item and thus carries with it a relatively high development effort, some of which may be undertaken by NASA Lewis as part of their nozzle research program. Of primary concern is the potential for airflow pressure distortion due to the combination of remote burners and transition duct design. The "S" duct on Configuration #2 adds to this concern.

The thrust reverser for Configuration #1 is felt to need design work to prevent hot gas impingement on aircraft structure due to nozzle placement below the elevon. This is true to a lesser degree for Configuration #2 where the nozzle is at wing level. In both cases, design work will be needed to prevent excessive deflections in the long, narrow panels for the thrust reverser and secondary flaps. In addition, it is anticipated that a nozzle mounting scheme will be developed to prevent thrust vectoring loads from being transmitted through the engine case. Two possible solutions are illustrated in Figure 3.2A.2-4.

At the onset of this study, it was decided to use the GE J85-21 engine rather than the -13 version used in prior NASA programs. It was felt that its higher thrust levels would present a "worst case" for evaluating propulsion effects on flight controls and stability, actuator sizing, etc. In addition, NASA is already involved with the -21 engine in its HIMAT program. One question which arose in taking this approach was whether or not the nacelles used in the previous studies could also be

EXHAUST SYSTEM MOMENT ISOLATION



STRUCTURAL ISOLATION OF EXHAUST SYSTEM (BELLOWS METHOD)

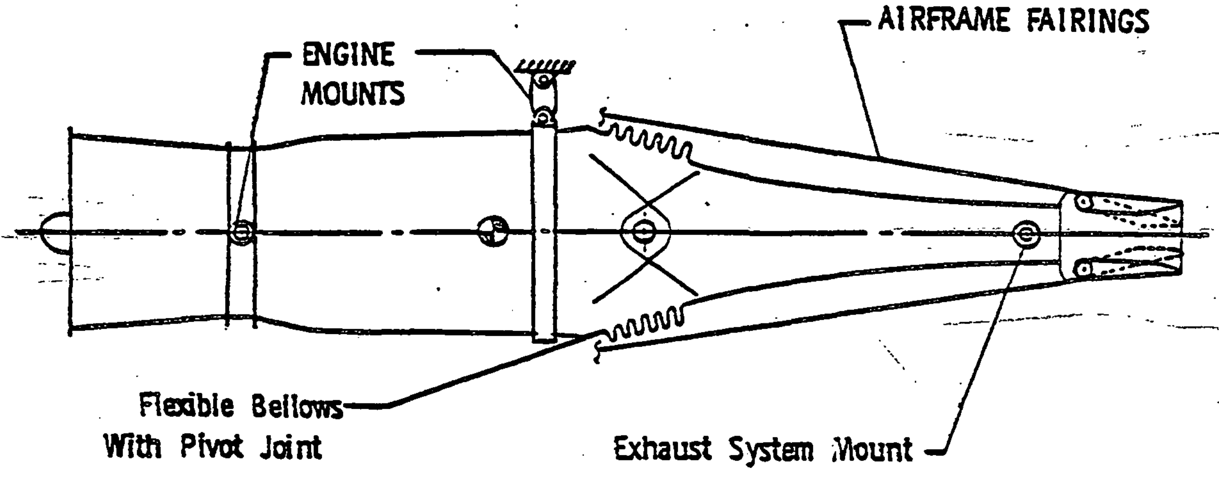


Figure 3.2A.2-4. Potential Mounting Schematic for Configurations No. 1 and No. 2

used with the J85-21. Preliminary evaluation shows this to be possible although the increased airflow requirements of the -21 over the -13 will necessitate a redesigned inlet.

3.2A.2.2 Configuration 3

For this configuration, the only change to the baseline propulsion system consisted of the replacement of the exhaust system with an aspect ratio 4 2D-CD nozzle (see Reference 3.2A.2-7 and Figure 3.2A.2-5). The baseline exhaust system consisted of a convergent nozzle and ejector nozzle combination. Besides improving propulsion performance at supersonic conditions, the ejector nozzle was used to "pump" secondary cooling airflow through the engine compartment. This task would also be required of the 2D-CD nozzle installation.

To compute installed engine performance for this configuration, it was necessary to adjust for the differences in nozzle internal performance plus any difference in external drag. Based on conversations with G.E., it was felt that the impact of the secondary airflow on thrust performance would be similar for the two installations. Thus the procedure used to calculate installed net thrust for Configuration 3 was as follows:

$$F_N' = (F_N + F_{RAM})/C_{fg} * C_{fg}' + \Delta D_{Aft} - F_{RAM}$$

2DCD NOZZLE

AR = 4

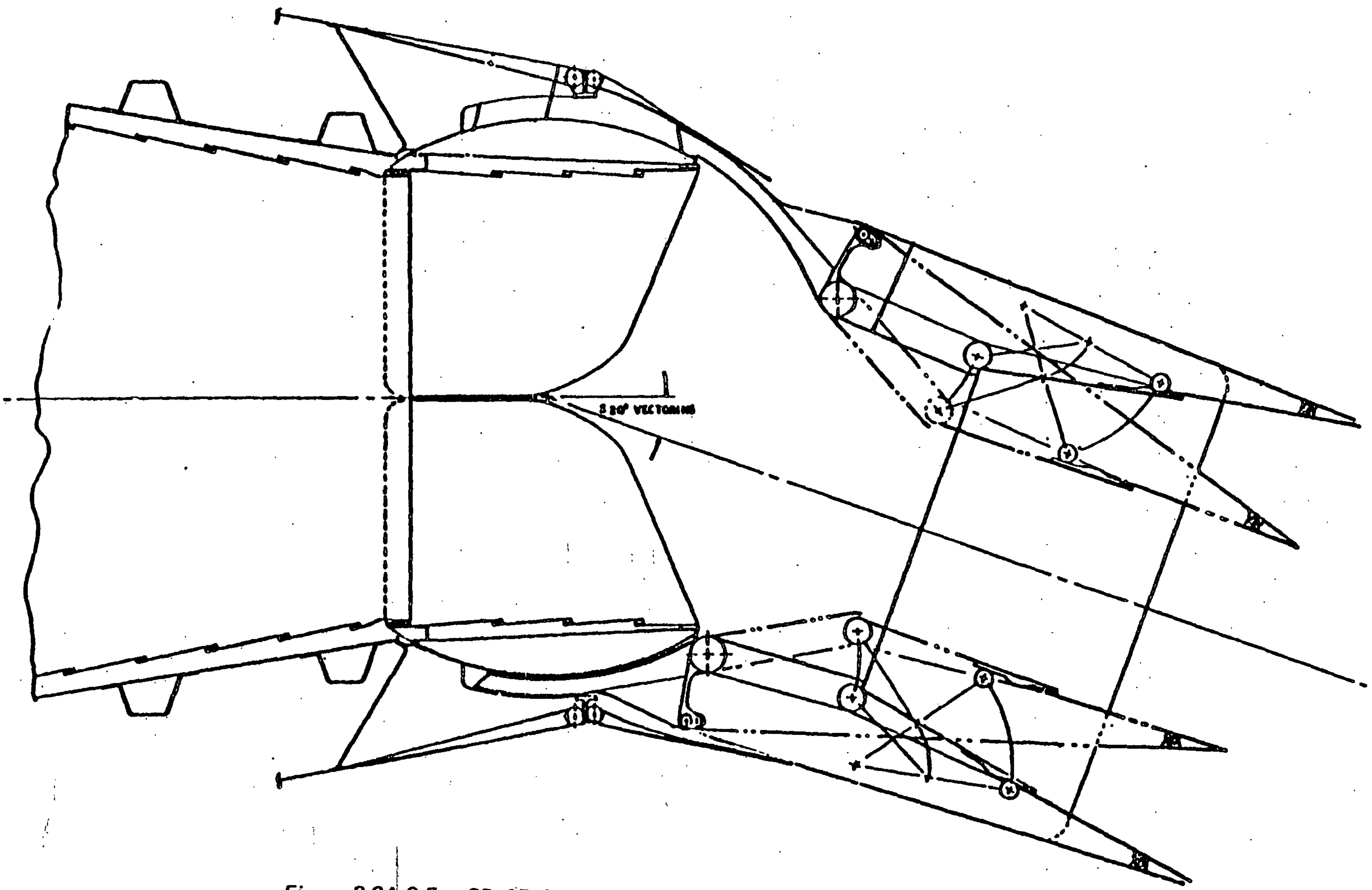


Figure 3.2A.2-5. 2D-CD Nozzle with Aspect Ratio (AR) = 4

where:

F'_N = installed net thrust with 2D nozzle

F_N = installed net thrust with baseline exhaust system (see Reference 3)

F_{RAM} = ram drag

C_{fg} = thrust coefficient of convergent nozzle

C'_{fg} = thrust coefficient of 2D-CD nozzle (see Table 3.2A.2-1)

ΔD_{Aft} = external drag difference between baseline and new exhaust systems ($+\Delta D_{Aft}$ indicates drag benefit)

Table 3.2A.2-2 details the various inputs to the above calculation, while Figure 3.2A.2-6 presents an installed sfc vs. net thrust plot of the data.

Since the only propulsion modification under Configuration 3 was the replacement of the current exhaust system with an AR 4 2D-CD nozzle, it was felt to present the fewest potential problems. The primary area of concern were the modifications to be made to the primary propulsion system. Since this aircraft concept visualizes the nozzle as a primary flight control, extra design work will have to be exercised to insure adequate redundancy in the nozzle actuation system.

In addition, due to the placement of the nozzle below the vertical tail and the location of the speed brake at the base of the tail, there exists the potential of hot gas impingement on aircraft structure and possibly a mechanical interference in the simultaneous operation of the speed brake and T/R. These would be addressed by tailoring of the thrust reverser design during an advanced design phase.

Table 3.2A.2-2. Installed Performance for Configuration No. 3 of F-106 Study

FLT. COND.	PS	F_N	F_G	NPR	C_V	C_{ej}	D_{AFT}	C_{fg}	WFT	F_N'	SFC'
M0./0.	Max A/B	17200	17200	1.88	.99	.976	0.	.966	46000	16783	2.741
	Mil	11650	11650	2.18	.995	.982	0.	.976	11500	11428	1.006
	NR	10450	10450	2.02	.995	.979	0.	.976	9900	10250	.966
	Idle	700	700	1.3	.99	.950	0.	.976	1375	711	1.932
M.2/0.	Max A/B	19400	21190	2.14	.995	.966	16	.966	50250	18798	2.673
	Mil	12300	14090.	2.25	.995	.983	24	.976	12300	12055	1.020
	NR	11000	12735.	2.08	.995	.980	24	.976	10700	10781	.993
	Idle	400	955.	1.3	.99	.945	24	.976	1370	439.	3.114
M.9/30K	Max A/B	12137	15963.	4.13	.97	.990	215.3	.968	28223	12319.	2.291
	Mil	6429	10255.	4.36	.968	.988	471.5	.978	7117	7006	1.016
	NR	5722	9478.	4.09	.97	.987	452.5	.978	6280	6253	1.004
	Idle	353	2370.	1.3	.99	.926	452.	.978	1209	776	1.557
M1.8/40K	Max A/B	14646	26074.	9.4	.925	1.074	138	.970	36034	16052	2.245
	50% A/B	11593	23021	9.8	.925	1.055	138	.980	31399	13100	2.397
	Mil	4907	16335.	10.6	.920	1.037	138	.980	6737	6110	1.103

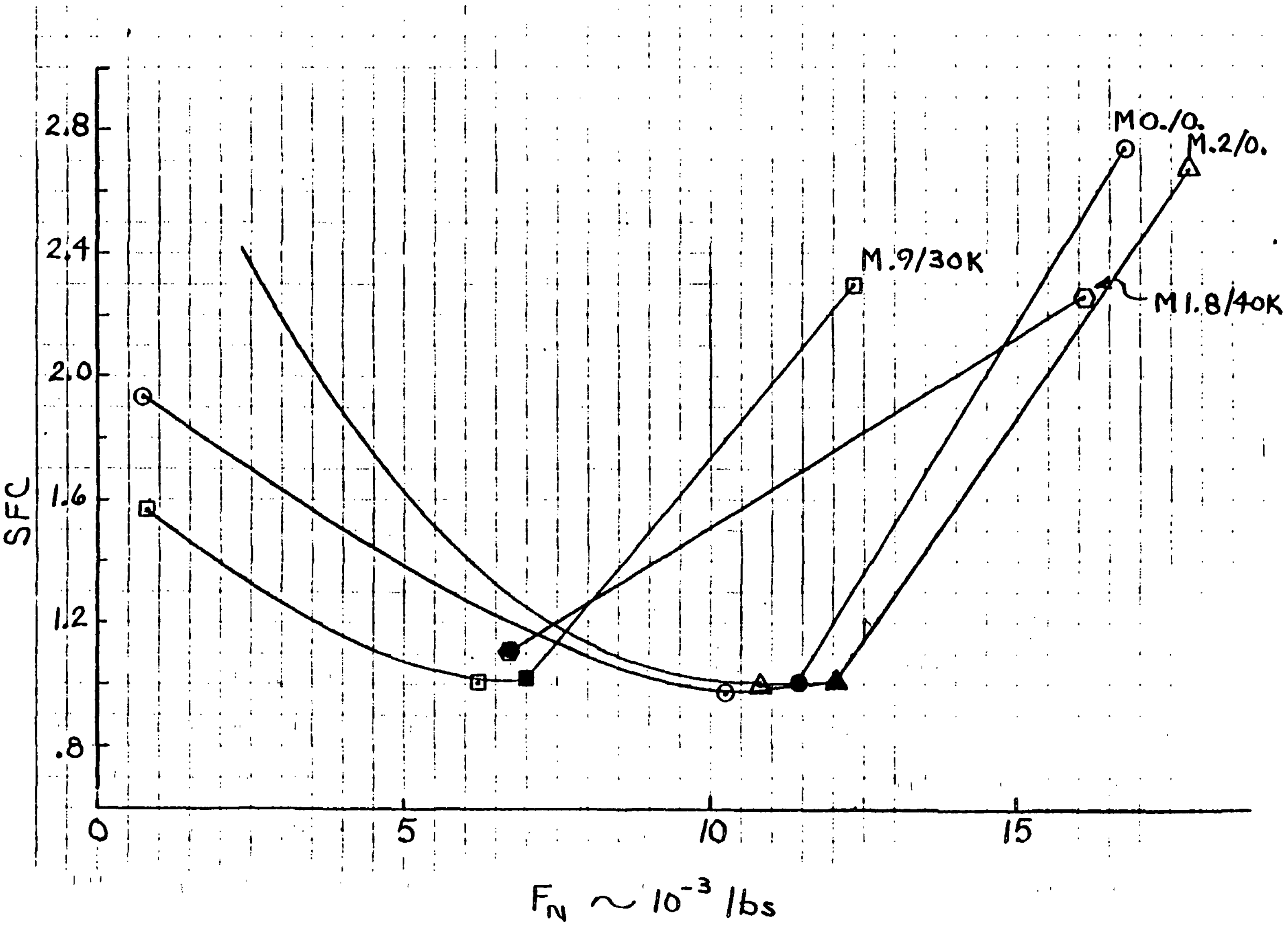


Figure 3.2A.2-6. Configuration No. 3 Installed Performance

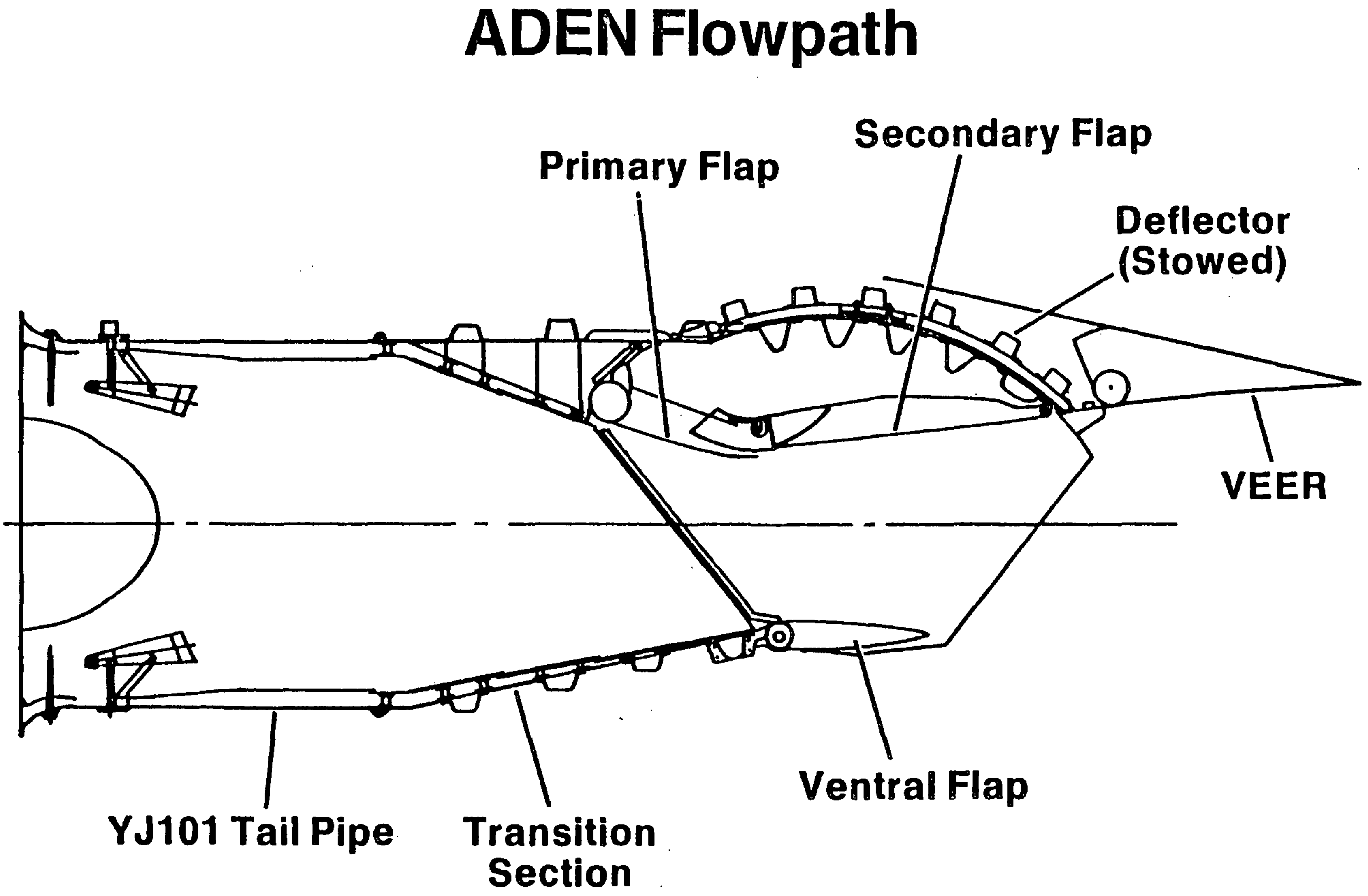
3.2A.2.3 Configuration 4

This configuration consisted of two overwing mounted F404-GE-400 engines equipped with normal shock inlets and ADEN nozzles (see Reference 3.2A.2-7 and Figure 3.2A.2-7). As in Configurations 1 and 2, the baseline propulsion system was left intact.

The PROP computer program was used to compute the installed engine performance from the uninstalled engine data (Reference 3.2A.2-5), the Reference 3.2A.2-2 No. 5 inlet maps, and an IMS generated aftbody drag map. Since airflow bleed and horsepower extraction requirements were unknown, no provision was made for them in the performance calculation. Baseline F404 nozzle internal performance was calculated from equations presented in Reference 3.2A.2-6, while the nozzle internal performance map was the same as used in the Boeing IRAD aircraft configuration 987-335 studies.

Due to installation requirements, this configuration was characterized by a long duct connecting the turbine exit and nozzle customer connect point. The added duct pressure losses associated with this type of installation were not included in the performance calculations. Figure 3.2A.2-8 presents the SFC - net thrust relationship for this configuration. Because of security considerations, the data has been normalized by performance for max power at takeoff.

Configuration 4 represented the most ambitious aircraft modification and, as expected, it exhibits the greatest number of potential problems. Of



ADEN Flowpath

Figure 3.2A.2-7. ADEN Nozzle Flowpath

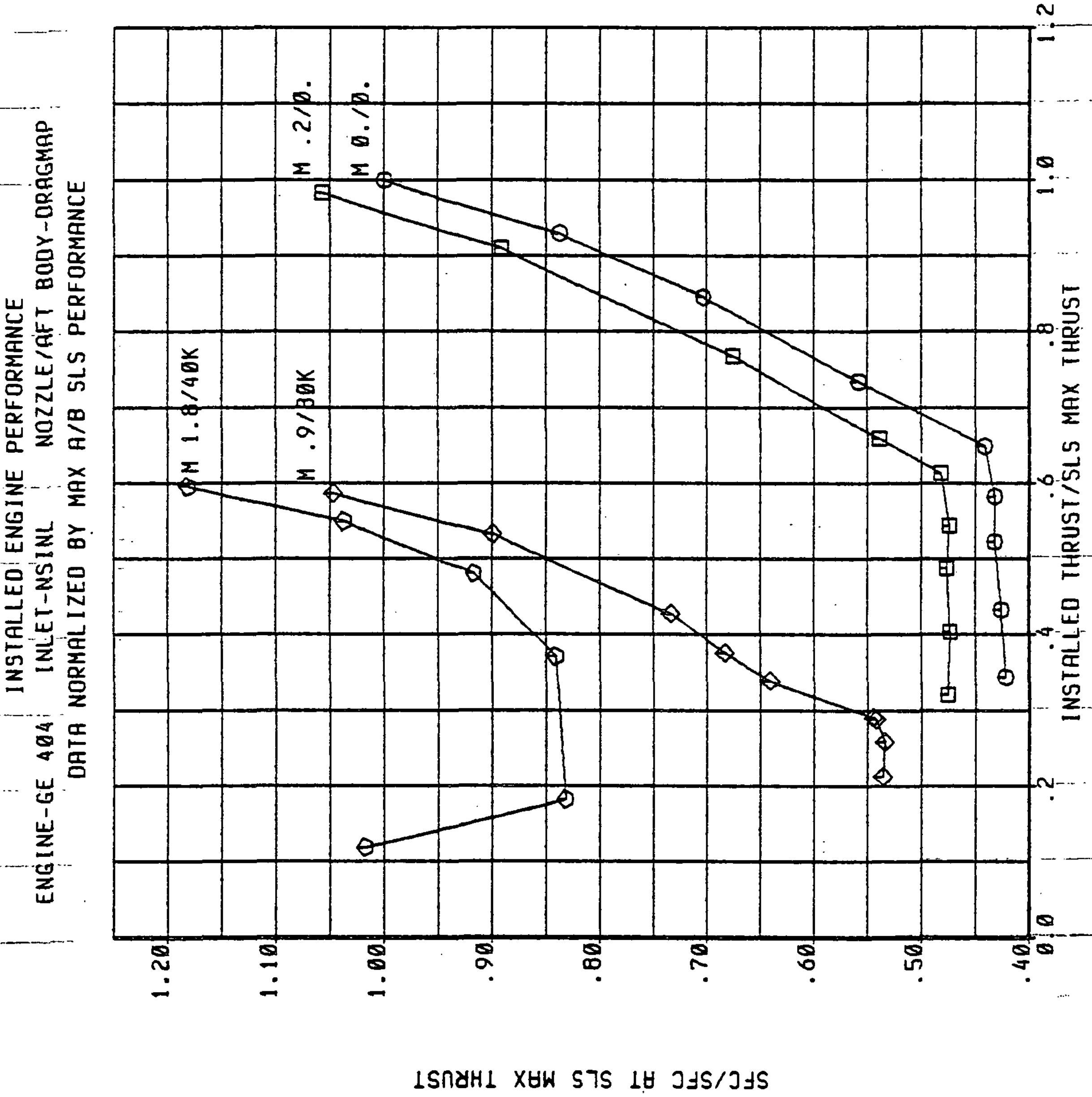


Figure 3.2A.2-8. Installed Engine Performance for Modification No. 4

greatest concern are the adverse effect of canard operation on the F404's inlet performance, the close proximity of the J75 and F404 inlets, afterburner design, thrust reverser design and placement, and fuel distribution.

Because of the location of the F404's inlet with regard to the canard, a concern exists for the possibility of ingesting canard tip vortices (particularly at high angles of attack) or for the canard to affect inlet airflow quality in general. In addition, the close proximity of the J75 and F404 inlets raises concern for adverse interaction between the inlets on airflow quality.

The afterburner design for the F404 is another potential problem area due to the long duct length between the engine and nozzle. Cooling and A/B stability considerations would dictate the placement of the afterburner equipment near the nozzle. This placement, in turn, could present light-off and possible A/B blow out problems due to the long duct length.

The use of the ADEN nozzle and its placement in this configuration present problems in designing a simple, effective, low weight thrust reverser. Care will have to be taken in the T/R design to avoid hot gas impingement and/or adverse pitching moments.

Finally, due to the size of the F404 engines, the additional fuel flow demand placed on the aircraft fuel distribution system's capacity could necessitate modifications or redesign. This redesign could entail only a resizing of the boost pumps or may require a more complex effort. A detailed examination will be needed to fully answer this question.

3.2A.3 Mechanical Systems

The four proposed configurations required by the F-106B nozzle feasibility study are shown in References 3.2A.3-1 to -4. Table 3.2A.3-1 shows the impact of the 2-D nozzle modifications on the secondary power systems of the NASA F-106B research aircraft. As shown, the pneumatic power systems will be unaffected by the modifications. Minor additions to the electrical system are required due to additional control systems for the 2-D nozzles and the additional aerodynamic control surfaces for Configurations 2 and 4, but these will not impact the existing system. Modifications to the hydraulic power system will be required for each of the four proposed configurations.

The modifications of the hydraulic system, Reference 3.2A.3-5, for the four configurations cause the hydraulic power demand to increase. For the first three configurations the increase in demand will not exceed the reserve capacity of the hydraulic generation system for the NASA F-106B aircraft. In the fourth configuration, demand may exceed capacity. A discussion of the hydraulic system capacity and demand follows.

Baseline F-106B hydraulic system demands required for the air-to-air combat maneuvering situation do not exceed 29.6 gpm, per Reference 3.2A.3-6. Total nominal hydraulic system capacity is 46 gpm at 100% N_2 rotor rpm. A M61A1 gun modification to the F-106B aircraft included incorporation of larger pumps, increasing this capacity to 51 gpm. This change may not have been incorporated in the NASA research aircraft. Therefore, we assume the reserve pump capacity is 16.4 gpm (46-29.6).

Table 3.2A.3-1. Mechanical/Electrical Technology F-106 System Modifications for Configurations 1 - 4

ITEM	CONFIGURATION NO.			
	1	2	3	4
Elevon	-	X	-	X
Rudder	-	X	-	X
T-Tail	-	X	-	-
Canard	-	-	-	X
Nozzle	X	X	X	X
Secondary Power				
A) Hydraulic	-	X	-	X
B) Electrical	-	-	-	-
C) Pneumatic	-	-	-	-
Starting Aux, Engines	?	?	-	?

- No effect

X Modification

? UNDETERMINED

For Configuration 1, the modifications involve installation of two auxiliary J-85 engines, and 2-D nozzles and controls, as shown in Figure 3.2A.3-1. Since the hydraulic power required by the 2-D nozzles is expected to be low, Reference 3.2A.3-7, the reserve capacity will be sufficient to meet the increase in demand.

The modifications required for Configuration 2, the installation of the two auxiliary engines and 2-D nozzles, and the installation of an F-101 T-Tail as a pitch trim control device, Figures 3.2A.3-2 through -5, cause an increase in the demand on the hydraulic system. The F-101 rudder installation and elevon modifications will either slightly decrease or not affect the hydraulic power demand. These modifications will cause an increase in the hydraulic power demand, but the increase is less than the reserve capacity of the hydraulic system.

The modifications required for Configuration 3, Figure 3.2A.3-6, is the installation of a 2-D nozzle and controls on the existing J-75 engine. This modification will cause an increase in the hydraulic power demand, but less than the reserve pump capacity.

The modifications required for Configuration 4, the installation of two canard surfaces and the installation of the two auxiliary engines with 2-D nozzles and controls, and the modification of the F-106B rudder and elevon surfaces, Figures 3.2A.3-7 through -9, will increase the hydraulic power demand. In addition, reduced main engine (J-75) thrust levels during low aircraft speed nozzle testing, causing N_2 rotor speed to

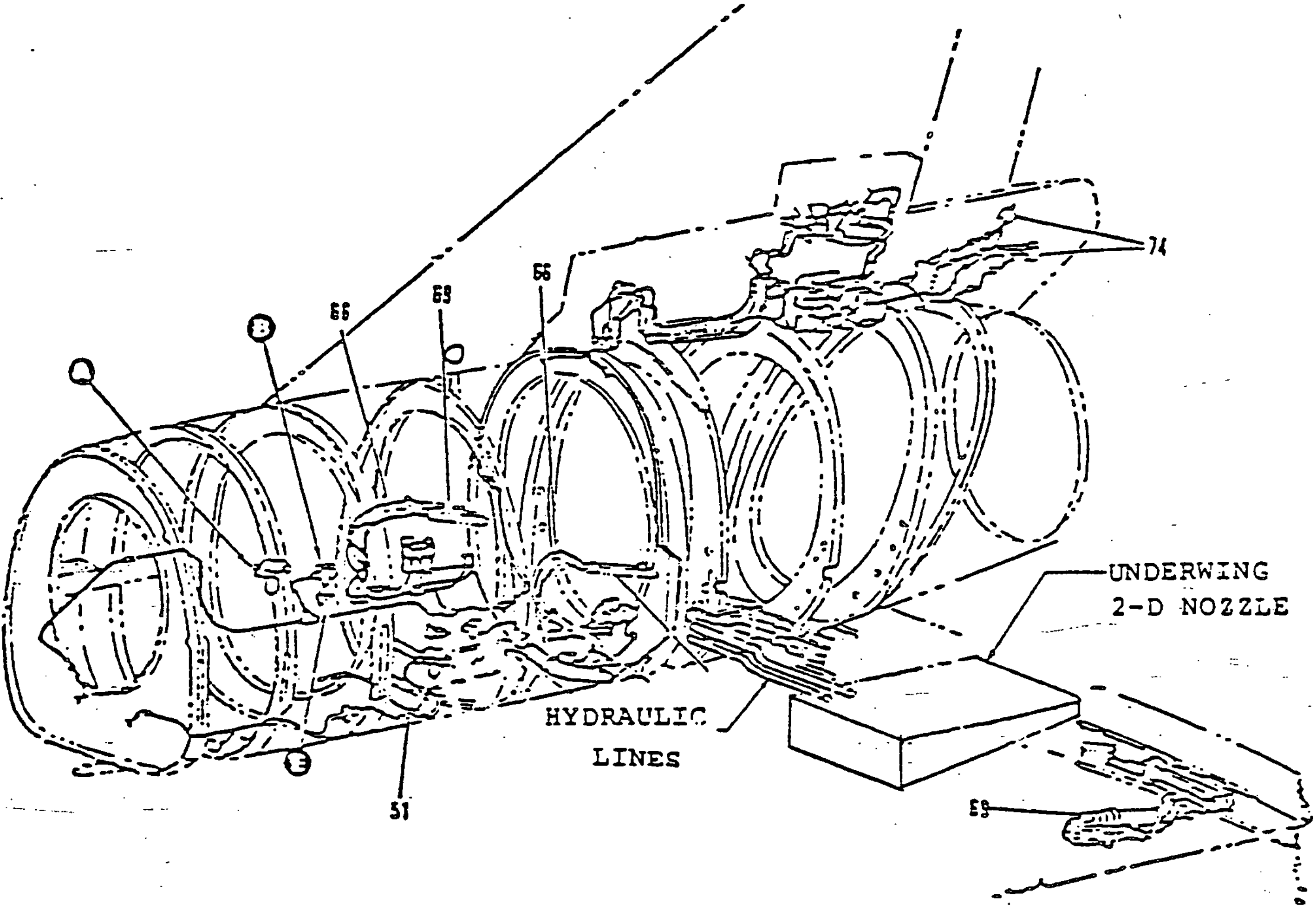


Figure 3.2A.3-1 F-106B Hydraulic System Configuration No. 1

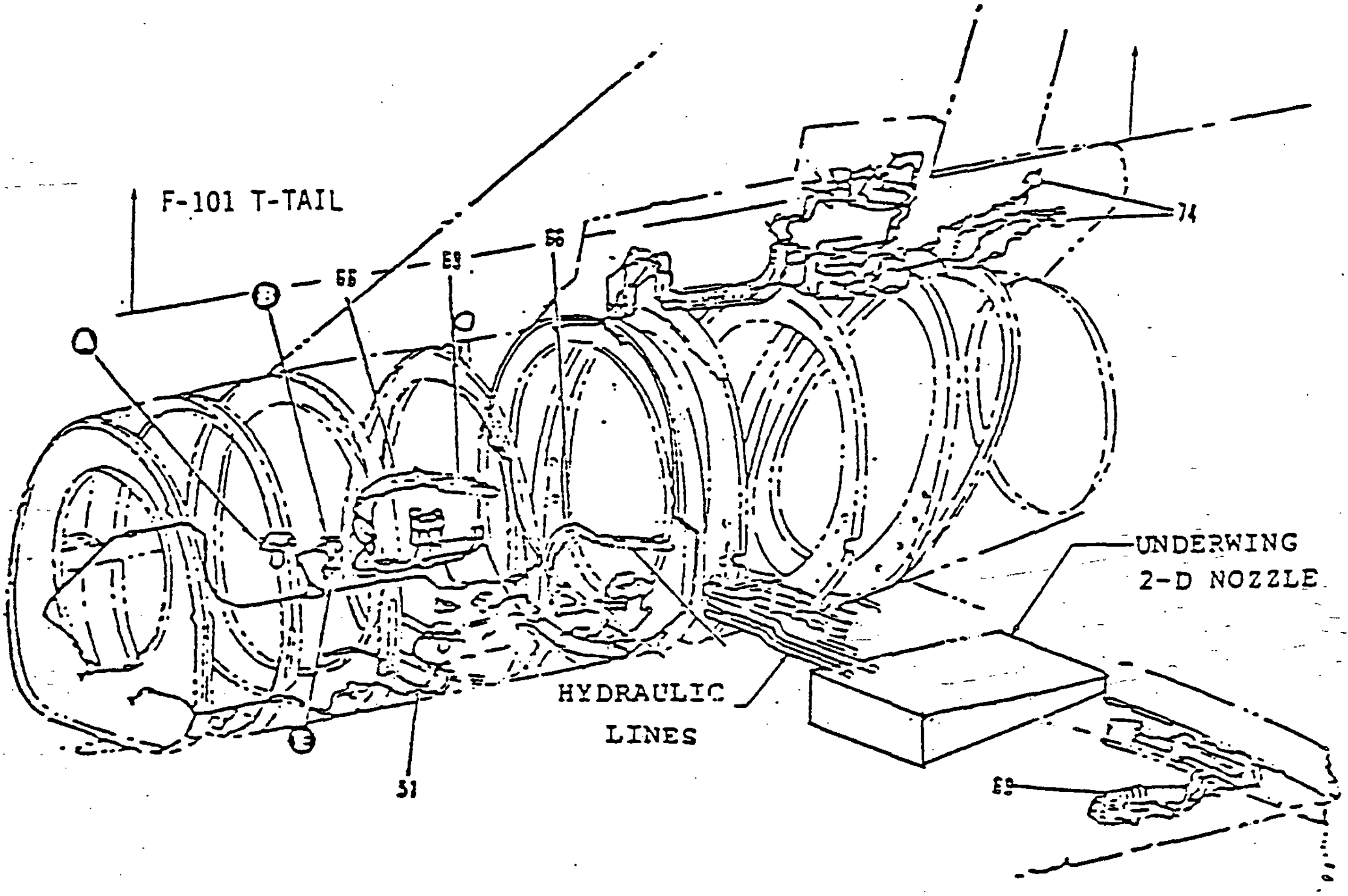


Figure 3.2A.3-2. F-106B Hydraulic System Configuration No. 2

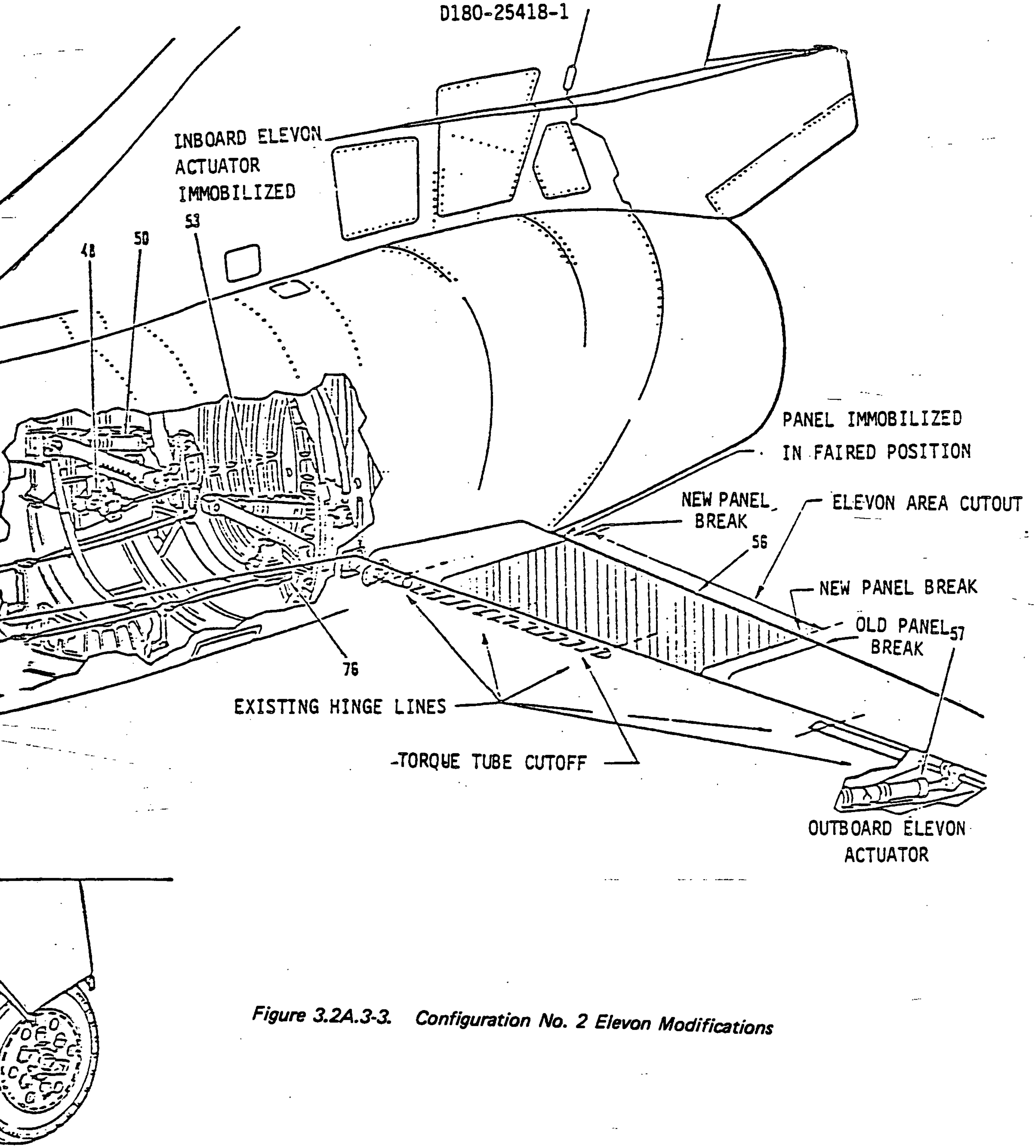


Figure 3.2A.3-3. Configuration No. 2 Elevon Modifications

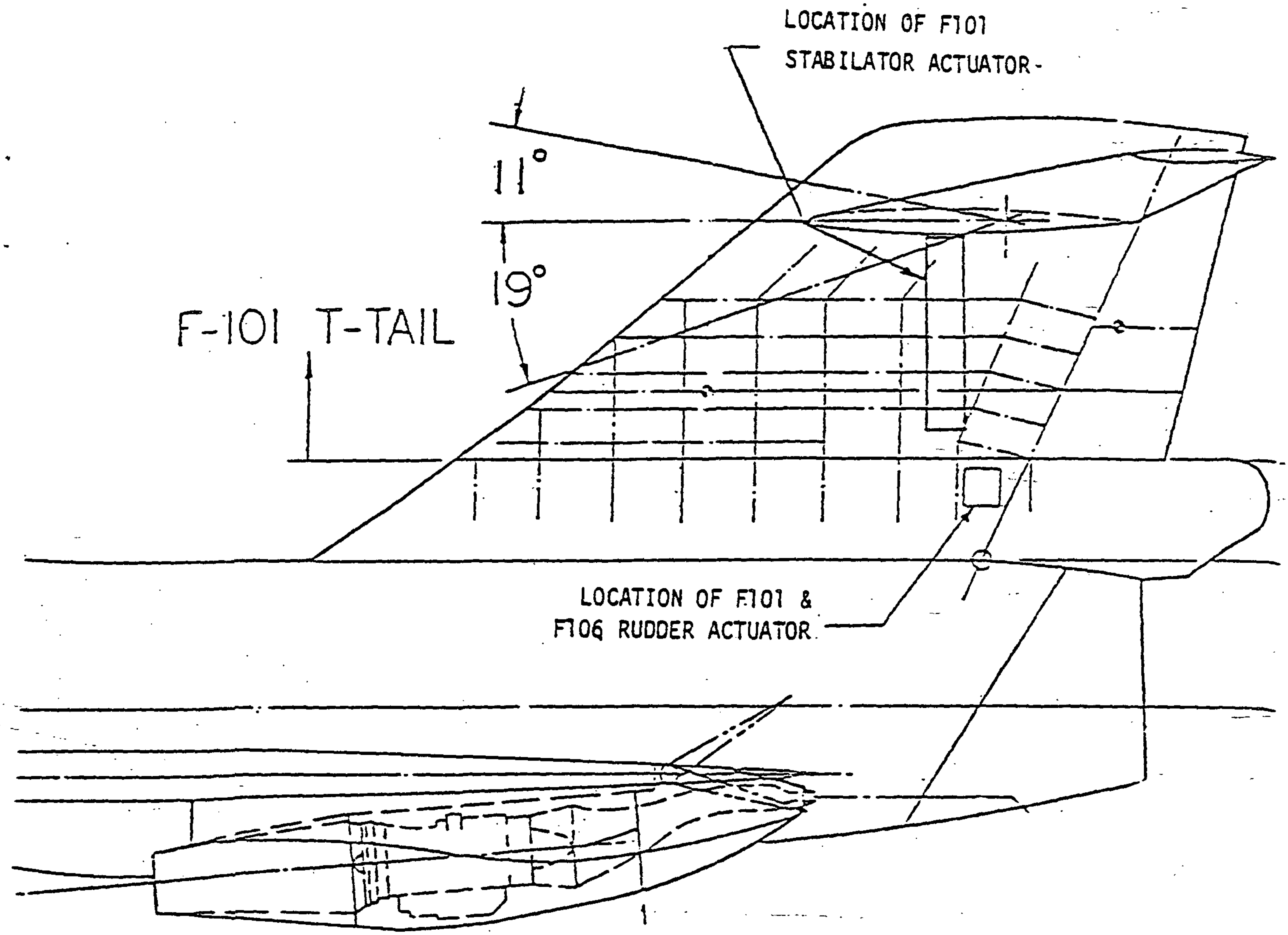


Figure 3.2A.3-4. F-101 T-Tail Empennage on F-106 Fuselage

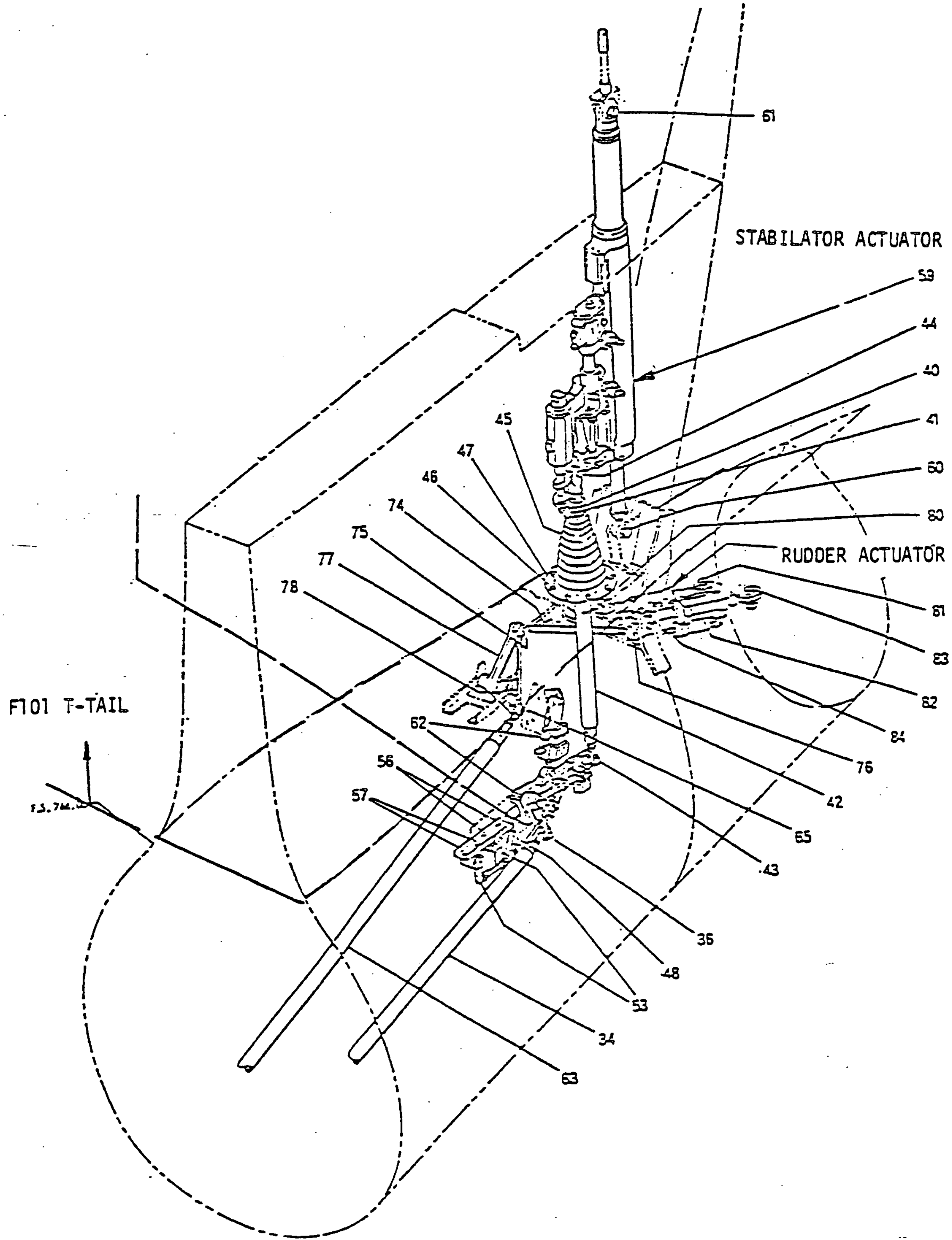


Figure 3.2A.3-5. F-101 Empennage Controls

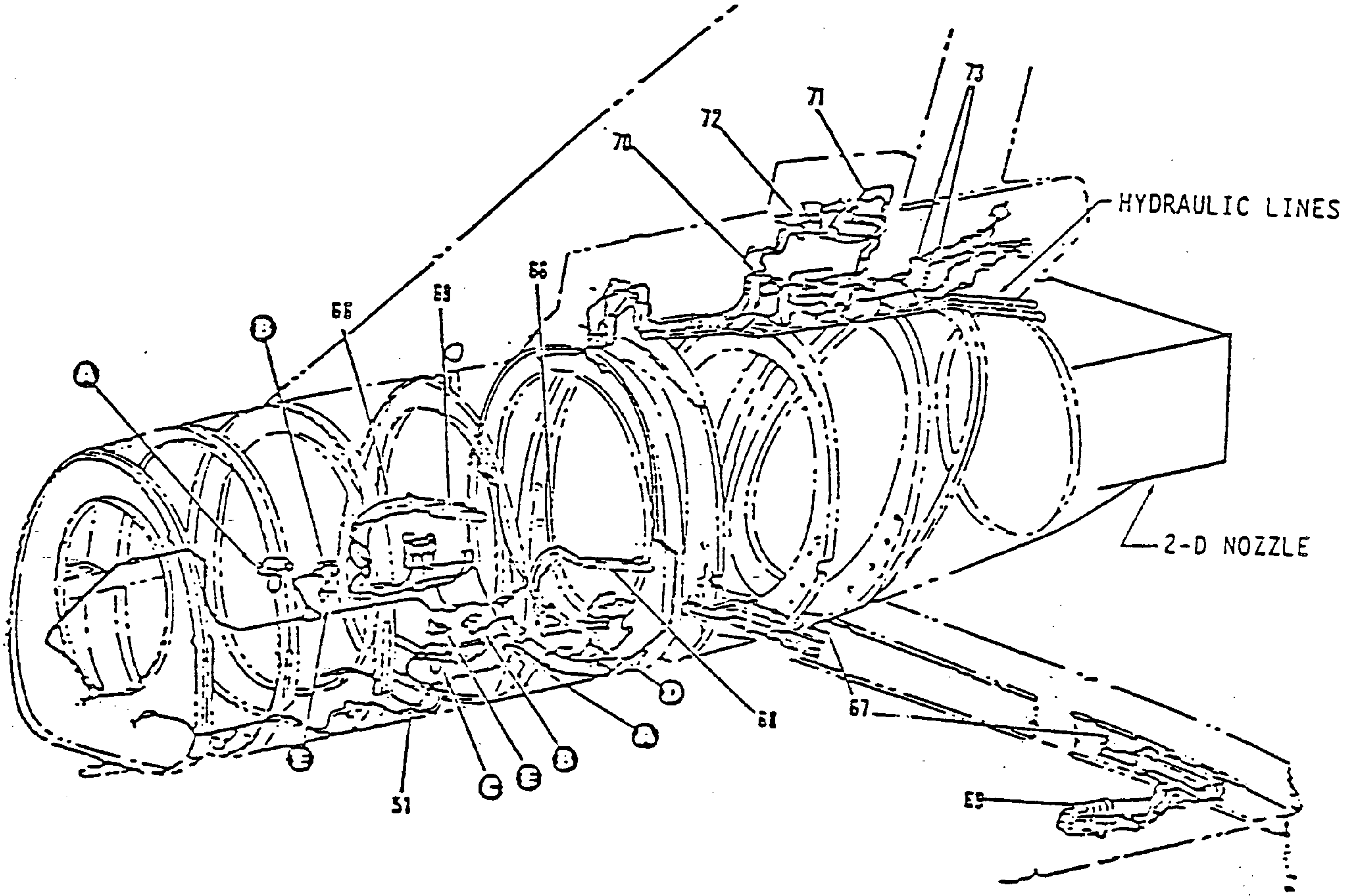


Figure 3.2A.3-6. F-106B Hydraulic System Configuration No. 3

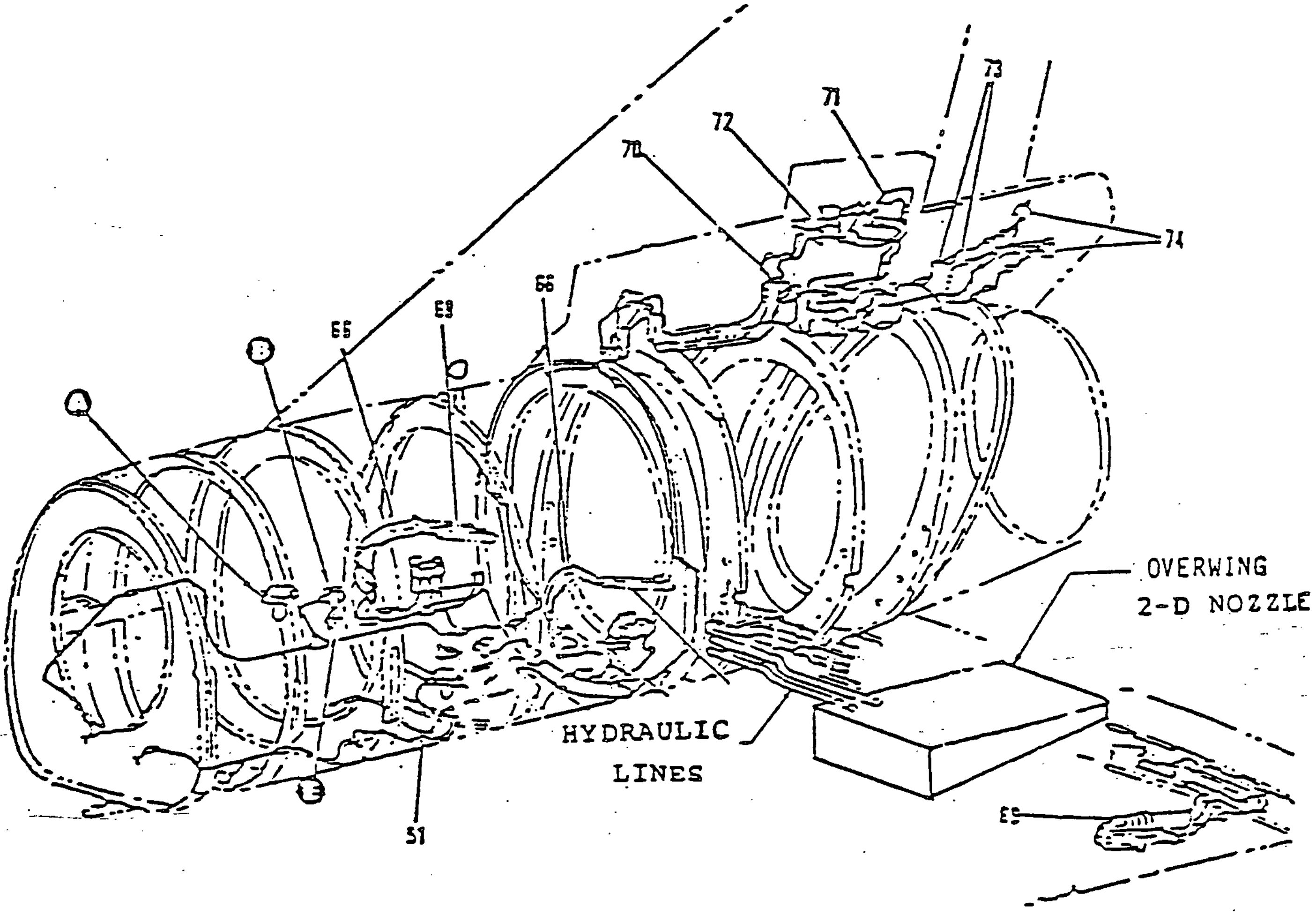
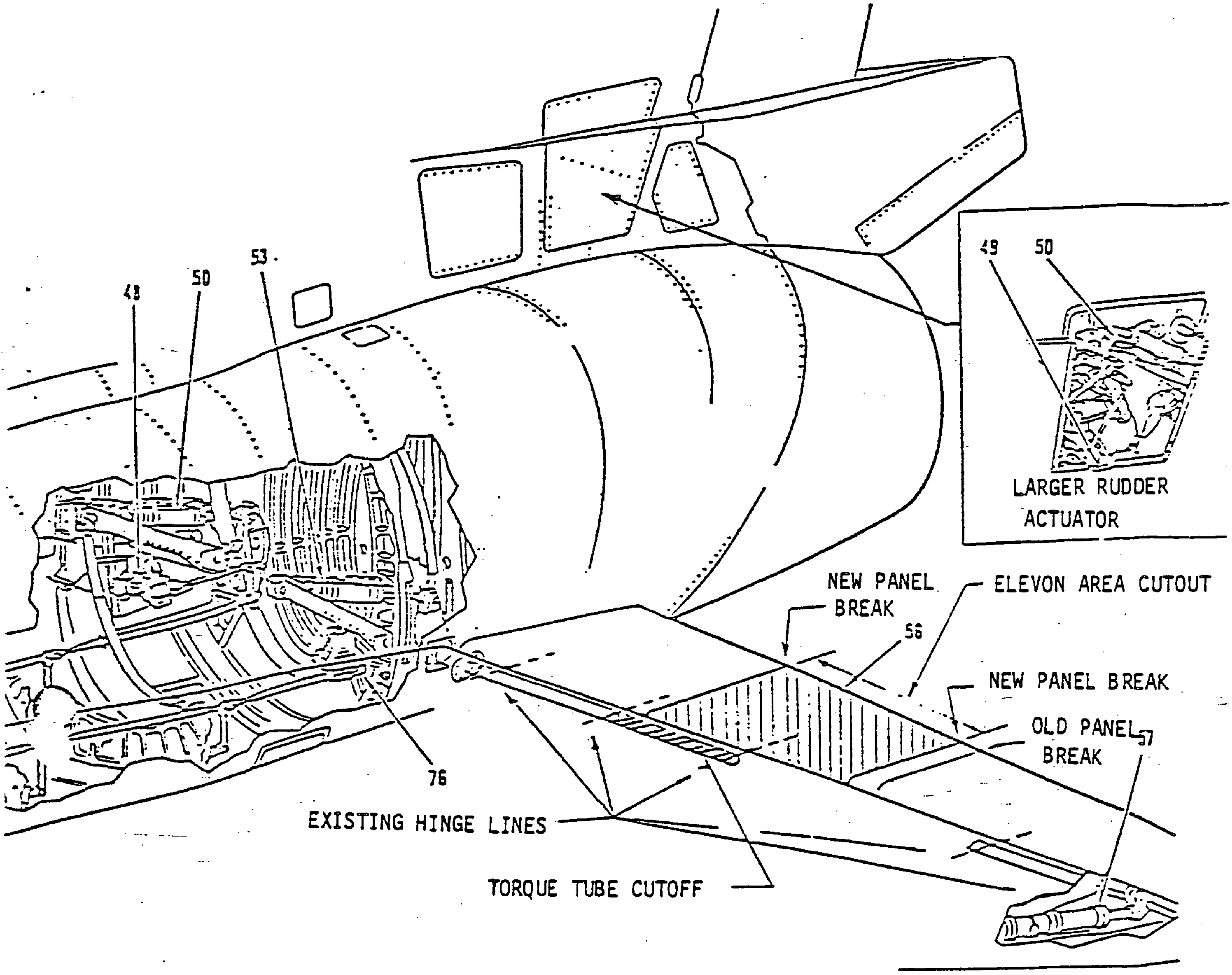


Figure 3.2A.3-7. F-106B Hydraulic System Configuration No. 4



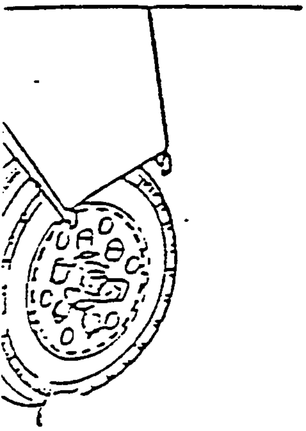


Figure 3.2A.3-8. Configuration No. 4 Elevon Modifications

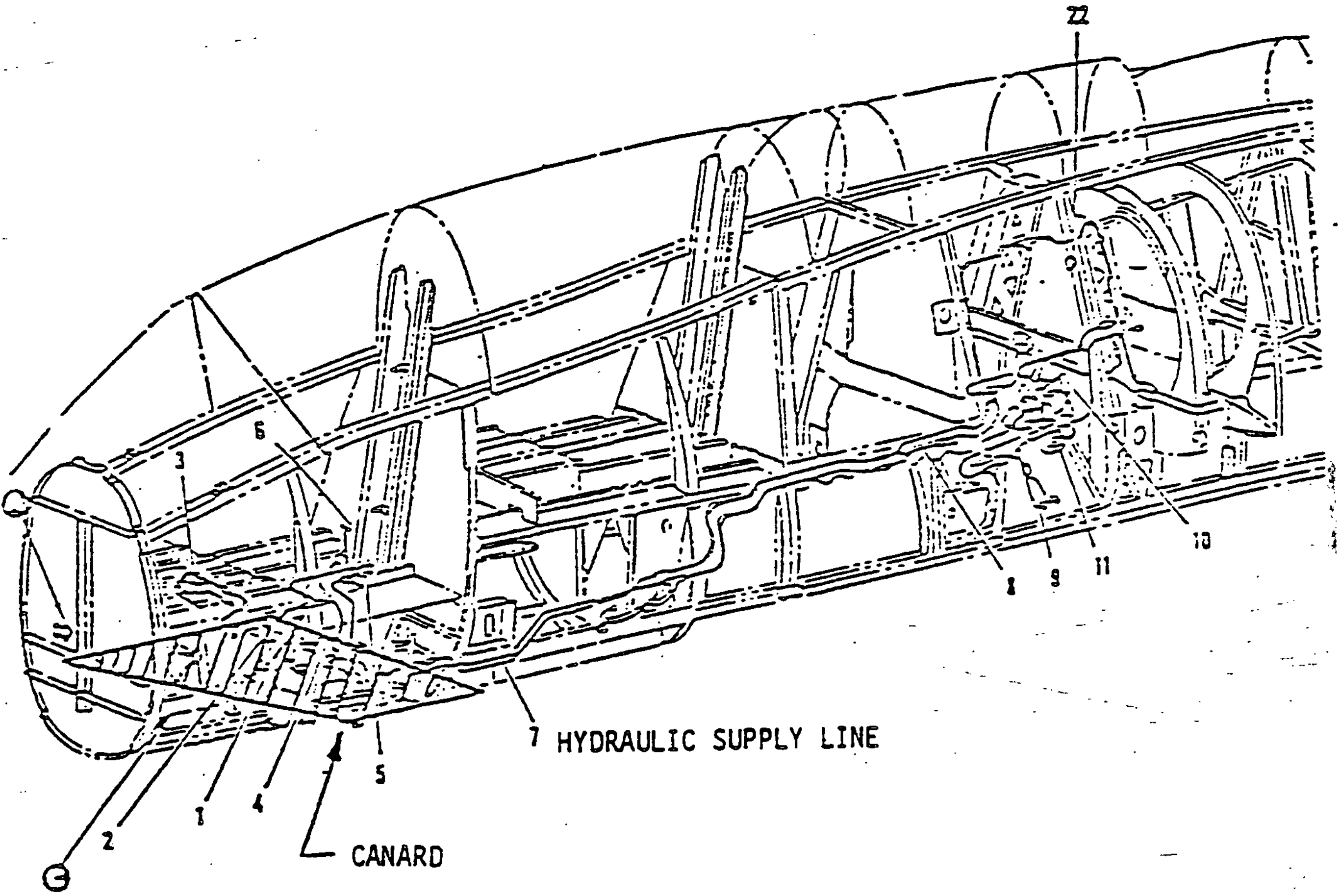


Figure 3.2A.3-9. Configuration No. 4 Canard Surfaces

decrease, results in reduced hydraulic pumping subsystem capability. The increase in demand and the decrease in hydraulic power available may result in insufficient hydraulic power to meet system demands.

Recommendation for the improvement in hydraulic system capability for Configuration 4 is as follows:

1. Installation larger hydraulic pumps in the primary and secondary hydraulic system.

2. Restrict airplane maneuver g limits to keep primary and secondary hydraulic system demand within the capacity of the currently installed pumps.

3. Remove the inboard elevon actuators and replace with smaller actuators designed to match the proposed inboard elevon aerodynamic surface modifications.

3.2A.4 Structures

This section provides discussion of general structural requirements for flight test vehicles, available strength in the 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 reduced these to 4.5 and -1.0 for design of the nacelle and its attachments. However, when large amounts of ballast are required the strength of the fuselage will not permit maneuvers to 4.5g.

Margins of safety on the existing NASA J85 flight test nacelle structure are less than .25. The lowest margins of safety are .07 in bearing and

.13 in bending. The structure will have to be analyzed in detail to accomodate vectoring capability.

Flutter clearance was previously obtained by NASA by demonstrating no flutter at .2 Mach above the required flight profile. The result for the two heaviest nacelles 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 to demonstrate maneuvers with vectoring.

Engine Installation Considerations

Both the J-85 and F-404 engines are intended for buried fighter-type installation rather than pod mounting where the inlet loads are carried by the compressor casing. The nacelle must therefore be designed to carry inlet and nozzle loads with the engine suspended inside. The nacelle assembly must then be suspended from 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.

The existing NASA J-85 nacelle is supported by fore and aft mounts which carry vertical and side loads and a load cell which reacts and measures for and aft loads. This arrangement can still be used but the single load cell measurement cannot be used with thrust vectoring. A more complex arrangement of strain gages would be needed to measure total nacelle forces and moments.

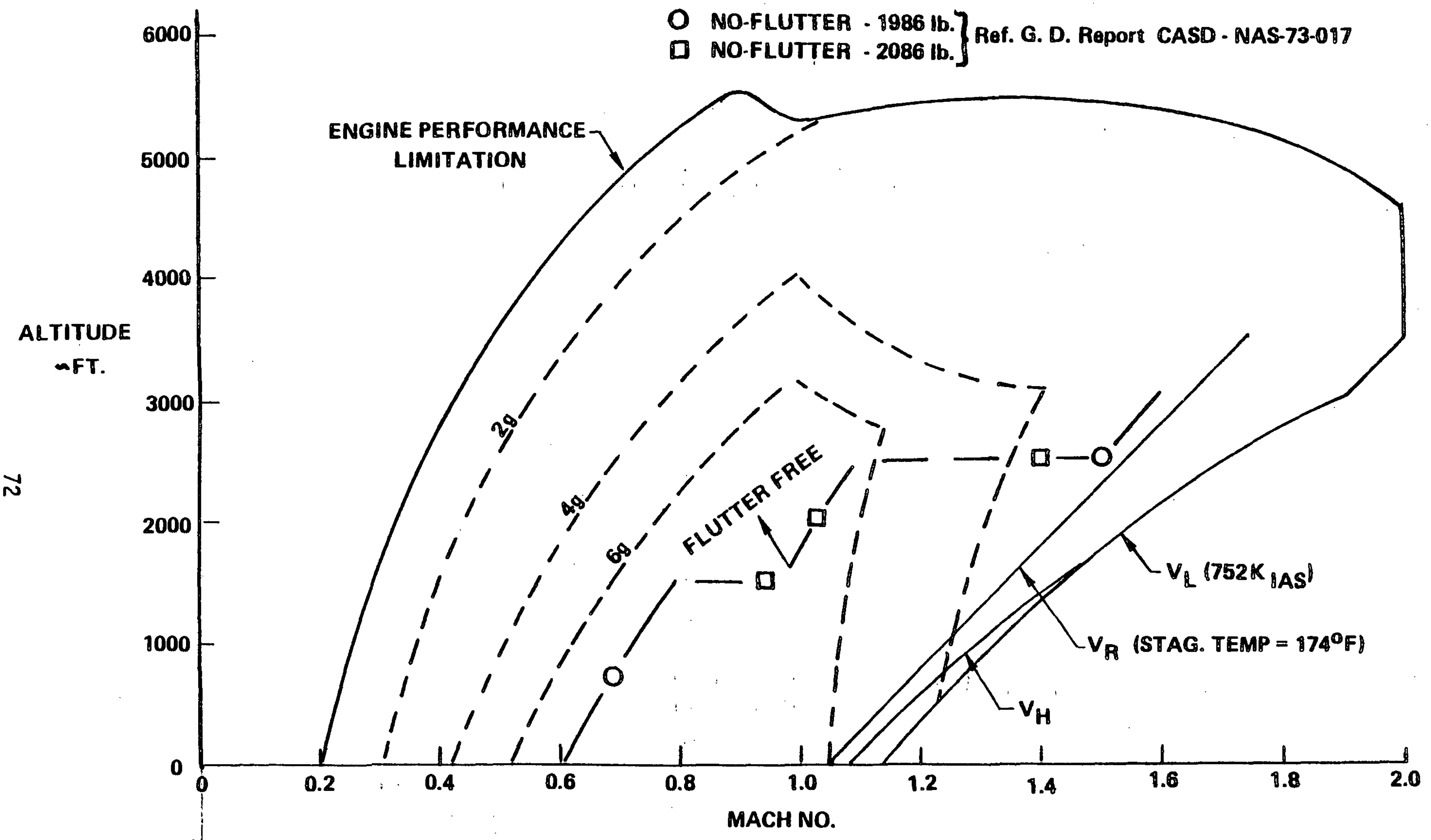


Figure 3.2A.4-1. Load Factor Capability F-106B W = 34780 lb. and J-85 Flight Flutter Results.

NOTE: MULTIPLY ORDINATE SCALE BY 10

A significant portion of the vertical nacelle load is due to aerodynamic interference with the lower surface of the wing. If this program procedes to the hardware stage it will be necessary to measure nacelle airloads in a wind tunnel with thrust vectoring.

Use of thrust reversers could require modification of the F-106 primary structure to replace aluminum with titanium or steel.

Modification No. 1.

This airplane is essentially the existing F-106B test bed without the elevon cut-out and with added thrust vectoring. While the nacelle support structure may require modification due to vectoring loads and the nacelle itself may have to be strengthened to take additional bending loads there are no major flaws to this configuration. Without proof loading the nacelle maneuver load factors would be limited to 3.6 (.8 x 4.5). Limiting flight to subsonic speeds below 25000 ft. as shown on Figure 1 should not affect flight demonstrations.

Modification No. 2

In this installation a portion of the elevon is fixed and thrust vectoring is used to induce lift. If this lift occurs primarily over the inboard part of the wing there should be no restrictions other than those for configuration 1. The addition of the fin and horizontal tail from an F-101, while feasible, will require considerable re-work and a structural adapter.

Design limit loads for the F-101 vertical and horizontal tails are 26000 lb and 34000 respectively. Design vertical tail load for the F-106 is 23000 so the basic structure should be adequate.

However, the additional rolling moment due to the T-tail may require strengthening of the F-106 fin attachment frames. The tail was flutter free to M = .95 at sea level (628 knots) and M = 1.85 at 40000 ft. but considerable analysis and testing will be required before these speeds can be approached. This should not affect a flight demonstration of thrust vectoring.

Modification No. 3

It is assumed that the vectoring nozzle loads will be carried by the aft fuselage structure since the engine casing has not been designed for high bending moments. The strength summary does not indicate low margins of safety anywhere in the aft fuselage so the existing structure should be adequate under vectoring loads.

When vectoring a center-line engine, attention must be given to vectoring in the opposite sense to a maneuver. Upward vectoring during a positive maneuver will increase the amount of lift to be carried by the wings and could lead to exceeding the design loads.

Modification No. 4

The addition of two overwing mounted F-404 engines and a canard control surface results in an extensively changed (high risk) configuration.

The canard is attached to the forward pressure bulkhead which may complicate the modification and will interfere with removal of the nose access doors where NASA have installed much of their data recorders. The strength summary does not indicate any low margins of safety in the forebody so it may be able to carry the canard loads without extensive modification.

Studies by General Dynamics have shown a maximum weight capability (ballast or equipment) of 1294 lb in the nose without reduction of the 6g maneuver load factors. Increasing this would require reduction in allowable load factors and could affect demonstration of lift enhancement.

The overwing nacelles will have considerable impact on the lift distribution. Such nacelles usually result in loss of lift locally so that the outboard wing will be more highly loaded. Spars 3, 4, 5 and 6 all show only small positive margins under current design loads so that allowable load factors will probably be further reduced. In any case, the flight demonstration will be limited due to the increase in OW from 25986 lb to 37261 lb. With the design fuel load of 60% normal fuel, the flight weight of 42238 lb. would reduce the allowable load factor to 4.9g without accounting for increased airloads on the outer wing. Reducing this 10% for airload redistribution, the 80% limit load flight placard would be 3.5g.

The strength summary shows small positive margins of safety during taxi and turning on the main gear at a weight of 40069 lb. The -1 handbook specifies a maximum weight of 43500 lb. so that any increases over this as a takeoff weight would risk damaging the gear.

No flutter studies have been done with a large mass simulating the proposed nacelle configuration. Since it is ahead of the wheel well, the tendency is for the engines to act as if they were body-mounted. This configuration cannot therefore be declared unsatisfactory from a flutter standpoint but a large effort would be necessary to assure safety of flight.

Any increase in vertical tail area carries the risk of requiring a beef-up but the strength summary does not indicate any low margins of safety on the fin or aft body. Low margins occur on the rudder near the actuator but they should not change provided the actuator is not changed.

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. Use of thrust reversers will require changing some of the F-106 primary structures from aluminum to titanium or steel.

3.2A.5 Flight Controls

SUMMARY

Preliminary flight control analyses have been completed for F-106B nozzle research study modifications. All modifications require restrictions on minimum operating speeds, nozzle vectoring angles, or maximum allowable thrust. Aerodynamic data, with appropriate adjustments for each modification, used for the analysis is that of Reference 3.2A.5-1. C.G. envelope is that of References 3.2A.5-2, 7 and 8.

Modification No. 1 can maintain control about all three axes for all nozzle deflections and engine failures, so long as a minimum speed of 150 knots is observed when operating the auxiliary engines.

Modification No. 2 can maintain control about pitch and yaw axes for all nozzle deflections and J85-21 engine thrust conditions analyzed. Roll control cannot be maintained with any engine failure at low speeds and is marginal at transonic speeds. The aircraft can be operated in these regimes if, following engine failure, the throttle of the good engine is retarded and allowance made in the operating envelope for the resulting transient. Verification of the acceptability of this procedure would have to be made using flight control simulation analyses.

Modification No. 3 has an effective trailing edge up nozzle deflection limit of zero and a positive or trailing edge down nozzle limit of 20° for max A/B power at low speeds. These limits are necessary to provide control for maneuvering above trim requirements for low speed operations. Control is adequate for 30° of A/B vectoring at transonic conditions.

Modification #4 incorporates the higher thrust F-404 engines and a canard. Longitudinally, the forward CG limits the angle of attack, for which 30° of transonic A/B thrust vectoring could be demonstrated, to 10 degrees. Modification No. 4 has low speed engine-out control limitations about all three axes. Directional control on the ground must be maintained by limiting the GE404 engines to military power in case of failure of one engine. Available lateral control, with an engine failure, limits F404 engine thrust to military power and zero thrust vectoring at low speeds, and military power with 20° thrust vectoring at transonic Mach Numbers. These limitations could be operationally circumvented if procedures are followed such that following a 404 engine failure, the thrust of the good engine is retarded and allowance made in the a/c operating envelope for the resulting transient. Such a procedure, including consideration of spin/stall characteristics, must be verified by simulation studies. This configuration nevertheless has hazardous flight control characteristics at high power settings and low forward speed should a 404 engine fail near the ground. This configuration was not intended to be considered for STOL flight research, and substantial reconfiguration would need to be investigated if this were to become an objective.

Analyses were also performed to determine potential improvement in maneuverability, incremental load factor, for each configuration with nozzle vectoring. Modifications No. 2 and 4 had positive increments on the order of 3/4 "g" transonically. Modification No. 2 had the greatest controllable increases. Modification 4 has the greatest potential load factor increments, but available control limits the useable load factor to less than that of No. 2. Modification #1, configured as a "nozzle test bed", is not intended to realize any maneuver benefit. Similarly, Modification #3 is intended to research the nozzle as a pitch control device; about .2"g" sustained transonic maneuver can be effected if the nozzle trailing edge is deflected up, thus enabling increased wing lift by deploying the elevons trailing edge down. Note that negative nozzle deflections are limited to 0° at low speed, due to control power restrictions. Therefore, to achieve the transonic maneuver benefit, maximum nozzle deflection must be scheduled with airspeed.

DISCUSSION

Modification No. 1 has two J85-21 engines added beneath the wing with vectorable nozzles. For this configuration, no induced lift due to thrust vectoring is assumed. Sufficient elevon control is available to trim maximum thrust vectoring (±30°) at all speeds for elevons trailing edge up and above 150 knots for elevons trailing edge down, see Figure 3.2A.5-1. The variation in trimmable speeds is due to an elevon authority limit of +8° trailing edge down and -25° trailing edge up. Rudder power is sufficient to provide control for maximum non-symmetrical engine thrust at all operating speeds, Figures 3.2A.5-2 and 3.2A.5-3. Minimum ground control speed was not determined because the location of the J85 engines behind the main gear, does not permit engine ground operation. For a failure condition of a nozzle hardover (±30°), with maximum engine thrust, control can be maintained about all three axes for all operating speeds, Figure 3.2A.5-4.

Modification No. 2 replaces the F-106B empennage with an F-101 empennage plus an adapter for the vertical tail-fuselage attachment. The mod also adds two J85-21 engines with thrust vectoring beneath the wings, which produces favorable induced lift. The F-101 horizontal tail is used for

F-106 V.T. with ENGINES AT B.L.=23.39

MAX A/B 2 J85-21 ENGINES

C.G. = .305 c̄

- ASSUMES NO INDUCED EFFECT FROM THRUST VECTORING ON WING
- δ_e at THRUST VECTORING EQUAL ZERO ARE TRIM REQUIREMENTS WT=32,000#

- MODIFICATION NO. 1

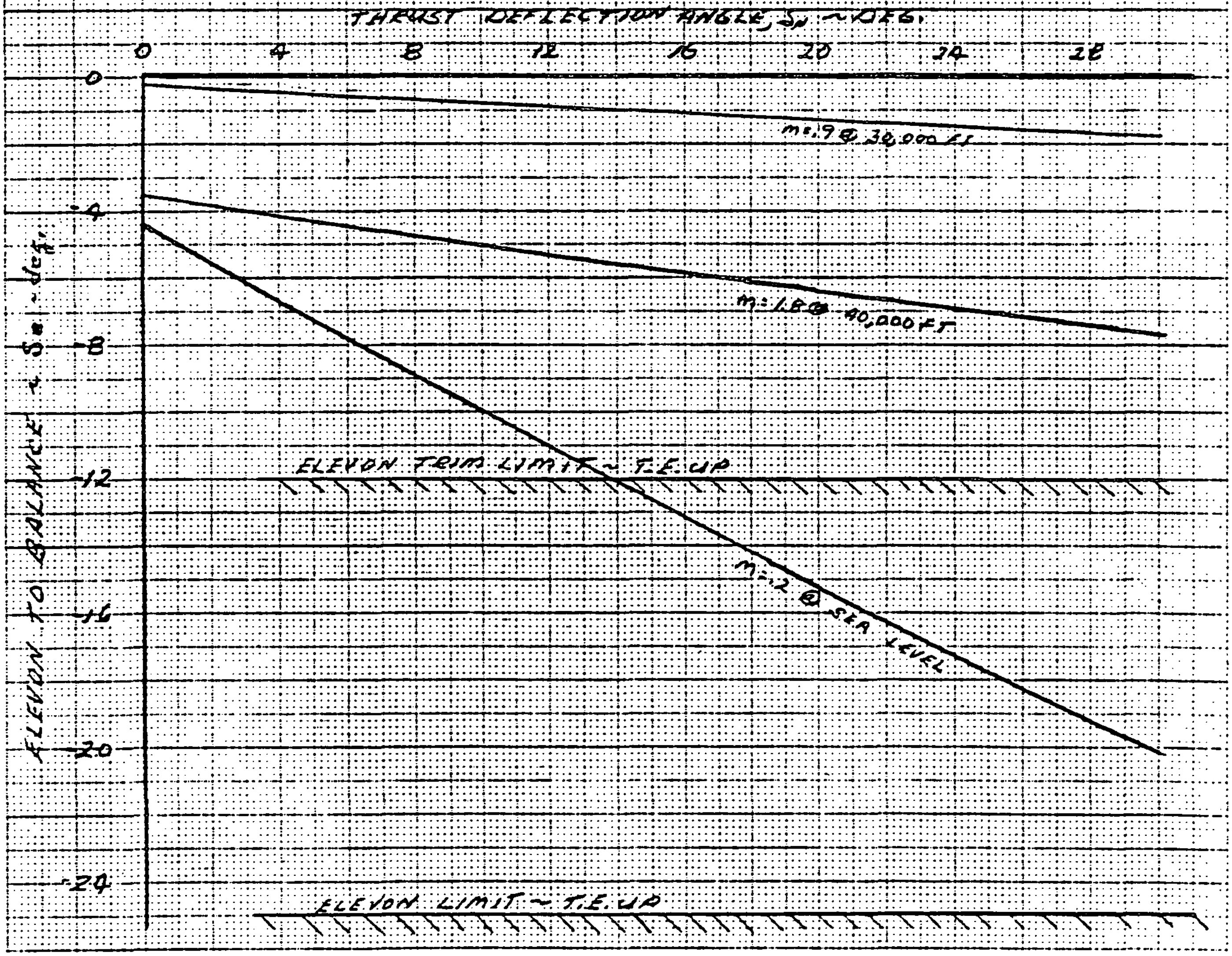


Figure 3.2A.5-1. Elevon Required to Balance Thrust Vectoring

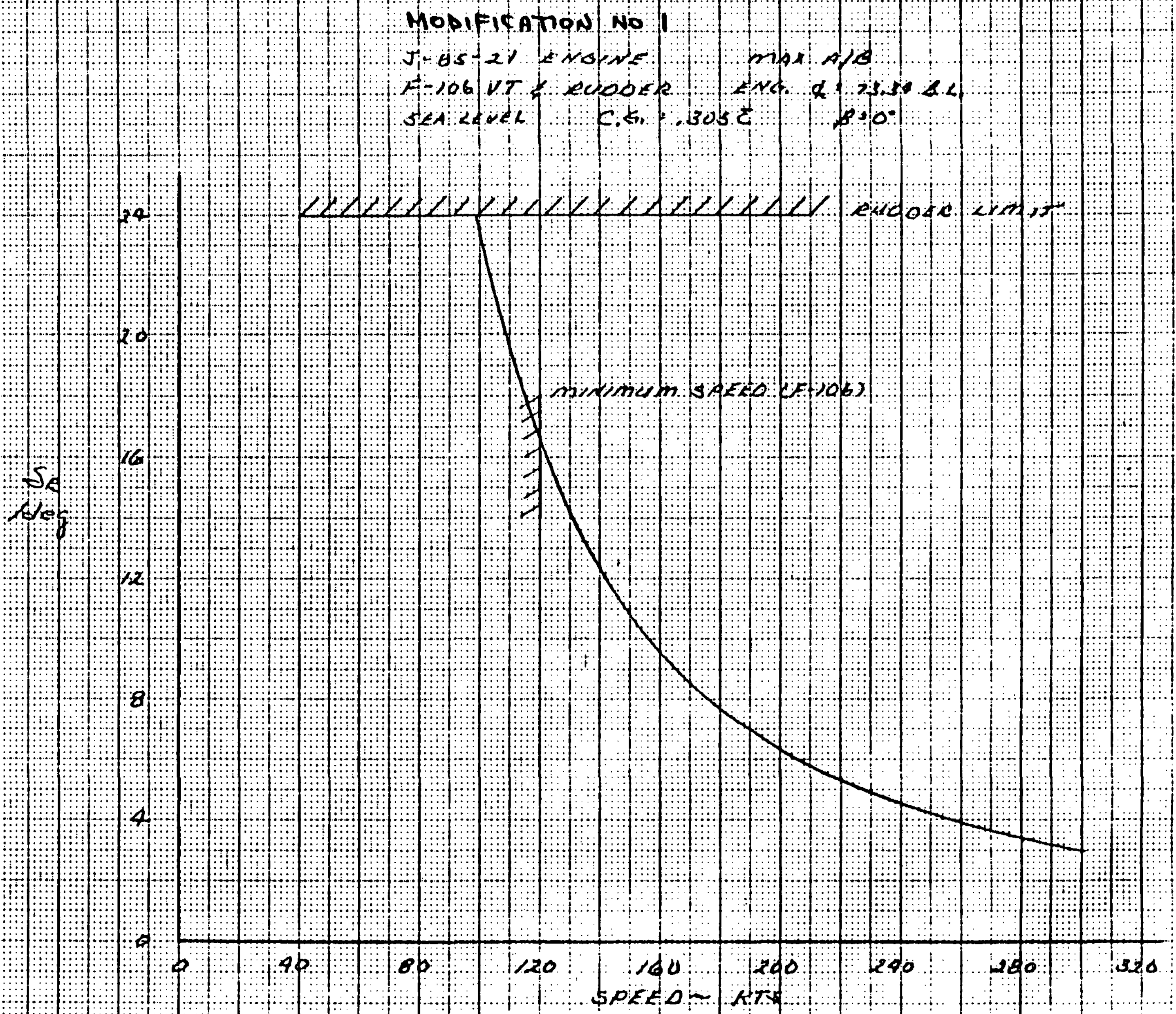


Figure 3.2A.5-2 Engine-Out Control, Sea Level

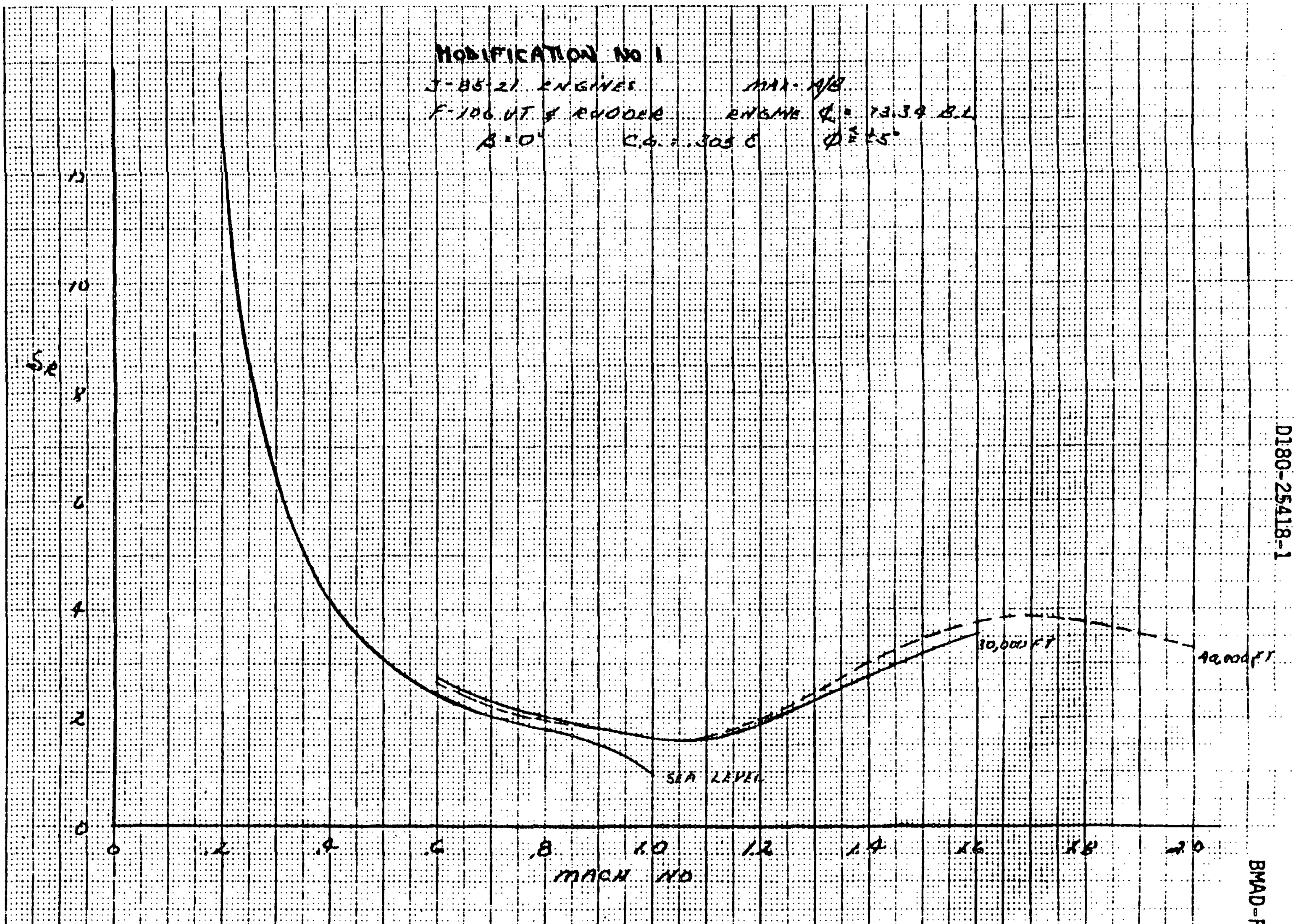


Figure 3.2A.5-3. Air Minimum Control Speed

MODIFICATION NO 1

J85-21 ENGINE ℄: 22.36 IN. MAX A/B
F-106 VT, RUDDER & ELEVONS C.G. = .3052
$\delta_{N_{max}} = 30°$ WT: 32,000 lb
ASSUMES NO INDUCED EFFECTS ON WINGS FROM THRUST VECTORING

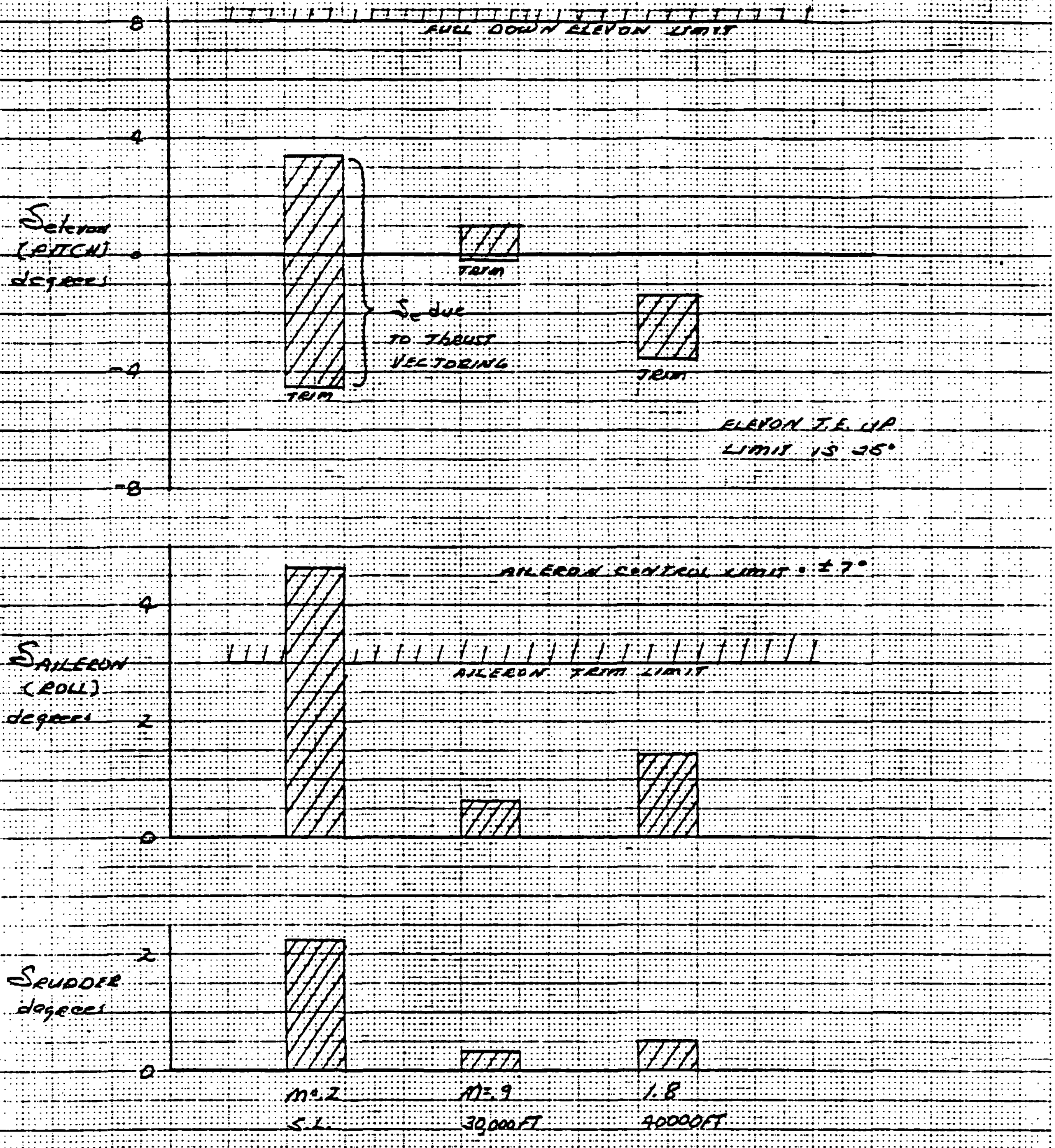


Figure 3.2A.5-4. Control Required to Balance One Nozzle Hardover to δ_{max}

trim and the F-106B elevons are used for maneuver. The elevons are reduced to only the outboard segment due to the high aspect ratio of the vectorable nozzles.

Directional stability was estimated equal that of the base F-106B at critical subsonic and supersonic Mach numbers, Figure 3.2A.5-5. Transonic directional stability is 93% of that for the base airplane at the worst condition. This degradation in stability is deemed acceptable, since the stability level at supersonic Mach numbers is more critical. Rudder power was increased compared to that of the basic airplane, Figure 3.2A.5-6. This increase is primarily due to a 12% increase in rudder area. Air minimum control speed, Figures 3.2A.5-7 and 3.2A.5-8, is the same as that of Modification No. 1, because F-101 rudder authority is ±20° vs ±24° for the F-106B rudder. Ground minimum control speed was not determined because location of the J-85 engines behind the main gear, does not permit engine ground operation.

Sufficient pitch control is available to balance any level of thrust vectoring for all operating speeds, Figure 3.2A.5-9. Pitch and yaw control can be maintained at all speeds for a maximum engine thrust nozzle hardover (±30°), Figure 3.2A.5-10. Available roll control limits to ±20° the controllable nozzle hardover at low speeds. This nozzle deflection hardover limitation might be overcome by operational methods. Some suggestions are: (1) deflecting the non-failed nozzle in the same direction as the failed nozzle or (2) reducing thrust of engines from max A/B. Roll control at transonic speed is marginal.

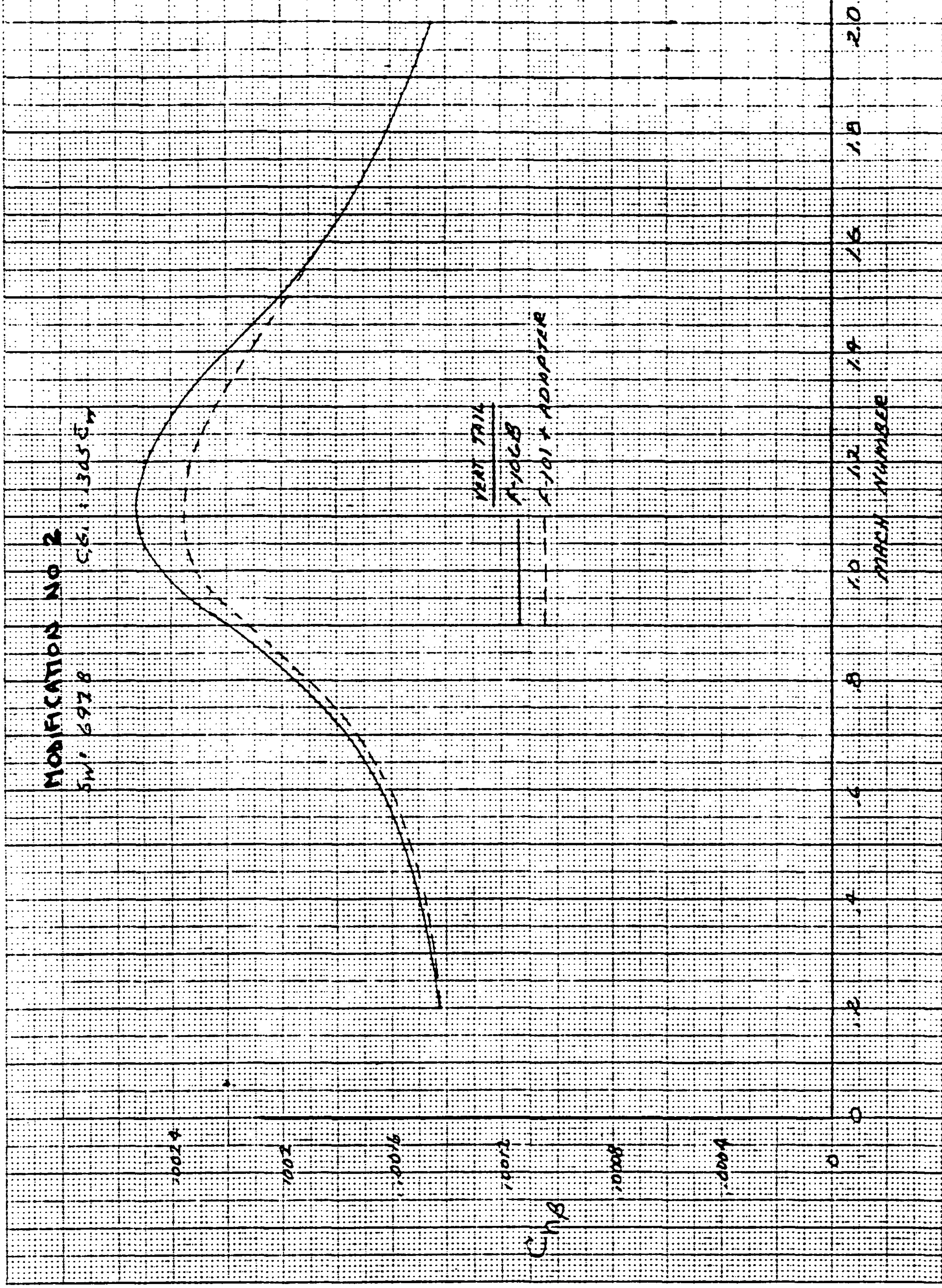


Figure 3.2A.5.6. Yawing Moment Due to Sideslip

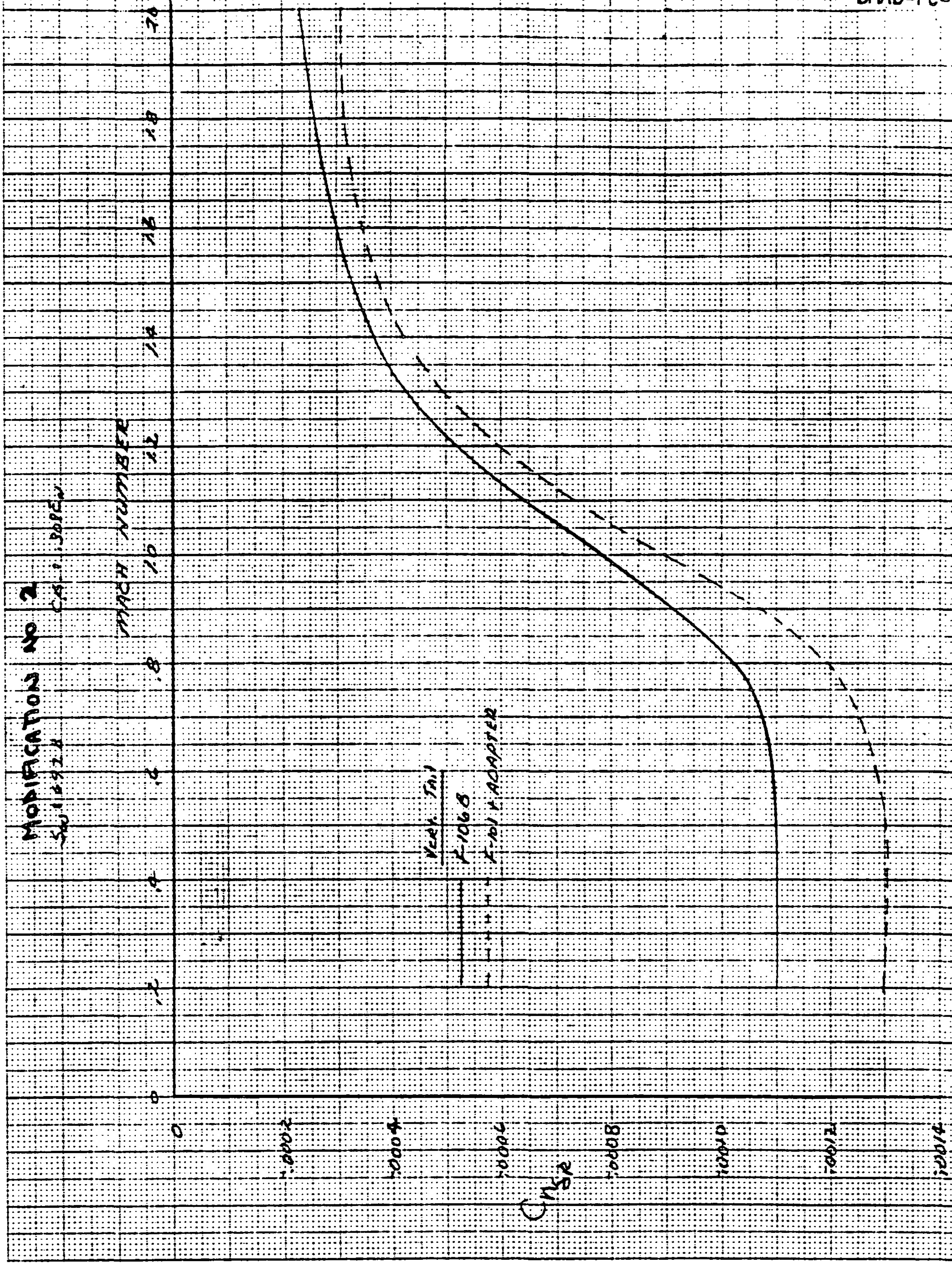


Figure 3.2A.5-6 Yawing Moment Due to Rudder, F-106B Mod. 2

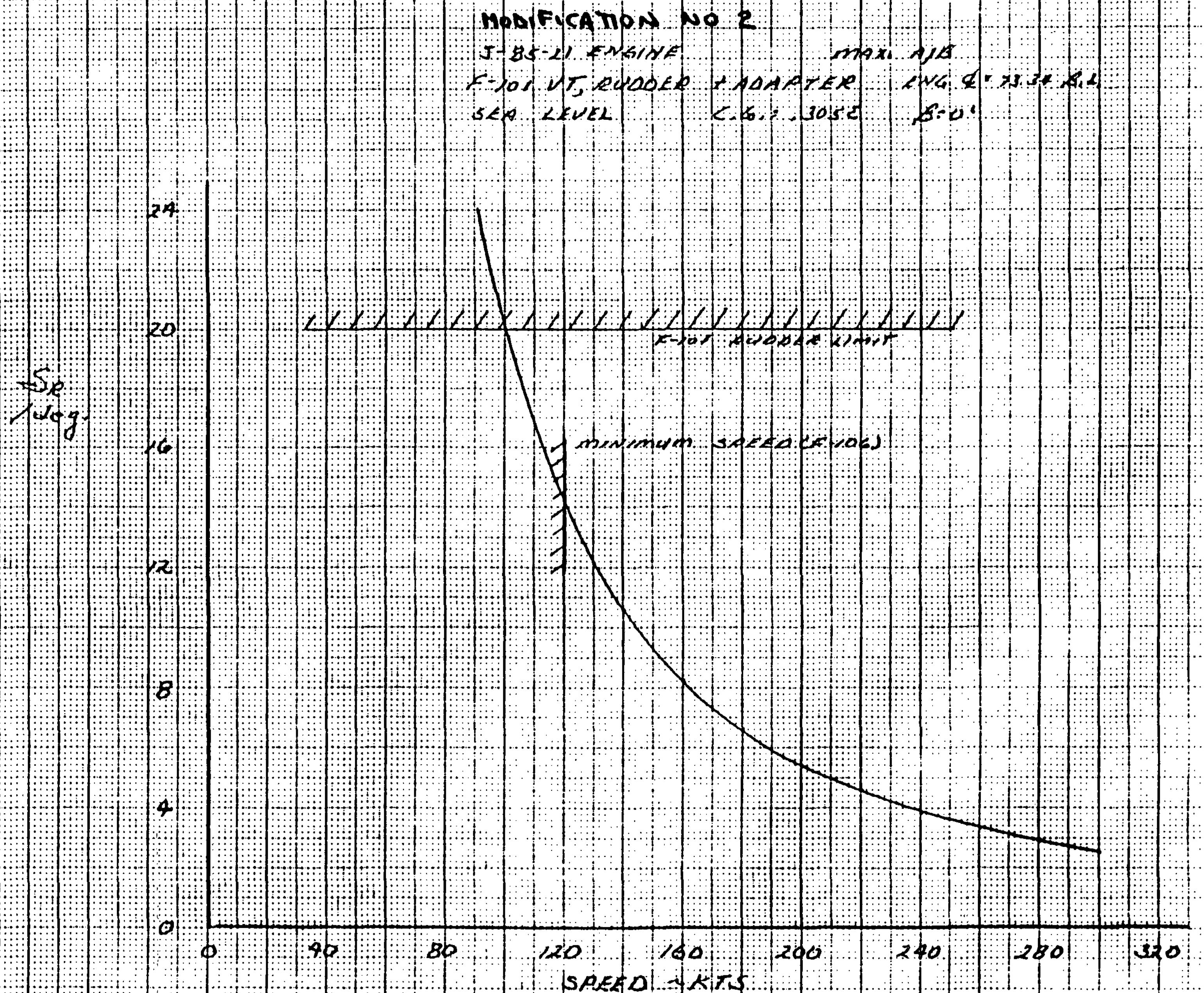


Figure 3.2A.5-7. Engine-Out Control, Sea Level F-101 VT.

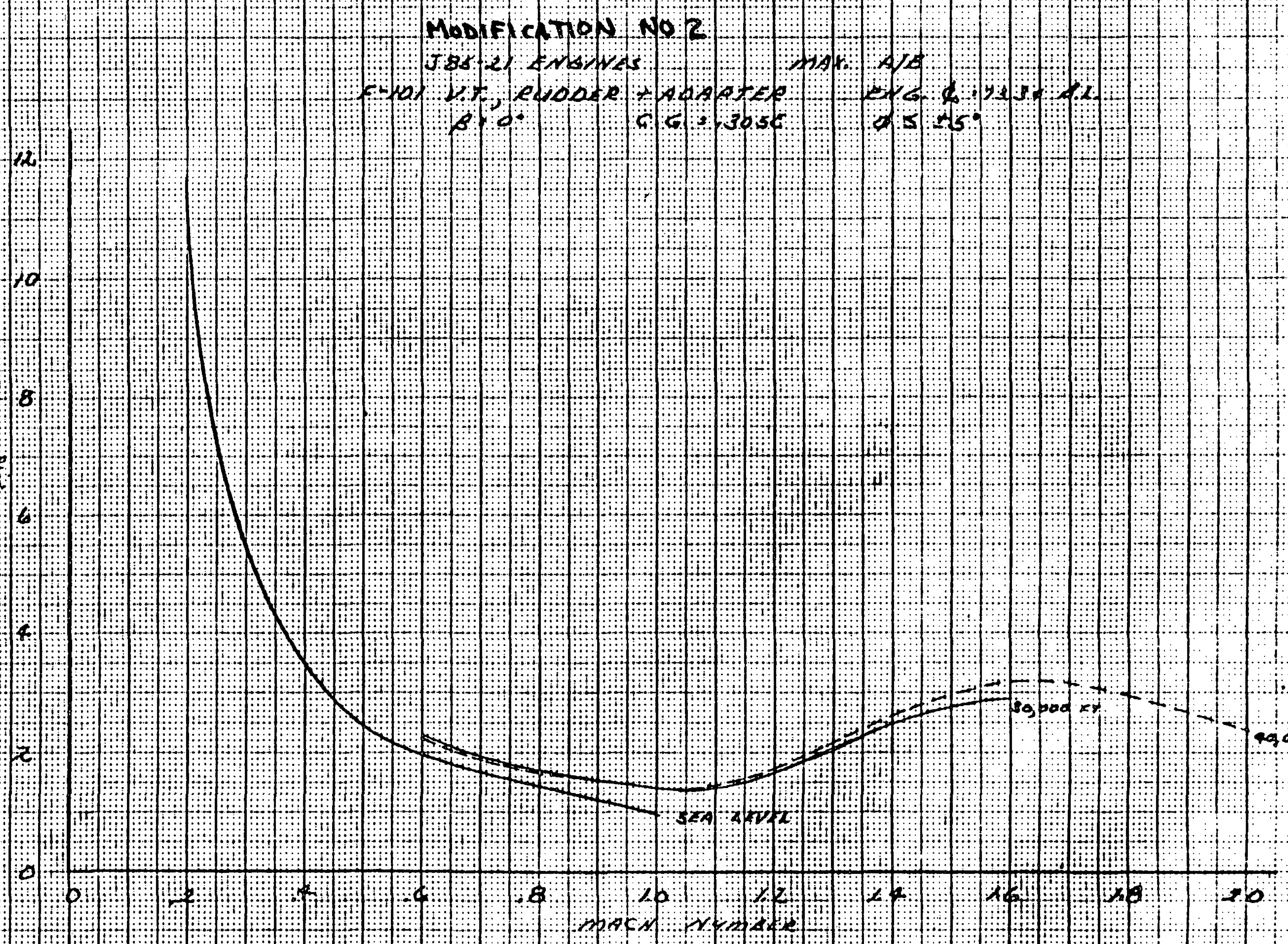


Figure 3.2A.5-8. Air Minimum Control Speed, F-106B Mod 2

BMAD-FC-153

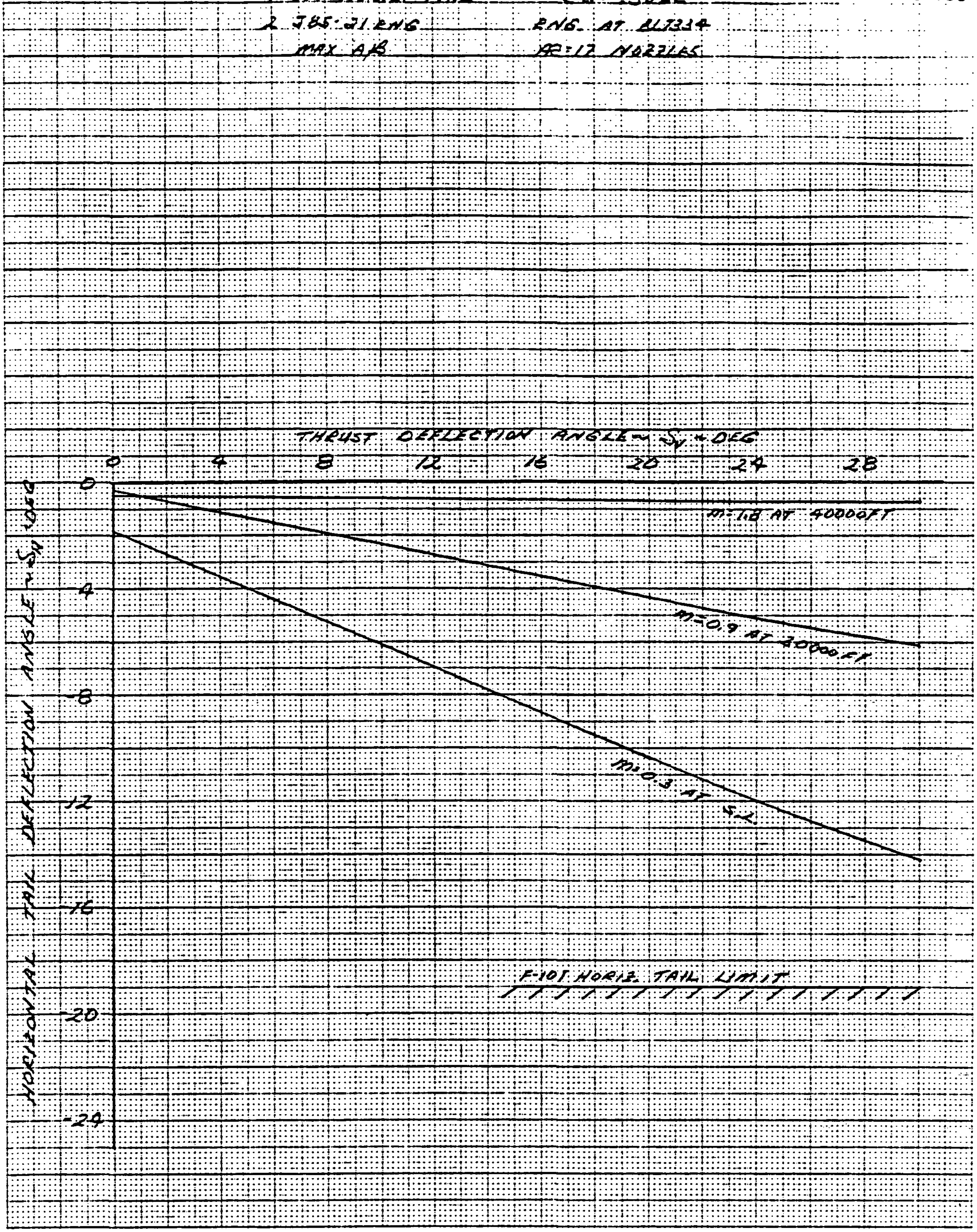


Figure 3.2A.5-9. Horizontal Tail Deflection Required to Balance Thrust Vectoring at Max Power , F-106B Mod. 2

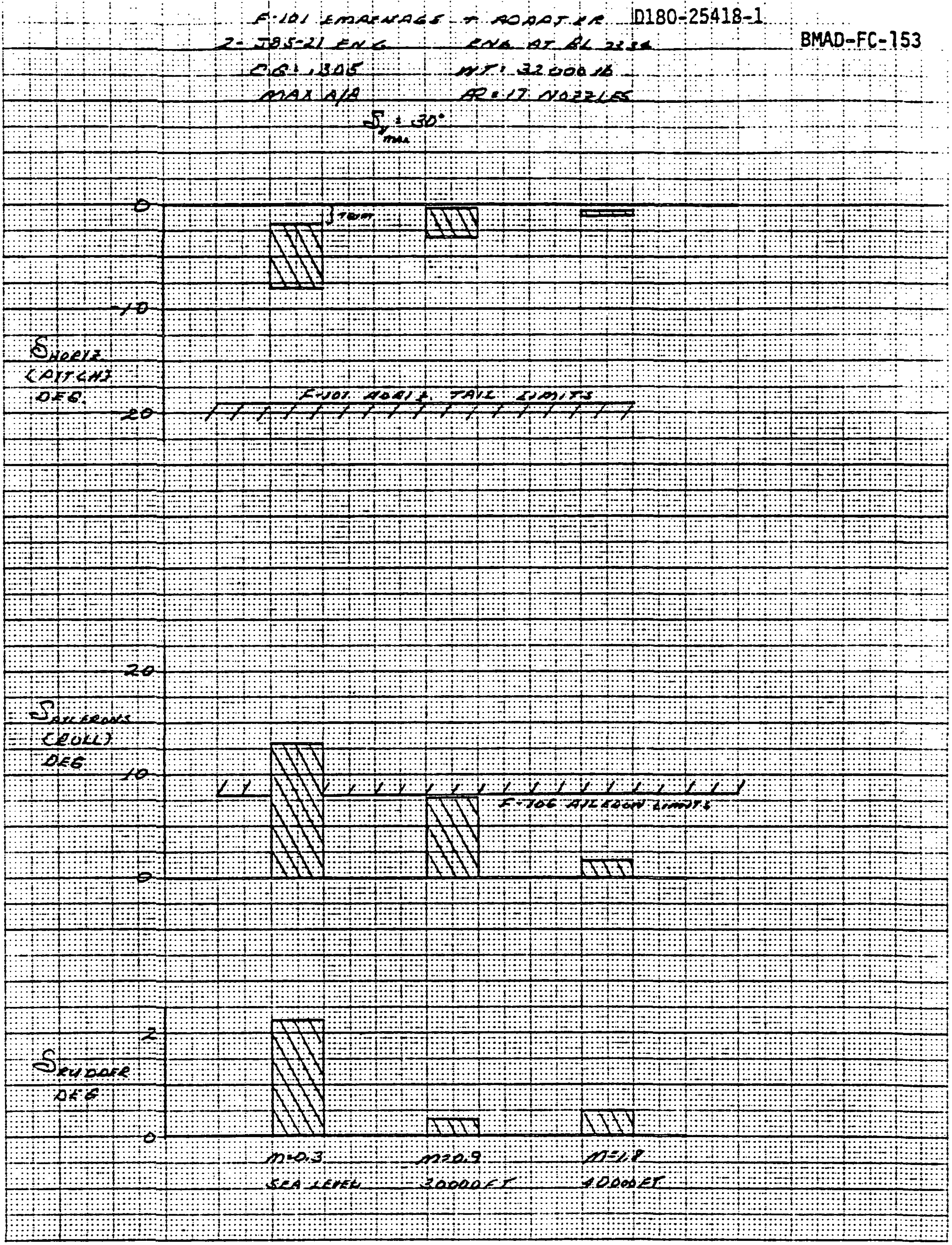


Figure 3.2A.5-10. Control Required to Balance One Nozzle Hardover to δ_{max}

Modification No. 3 is addition of a vectorable nozzle to the existing F-106B J-75 engine. Since this is a centerline engine configuration, only pitch control is of concern. Nozzle deflection limitations are required to maintain trim for either maneuvering with thrust vectoring or for protection from a nozzle hardover failure. Figures 3.2A.5-11 and 3.2A.5-12 present pitch trim requirements for various nozzle deflections. Negative or trailing edge up nozzle deflections are limited to 0o, whereas positive or trailing edge down nozzle deflections are limited to 20o. These limits are necessary to provide sufficient maneuver capability beyond trim requirements at low speeds. The effect of thrust vectoring on pitch control requirements is emphasized for this modification because of the nozzle extreme location aft of the wing trailing edge.

Modification No. 4 has two F404 engines mounted on top of the wing, a 50 sq. ft. exposed area canard at F.S.102, and an increased area vertical tail and rudder. Ground rules used to analyze this configuration were to maintain F-106B static stability levels. Maintaining F-106B stability levels necessitated moving the CG envelope forward because of the forward a.c. shift due to a canard and engine nacelles, Figure 3.2A.5-13. Vertical tail area was increased to offset directional destabilizing effects of engine nacelles mounted forward of the wing leading edge.

To maintain stability at F-106 levels resulted in a forward C.G. which severely limits useable angle of attack envelope when thrust vectoring is used. Figure 3.2A.5-14 presents these limitations at Mach = 0.9. Angle

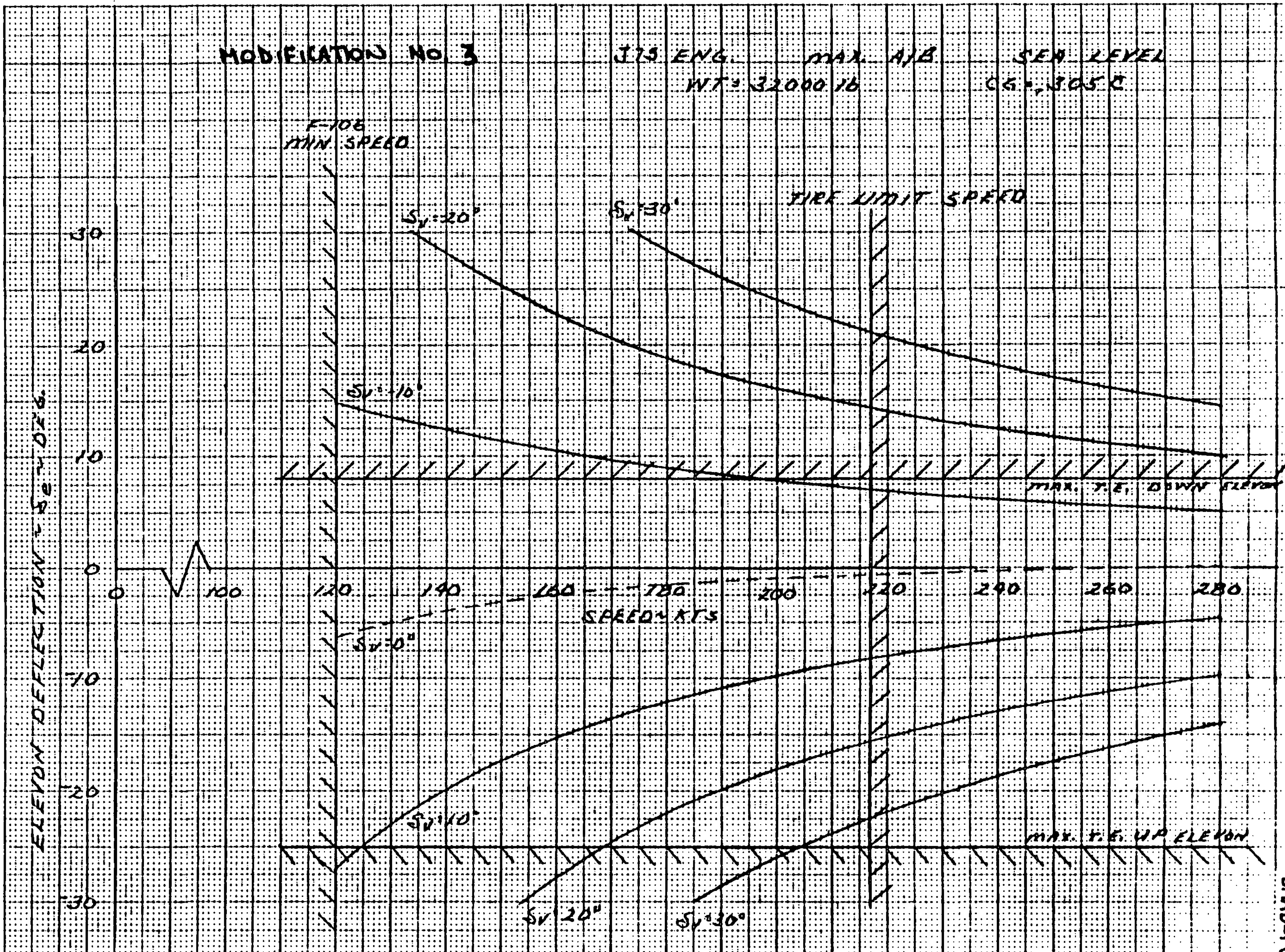


Figure 3.2A.6-11. Elevon Required to Trim Thrust Vectoring vs. Speed

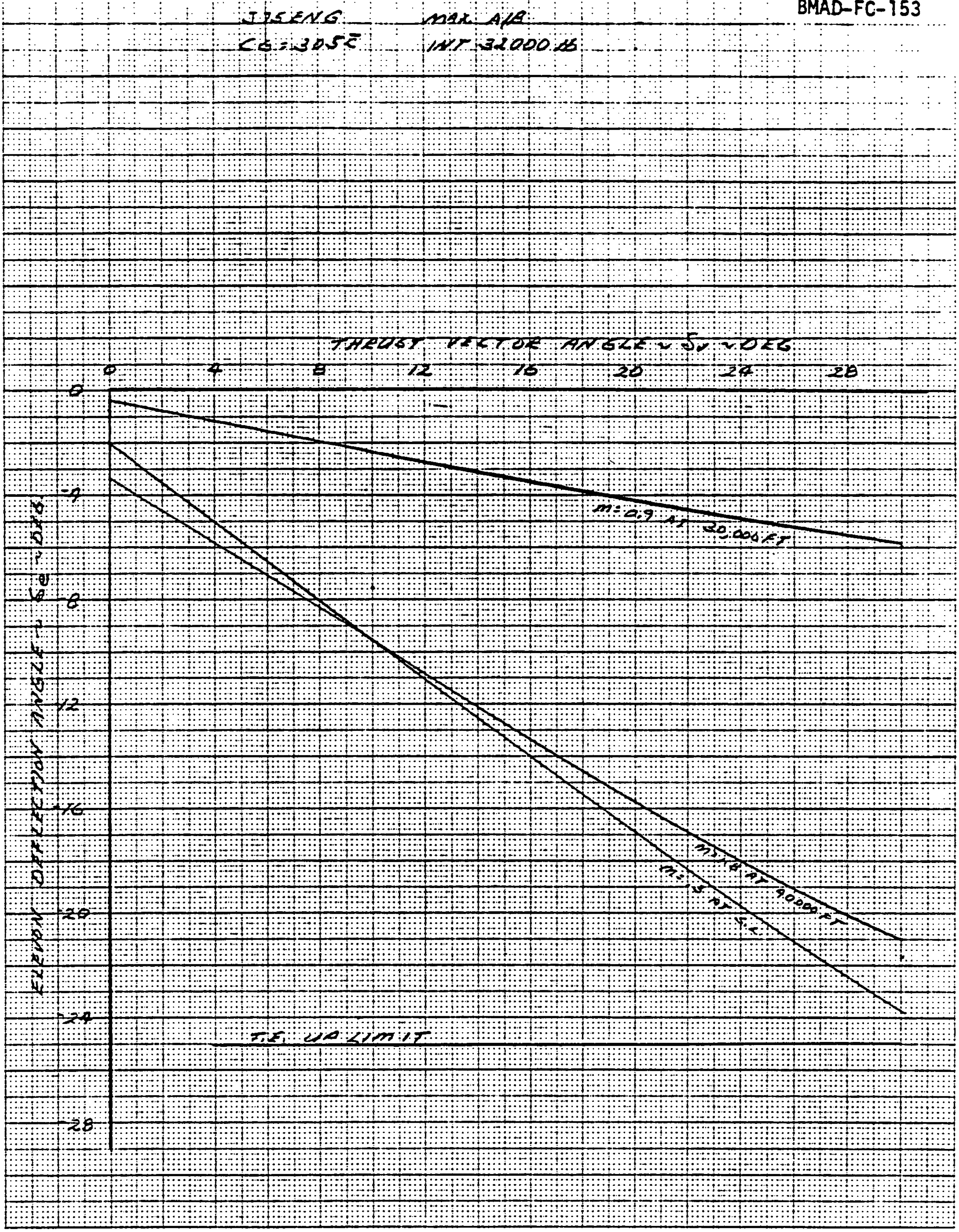


Figure 3.2A.5-12. Elevon Required to Trim Thrust Vectoring F-106B Mod. 3

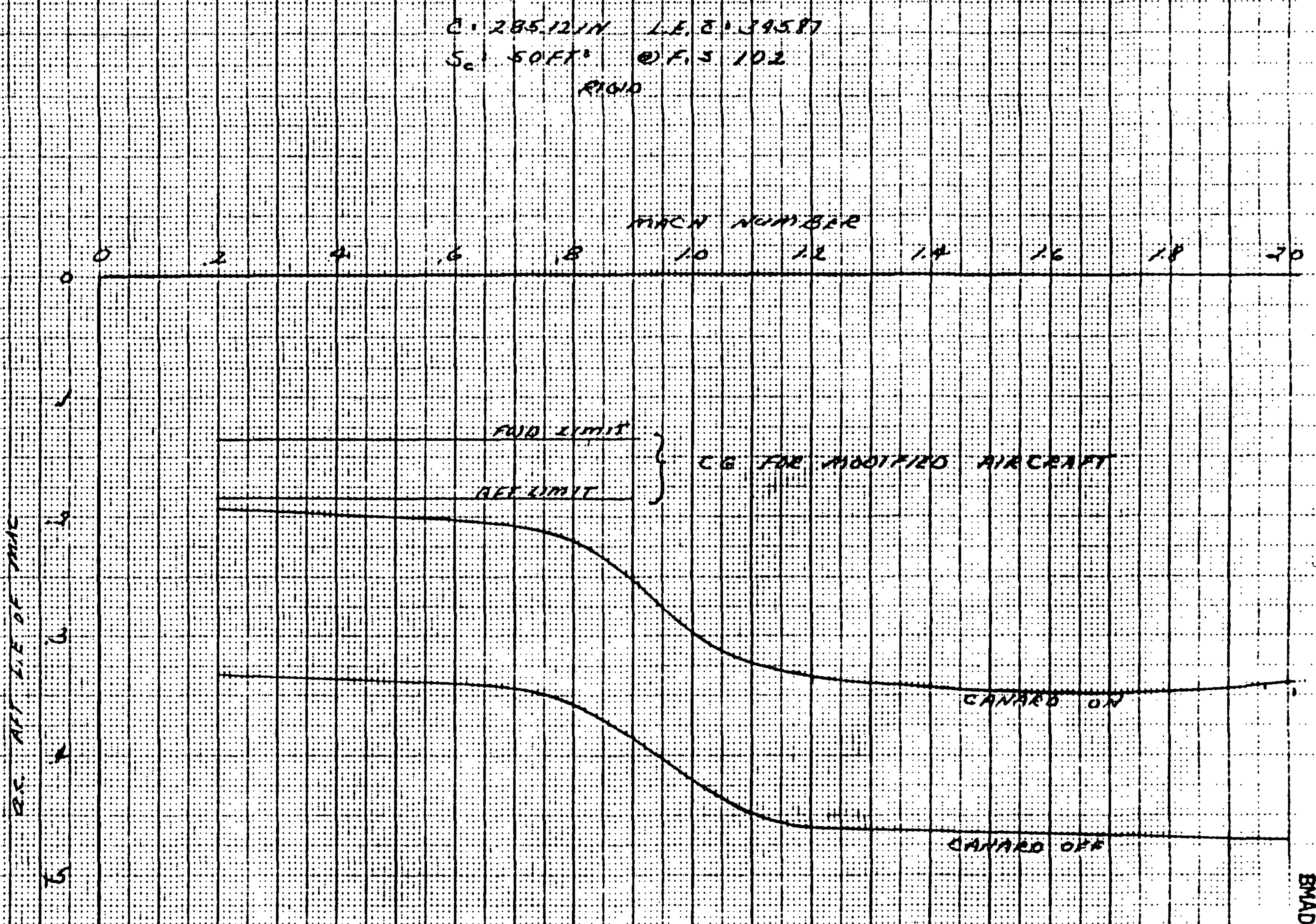


Figure 3.2A.5-13. Aerodynamic Center Canard on and off F-106B Mod. 4

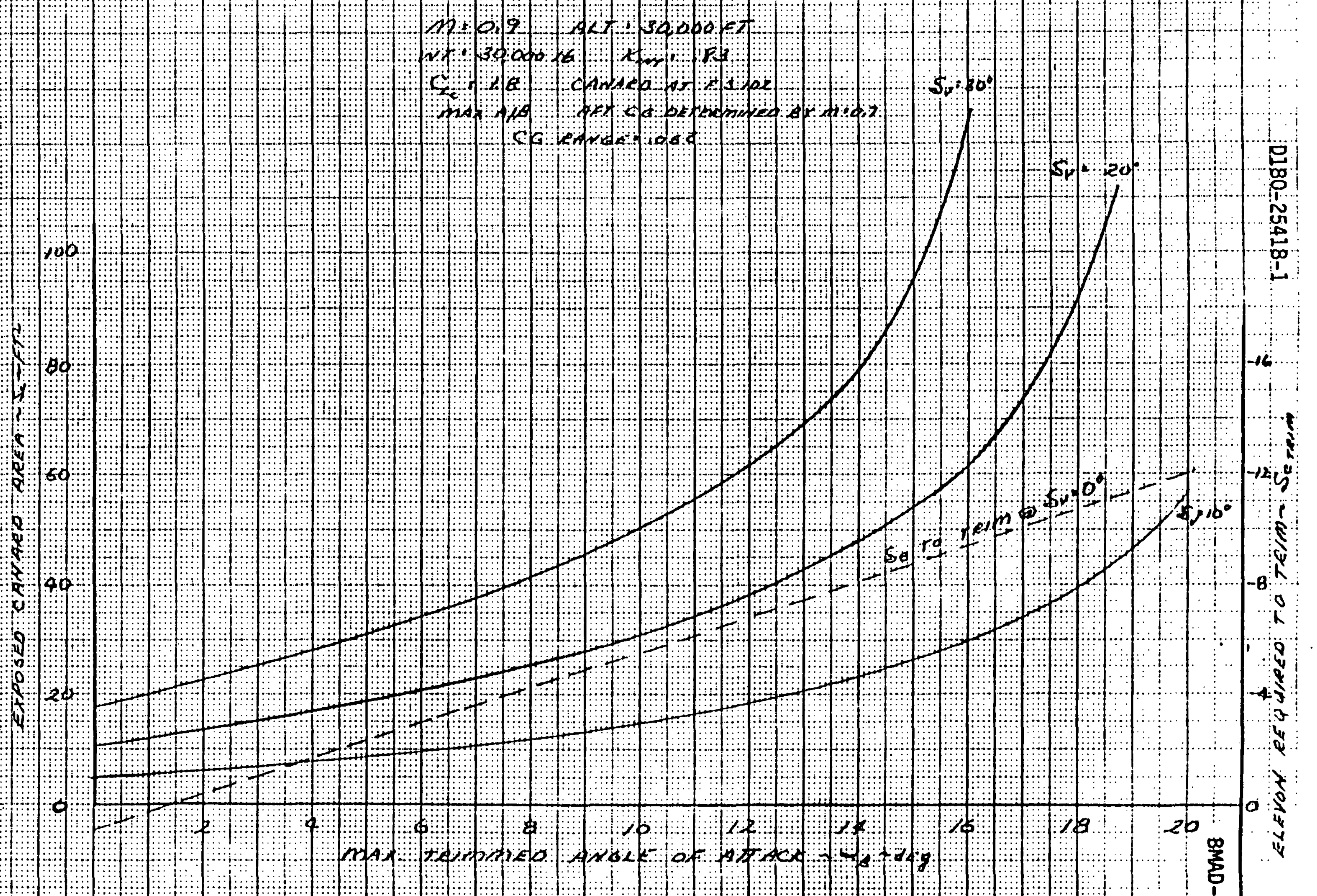


Figure 3.2A.5.14. Effect of Thrust Vectoring on Canard Size for a Required cg. Range. Elevons Trim for $\delta_v = 0$
F-106B Mod. 4

of attack for this case is limited to 19° with 10° thrust vectoring and 10° angle of attack with 30° of thrust vectoring. The elevons are used for trim with canard and nozzle at zero deflection, and the canard used to balance the moments induced by nozzle vectoring. (The unmodified F-106B has a 20° flight angle of attack limit.)

Nose wheel lift off speeds would be increased by approximately 30 kts over F-106B speeds due to the forward CG movement.

Figure 3.2A.5-15 and 3.2A.5-16 present canard or elevon deflection required to balance thrust vectoring for three flight conditions. Low speed constant angle of attack thrust vectoring would be limited by either elevon deflection limits, canard maximum lift or canard deflection limits. Large canard deflections are also a potential problem, due to the canard's low location and the F-106B body shape in the area of the canard. Unporting would occur for large canard deflections. Canard unporting would reduce available lift, resulting in still larger deflections or increased canard area.

Directional stability, Figure 3.2A.5-17, compared to basic F-106B, is estimated to be equal at low speeds, slightly lower at transonic Mach numbers, and better at supersonic Mach numbers. Degradation in transonic stability level is deemed acceptable since supersonic stability level is generally more critical. To maintain approximately F-106B directional stability levels required a 12 inch extension to the vertical tail tip, a 12 inch chord trailing edge extension and a 7 sq. ft. dorsal added at the

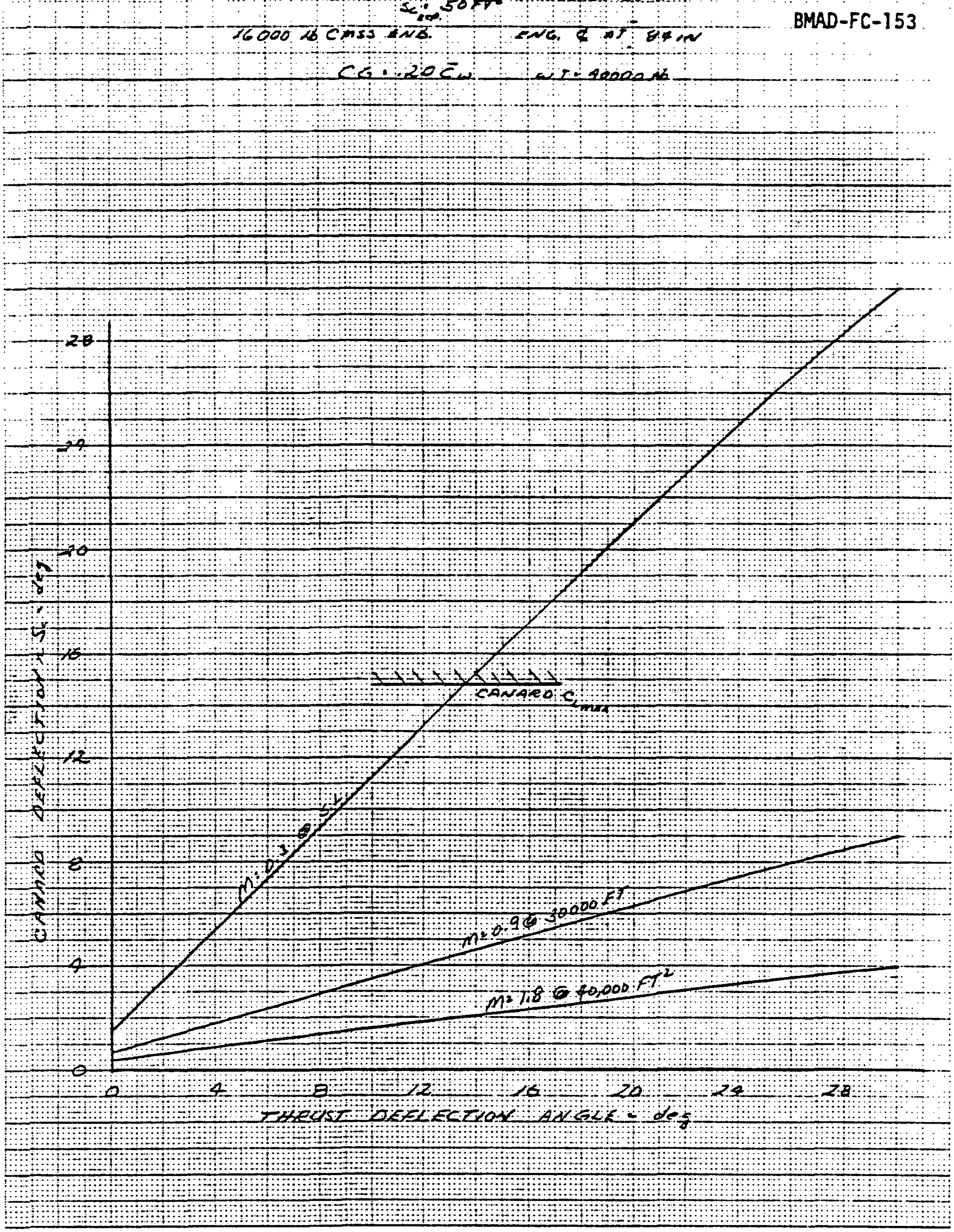


Figure 3.2A.5-15. Canard Required to Balance Thrust Vectoring F-106B Mod. 4

S = 150 FT²

16 000 lb CLASS ENG. ENG. ℄ AT 54 IN

C.G. = 20%c̄ WT = 40000 lb

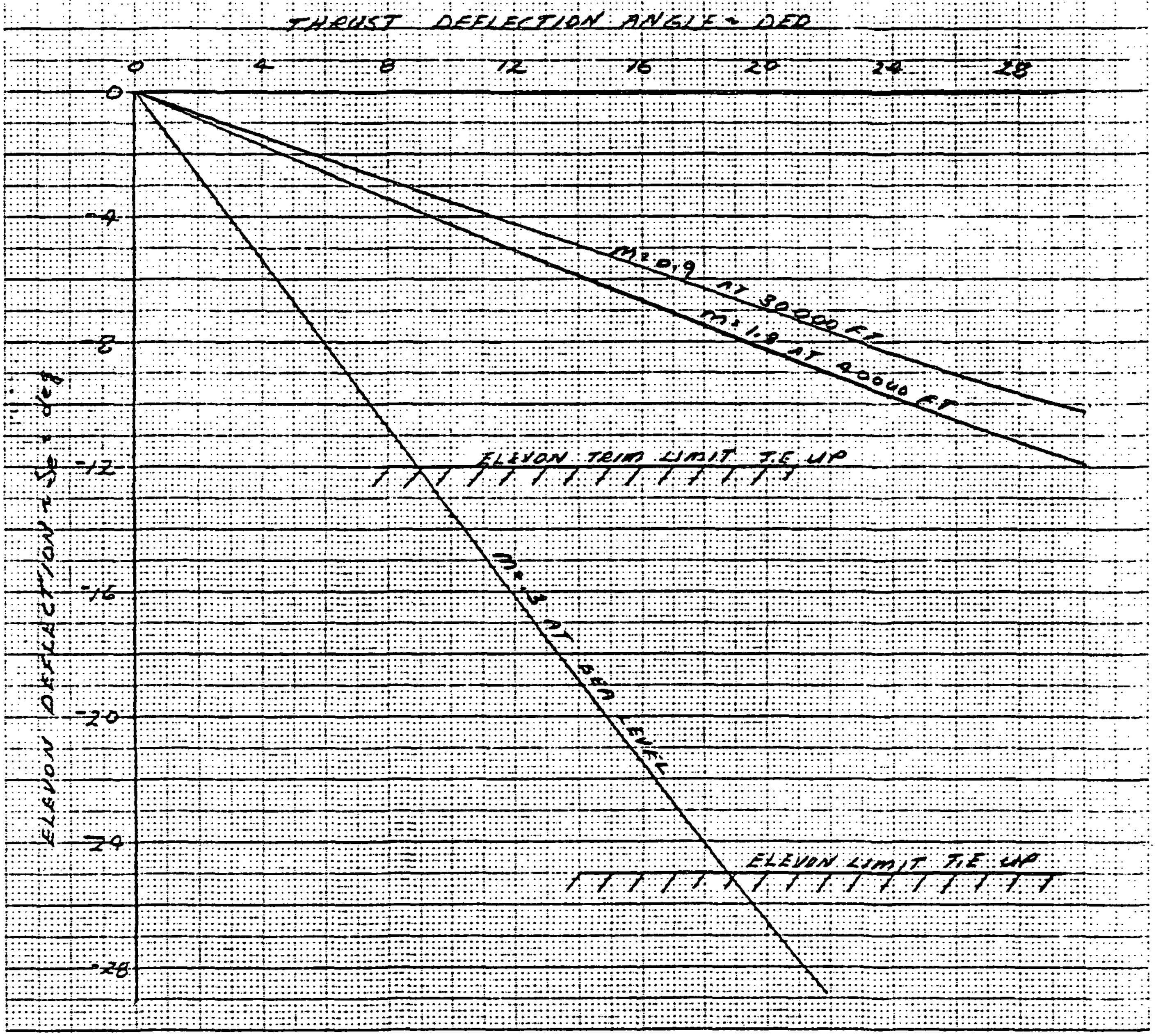


Figure 3.2A.5-16. Elevon Required to Balance Thrust Vectoring F-106B Mod. 4

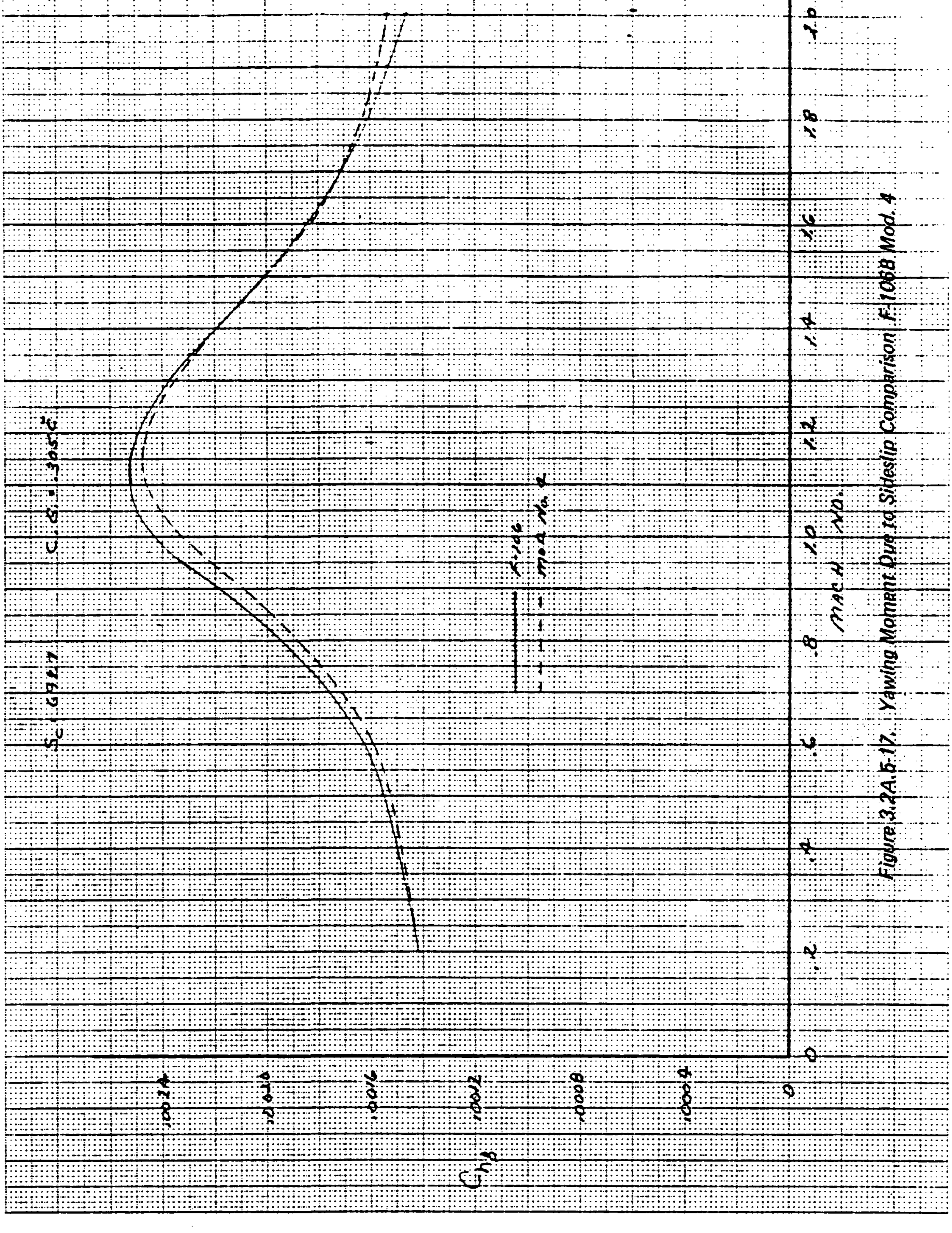


Figure 3.2A.5-17. Yawing Moment Due to Sideslip Comparison F-106B Mod. 4

base of the vertical tail. This increase in vertical tail area was required to compensate for instability that resulted from engine nacelle placement in front of the wing leading edge.

Ground minimum control speed, Figure 3.2A.5-18, limits the F404 engines to military power for takeoff. Military power results in a minimum control speed of 160 kts, compared to 200 kts for maximum A/B power. For flight conditions investigated, air directional control could be maintained for all power settings except at low speeds when engine thrust again must be limited to military power below 200 kts, Figure 3.2A.5-19.

Lateral control, Figure 3.2A.5-20 through 3.2A.5-22, will limit engine thrust and corresponding thrust vectoring angles. At low speed, available lateral control limits thrust vectoring to zero deflection with military power; at Mach .9, to 20° nozzle deflection with military power. These limitations are due to high differential loads induced on the wing with only one engine vectoring and the small aileron travel available for the F-106B. F-106B small aileron travel resulted from an airplane with a centerline engine and ailerons sized for maneuver and not engine out control.

Figure 3.2A.5-23 presents the summary of control requirements for nozzle hardover and A/B power.

16000 lb CLASS ENG. ENG. ℄ AT 84 IN

F-106 EXTENDED CHORD (1/3) RUDDER

SEA LEVEL $\delta_{R_{max}} = 28°$ $\beta = 0°$

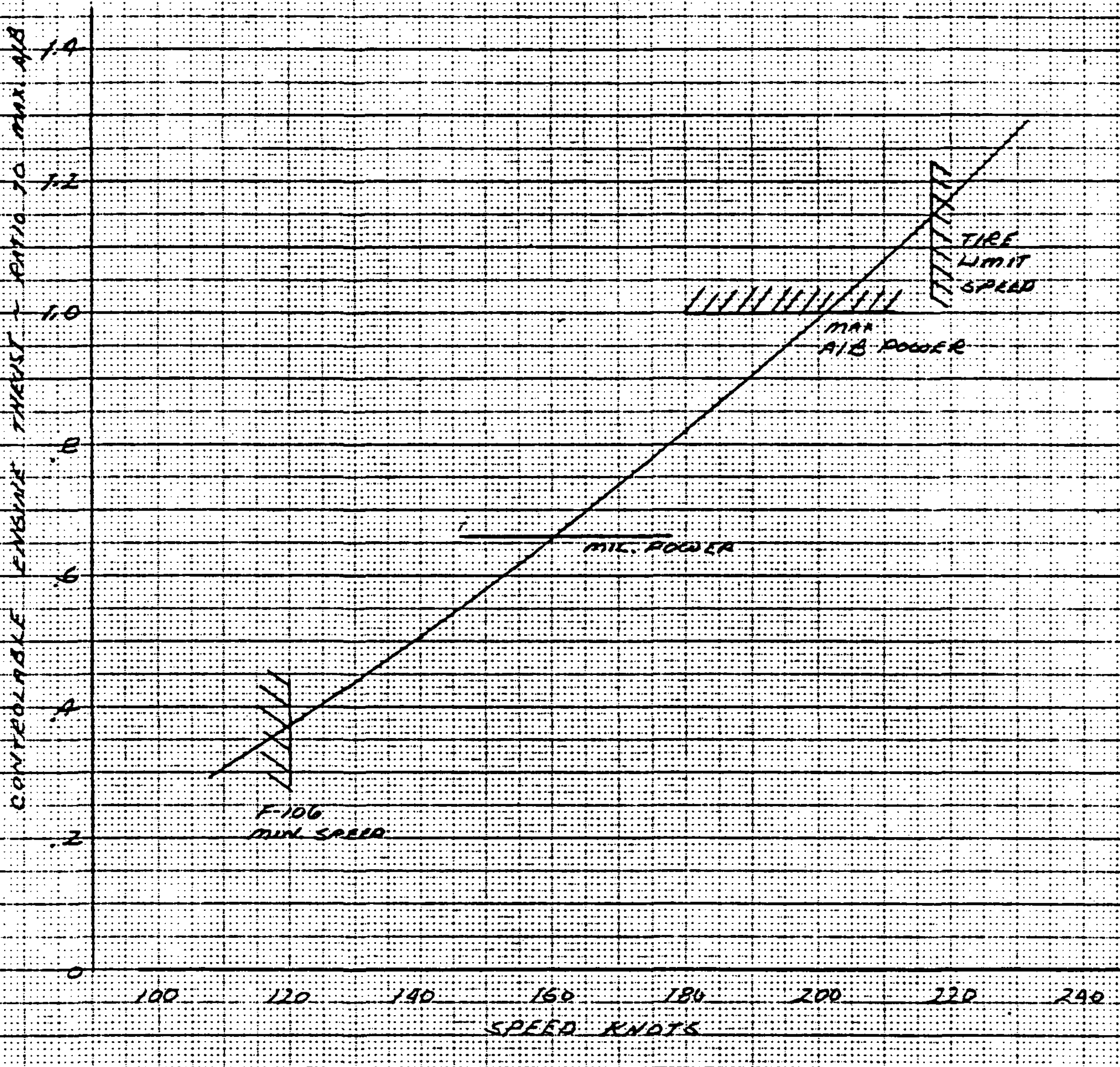


Figure 3.2A.5-18. Minimum Ground Control Speed, Engine out, F-106B mod. 4

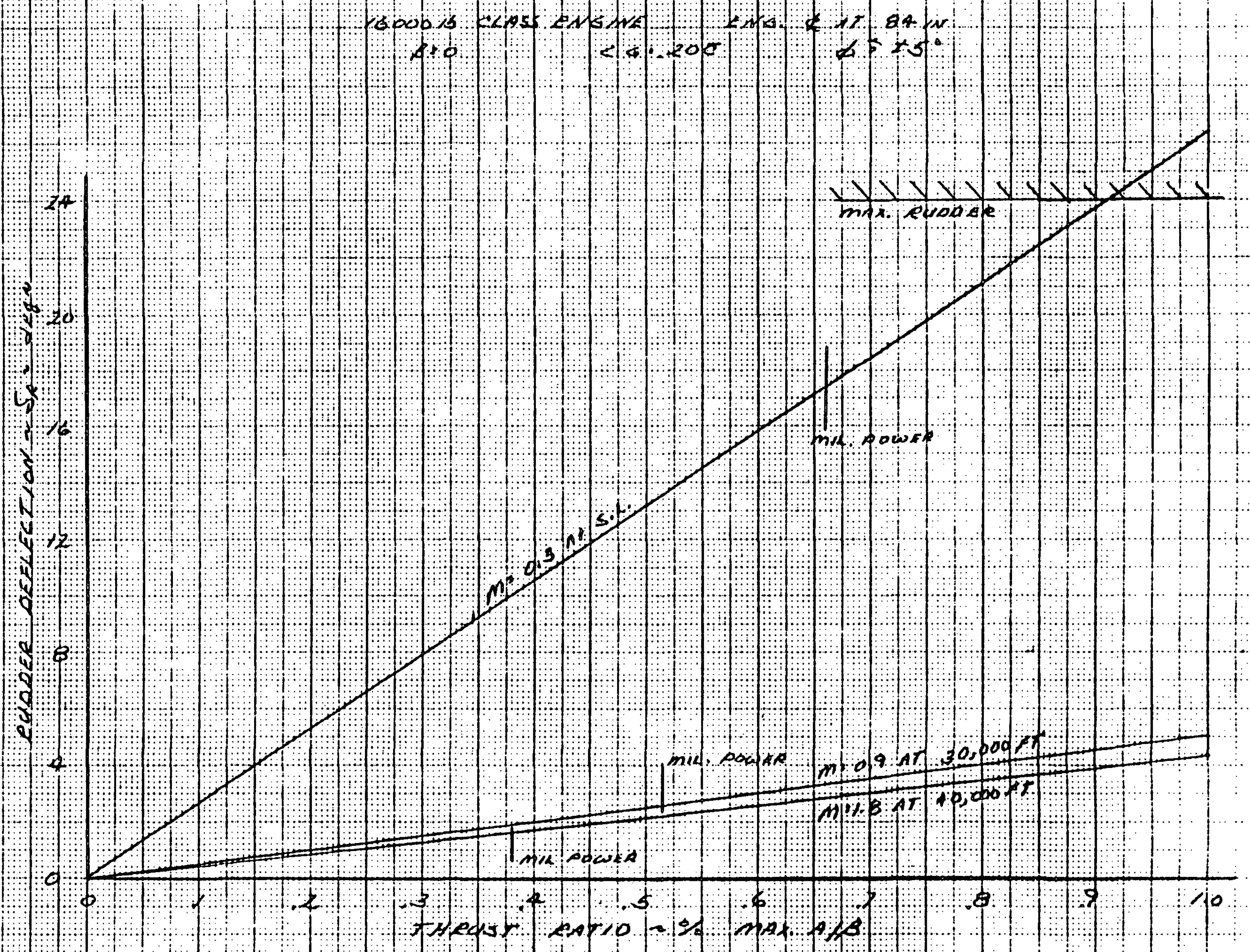


Figure 3.2A.5-19. Rudder Required to Balance One Nozzle Hardover to Max Deflection F-106B Mod. 4

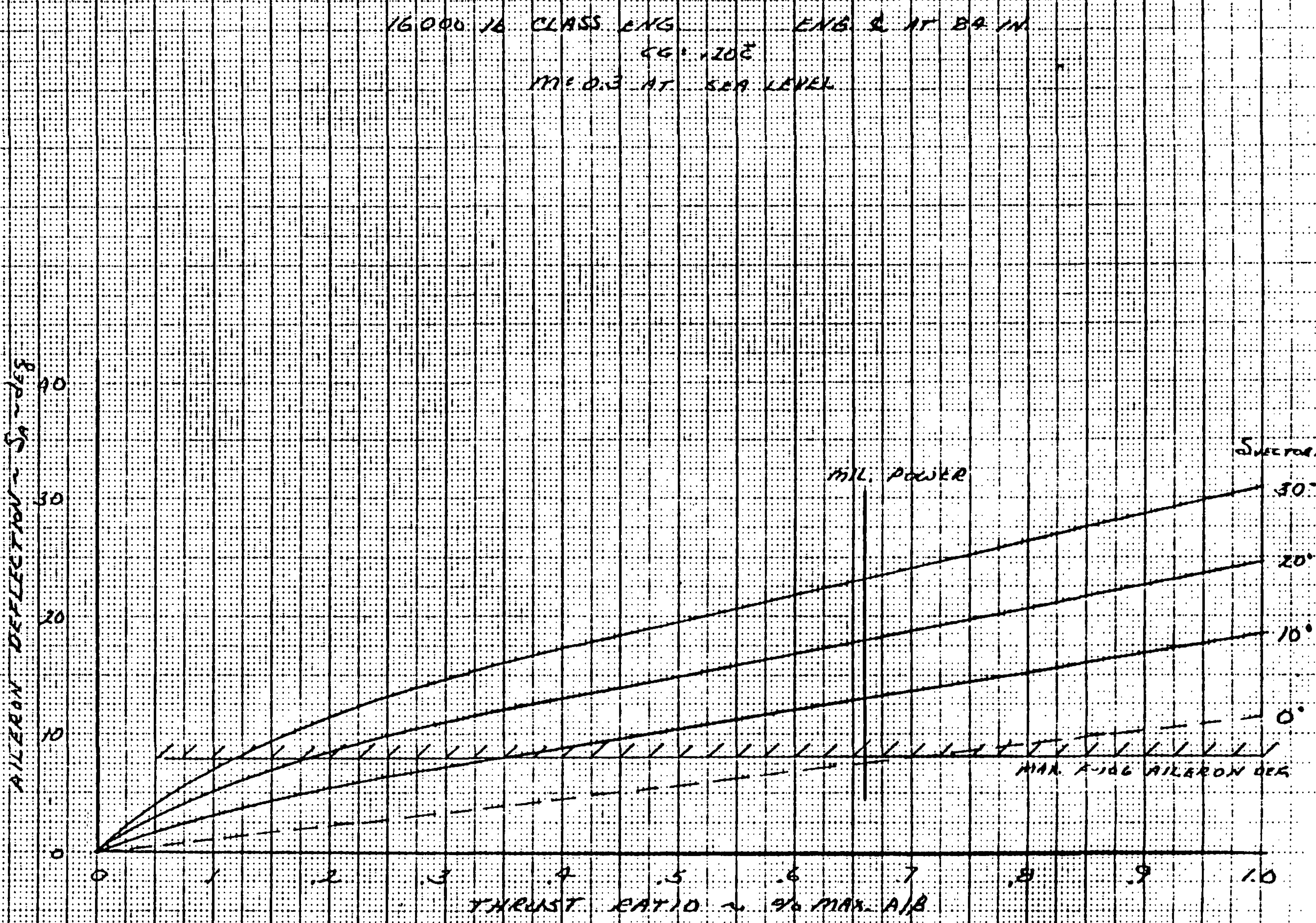


Figure 3.2A.5-20. Aileron Required to Balance One Nozzle Hardover to Max Deflection F-106B Mod. 4

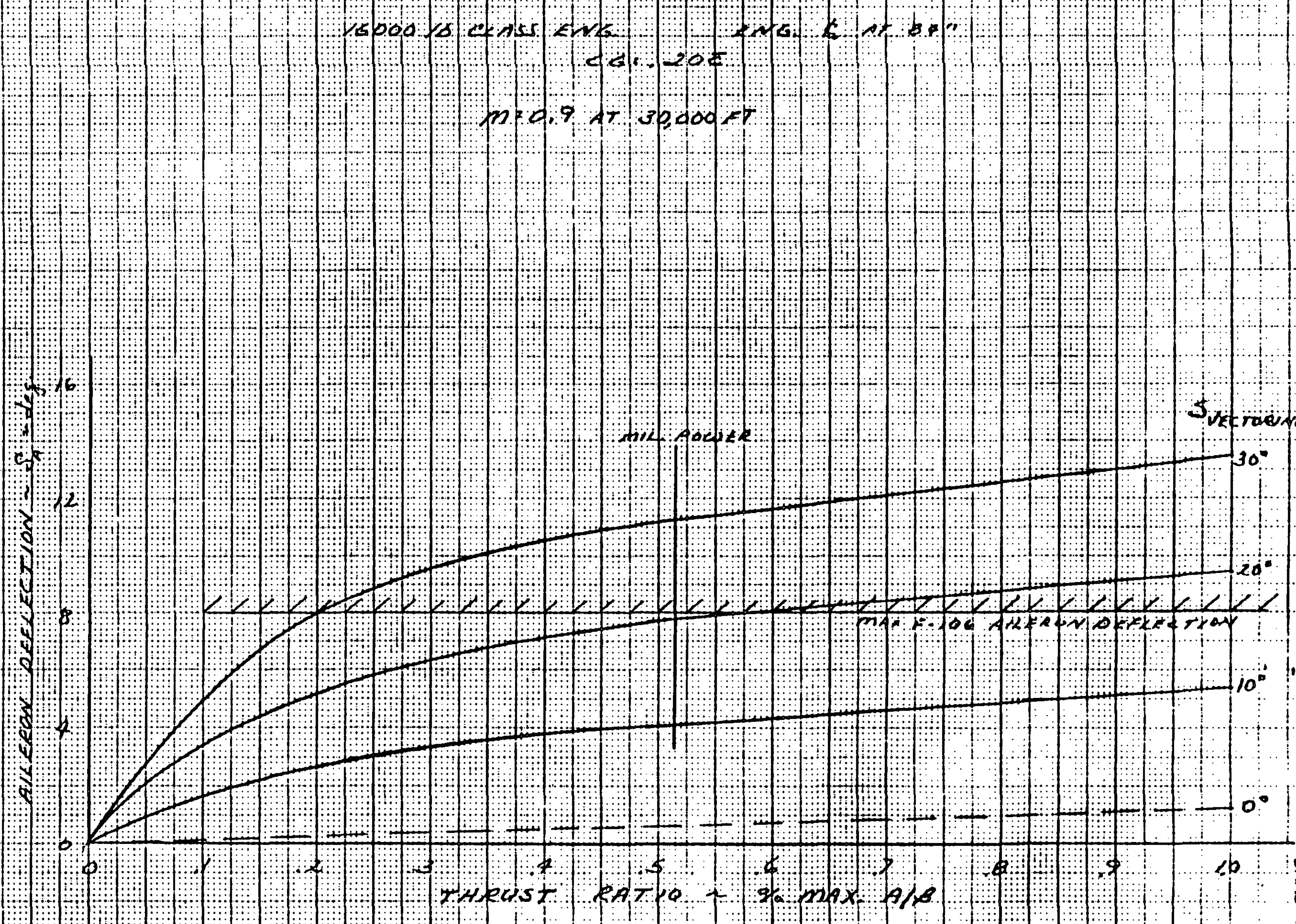


Figure 3.2A.6-21. Aileron Required to Balance One Nozzle Hardover to Max Deflection F-106B Mod. 4

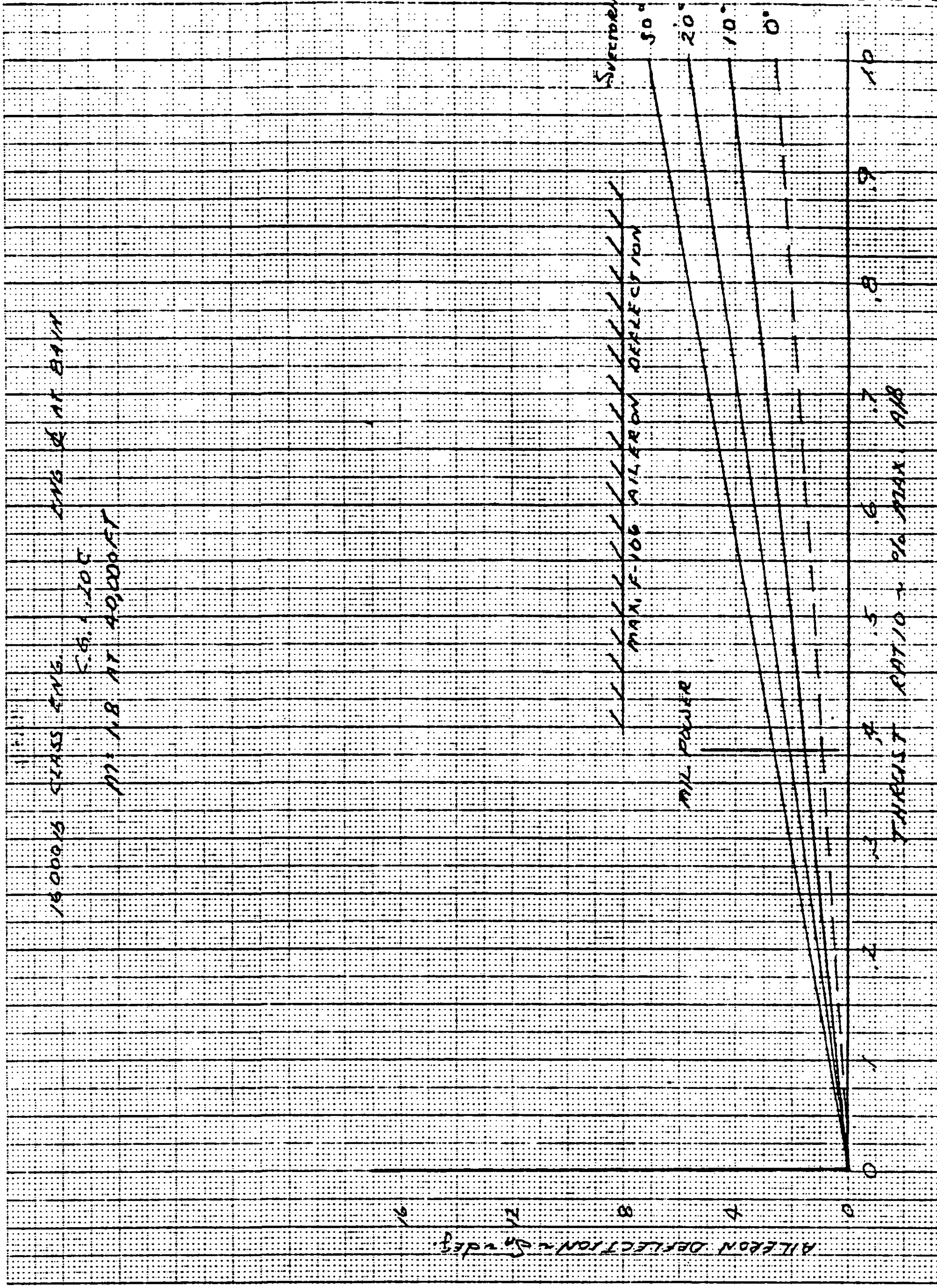


Figure 3.2A.5.22 Aileron Required to Balance One Nozzle Hardover to Max Deflection, F-106B Mod. 4 M= 1.8

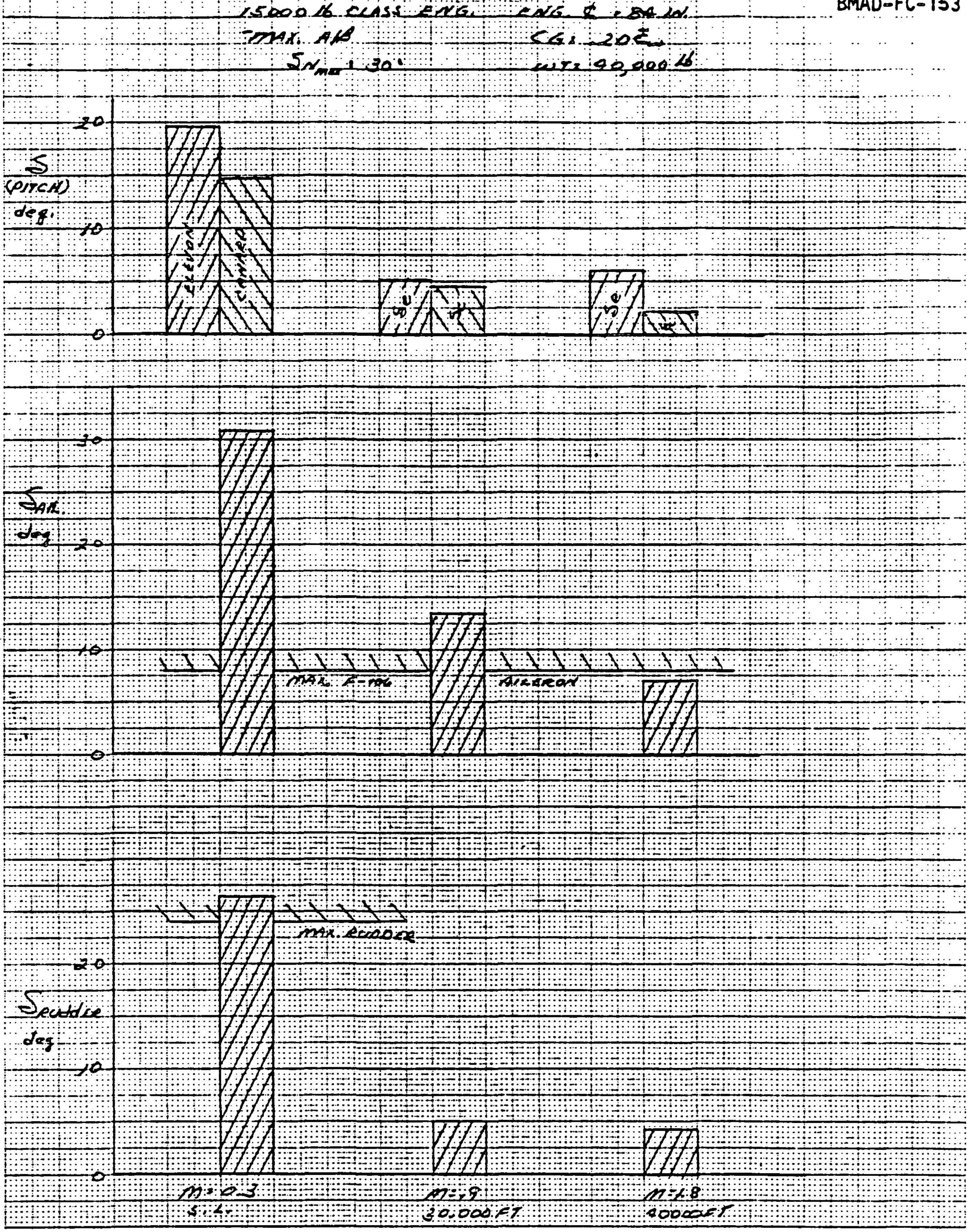


Figure 3.2A.5-23. Control Required to Balance One Nozzle Hardover to Max Deflection F-106B Mod. 4

In summary, all four configurations appear to be feasible if minimum operating speeds, nozzle deflection limits or engine thrust limits are imposed with modification No. 4 being the most highly constrained for test purposes. These limitations are:

Modification No. 1: Minimum operating speed of 150 knots for maximum negative nozzle vectoring is required when the J-85's are operating at max A/B thrust.

Modification No. 2: Nozzle deflection limited to ±20° when the J-85's are operating at max A/B thrust.

Modification No. 3: Maximum nozzle deflections limited to 0 to +20°.

Modification No. 4:

(1) Longitudinally the allowable CG envelope restricts angle of attack to less than 10° with 30° of thrust vectoring regardless of power setting

(2) Directionally, available rudder power limits engine A/B power to speeds above 200 kts.

(3) Lateral control (roll) limits maximum controllable asymmetric engine thrust to military power and no vectoring at low speeds or military power and 20° of vectoring at the transonic maneuver condition.

In addition to the control power limits listed above, Modification No. 4 has other potential problem areas, such as:

(1) Canard wake/engine inlet distortion.

(2) Canard wake/fin interference leading to directional stability problems.

3.2A.6 Aerodynamics

The F-106B configurations, Modifications No. 1 and No. 2, were reviewed and the increased drag due to the added modifications was estimated. For Mod. No. 1, drag estimates were included for nacelle wetted area, cross sectional area effects, excrescences of the nacelles, the inlet diverter, and the base type region between the nozzle and the elevon. For Mod. No. 2, the nacelle drag was added as it was for Mod. No. 1 except the base region between the nozzle and the elevon was eliminated due to elevon removal in the nacelle region, and the drag of the horizontal tail was added. The incremental zero lift drag of these two modifications relative to the baseline F-106 is indicated in Table 1. These increments were added to the baseline F-106B drag in Reference 3.2A.6-2.

TABLE I INCREASED DRAG DUE TO MODIFICATION

	Mod No. 1		Mod. No. 2	
	$M = 0.9$	$M = 1.8$	$M = 0.9$	$M = 1.8$
ΔC_D*	0.0012	0.0028	0.0014	0.0044

$^*S_{ref} = 695$ ft^2

The basis used for the performance calculations are summarized in References 3.2A.6-1 through -4. Drag differences between the configurations were ignored for the takeoff and landing calculations.

The takeoff distance performance is summarized in Figure 3.2A.6-1 for only the J75 operating, since the landing gear obstructs the J85 inlets.

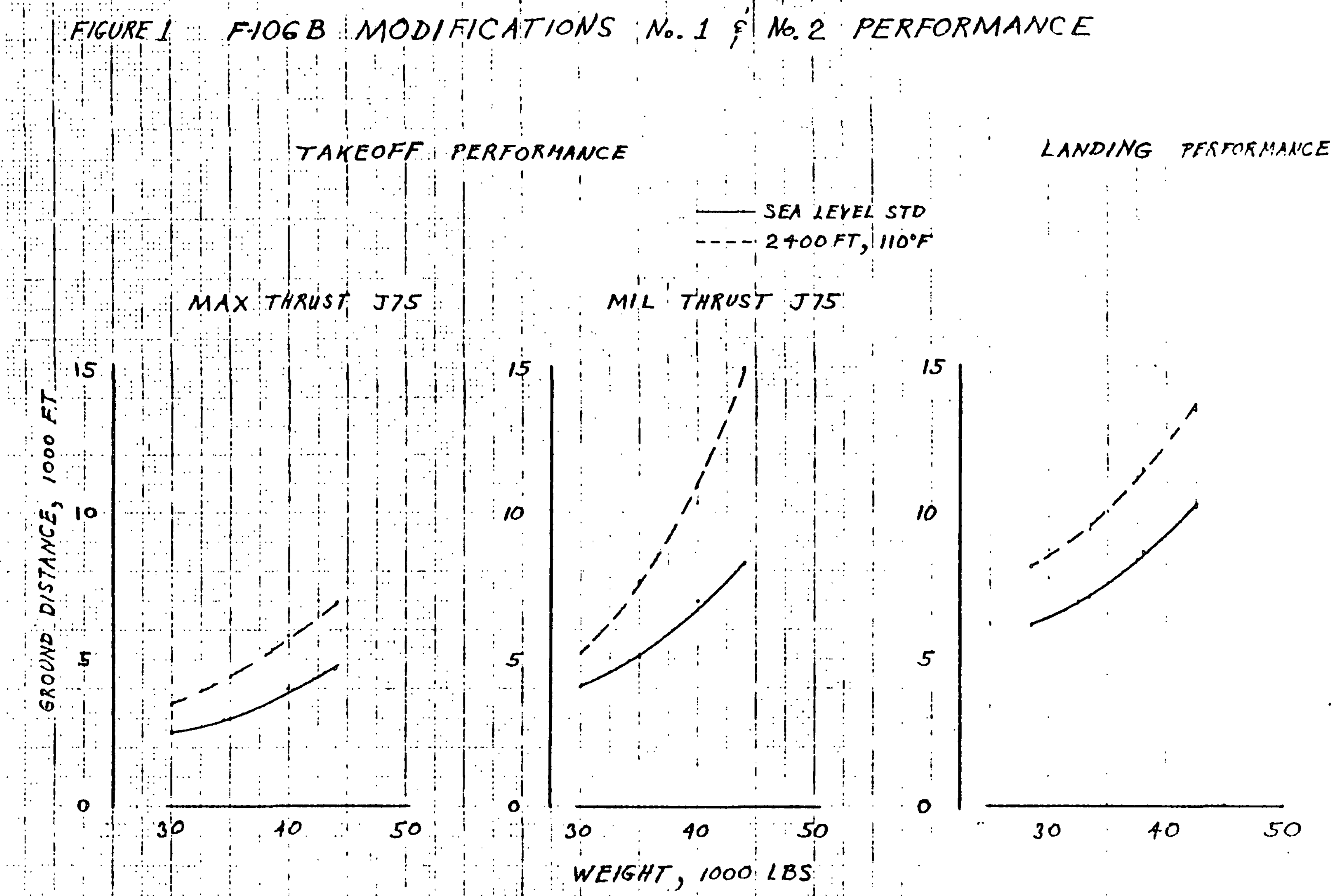


Figure 3.2A.6-1. F-106B Modifications No. 1 and No. 2 Performance

Distances for both Maximum and Military thrust are indicated because the Edwards-hot day condition results in long ground runs at the Military rating and heavy weights.

The landing distance performance is also indicated in Figure 3.2A.6-1. Thrust vectoring cannot be considered for these two configurations to shorten ground run because there is no forward control device to balance the pitching moments generated by the nozzle.

The subsonic and supersonic mission performance for both Modification No. 1 and No. 2 are indicated in Figure 3.2A.6-2. The baseline F-106B performance has been included for reference. The range performance for the modified configurations relative to baseline F-106B has been preserved due to the fact that 3890 lb of fuel were added in the missile bay and 1379 lb of weapons have been removed. (The data on Figure 3.2A.6-2 were developed for J85 nozzles that were originally drawn with a maximum width of 30.8 in and with the assumption that the J85 inlet weight would be no different than that of the NASA inlet.)

Figure 3.2A.6-3 illustrates the effect of 48 in wide nozzles (final drawing) and an arbitrary dead weight increment of 1000 lb, on Mod. No. 2 performance. The 1000 lb increment, reflecting a possible difference between new J85 inlets and the NASA inlets, degrades subsonic performance by 29 n.mi. and supersonic performance by 7 n.mi. The wider nozzles cause an additional degradation of 3 n.mi. on supersonic performance but have a negligible effect subsonically. Mod. No. 1 performance would be affected to a similar degree.

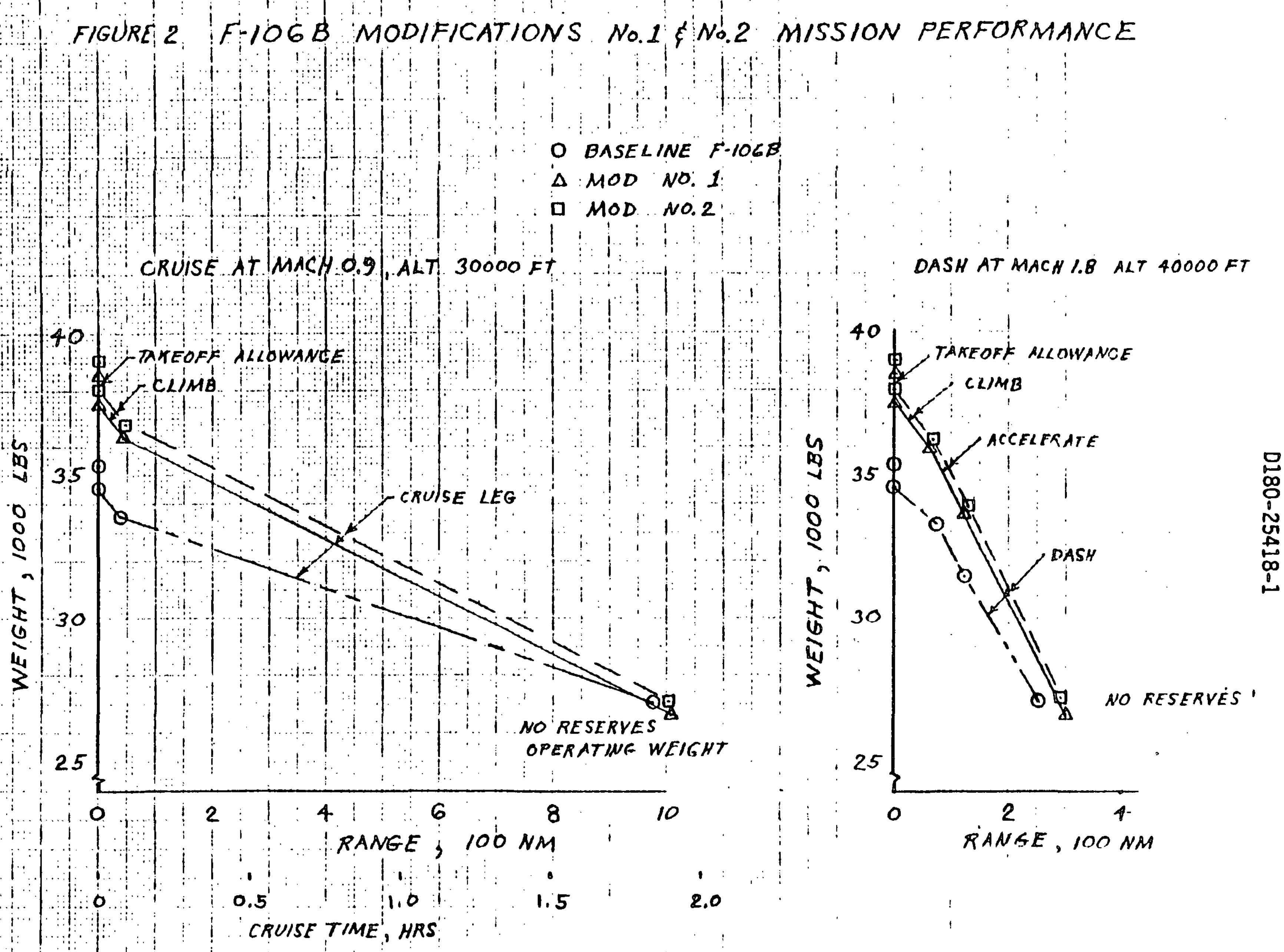


Figure 3.2A.6-2. F-106B Modifications No. 1 and No. 2 Mission Performance

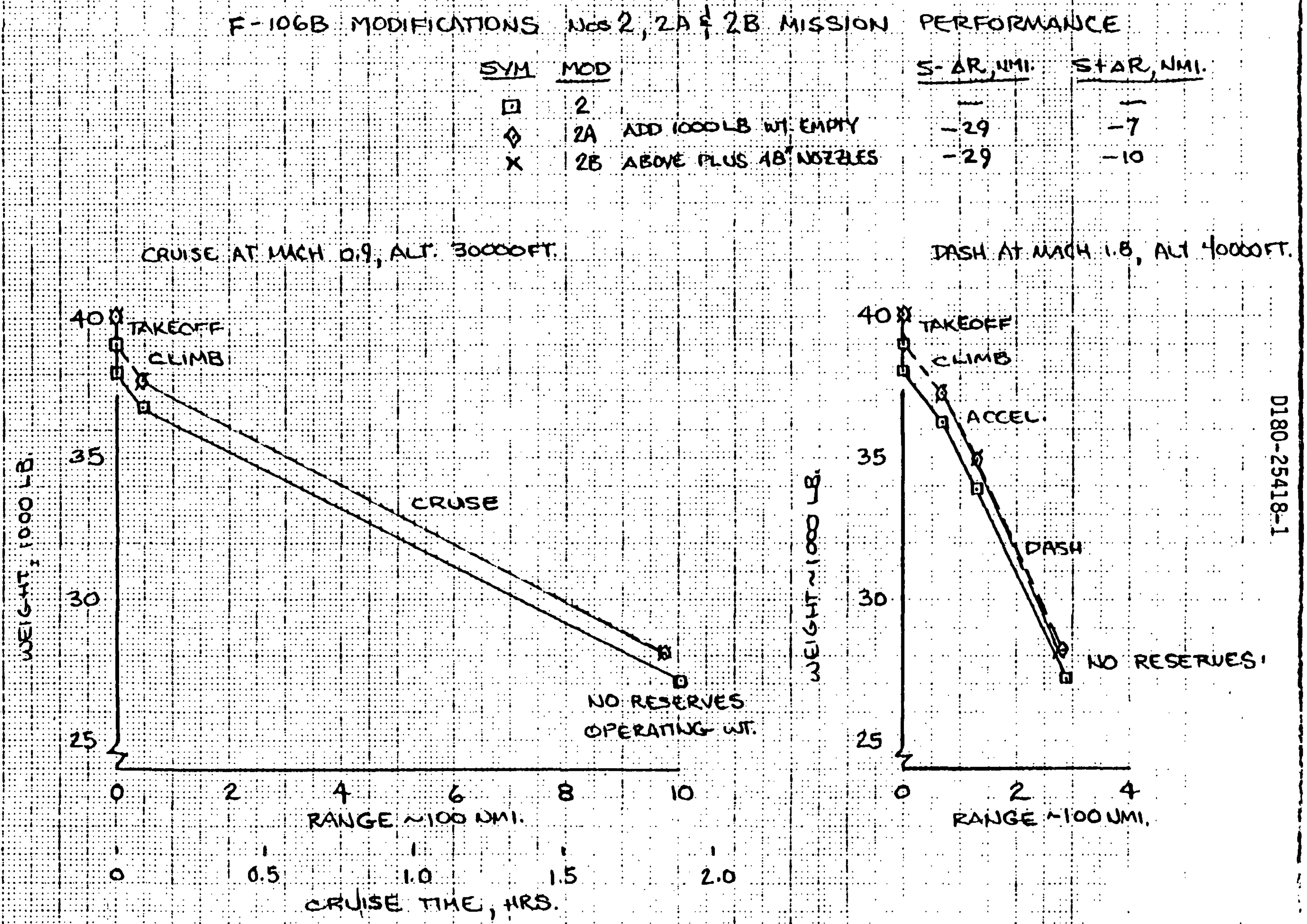


Figure 3.2A.6-3. F-106B Modifications No. 2, No. 2A and No. 2B Mission Performance

The assumptions made to keep these performance calculations simple and the performance representative are summarized. The takeoff/accelerate-to-climb-speed fuel allowance was computed as if all three engines were operating at Military power for three minutes. Operationally, for these configurations, the J85 engines would be started in the air after gear retraction because the gear strut wake will enter the J85 inlet. The climb and the supersonic acceleration were computed on the basis that the J85 thrust equaled the increased drag due to the modification, and the J75 fuel and F-106B performance was the same as the T.O., Reference 3.2A.6-3, with the J85 fuel added. The cruise, M = 0.9, and dash, M = 1.8, fuel were computed on the basis of total thrust equals drag with the J85 engines at Military and Maximum power, respectively.

The Modification No. 3 configuration was compared with the baseline F-106B configuration, and the increased drag due to the addition of a 2-D nozzle/extension was calculated. Since there were no detailed lines for the nozzle boattails and the area ratios were similar, the external wave drags were considered equal for this preliminary estimate. The increased drag used is indicated in Table II.

TABLE II INCREASED DRAG DUE TO MODIFICATION

	Mach 0.9	Mach 1.8
ΔC_D (S_{ref} = 695 ft^2)	0.0002	0.0002

The ground run distance for takeoff and landing performance are indicated in Figure 3.2A.6-4. The thrust minus drag for this configuration is essentially the same as the baseline configuration. However, the nozzle extends further aft restricting the angle-of-attack for liftoff and touchdown to three degrees less than the baseline configuration. Thus, the landing and takeoff distances are increased. For this set of calculations, the nozzle was assumed undeflected.

The subsonic and supersonic mission performance is indicated in Figure 3.2A.6-5. Once again, the baseline performance has been included for reference. The range performance has been preserved due to the fact that a slight improvement in SFC (advanced 2-D nozzle technology vs. 1956 axisymmetric nozzle technology; see Section 3.2A.2) compensates for the increased weight of the modification.

The mission performance was computed by modifying T.O. performance for climb and acceleration to adjust for thrust and drag changes. The takeoff allowance was based upon three minutes at Military power. Cruise and dash performance were based upon an average weight.

The Modification No. 4 configuration was compared with the baseline F-106B configuration in order to compute the increased drag due to the modification. These additional items were the canard, the auxiliary engine nacelles, and the increased vertical tail area of nearly 18 ft^2. The increased drag estimate is indicated in Table III.

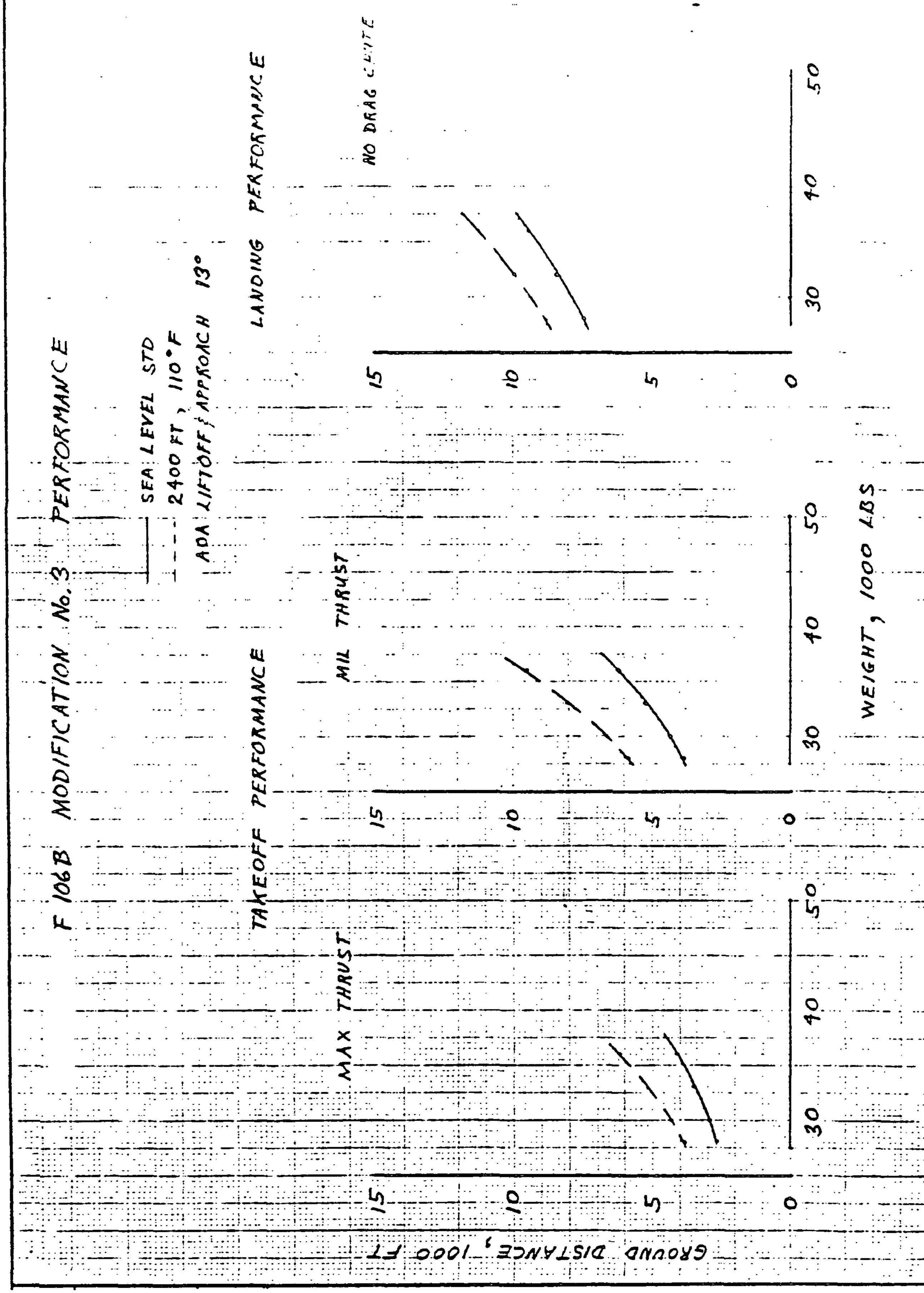


Figure 3.2A.6-4. F-106B Modification No. 3 Performance

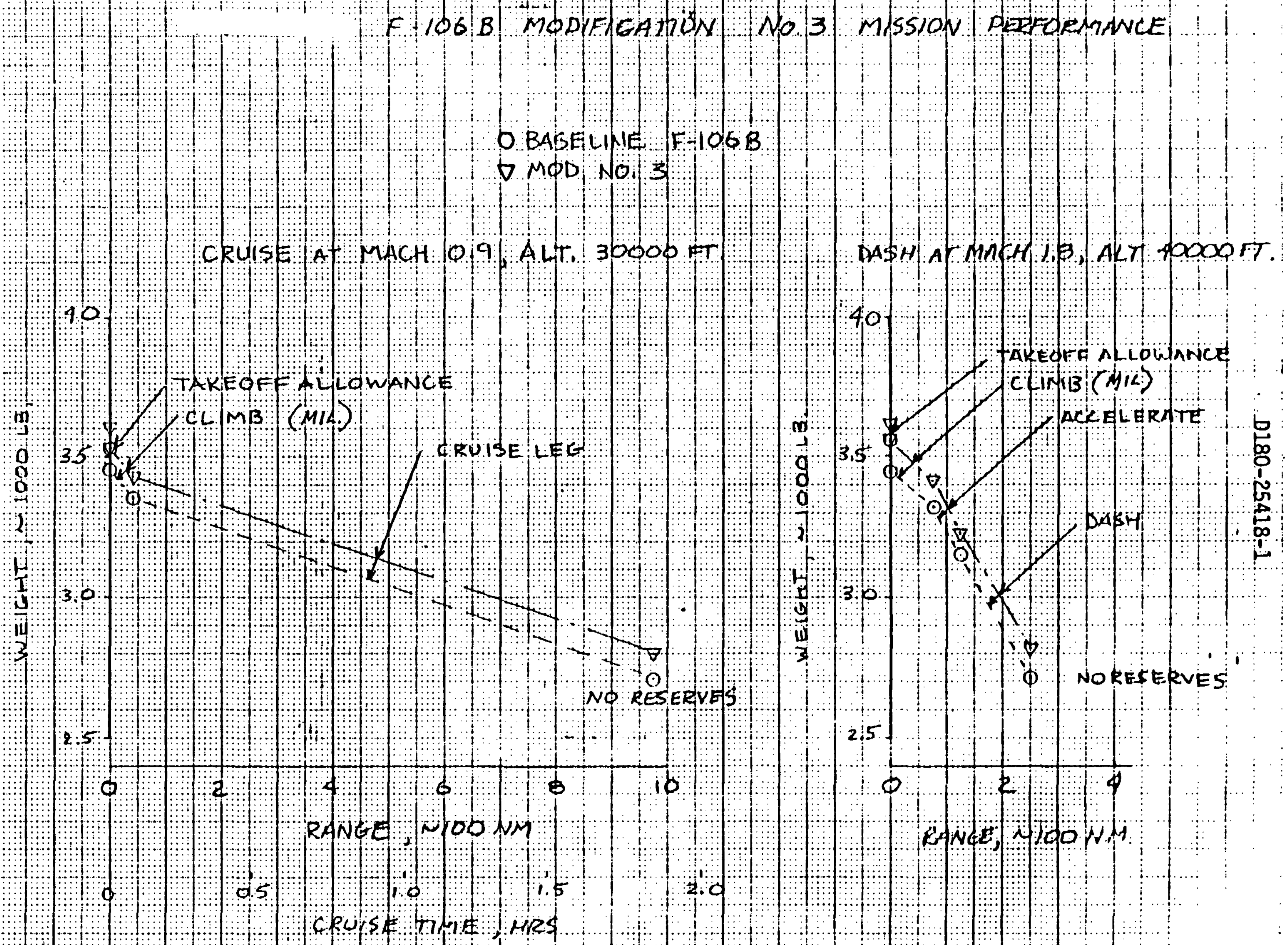


Figure 3.2A.6-5. F-106B Modification No. 3 Mission Performance

TABLE III INCREASED DRAG DUE TO MODIFICATION

	Mach 0.9	Mach 1.8
ΔC_D (S_{ref} = 695 ft^2)	0.0026	0.0075

The field length performance for both takeoff and landing is indicated in Figure 3.2A.6-6. The nacelle ground clearance for this configuration is the same as the baseline. Thus, liftoff and approach attitudes are the same and the only significant change in performance is for takeoff with the auxiliary engines operating. For this case the field lengths are reduced by almost one half.

Modification No. 4 subsonic and supersonic mission performance is indicated in Figure 3.2A.6-7. The flight time for the cruise mission is reduced by half from the baseline, and for the dash mission flight time is reduced by 25%. This reduction is caused by both a 2544 lb ballast requirement and an increased basic operating weight, which in turn causes the off-loading of nearly 5,100 lb of fuel in order to stay within the 44,000 lb gross weight limit of the aircraft. Considering ten minutes of reserve for the cruise mission, flight time at altitude would be 35 minutes. The dash mission only has 3.1 min. at Mach 1.8 without any consideration for reserves.

The mission performance basis consisted of the following assumptions. The takeoff fuel allowance is that fuel required for all three engines at military power for three minutes. The climb performance was based upon

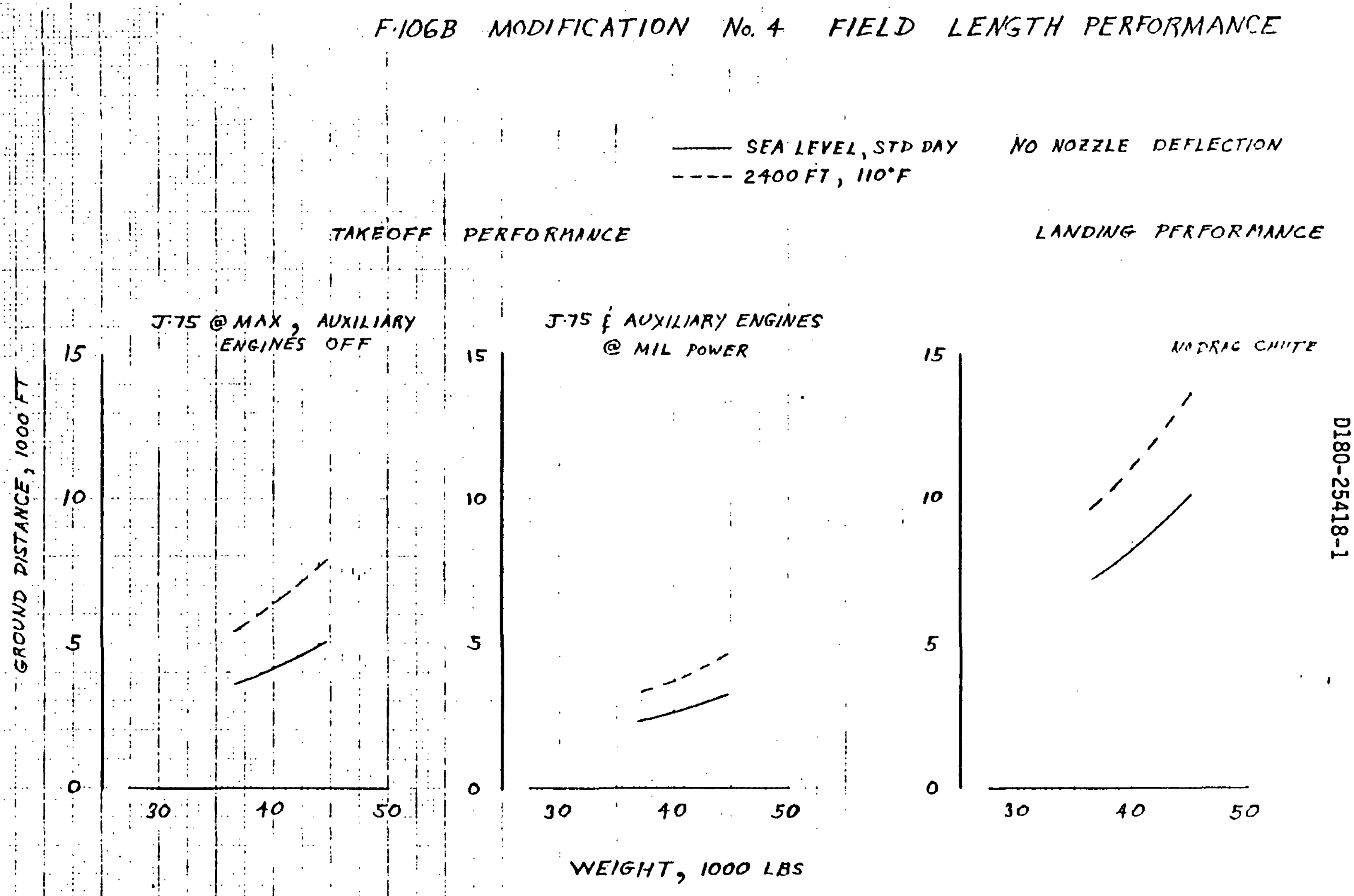


Figure 3.2A.6-6. F-106B Modification No. 4 Field Length Performance

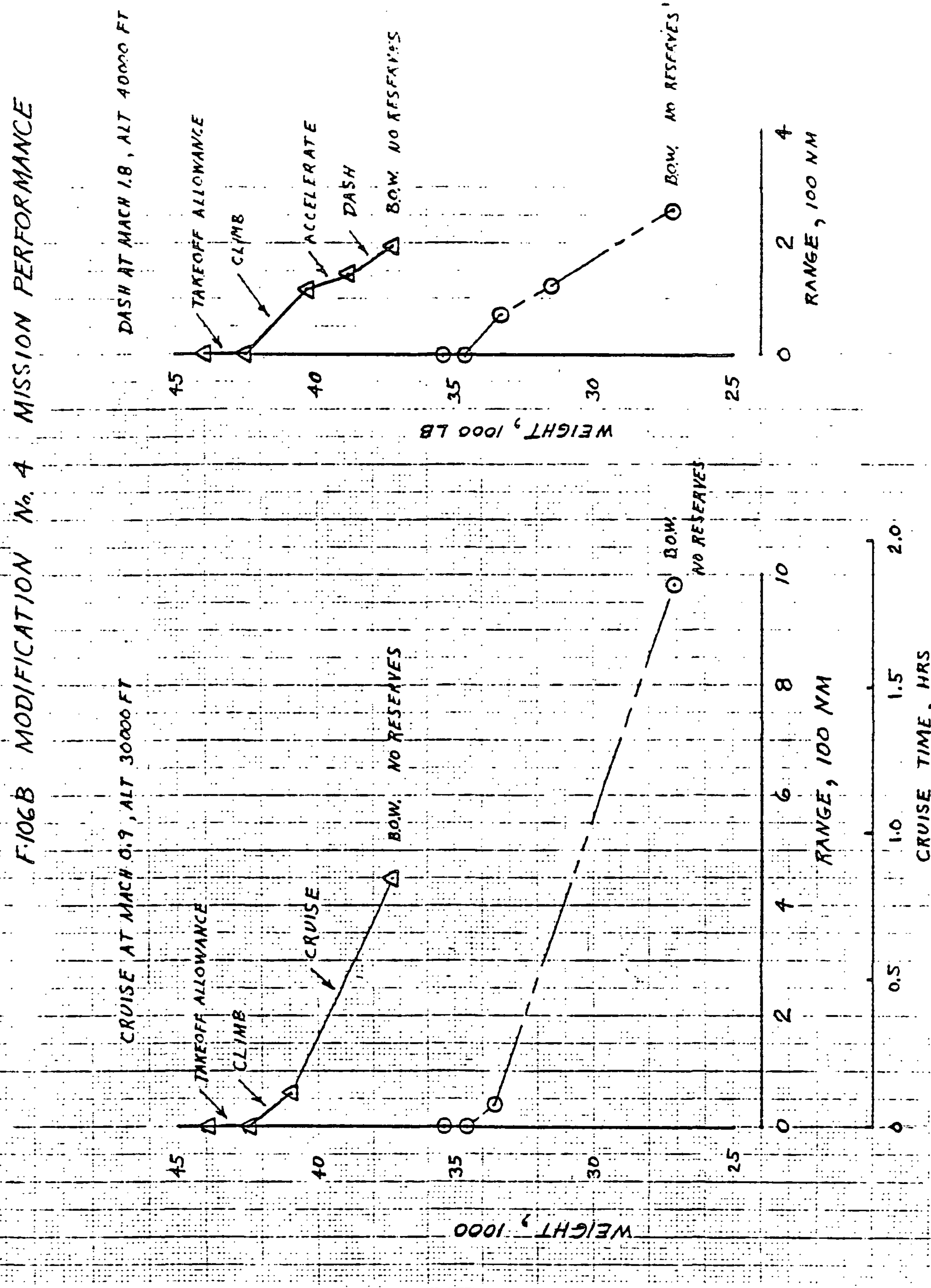


Figure 3.2A.6-7. F-106B Modification No. 4 Mission Performance

the J75 at military power, and the auxiliary engines at a level to overcome the drag due to the modification. The cruise performance was based upon the J75 at flight idle and the auxiliary engines matching the remaining drag. The acceleration was computed with the J75 at military power and the auxiliary engines at maximum power since this technique provided ample excess thrust and better SFC's than including the J75 at maximum. The dash was computed with the J75 again at military power, and the auxiliary engines at partial afterburner to match the remaining thrust required.

Performance of all four proposed modifications is compared to baseline F-106B performance in the Figure 3.2A.6-8 and 3.2A.6-9 summary bar charts. Field performance at ambient conditions typical for Edwards is presented in the first figure, where takeoff ground run distances are shown for the appropriate takeoff weight of each configuration and landing ground run distances are shown for similarly appropriate landing weights. The second figure summarizes both subsonic and supersonic range performance. Differences are due to weight, drag and propulsion system performance changes associated with the proposed modifications. it is notable that Mod. No. 4 has substantially poorer performance in both missions, primarily due to its heavier operating weight.

Mod. No. 2 Wing/Tail Interaction

In response to concern that the F-101 horizontal tail proposed for use on Mod. No. 2, might affect the wing flow field, Figure 3.2A.6-10 is presented. The figure shows that the horizontal tail, positioned 2.3

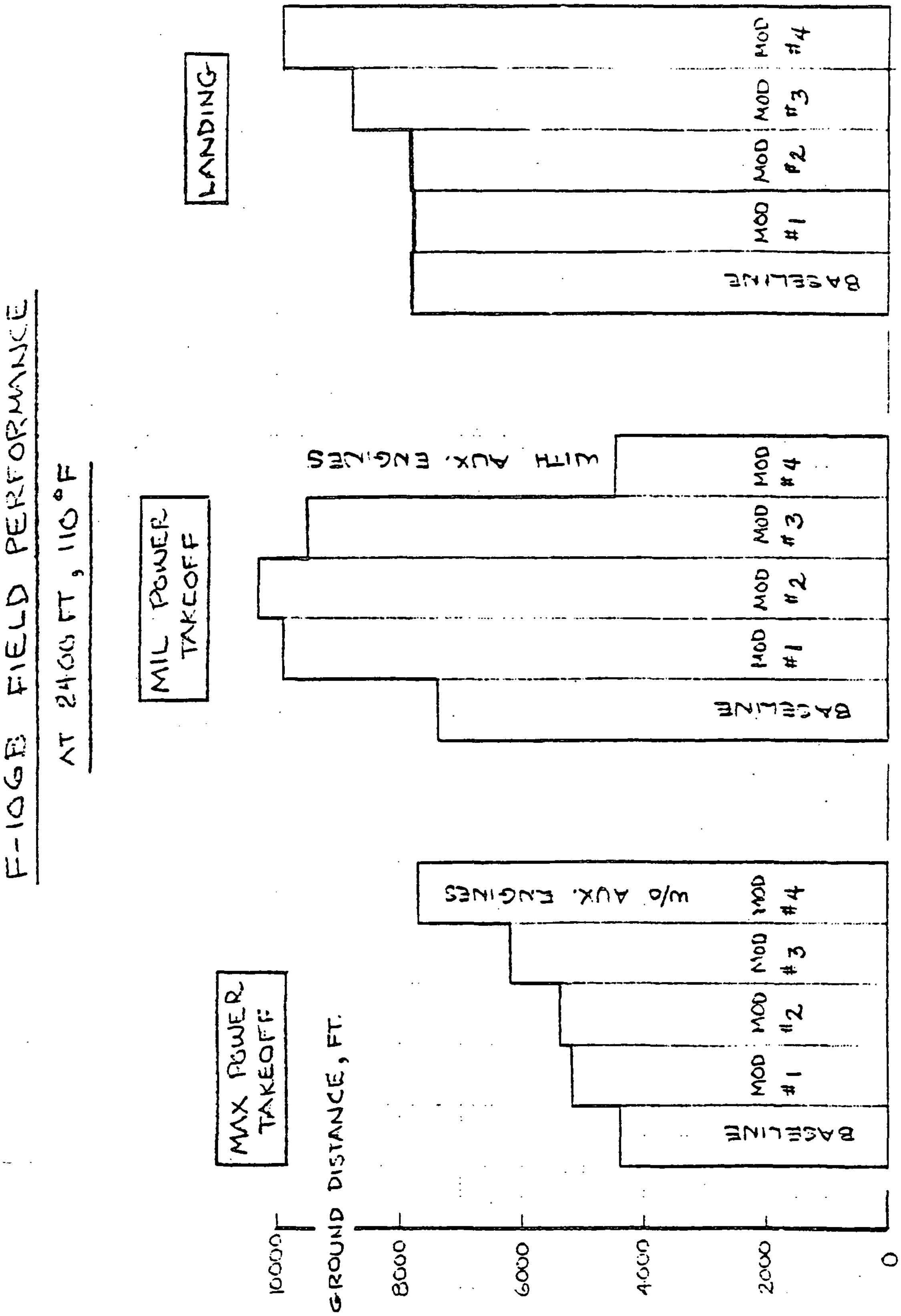


Figure 3.2A.6-8. F-106B Field Performance Comparison of Baseline and All Modifications

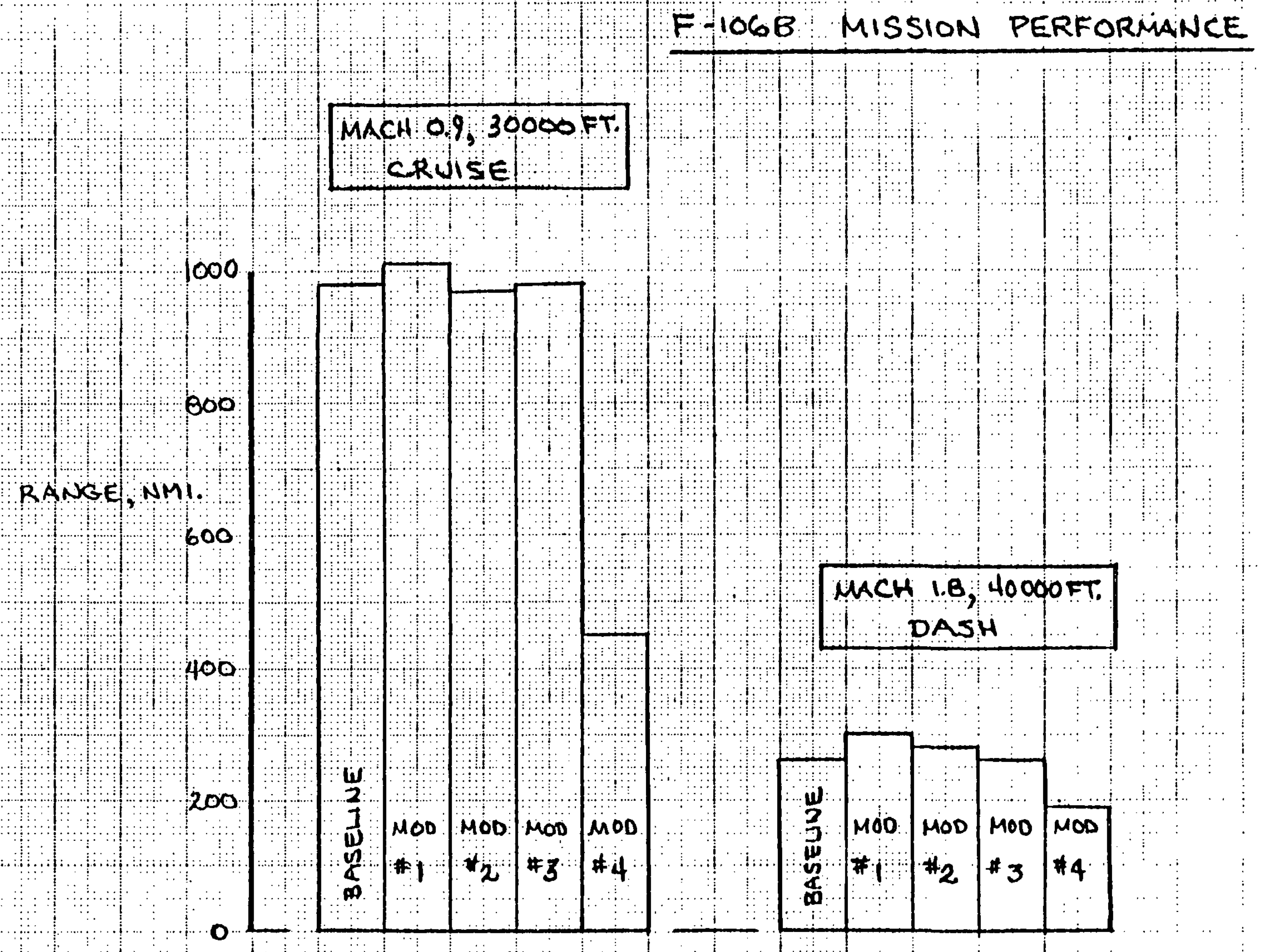


Figure 3.2A.6-9. F-106B Mission Performance Comparison of Baseline and All Modifications

THE HORIZONTAL TAIL FLOW FIELD WILL NOT INTERFERE WITH
THE WING ELEVON CONTROL

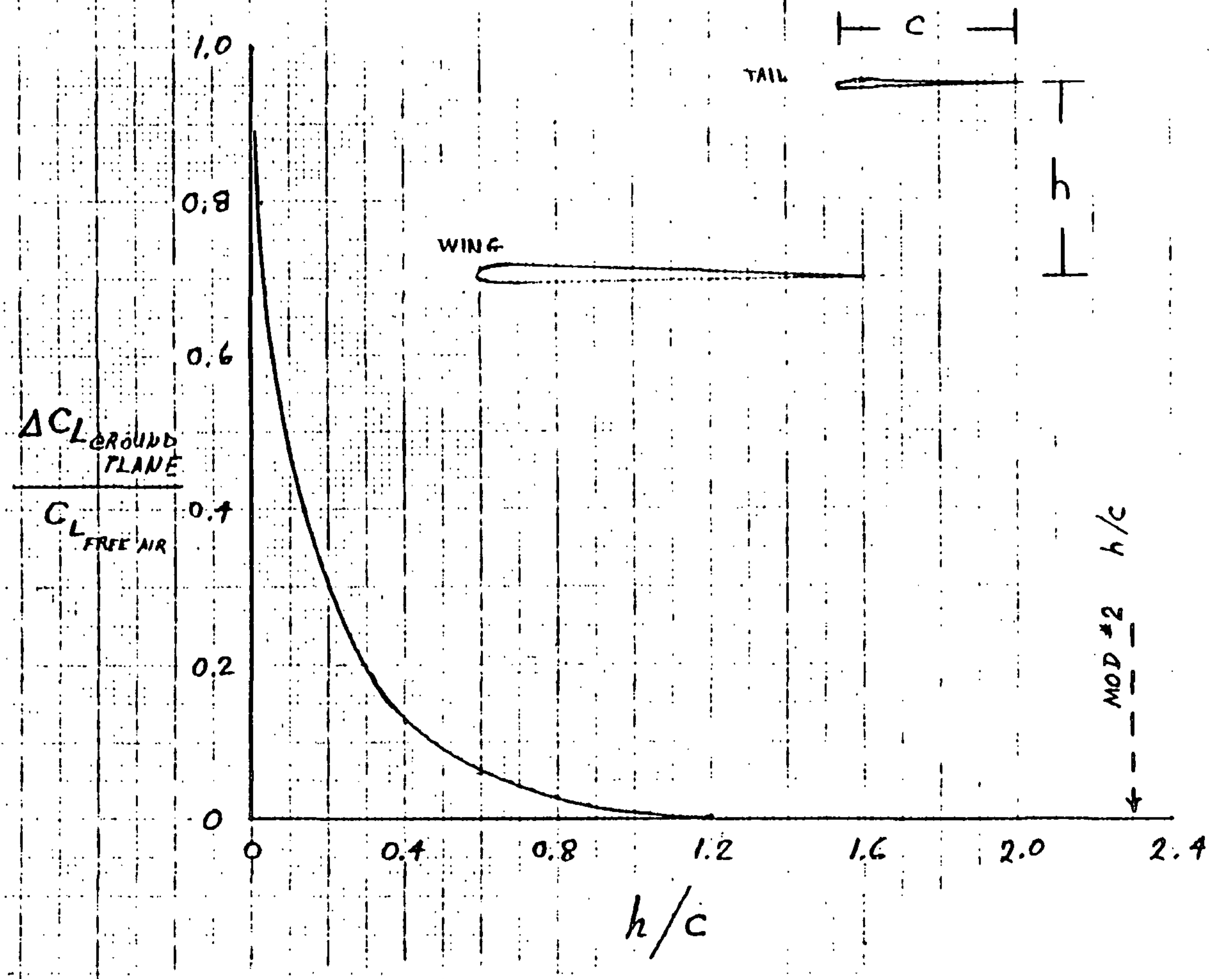
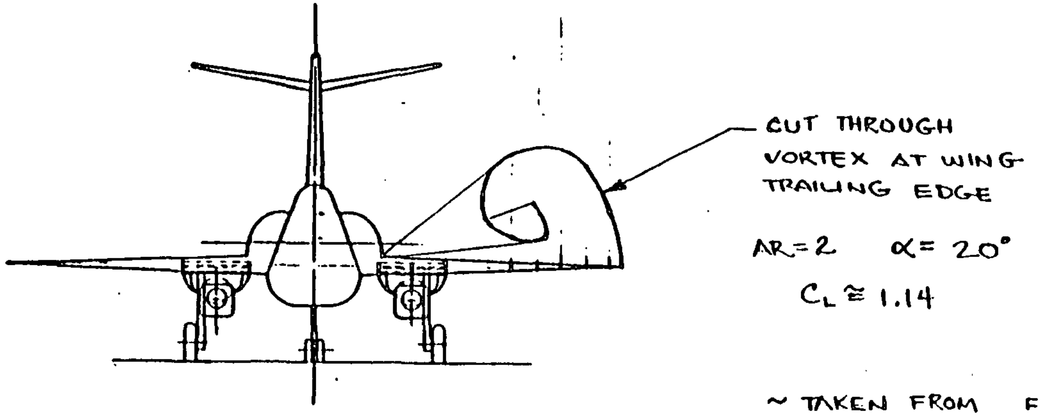


Figure 3.2A.6-10. Horizontal Tail Flow Field Will not Interfere with the Wing Elevon Control

tail chords above the wing plane, is sufficiently high to have negligible effect on the wing and, therefore, would not interfere with induced lift measurements.

Figure 3.2A.6-11 is presented to alleviate concern relative to wing leading edge vortex interference on the horizontal tail at low speeds and high angles-of-attack. The figure shows a trailing edge cut through a wing leading edge vortex developed for an aspect ratio 2 delta planform at 20 degrees angle-of-attack. (The F-106 has an aspect ratio of 2.2.) Once again, the F-101 horizontal appears to be sufficiently high to avoid vortex interference.

F-106B MOD # 2



AR = 2 $\alpha = 20°$

$C_L \cong 1.14$

~ TAKEN FROM F.T. JOHNSON AND E.N. TINOCO, RECENT ADVANCES IN THE SOLUTION OF THREE-DIMENSIONAL FLOWS OVER WINGS WITH LEADING EDGE VORTEX SEPARATION AIAA, JAN 1979

Figure 3.2A.6-11. F-106B Modification No. 2 Schematic of Three-Dimensional Flow over Wing

3.2B Task 2 CONFIGURATION EVALUATION

In addition to the feasibility analyses described for each of the aircraft technologies in Section 3.2A, the overall performance of each of the study configurations was briefly examined. Maneuver load factors, incremental propulsive-related lift and potential for reduced field length performance are summarized in this section. In addition, a final qualitative assessment of the feasibility, limitations, and areas to concentrate on for advanced design studies is given for study modifications #1 to #4.

3.2B.1 Incremental Maneuver and Lift

Analyses were performed to determine potential lift and maneuverability improvements (incremental load factor) obtainable with nozzle vectoring for each modification, Figure 3.2B.1-1 and 3.2B.1-2. The following maneuver was analyzed to determine maneuverability gains: while at power for level flight, the nozzle is deflected, engine thrust is increased to maintain speed, and concurrently pitch trim is used to balance moments induced by vectoring. Two flight conditions were analyzed for each modification: Mach = 0.3 at 5000 ft and Mach = 0.9 at 30,000 ft for mid weight and appropriate CG. Modification No. 2 had the largest increase in incremental load factor at these flight conditions.

Modification No. 1, designed only as a flying testbed for the advanced nozzles, produced a negative incremental load factor for all positive

M: 0.3 ALT = 5000 FT

POWER FOR LEVEL FLIGHT

	MOD #	WT.	C.G.	Λ_{LE}	ENG.	NOZZLE	TRIM SURFACE
———	1	32000	.24c̄	11.5°	2/J85-21 + J75	AR=17	ELEVONS
—·—	2	32000	.24c̄	11.5°	2/J85-21 + J75	AR=17	HORZ TAIL
– – –	3	31791	.29c̄	12°	J75	AR=4	ELEVONS
—··—	4	39134	.136c̄	15°	2/F404 + J75	ADEN	CANARD

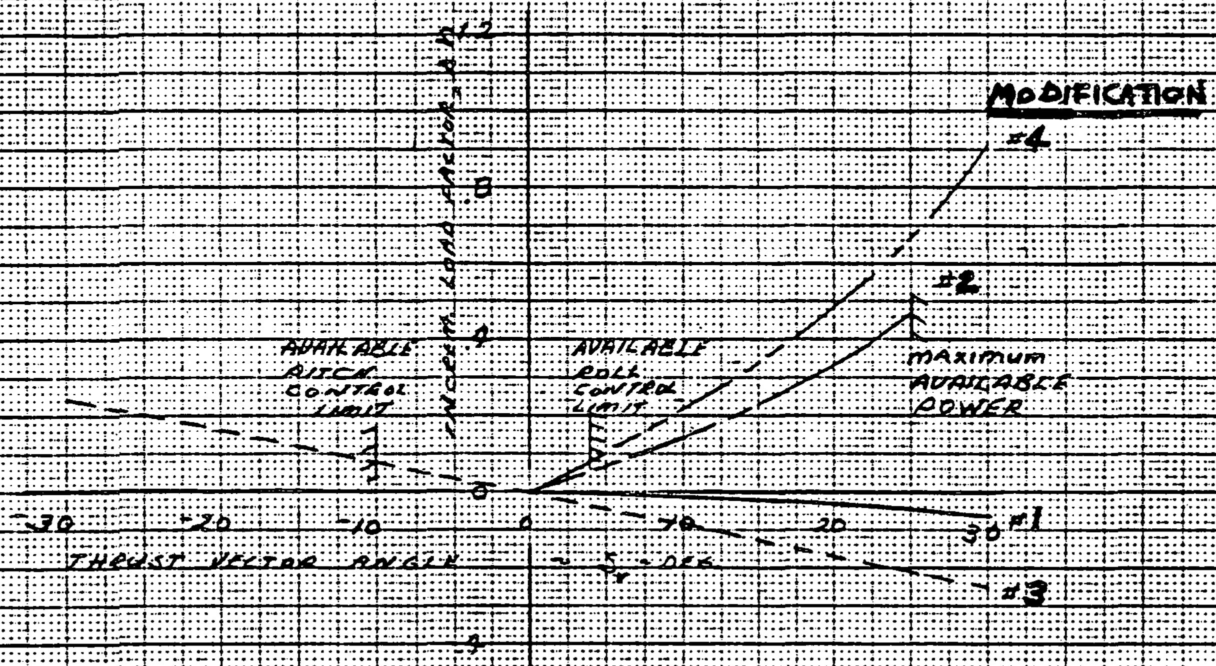


Figure 3.2B.1-1. Effect of Thrust Vectoring on Load Factor M = 0.3 Alt. = 5000ft.

BMAD-FC-153

M = 0.9 ALT = 30,000 FT

POWER FOR LEVEL FLIGHT

	MOD. #	WT.	CG	α_{1g}	ENG	NOZZLE	TRIM SURFACE
————	1	32000	.24$\bar{c}$	2.7°	2/J85-21 + J25	AR=17	ELEVONS
—— - ——	2	32000	.29$\bar{c}$	3.7°	2/J85-21 + J25	AR=17	HORZ. TAIL
— - — - —	3	31191	.29$\bar{c}$	3.5°	J25	AR=4	ELEVONS
—— -- ——	4	39137	.156$\bar{c}$	4.2°	2/F404 + J25	ALBEN	CANARD

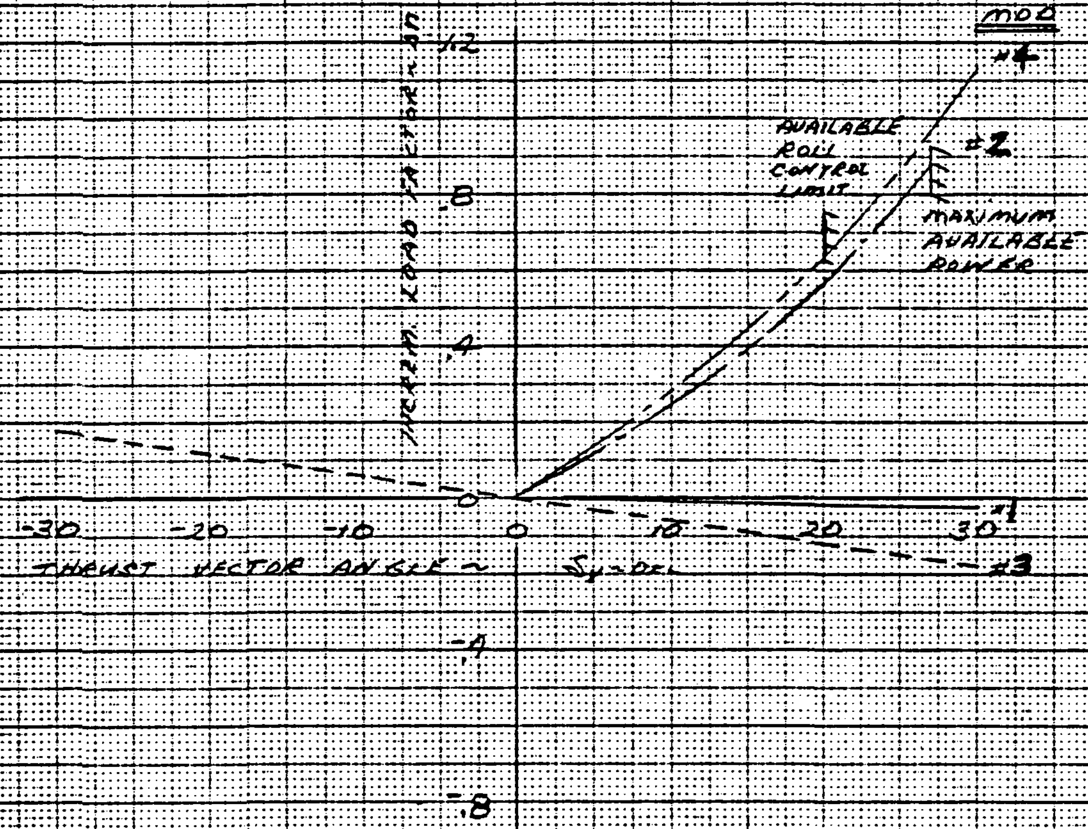


Figure 3.2B.1-2. Effect of Thrust Vectoring on Load Factor M = 0.9 Alt. = 30 000 ft.

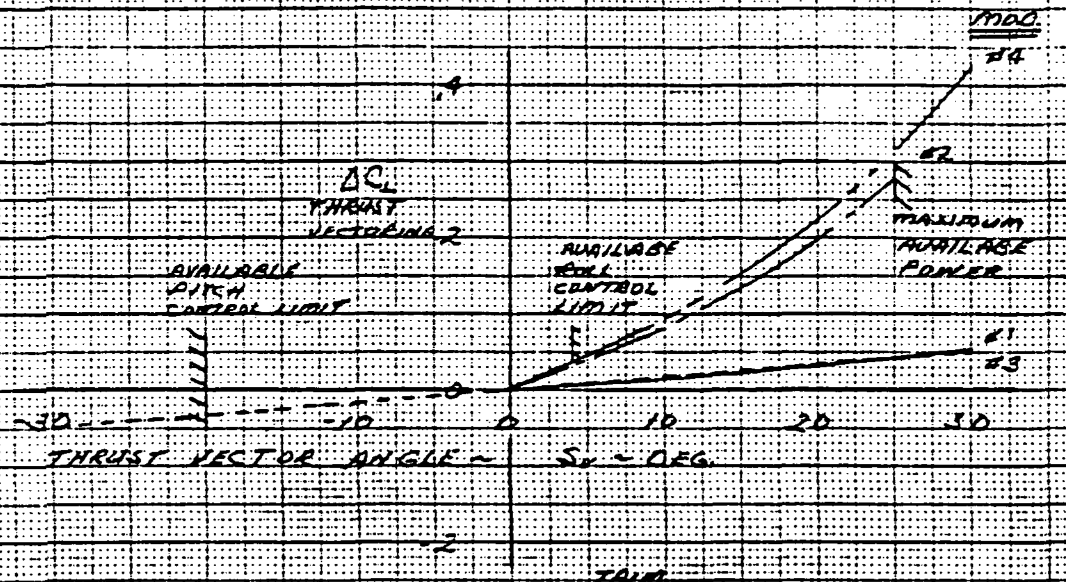
nozzle vector angles. Negative incremental load factors are the result of the vectorable nozzle-wing placement and use of the elevons for trim. The resultant elevon C.P., being in front of the nozzle C.P., results in a negative elevon lift force that is larger than the positive lift force produced by the vectored nozzle, Figures 3.2B.1-3 and 3.2B.1-4. Therefore negative incremental load factors result.

Modification No.2 produced the largest resultant incremental load factor of any modification. Maximum A/B power was obtained on the J85-21 engine prior to limiting nozzle deflection for both conditions. The F-101 horizontal tail was used for pitch control. The induced lift produced by vectoring is forward on the wing while the trim force produced by the horizontal tail is aft of the wing. This results in small negative trim lift forces in relationship to the positive induced lift, Figures 3.2B.1-3 and 3.2B.1-4. Therefore incremental load factors are relatively large.

Modification No. 3, designed as a pitch control device, had a decrease in incremental load factor for all positive nozzle deflection angles. This negative load factor was due to the extreme aft location of the nozzle in relation to the elevons. To balance nozzle pitching moment required elevon lift increments that were larger than, and of opposite sign to, the vectored lift, Figures 3.2B.1-3 and 3.2B.1-4. Positive load factor could be obtained with negative nozzle deflections at transonic speeds, but not at low speed due to limitations on positive elevon travel, which are critical.

M: 0.3 ALT: 5000 FT

POWER FOR LEVEL FLIGHT



	MOD. #	WT	C.G.	α	TAIL SURFACE
———	1	32000	.24c̄	11.8	ELEVONS
—·—	2	32000	.24c̄	11.8	HORIZ. TAIL
- - - -	3	31191	.29c̄	12	ELEVONS
— — —	4	39734	.156c̄	16	CANARD

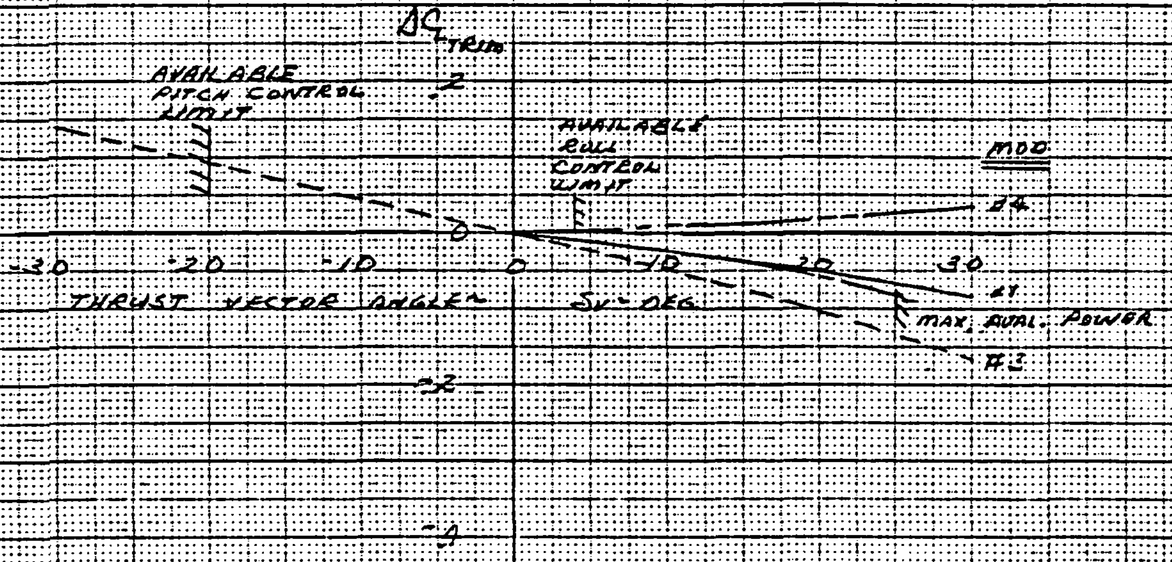
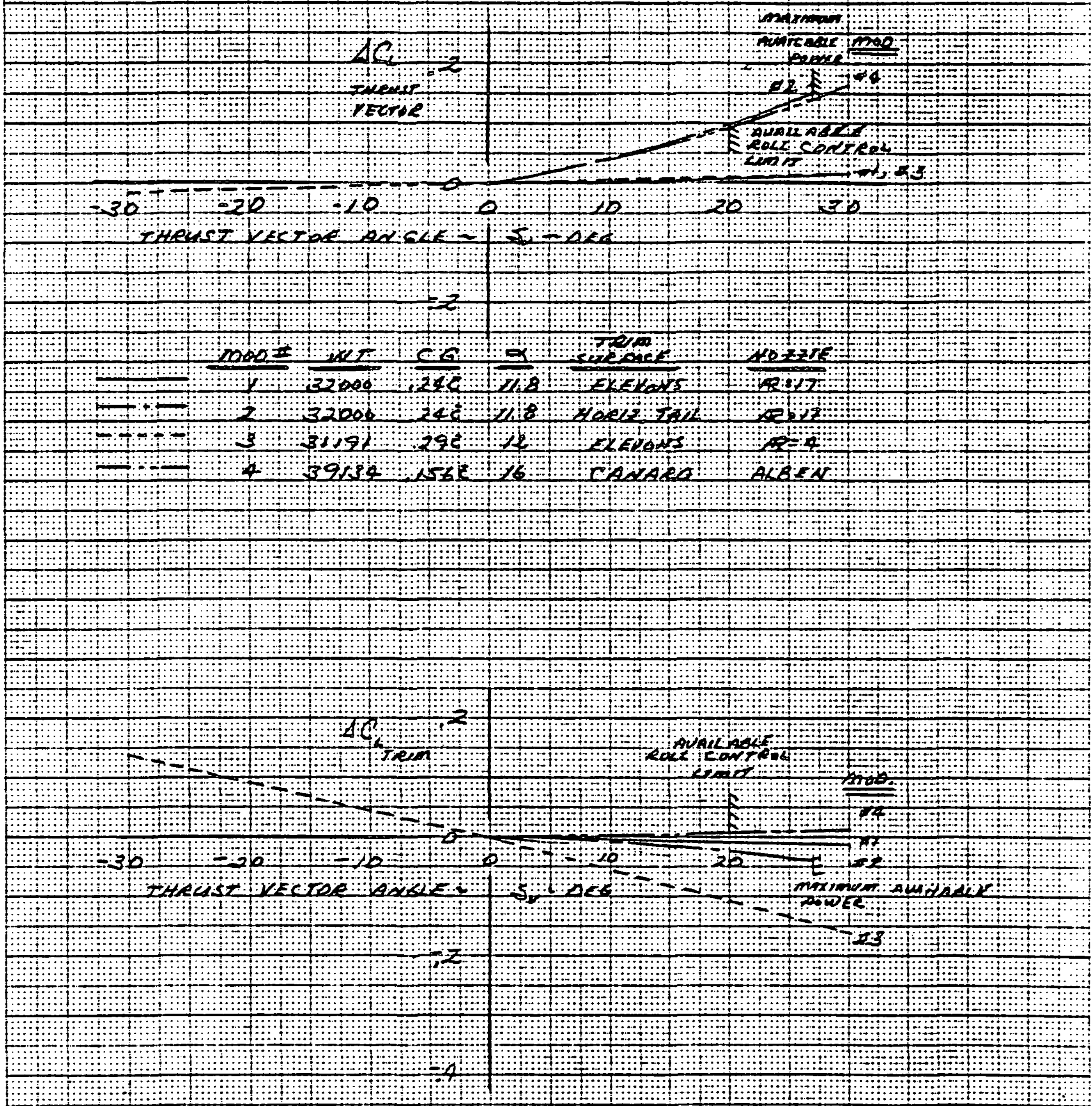


Figure 3.2B.1-3. Effect of Thrust Vectoring on Lift Coefficient M = 0.3 Alt. = 5 000 ft.

M=0.9 ALTITUDE = 30000 FT

POWER FOR LEVEL FLIGHT



	MOD #	WT	CG	α	TRIM SURFACE	NOZZLE
———	1	32000	.24c̄	11.8	ELEVONS	AR=17
—·—	2	32000	.24c̄	11.8	HORIZ TAIL	AR=17
- - - -	3	31191	.29c̄	12	ELEVONS	AR=4
— - —	4	39134	.156c̄	16	CANARD	ALBEN

Figure 3.2B.1-4. Effect of Thrust Vectoring on Lift Coefficient M = 0.9 Alt. = 30 000 ft.

Modification No. 4 had positive incremental load factor for positive nozzle deflections at both conditions. A 50 sq. ft. exposed area canard is used for pitch control. Available roll control limits asymmetric (failure case) nozzle deflections to 4° at Mach = 0.3 at 5000 ft and 20° at Mach = 0.9 at 30,000 ft. Potentially this modification could have the largest incremental load factor increase, if the engine-out limitations could be overcome. But these limits are serious at low speed (pitch, yaw and roll control).

3.2B.2 Landing and Takeoff

Both Modifications #1 and #2 show (acceptable) increases in takeoff ground run relative to an unmodified F-106B due to the J85 pod weight, assuming no use of the J85's for thrust. If the Mod. No. 2 strut/inlet interference problem is ignored, the benefits of trimmed, thrust induced lift and deflected thrust have the potential to reduce landing ground runs by about 30% for this configuration, see dashed line on Figure 3.2B.2-1. This potential was calculated based on a demonstration condition of Mach 0.3, 5000 ft altitude, Mod. No. 2 at 32000 lb. Maximum available power was used with the J85 nozzles deflected 25 degrees and trimmed with -12.4 degrees of horizontal tail deflection.

Speed reduction potential, allowed by thrust vectoring with the Mod. No. 3 2-D nozzle, is illustrated in Figure 3.2B.2-2. The figure shows speed variation and elevon angles for trim versus nozzle vector angle for part power, thrust-equal-to-drag and MIL power with two center-of-gravity locations. The illustrated relationships are for equilibrium conditions.

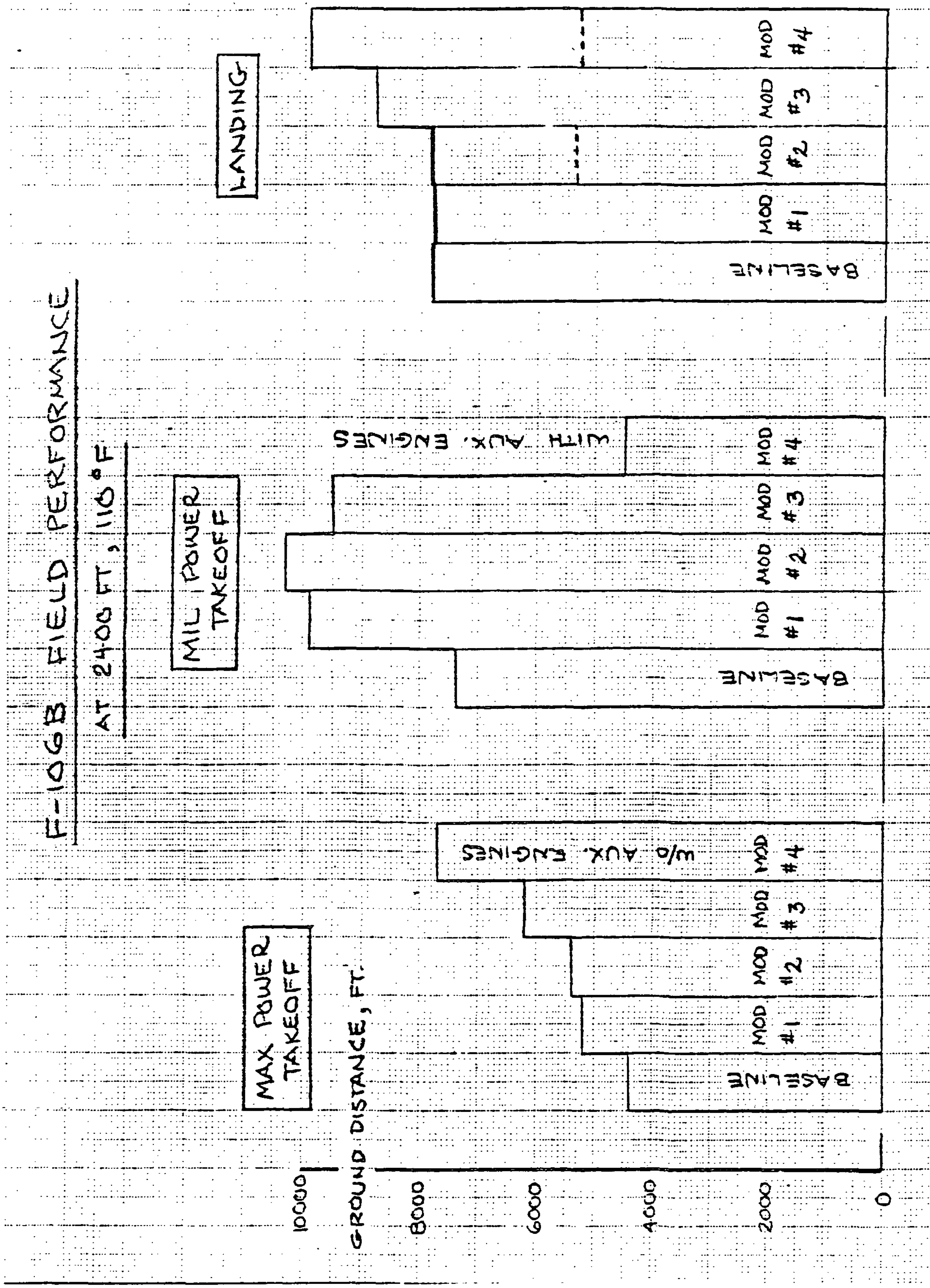


Figure 3.2B.2-1. F-106B Field Performance

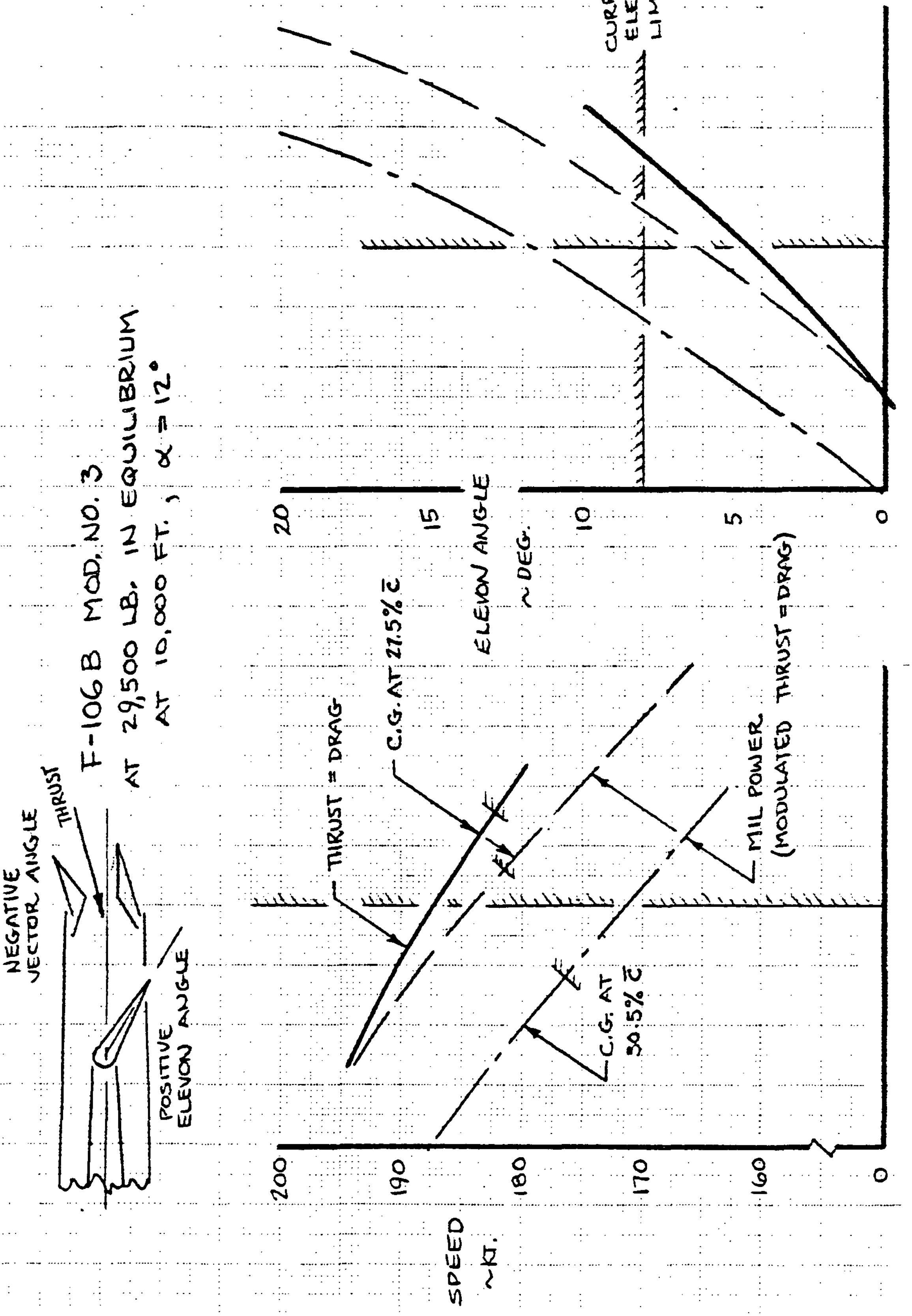


Figure 3.2B.2-2. Speed Reduction with Vectoring

Therefore, the MIL power analyses assume that the longitudinal thrust vector has been modulated such that it is just equal and opposite to drag forces. Relationships beyond nozzle and elevon deflection limits and at the more aft center-of-gravity location are illustrative only. Further modifications to Mod. No. 3, as drawn, would be required to demonstrate the additional capability. These include: increasing the F-106B down elevon deflection limit, increasing the deflection limits of the proposed 2-D nozzle and modification of the flight control system to handle the case where the stability margin has been reduced.

The potential for speed reduction due to the benefits of deflected thrust and induced lift, was assessed for Mod. No. 4 as well. All engines were assumed operating and no account of control limitations for engine-out was taken. With the F-404 nozzles deflected 23 degrees (positive), equilibrium speed (equivalent) is reduced from 181 to 132 kt (just prior to canard stall). Such a speed reduction has the potential to shorten landing ground roll by about 50% (see dashed line on Figure 3.2B.2-1 shown earlier). This benefit is derived from lift contributions from engine thrust, thrust induced wing lift and canard lift. These analyses were performed for Mod. No. 4 at 39134 lb, center-of-gravity at 15.6% c and 5000 ft altitude.

3.2B.3 Configuration Feasibility Summary

As as result of the technology and design analyses accomplished in this program, a qualitative summary assessment of each study configuration was prepared, see Figure 3.2B.3-1. Considering all the analysis

SUMMARY CONFIGURATION ASSESSMENT

	MOD # 1	MOD # 2	MOD # 3	MOD # 4
TECHNICAL FEASIBILITY	FEASIBLE	FEASIBLE	FEASIBLE WITH LIMITATIONS	FEASIBLE WITH LIMITATIONS
PROBABLE OPERATING LIMITATIONS	● 6 g's WITH < 60% FUEL ● J85's ON FOR GEAR UP ONLY	● 6 g's WITH < 60% FUEL ● J85's ON FOR GEAR-UP ONLY ● INSUFFICIENT ROLL CONTROL FOR LOW SPEED NOZZLE HARDOVER (ENGINE OUT)	● FORWARD BALLAST ● A/C ROTATION ANGLE ● LOW SPEED THRUST VECTORING ANGLES ($0 < \delta_N < 20$) ● MAXIMUM NOZZLE DEFLECTION ACHIEVABLE FOR MIL POWER OR LESS	● OFF-LOADED FUEL/ENDURANCE ● FORWARD BALLAST ● 30^o A/B VECTORING ONLY AT LOW AIRCRAFT ANGLES OF ATTACK (M 0.9) ● MIL POWER OR LESS BELOW 200kts. (ENGINE OUT) ● INSUFFICIENT ROLL CONTROL FOR LOW SPEED NOZZLE HARDOVER (ENGINE OUT)
FOCUS FOR ADVANCED DESIGN EFFORTS	● RESIZED INLET FOR J85-21 ● NOZZLE BASE AREA ● STRUCTURAL LOADPATHS FOR VECTORING LOADS ● THRUST REVERSER FLOW DIRECTIVITY ● LIGHTENING OF NASA NACELLES	● RE-SIZED INLET FOR J85-21 ● STRUCTURAL LOADPATHS FOR VECTORING LOADS ● THRUST REVERSER FLOW DIRECTIVITY ● LIGHTENING OF NASA NACELLES ● T-TAIL/WING INTERACTIONS -TAIL STALL -WING INDUCED LIFT ● STRUCTURAL ATTACHMENT & ACTUATION OF T-TAIL ● INTEGRATION OF H-TAIL/ ELEVON CONTROLS ● NOZZLE HARDOVER THRUST LIMITER	● STRUCTURAL LOADPATHS FOR VECTORING LOADS ● NOZZLE MAXIMUM DEFLECTION/ THRUST LIMITER/REDUNDANCY ● THRUST REVERSER INTEGRATION -FLOW DIRECTIVITY -USE WITH SPEED BRAKE ● ELEVON DOWN AUTHORITY INCREASE	● RE-EXAMINE CONFIGURATION ARRANGEMENT FOR STOL ● STRUCTURAL INSTALLATION OF ENGINE & PODS ● VERTICAL STABILIZER MODIFICATION ● INLET DISTORTION -INLET-TO-INLET -CANARD-TO-INLET ● BALLAST INSTALLATION ● ELEVON DOWN AUTHORITY INCREASE ● CANARD STRUCTURAL INSTALLATION ● INTEGRATION OF CANARD/ELEVON CONTROLS ● HIGH $C_{L_{max}}$ CANARD ● NOZZLE MAXIMUM DEFLECTION/ THRUST LIMITER
REMARKS				

Figure 3.2B.3-1. Summary Configuration Assessment

3/13/79 MBS

implications, it is judged that each configuration appears feasible as a vehicle capable of researching selected features of advanced non-axisymmetric nozzles. This feasibility is contingent on each configuration being operated within certain envelope restrictions as noted in the figure. In particular, the low speed limitations for Configuration #4 are significant. Moreover, each study configuration has unique design questions which must be addressed more fully than could be accomplished in this feasibility assessment. These design areas are identified for each configuration in Figure 3.2B.3-1. It is anticipated that should government or industry interest exist to pursue a flight research program based upon any of the study configurations, that a preliminary design phase addressing the identified design questions in detail would precede a program go-ahead.

3.3 TASK 3 - RESEARCH PROGRAM DEFINITION

Typical flight research programs were formulated for each of the four study configurations. No attempt was made to formulate detailed tasks and schedules. Rather, the intent was to provide an overall definition of major requirements so that preliminary schedules and budgetary costs could be developed.

The initial step in formulating the flight programs was to envision the probable desired data output. To this end, technical objectives were formulated consistent with the research interests specified by NASA in the contract work statements, see Table 3.3-1. (The NASA-specified research interests were assembled based upon an industry-wide workshop held at NASA Lewis on May 23-24th, 1978.) Figures 3.3-1 through 3.3-8 illustrate typical research output which could be achieved depending on the study configuration selected for the flight program.

Next, prerequisite analyses and tests required to develop the flight research aircraft configurations were defined. Foremost in this regard are tasks associated with the nozzle development. Table 3.3-2 itemizes some of these key efforts.

Finally, based on knowledge of: the required modifications, desired data output and prerequisite tests and analyses, a preliminary schedule of

TABLE 3.3-1

PRINCIPAL CONCERNS IDENTIFIED AT THE NONAXISYMMETRIC NOZZLE WORKSHOP, LEWIS RESEARCH CENTER, MAY 23-24, 1978

AIRFRAME/NOZZLE:

1. Accurate prediction of T-D performance during thrust vectoring and reversing
2. Utililation of propulsive lift effects with canards and control effectiveness
3. Reversed exhaust plume effects on structure and control effectiveness
4. Verification of model data on a realistic and relevant engine/nozzle/airframe

ENGINE/NOZZLE

1. Engine stability during vectoring and reversing
2. Nozzle cooling/performance/weight/complexity trade data (analysis, wind tunnel test, static test, flight)
3. Nozzle ram air cooling trade data
4. High aspect ratio nozzle transition duct design and flow distortion at remote burners

SYSTEMS INTEGRATION AND CONTROLS:

1. Active controls (digital)
2. Integration of vectoring and reversing into flight controls
3. Airplane aerodynamics and stability and control during vectoring and reversing

OPERATIONAL APPLICATIONS:

1. Explore effects of thrust reversing and vectoring on both instantaneous and sustained maneuvering
2. Identify STOL requirements and improvements
3. Investigate man/machine interfaces

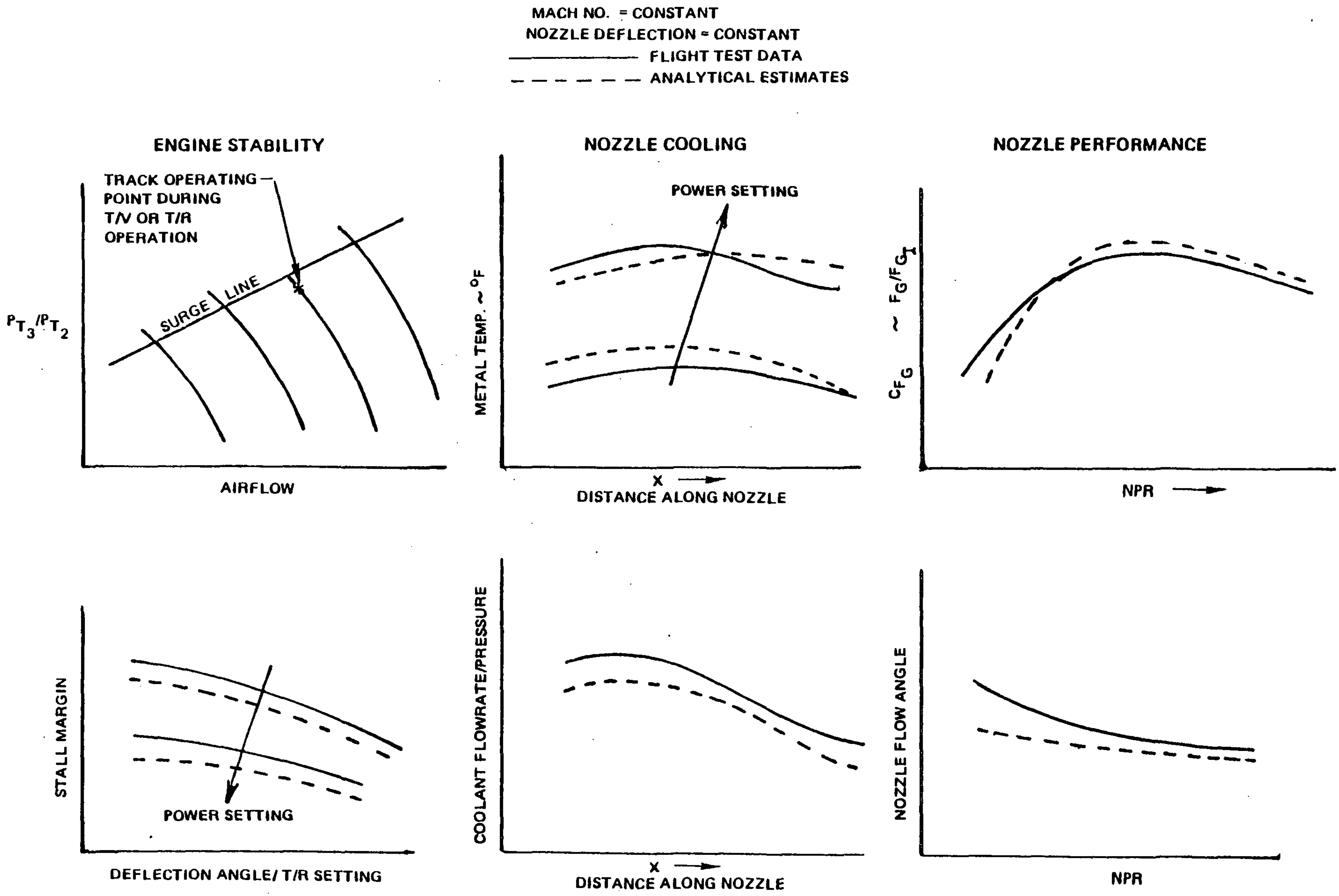


Figure 3.3-1. Typical Flight Research Output ~ Engine/Nozzle Characteristics

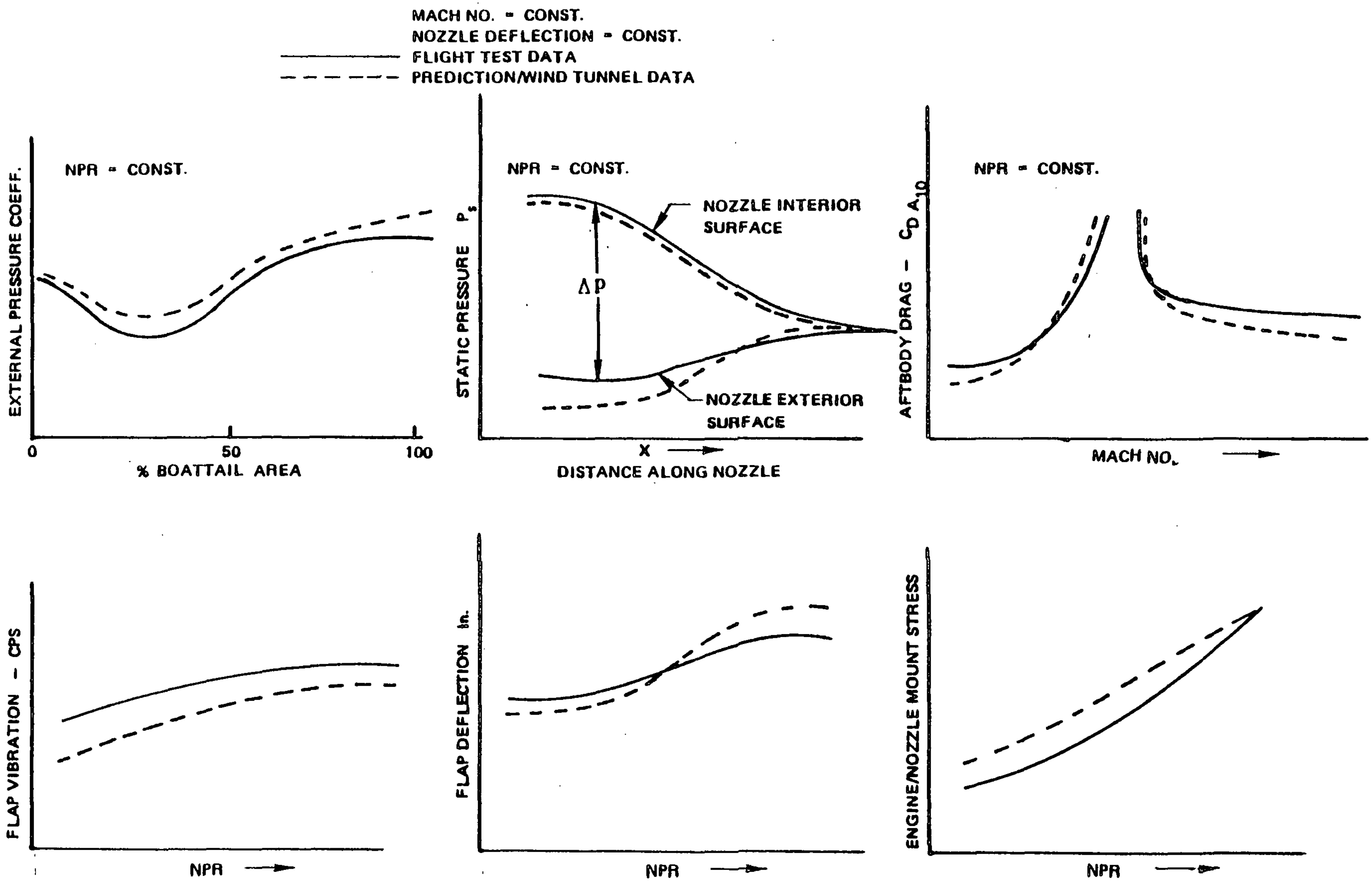
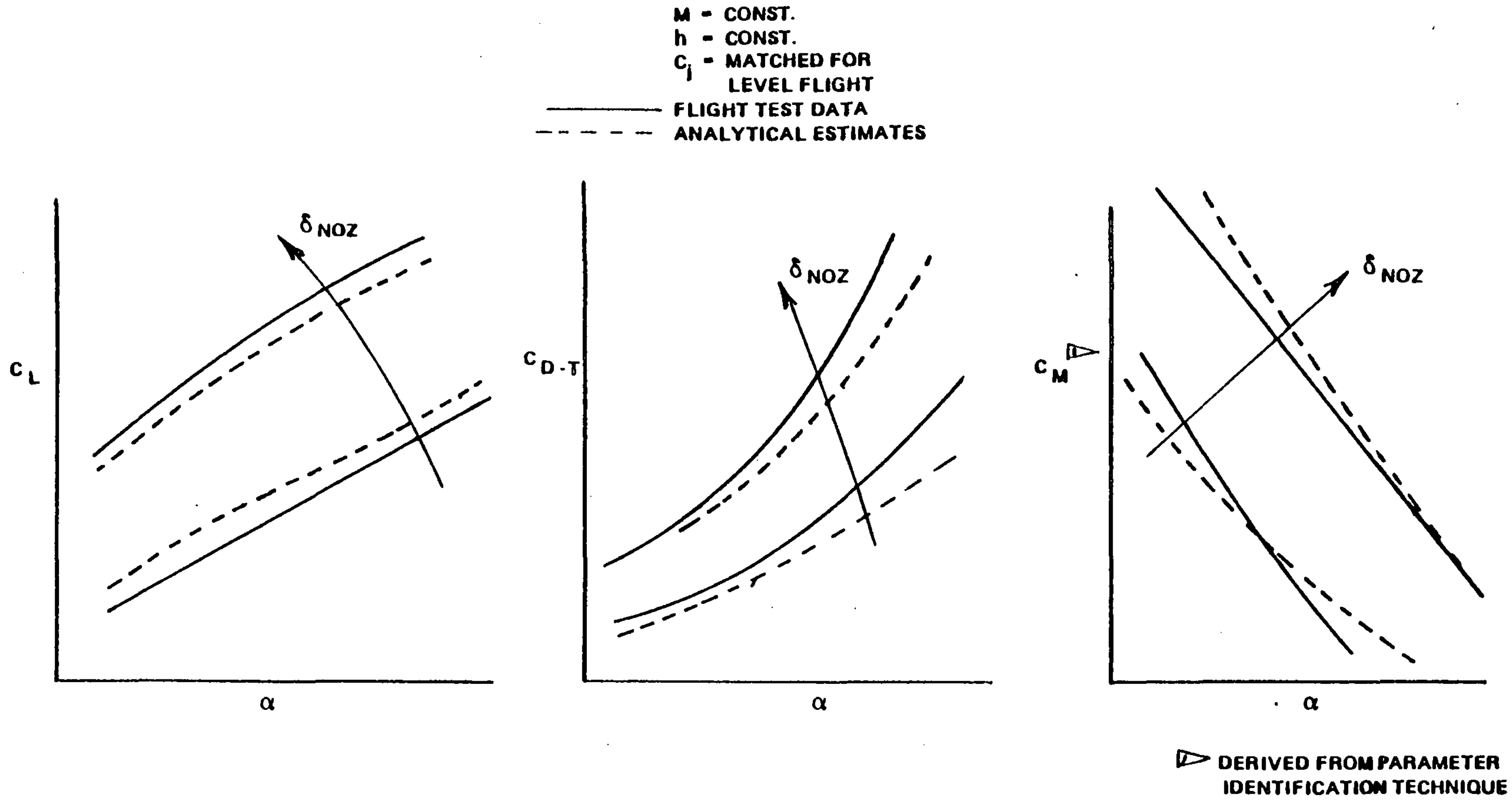


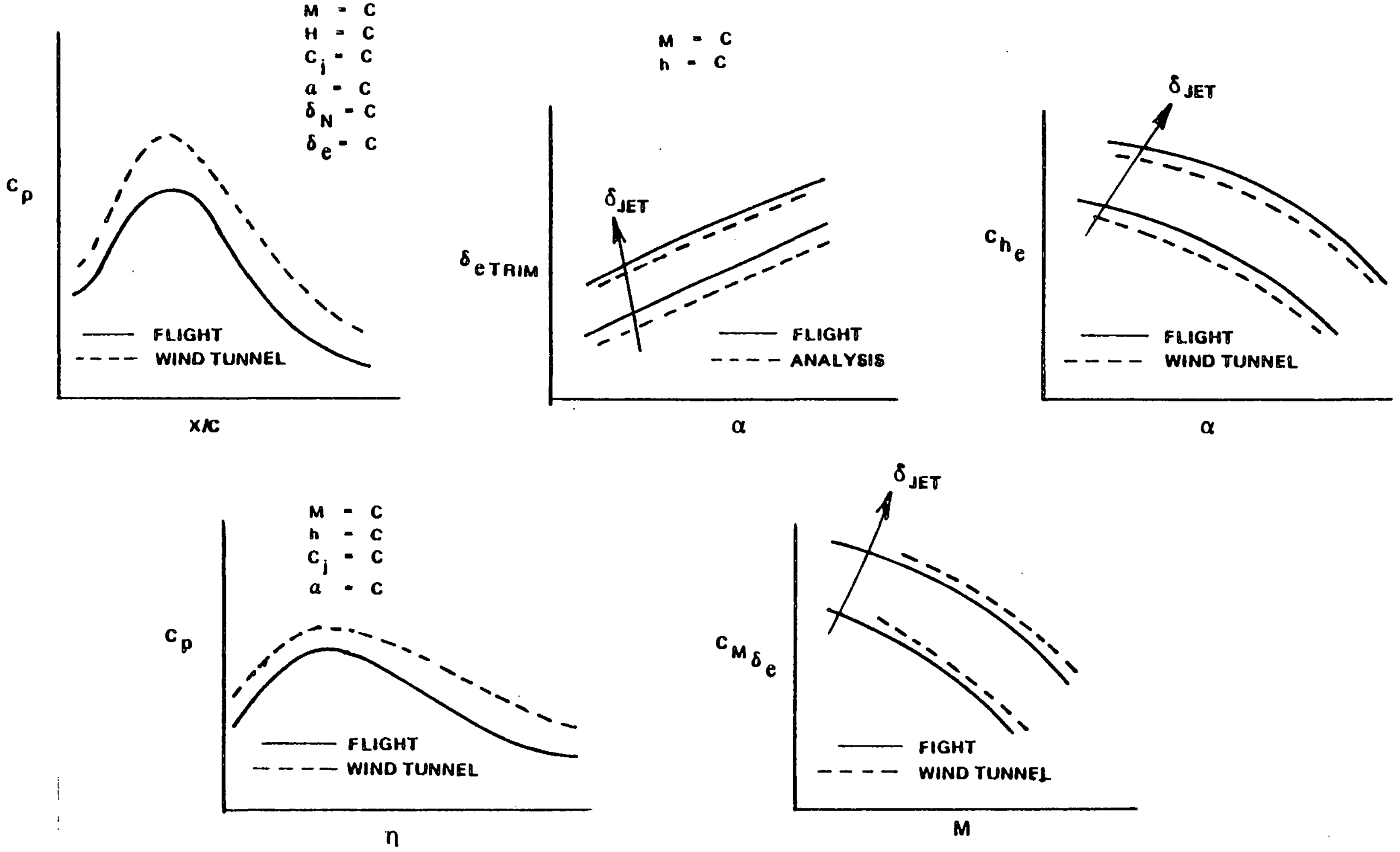
Figure 3.3-2. Typical Flight Research Output ~ Engine/Nozzle Loads



REQUIRES:

- AOA, V, W, F_N, F_G, C.G. LOCATION, δ_e, $dc_M/d\delta_e$, δ_{NOZ}
- PRIOR CALIBRATIONS OF AIRCRAFT SPEED, ENGINE THRUST, ELEVON

Figure 3.3-3. Typical Flight Research Output ~ Airframe/Nozzle Aerodynamics



δ_e - TRIM SURFACE DEFLECTION

Figure 3.3-4. Typical Flight Research Output ~ Wing and Control Surface Aerodynamics

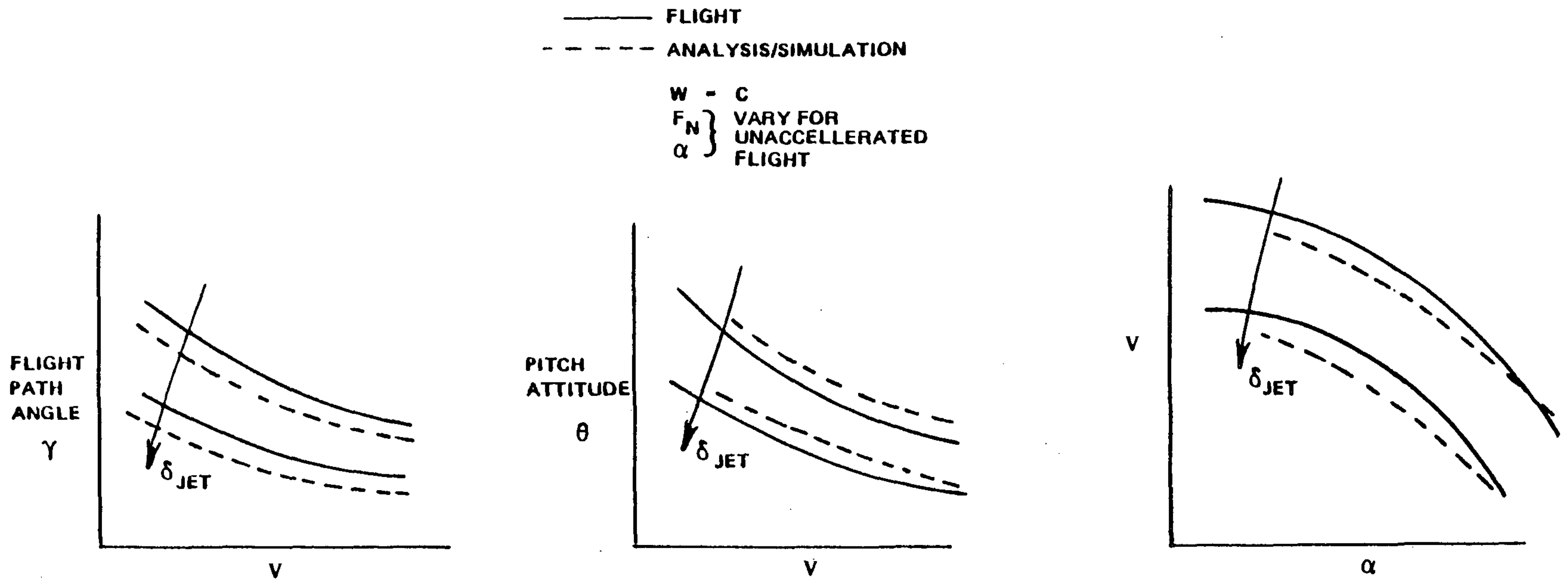


Figure 3.3-5. Typical Flight Research Output ~ Performance Characteristics

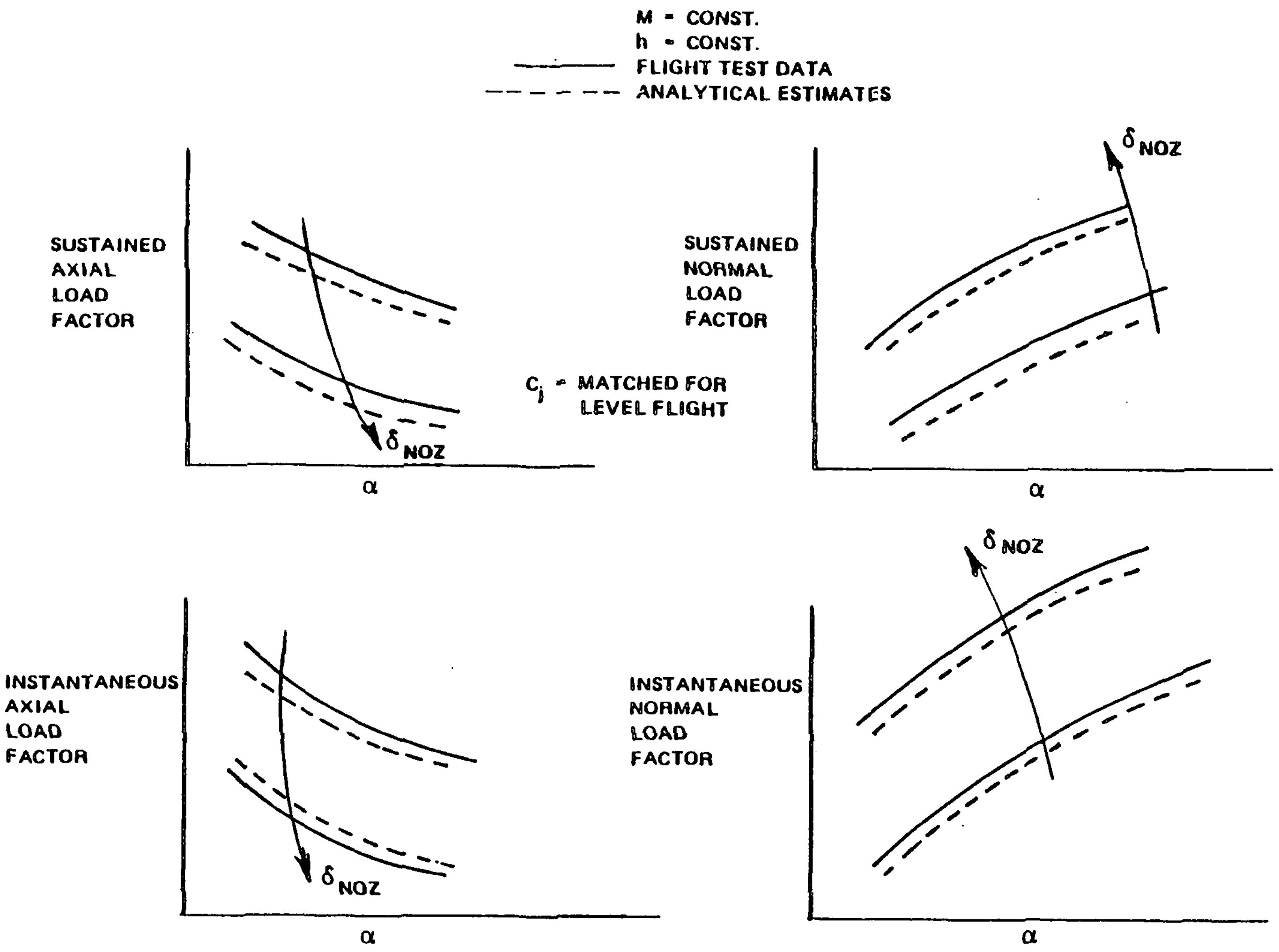


Figure 3.3-6, Typical Flight Research Output ~ Operational Characteristics

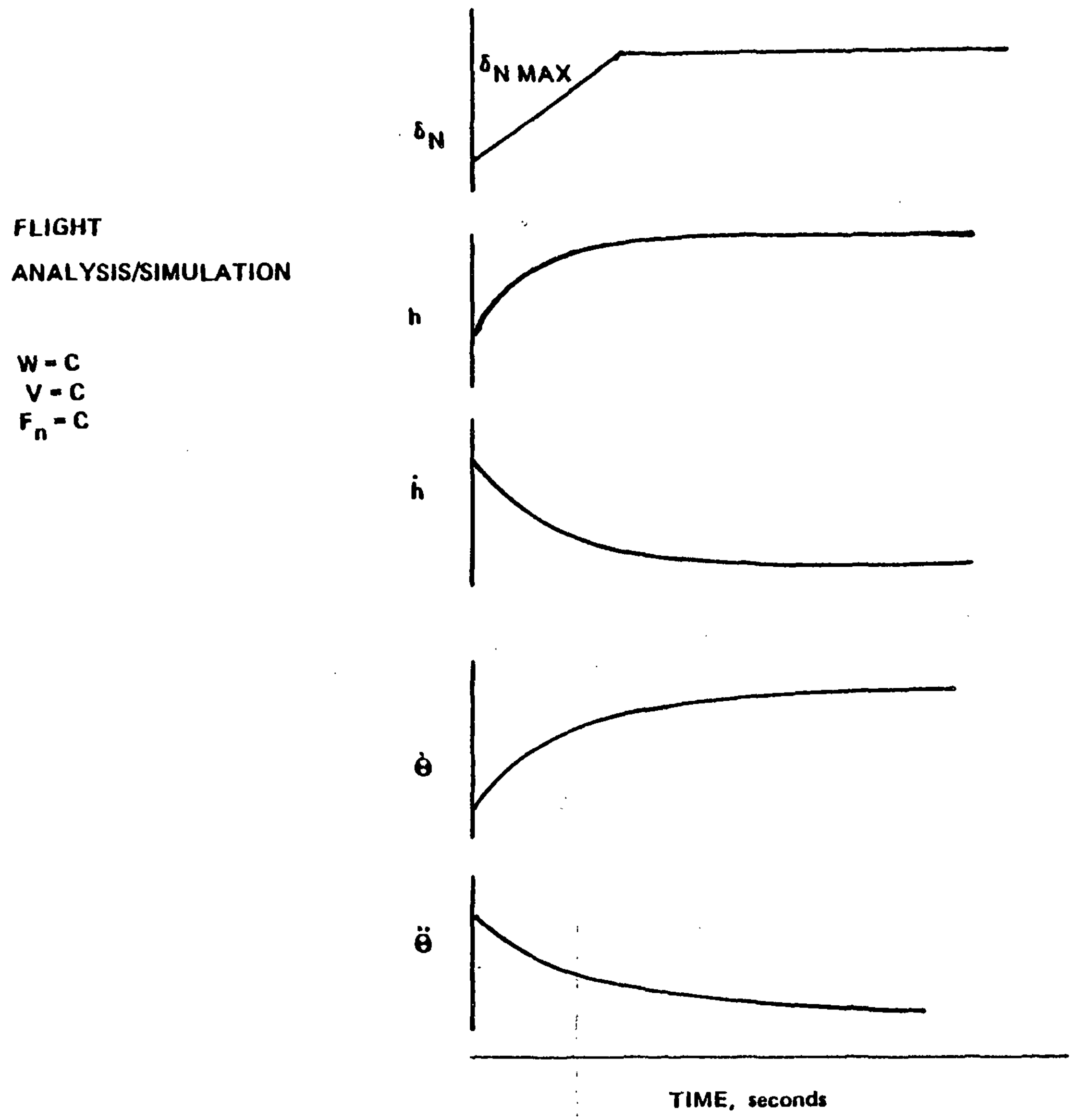


Figure 3.3-7. Typical Fight Research Output ~ Pitch Dynamics Characteristics

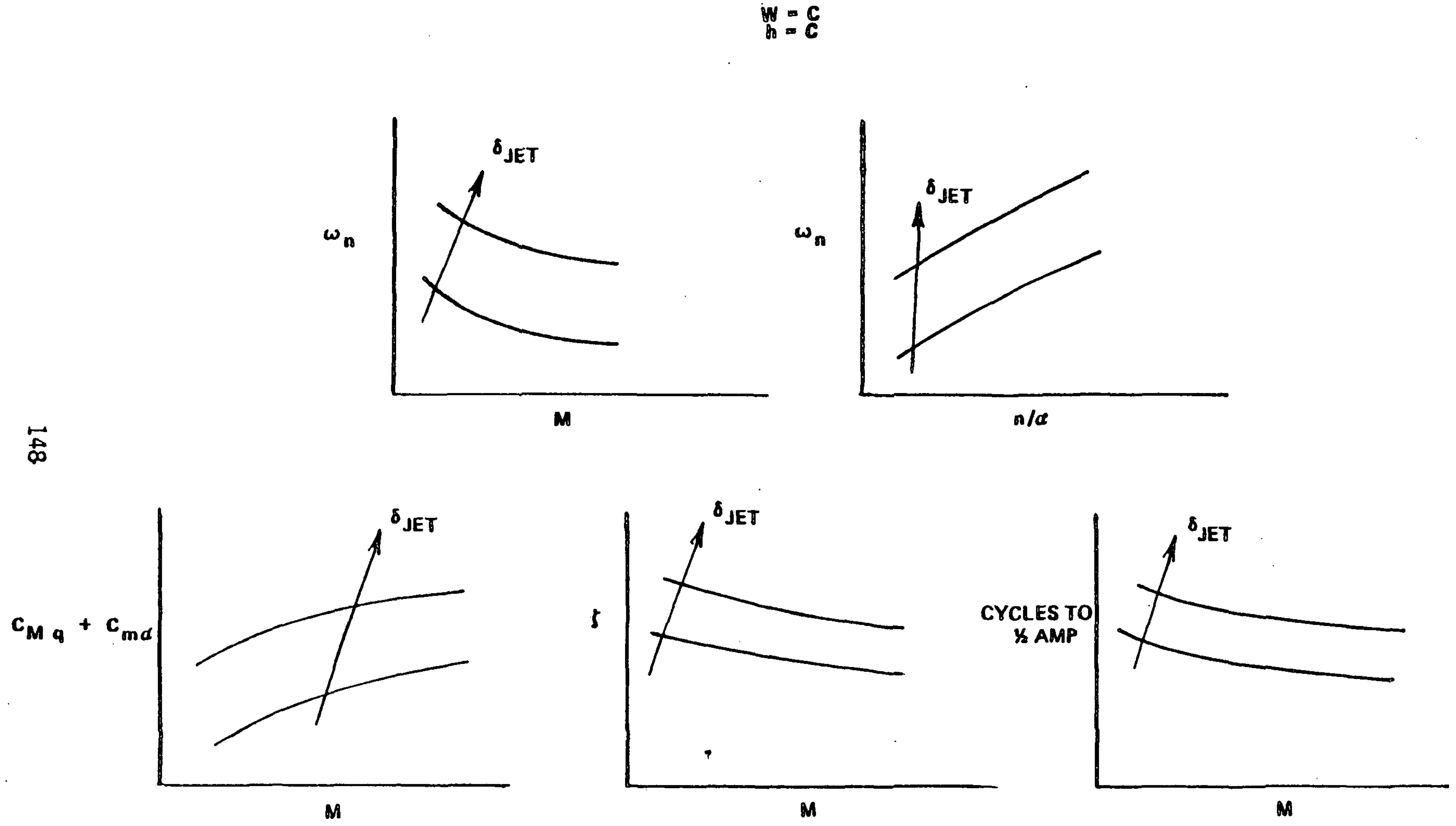


Figure 3.3-8. Typical Flight Research Output~Short Period Aircraft Dynamic S & C Characteristics

TABLE 3.3-2

PREREQUISITE ANALYSIS/TEST--NOZZLE DEVELOPMENT

(1) Detail mechanical design - Structure - Cooling Circuit - Controls/Actuation - Mount System	Note: o Configuration #4 - primairly thrust reverser and mount system
(2) Transition duct/burner development - Potential flow analysis - Model duct cold flow tests - Burner design - Burner component tests - Duct/burner full scale rig tests	Note: o Configuration #3 - some tuning of A/B fuel flow pattern may be required o Configuration #4 - long duct & burner analysis required along with some component testing.
(3) Scale model cooling system validation	
(4) Scale model static performance tests - Forward Thrust - Vectored Thrust - Reverse Thrust - Loads - Flow Coefficients	Note o Only reverser tests should be required for Configuration #4

work to accomplish the flight research program was developed. These schedules were the basis for the budgetary cost estimates described in Section 3.4. Figures 3.3-9 through 3.3-12 give these program plans for F-106 modifications, #1 through #4, respectively. It should be noted that program duration is paced by the nozzle development activities. Moreover, no 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.

F-106 2-D Nozzle Program Modification No. 1

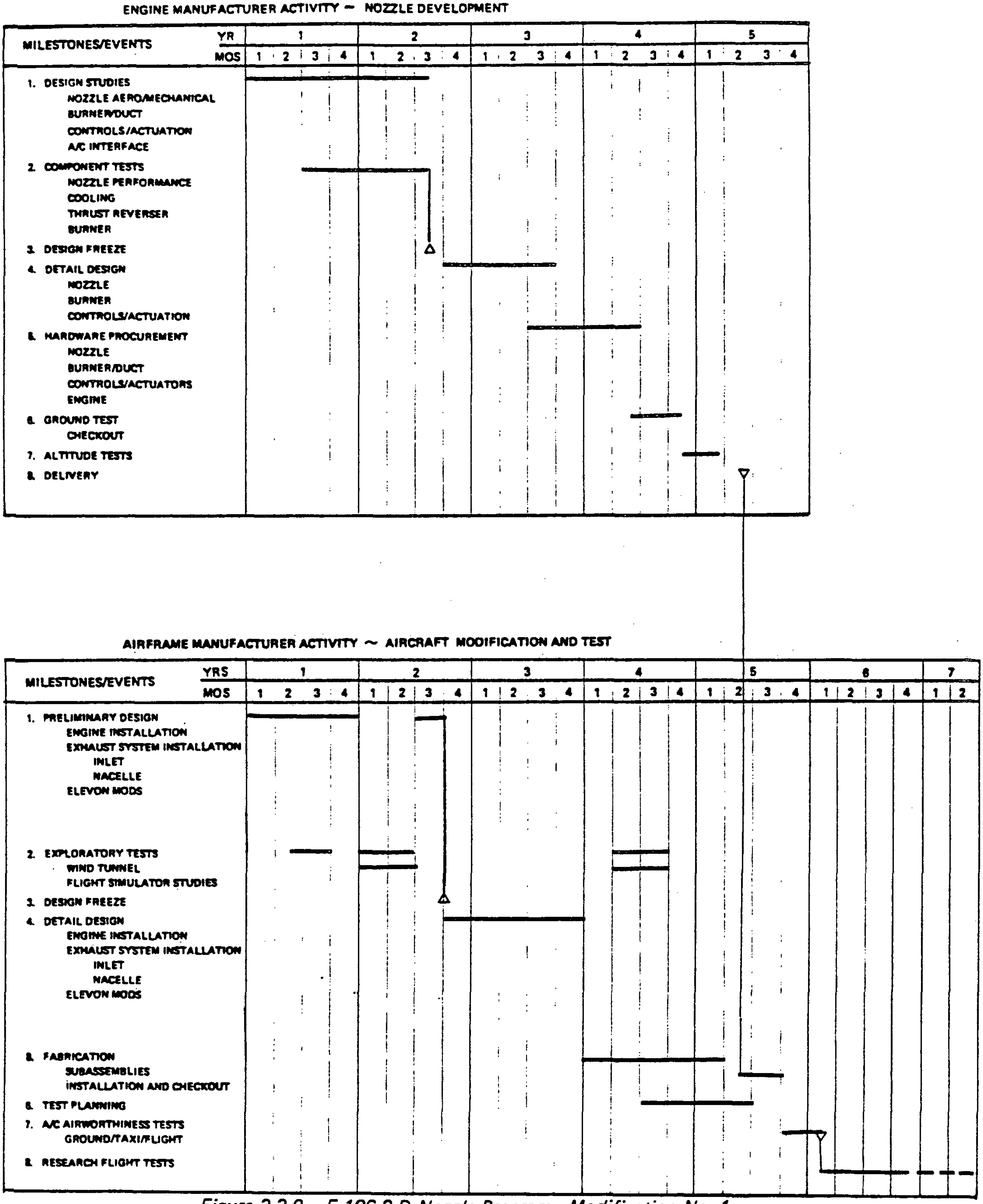


Figure 3.3-9. F-106 2-D Nozzle Program Modification No. 1

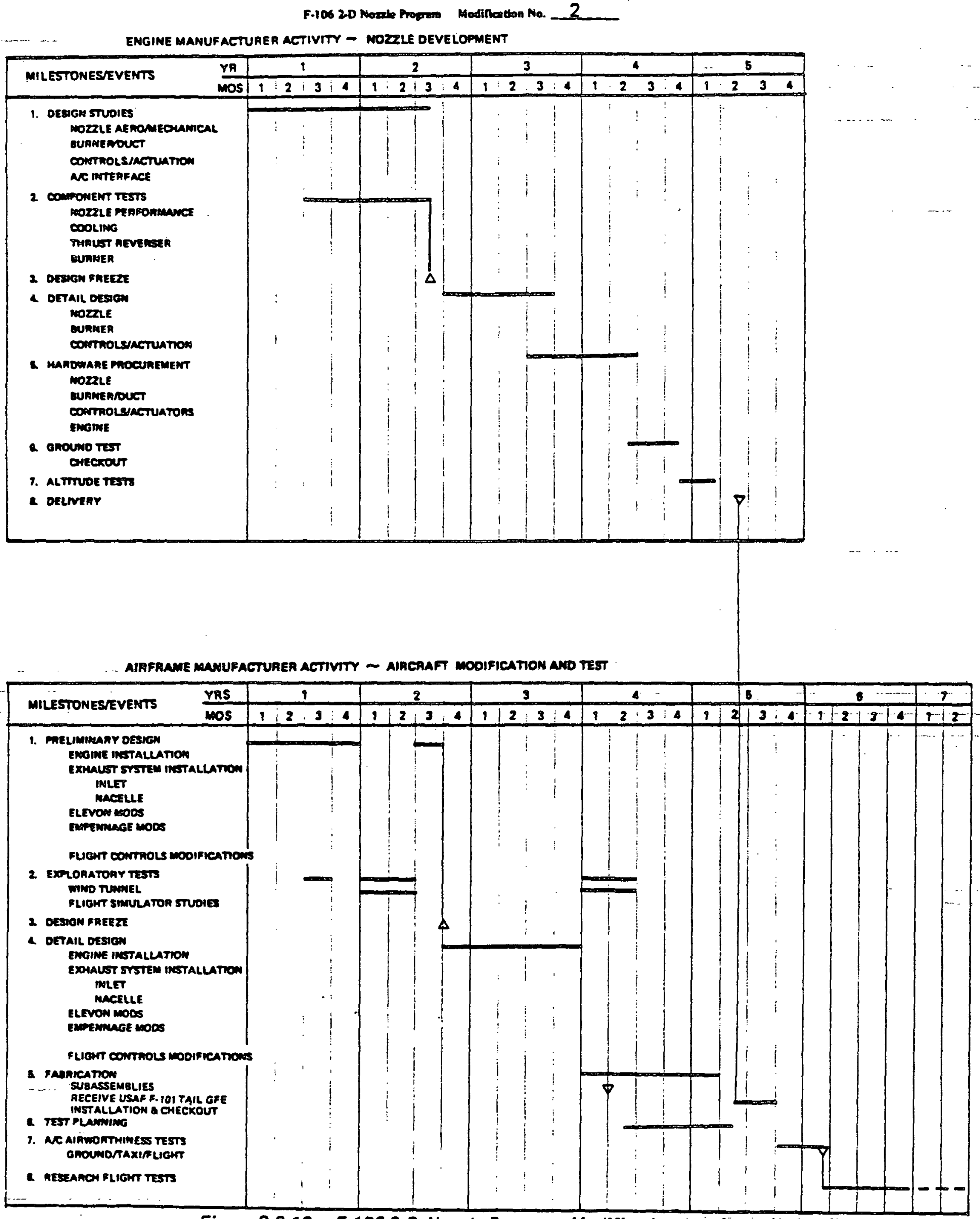


Figure 3.3-10. F-106 2-D Nozzle Program Modification No. 2

F-106 2-D Nozzle Program Modification No. 3

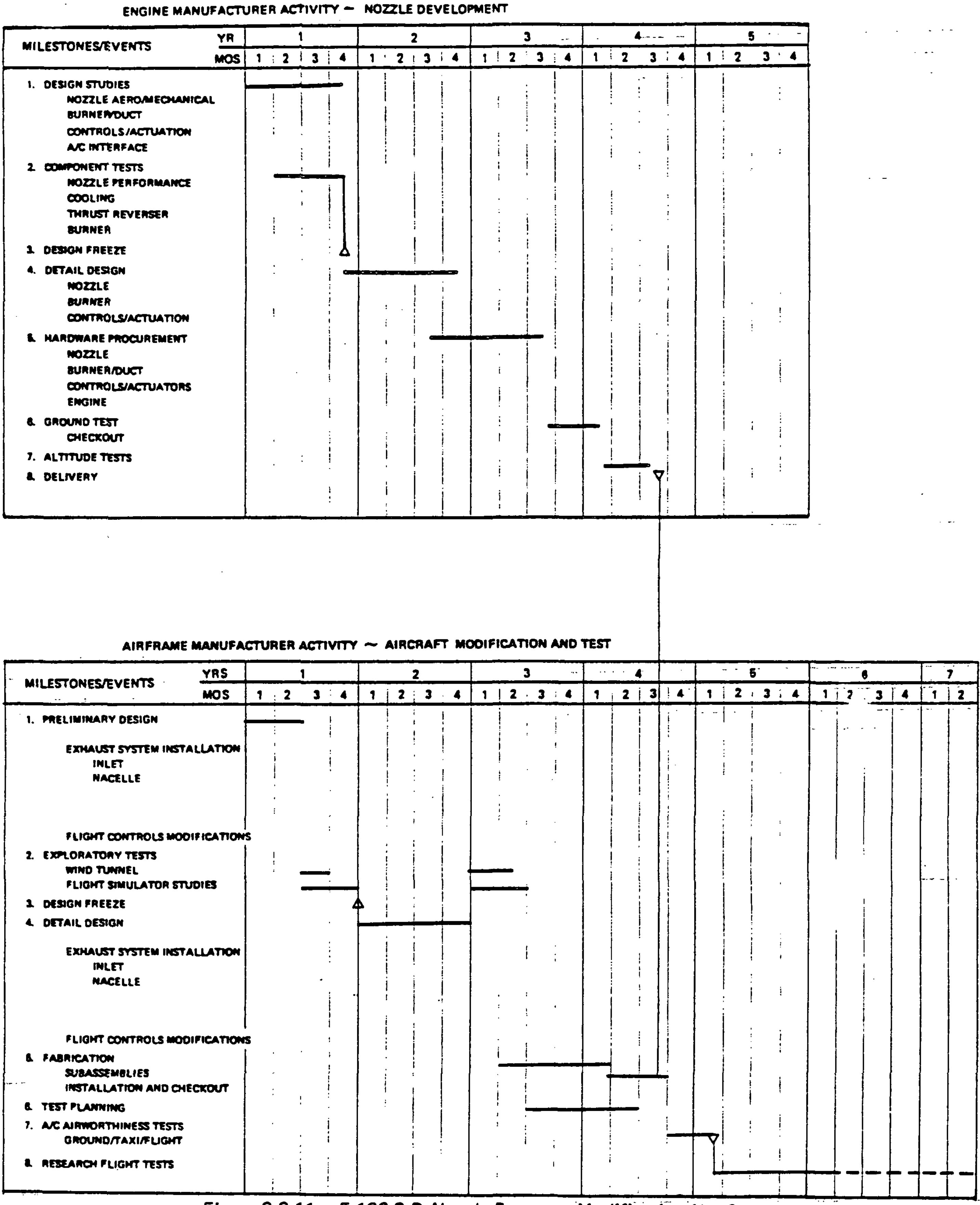


Figure 3.3-11. F-106 2-D Nozzle Program Modification No. 3

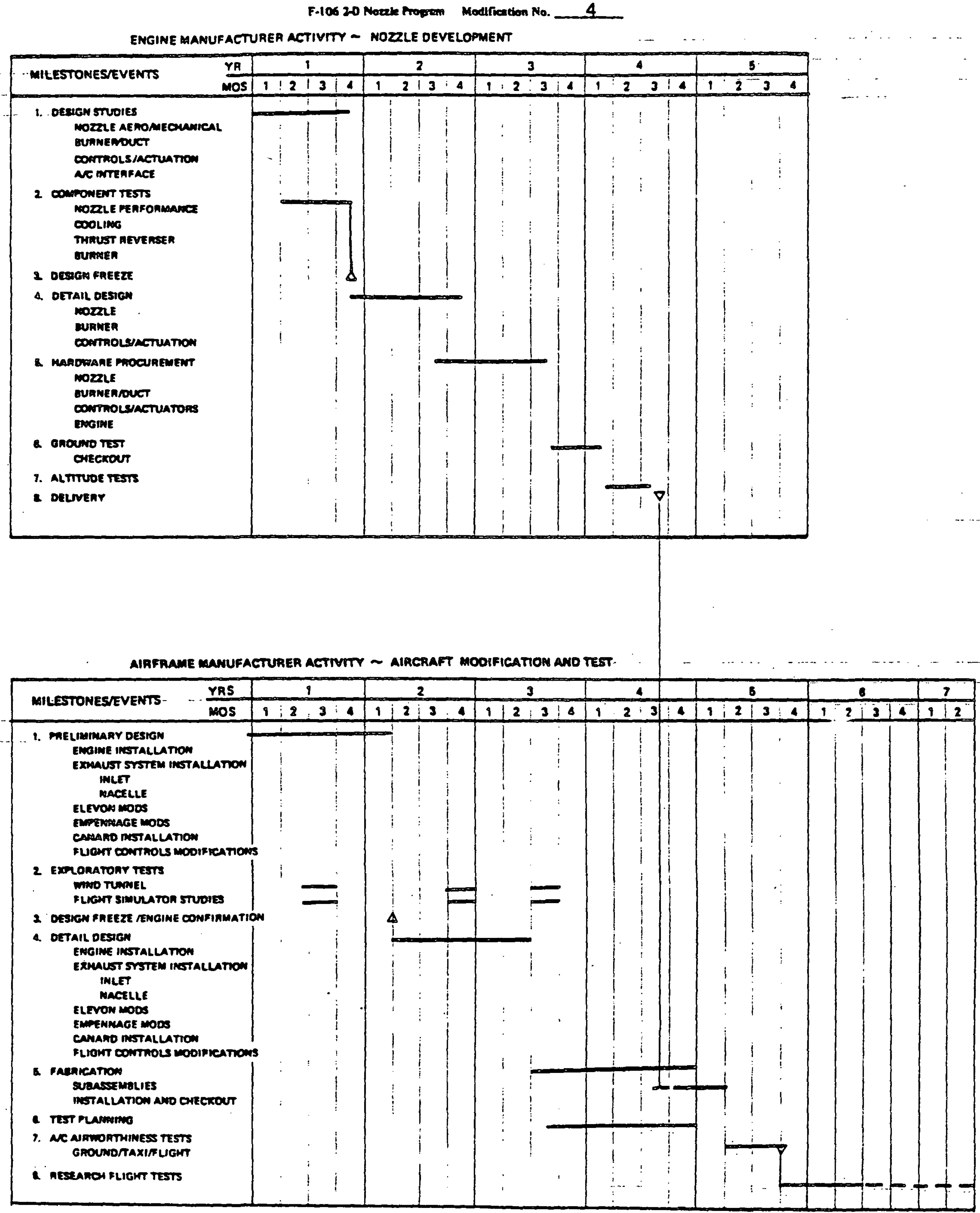


Figure 3.3-12. F-106 2-D Nozzle Program Modification No. 4

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 intial 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

Cost estimates have been made for the design and development of exhaust nozzles for F106 configurations 1, 2 and 4. In addition to the basic configurations, several optional programs were considered. These included seven options for configurations 1 and 2 and three options for configuration 5 as discussed below.

Configurations 1 and 2

For costing purposes, configurations 1 and 2 were considered as being the same. The basic configuration would consist of 2 exhaust nozzles incorporating the following features:

- o 2DCD with gimbal vectoring
- o Dry throat aspect ratio of 17
- o ±20° vectoring
- o Variable throat and exit area
- o Advanced 2D afterburner
- o Thrust reversing (non A/B)

It is further assumed that:

1) No engine nacelle/inlet work is required
2) Two GFE J85-21 engines in flight-ready condition will be delivered to GE with engine control systems at least 5 quarters before delivery of the engine/nozzles to Boeing for flight test. No cost has been included for engine refurbishment.
3) 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
4) The nozzle throat and exit areas will be controlled and driven by the engine. Modified existing GFC J85 controls will be used.
5) Thrust vectoring will be aircraft controlled with actuators supplied by GE and hydraulic power supplied by the aircraft.

6) The existing engine controls will be modified to be compatible with thrust reversing requirements. The T/R will be aircraft controlled and hydraulic power will be supplied by the aircraft.
7) A 50 hour Safety of Flight Test will be conducted at the GE Peebles outdoor test site.
8) An altitude test is recommended to be conducted in a GFE facility. No support or test costs for such a test have been included.

Costs are estimated through delivery of engines and nozzles to Boeing for flight test. Flight test support is not included.

Optional Configuration A

For option A, it was assumed that only one new nozzle could be fabricated.

Optional Configuration B

For option B, it was assumed that the engine would be operated in the dry mode only and the advanced 2D afterburner would be deleted.

Optional Configuration C

Same as B, except only one new nozzle required

Optional Configuration D

Delete the thrust reverser requirement from the basic program (Configuration 1 or 2).

Optional Configuration E

Same as D, except only one new nozzle

Optional Configuration F

Dry only with no thrust reverser

Optional Configuration G

Same as F, except only one nozzle

Configuration 4

For configuration 4, 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 are:

1) Two GFE F404 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/nacelled 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 F404 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 F404 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 F404/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 except in cases where an advanced 2D afterburner was required. The 2D afterburner was estimated to add 1 year to the program.

Estimated Budgetary Costs

The estimated budgetary costs of the three configurations (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 assume a program start date of January 1, 1980.

It should be noted that no budgetary cost estimates are provided for Configuration 3. That configuration has been scaled by Boeing to be compatible with the J75 engine, which is not part of General Electric's product line. For that reason, it is impossible for General Electric to estimate the costs of designing and fabrication Configuration 3.

ENGINE MANUFACTURER'S
ESTIMATED BUDGETARY COSTS

(CPFF in $1,000,000)

CONFIGURATON	OPTION	EST.COST
1 & 2	--	12.7
	A	11.8
	B	9.0
	C	8.2
	D	10.7
	E	9.9
	F	6.3
	G	5.8
4	--	9.9
	A	8.8
	B	6.8
	C	5.7

Note: Budgetary cost estimates for Configuraton #3 were not provided by GE since the nozzle installation is intended for the J-75 engine, not a part of GE's product line. To suport the feasibility study, Boeing has taken a low aspect ratio 2-D-C-D design provided by GE and scaled its size and weight as appropriate to the J-75 engine size. Similarly, Boeing has estimated a budgetary cost of $8 million dollars for the engine manufacturer effort for configuration #3. Since only a single, low aspect ratio nozzle is involved, the costs were judged comparable but slightly less than that for configuration #4.

3.4.2 Total Program Costs

Total program costs were estimated by Boeing including the baseline engine manufacturer costs using none of the optional deletions for each configuration. Some general ground rules included the following:

- All wind tunnel tests were assumed to be accomplished at government facilities. Existing F-106 models at NASA Lewis would be used. Some modification costs were allowed for in the program costs.
- An initial simulation of the F-106 and occupancy of a suitable flight simulator were assumed to be GFE. Development of modifications to the simulation and support of simultor tests were allowed for in the program costs.
- An initial period of ground and flight tests validating safety of the modified aircraft was assumed to be accomplished at Boeing prior to ferrying the research aircraft to NASA. Subsequent flight research tests were assumed to be accomplished at a NASA facility supported by NASA personnel.
- Costs have been allowed for Boeing and engine manufacturer personnel to develop test planning and suport data analysis for the initial year of flight research in conjunction with NASA personnel.

Some specific ground rules and summary costs for each study configuration are described separately below.

Configuration #1

- It was assumed the J-85 pods previously used by NASA with the F106B would be available and GFE. The pods would be modified to accomodate the J85-21 engine and the high aspect ratio 2-D C-D nozzle.
- A new normal shock inlet and installation for the 2-D-C-D nozzle will be designed and fabricated.;
- Cockpit controls, displays and hydraulic system power for engine thrust vectoring and hydraulic system power for thrust reversing will be provided.
- The aircraft will be modified to the study configuration and appropriate instrumentation installed.

COST SUMMARY

General Electric Efforts (J-85 Engines)	$12.7 M
Engineering	
Project	.885 M
Staff	1.702 M
Other	.386 M
Sub Total Eng.	$ 2.943 M
Simulation & Wind Tunnel Efforts	$ .666 M
Dev. Shop Support (To Design & Exploratory Tests)	$ .392 M
Production (Aircraft Mod)	
Tooling	$ .240 M
Production Mat. & Purch. Equip.	$ .037 M
Prod. Labor	$ .620 M
Instrumentation	$ .100 M
Flight Test Support (Technicians)	$ .613 M
P.M.O., Travel, Per Diem, Etc.	$ .661 M
Total Effort	$18.972 M

Configuration #2

The following are in addition to the first three ground rules enumerated for Configration #1:

- The existing elevons would be notched and re-rigged.
- A structural adapter for the F-101 empennage would be designed and fabricated. The F-101 empennage is GFE. Rudder and horizontal tail controls will be integrated as required to the basic F-106 flight control system.
- The aircraft will be modified to the study configuration and appropriate instrumentation installed.

COST SUMMARY

General Electric Efforts (J 85 Engines)	$ 12.7 M
Engineering	
Project	$ 1.750 M
Staff	4.062 M
Other	.386 M
Sub Total Eng.	$ 6.198 M
Simulation & Wind Tunnel Efforts	$ 1.366 M
Dev. Shop Support (To Design & Exploratory tests)	$ .435 M
Production (Aircraft Mod)	
Tooling	$ .408 M
Prod. Mat. & Purch. Equip.	$ .056 M
Production Labor	$ 1.312 M
Instrumentation	$ .140 M
Flight Test Support (Technicians)	$ .623 M
P.M.O., Travel, Per Diem, Etc.	$ 1.265 M
Total Effort	$24.503 M

Configuration #3

- The basic aircraft J75-P-17 and one spare engine will be provided GFE.
- Cockpit controls/displays and hydraulic system power for engine thrust vectoring and thrust reversing wil be provided.
- The aft section of fuselage will be modified as required to accept the low aspect ratio 2-D C-D nozzle.
- Aircraft elevons will be re-rigged and new actuators installed as required to achieve 25° down deflection.
- The aircraft will be modified to the study configuration and appropriate instrumentation installed.

COST SUMMARY

Engine Manufacturer		$ 8.0 M
Engineering		
Project		$ 1.099 M
Staff		$ 2.268 M
Other		$ .386 M
	Sub Total Eng.	$ 3.753 M
Simulation & Wind Tunnel Efforts		$ .766 M
Dev. Shop Support (To Design and Exploratory Tests)		$ .512 M
Production (Aircraft Mod)		

Tooling	$ .135 M
Prod. Mat. & Purch. Equip.	$ .024 M
Prod. Labor	$ .405 M
Instrumentation	$ .060 M
Flight Test Support (Technicians)	$ .613 M
P.M.O., Travel, Per Diem, Etc.	$ .752 M
Total Effort	$15.020 M

Configuration #4

- New inlets and pods will be designed and fabricated for the GE F-404 engines. The pods would accomodate installation of the ADEN nozzles.
- Cockpit controls/displays and hydraulic system power for thrust vectoring and reversing will be provided.
- The existing elevons would be notched and re-rigged.
- The rudder and fin would be modified to the larger size required.
- A canard installation will be designed, fabricated and integrated with the basic airframe and aircraft flight control system.
- The F-106D refueling receptacle will be reactivated.
- The aircraft will be modified to the study configuration and appropriate instrumentation installed.

COST SUMMARY

General Electric Efforts (F404 Engines)		$ 9.9 M
Engineering		
Project		$ 3.214 M
Staff		$ 6.654 M
Other		.386 M
	Sub Total Eng.	$10.254 M
Simulation & Wind Tunnel Efforts		$ 1.988 M
Dev. Shop Support (To Design & Exploratory Tests)		$ 1.804 M
Production (Aircraft Mod)		
Tooling		$ 1.771 M
Prod. Mat. & Purch. Equip.		$ .143 M
Prod. Labor		$ 2.493 M
Instrumentation		$ .140 M
Flight Test Support (Technicians)		$ .662 M
P.M.O., Travel, Per Diem, Etc.		$ 2.311 M
	Total Effort	$31.466 M

A breakdown of costs by task for the four study configurations is given in Table 3.4-1.

TABLE 3.4-1 PROGRAM COST BREAKDOWN BY TASK

(All numbers in $\$X10^6$)

	MOD #1	MOD #2	MOD #3	MOD #4
Task 1 Preliminary Design	.442	.949	.703	1.878
Task 2 Exploratory Tests	.583	1.621	.776	2.832
Task 3 Design Freeze	0	0	0	0
Task 4 Detail Design	1.825	4.180	2.403	8.108
Task 5 Fabrication	.997	1.961	.624	4.547
Task 6 Test Planning & PMO	1.023	1.682	1.114	2.673
Task 7 A/C Airworthiness Tests	.374	.374	.374	.374
Task 8 Research Flight Tests	1.026	1.036	1.026	1.155
Engine Manufacturing Costs	12.700	12.700	8.000	9.900
TOTAL COST	18.970	24.503	15.020	31.467

3.4.3 Opportunities for Reduced Program Costs

Although a detailed analysis of cost-reduction possibilities was not within the scope of the present study, some obvious opportunities for cost reduction were estimated. As example, consider configuration #4.

	Basic Program Costs		$31.5 M
o	If afterburning capability were deleted	projected savings	($ 1.1 M)
o	If thrust reversing capability were deleted	projected savings	($ 3.1 M)
o	If initial safety of flight tests were accomplished at Government rather than contractor facilities	projected savings	($ 0.4 M)
o	If contractor test planning & data analysis support were deleted	projected savings	($ 1.5 M)
o	If attention were restricted to one flight regime (say low speed) rather than providing low speed, transonic and supersonic flight research capability	projected savings	($ 3.4 M)
		Reduced Scope Program Costs	$22.0 M

Additional cost reduction might be possible through such techniques as schedule compression, value engineering and additional use of government facilities for certain fabrication efforts. To evaluate these reductions would, however, require additional detailed breakdown of key program tasks and hardware components. Such an evaluation is left for future study.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Four modifications of the F-106B aircraft were studied to evaluate the feasibility for flight research of advanced non-axisymmetric nozzle concepts. Emphasis was placed on achieving 30 degrees of vectoring during transonic operation. 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:

- Each of the four study configurations was judged to be technically feasible and capable of providing research data for thirty degrees of thrust vectoring at transonic conditions provided certain operational limitations are observed. These included:
    - operation at low speed and low altitude solely with the basic J-75 powerplant for configurations #2 and #4. This results from auxiliary-engine-out control requirements exceeding available capability at low dynamic pressure conditions; this is consistent with previous, similar use of the aircraft by NASA Lewis Research Center to support SST nozzle research several years ago.

- operation at transonic conditions, for configuration #4, such that should an F404 engine failure occur, sufficient room is allowed for in the flight envelope to accommodate the transient motion involved in trimming the aircraft to J75 thrust only. Under this failure circumstance, the aircraft would terminate the research test and proceed back to base under J75 power.

o Study configurations #1, 2 and 3 will provide, for research testing, on the order of 1 1/2 to 2 hours of transonic flight time. Configuration #4, without inflight refueling, would be limited to about 30 minutes for the as-drawn modification.

o Configuration #1 is well-suited to research objectives exploring flight-effects associated with design aspects of engine/nozzle integration. Configuration #2 would further enable investigation of nozzle/airframe integration aspects including jet-induced wing lift. Configuration #3 would allow evaluation of the nozzle as a pitch control device (which is especially appropriate to a tailless delta-wing aircraft) as well as evaluation of engine/nozzle integration aspects. Configuration #4 would provide research opportunities similar to Configuration #2 but with a more-to-scale wing/power plant configuration. Configuration #4 further allows exploration of certain design aspects of canards.

- 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.

- Budgetary contractor costs for the total development program (engine and airframe manufacturer) were estimated to be between $15 million to $30 million depending on the configuration selected, the flight regime capability required of the modified aircraft and the level of contractor effort required for preliminary safety of flight testing and for planning and conduct of initial research tests.

In light of low speed operating limitations suggested by the analysis for several of the study configurations and taking account of recent government interest in STOL capability for advanced tactical aircraft, it is recommended that future study address modifications to the present study configurations compatible with feasible design objectives for STOL capability.

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3.2A.3-2 Drawing LO-PD-TS-3A, F106B Nozzle Research Study - Modification #2.

3.2A.3-3 Drawing LO-PD-TS-4A, F106B Nozzle Research Study - Modification #3.

3.2A.3-4 Drawing LO-PD-TS-5A, F106B Nozzle Research Study - Modification #4.

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3.2A.5-5 Drawing LO-PD-TS-3A, F-106 Nozzle Research Study - Modification No. 2

3.2A.5-6 Drawing LO-PD-TS-4A, F-106 Nozzle Research Study - Modification No. 3

3.2A.5-7 Rankin, R. W., C/S WTS-BMAD-79-278, Weight and Balance F-106B Nozzle Research Study Modification No. 3, 11 January 1979.

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3.2A.6-4 Baseline Installed J75-P-17 Engine Performance for F-106 A/C 2-8050-598-1441A

APPENDIX A

STATEMENT OF WORK

NAS4-2554

D180-25418-1

STATEMENT OF WORK

NAS4-2554

FEASIBILITY STUDY FOR NONAXISYMMETRIC NOZZLE FLIGHT RESEARCH USING A F-106 AIRCRAFT

June 23, 1978

1.0 OBJECTIVE

The objective of this study is to explore the utility of the F-106 aircraft as a low cost alternative vehicle on which to conduct nonaxisymmetric nozzle research. NASA's primary interest in using the F-106 is as a propulsion research test bed. However, preliminary studies by the contractor have shown that the F-106 has the potential of being a reasonable low cost demonstrator for the total nonaxisymmetric nozzle/aircraft integration problem.

2.0 SCOPE

This feasibility study will investigate four different configurational arrangements of a F-106 aircraft. Two test bed concepts are delineated by the NASA and two major modifications demonstrator concepts are to be developed by the contractor. For these four configurations, the contractor will define the feasibility, identify problem areas, determine potential research tasks and experiments, and develop cost and schedule information upon which a meaningful research program can be planned. The selected approaches should strongly consider using existing or parallel technology developments and hardware where possible, especially in the engine and nozzle areas. This study will consist of four tasks.

3.0 DESCRIPTION OF TASKS

3.1 Configuration Identification (Task 1)

The contractor shall study four configurations of a F-106B aircraft as a flight test vehicle for nonaxisymmetric nozzle research. Two government delineated configurations will be explored by the contractor while, with government approval, the contractor shall select the two remaining configurations.

3.3.1 The first government delineated configuration seeks to use the F-106 as a general purpose test bed capable of extending ground based engine/nozzle research on nonaxisymmetric thrust reversing and vectoring nozzles into the flight environment. In particular, this configuration shall be studied with a remotely augmented high aspect ratio nonaxisymmetric nozzle on a J-85 engine mounted in an under-the-wing pod. The contractor shall evaluate the use of only one vectoring/reversing nozzle (with an axisymmetric nozzle on the other wing pod) versus the necessity, if any, for two such nozzles. Neither auxiliary trimming devices nor other major modifications will be made to the airframe other than those required to insure the engine wing pod installations are safe throughout the flight envelope of the F-106.

3.1.2 The second government delineated configuration represents a more versatile test bed. The contractor shall determine the feasibility of modifying a F-106 to carry a J-85 engine/nonaxisymmetric nozzle (vectorable and reversable) in a pod under each wing with the use of a T-tail as an auxiliary trimming device. The T-tails studied shall use only off-the-shelf hardware such as that used on the F-104 and F-101. The configuration shall be capable of supersonic operation to a minimum of 1.4 Mach number.

3.1.3 The two remaining configurations will be selected as vehicles to investigate the complete aerodynamic, nozzle, and controls integration problems associated with nonaxisymmetric nozzle applications. A matrix of powerplants, nozzles, engine installation concepts and aircraft trimming systems suitable for demonstrating key nonaxisymmetric nozzle technology features will be selected with government coordination. Considerations for selection of the study matrix shall include: expected availability of powerplant; prior design and/or development experience; anticipated cost and cost constraints; ability of the overall matrix to provide data on configuration elements of interest. Based on these considerations, the contractor shall select two configurations from the matrix which best represent the total problems associated with nonaxisymmetric nozzles.

3.1.4 The contractor shall make a preliminary evaluation of the feasibility, identify problem areas, and determine the research potential of each of the four configurations. In addition, the contractor shall provide the rationale for all configuration selections made by him to this time. The contractor shall also provide a set of layout drawings for the four configurations. Each set shall include the modifications appropriate to the selected 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. Based on the information required in this paragraph, the contractor shall obtain government approval of the selected configurations and proceed with the evaluation and design studies.

3.2 Evaluation and Design Studies (Task 2)

3.2.1 The contractor shall examine and develop the four configurations to enhance their capabilities to provide relevant research into the areas of principal concern in the development of nonaxisymmetric nozzle technology identified by industry and government participants at the Nonaxisymmetric Nozzle Workshop held May 23-24, 1978, at Lewis Research Center (attachment 1). "Relevant" is defined here as the ability of a flight research program to address an issue in a logical fashion and provide meaningful data.

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 change, structural load paths, aircraft stability, control and balance requirements, canard and T-tail installation, special cooling requirements, 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 modification 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 Definition (Task 3)

3.3.1 The contractor shall develop at least one preliminary flight research program plan for each of the four configurations. For each plan, the contractor shall delineate the expected results. A preliminary development plan for any nozzle hardware not already in development shall be outlined here. The preliminary plan shall be submitted for government approval.

3.3.2 Following government approval, the selected plans will be developed in more detail. With the objective of minimizing program cost, the contractor shall delineate in the plans key program research objectives and analysis, design, fabrication and test milestones. The comtractor shall identify need for NASA support and shall consider that all NASA facilities, models, and support will be available when and where needed.

Attachment 1

Principal Concerns Identified at the Nonaxisymmetric Nozzle Workshop, Lewis Research Center, May 23-24, 1978

AIRFRAME/NOZZLE:

1. Accurate prediction of T-D performance during thrust vectoring and reversing
2. Utilization of propulsive lift effects with canards and control surfaces
3. Reversed exhaust plume effects on structure and control effectiveness
4. Verification of model data on a realistic and relevant engine/nozzle/airframe

ENGINE/NOZZLE:

1. Engine stability during vectoring and reversing
2. Nozzle cooling/performance/weight/complexity trade data (analysis, wind tunnel test, static test, flight)
3. Nozzle ram air cooling trade data
4. High aspect ratio nozzle transition duct design and flow distortion at remote burners

SYSTEMS INTEGRATION AND CONTROLS:

1. Active controls (digital)
2. Integration of vectoring and reversing into flight controls
3. Airplane aerodynamics and stability and control during vectoring and reversing

OPERATIONAL APPLICATIONS:

1. Explore effects of thrust reversing and vectoring on both instantaneous and sustained maneuvering
2. Identify STOL requirements and improvements
3. Investigate man/machine interfaces