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Study of an Engine Flow Diverter
System for a Large Scale Ejector
Powered Aircraft Model

R. J. Springer
L. G. Hunter
B. F. Langley
O. R. Brock
T. J. Plant

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CONTRACT NAS2-10680
July 1981

NASA



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System for a Large Scale Ejector
Powered Aircraft Model

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L. G. Hunter
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T. J. Plant
General Dynamics
Fort Worth Division
Fort Worth, Texas

Prepared for
Ames Research Center
under Contract NAS2-10680



National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035

1181-28096#

NASA CR-166163

**STUDY OF AN ENGINE FLOW DIVERTER
SYSTEM FOR A LARGE SCALE EJECTOR
POWERED AIRCRAFT MODEL**

JULY 1981

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**PREPARED UNDER CONTRACT NAS 2-10680
BY
GENERAL DYNAMICS
FORT WORTH DIVISION
FOR
AMES RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION**

FOREWORD

The work reported herein was performed under NASA Contract NAS 2-10680 under the direction of NASA/Ames (National Aeronautics & Space Administration, Ames Research Center), Moffett Field, California. Mr. George Aoyagi (NASA/Ames) was the Project Monitor.

This report is the result of a conceptual design study to analyze and design an engine flow diverter system along with accommodations for an ejector system in an existing large scale wind tunnel model equipped with YJ-97 engines.

The contractor was General Dynamics Fort Worth Division, Fort Worth, Texas. Mr. R. J. Springer (Program Manager) directed the study with the support of Dr. L. G. Hunter, B. F. Langley, and O. R. Brock. The overall effort was under the supervision of Mr. C. F. Crabtree, Engineering Chief, Propulsion Design Group. General Electric, General Dynamics subcontractor, provided the engine performance data and performed the Conceptual design study for the engine flow diverter valve. General Electric's technical efforts were directed by Mr. T. Plant who was supported by J. Holowach, K. S. Scheffel, and T. A. Hauer.

This report describes the results of work conducted during the period 6 August 1980 to 6 July 1981.

SUMMARY

A conceptual design baseline configuration for an engine flow diverter - duct system was developed for an ejector installation into an existing large-scale fighter model with two YJ-97 engines. The ejector selected for the conceptual design study was a short diffuser type (Alperin ejector) and was to be located in the strake of the model. The program objective was to accommodate the engine flow diverter, ducting, and lift ejector system within the existing contours using as much of the existing model parts as possible.

Due to structural arrangements and available space in the model, the system could not be accommodated within the existing model without significant modifications. Various model modification options were evaluated. The most extreme modification option required, in addition to moving the engine nacelles outboard, a five foot extension to lengthen the model. A limited modification option did not include the five foot extension. The limited modification was selected by NASA and was an option in which the ejector was sized to take 50% of the engine flow with the remaining flow going to the existing VEO nozzles. This modification is summarized in Figure 1.2. Since the program objective was to evaluate the lift ejector performance, no consideration was given to the location of the center of gravity or aerodynamic center of the model.

Circular and rectangular engine flow diverter valve and duct designs were evaluated. A rectangular diverter valve and duct design was selected in order to provide acceptable flow losses in the limited space available in the model.

Design tasks for the lift ejectors were not a part of this program. Since there was no finalized definition available during this study the ejector configuration and size was

scaled up from the preliminary design provided from a 0.2 scale model of the E205 Alperin ejector configuration.

A computer program was developed to accommodate three modes of operation for evaluation of the engine flow diverter and lift ejector system. The first mode of operation provides performance evaluation with all engine exhaust flow out the VEO nozzle and none through the ejectors. The second mode of operation provides split flow to the lift ejectors and through the VEO nozzle. The third mode of operation provides all flow to the lift ejectors with ejector bleed nozzle flow.

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NOMENCLATURE

A_e	effective flow area (physical area X discharge coefficient), in. ²
A_{∞}	Primary Jet Area
BL	Buttock line outboard of aircraft centerline, in.
C_D	discharge coefficient
M	Mach Number
NPR	nozzle pressure ratio (jet exit total pressure/ambient static pressure)
NS	nacelle station, in.
$N/\sqrt{\theta}$	corrected engine rotor speed, %.
P_{AMB}	ambient static pressure, psi.
P_T	total pressure, psi.
q	dynamic pressure, psi.
SMIC	compressor stall margin, %
SWB	spanwise blowing

NOMENCLATURE

S	Diffuser Jet Area
T_T	total temperature, °R
VEO	vectored engine over (wing)
W	engine mass flow rate, lb _m /sec
WL	water line, in.
X	axial station, in.
	gas ratio of specific heats

Subscripts Fig. 3-10

5.1	engine turbine outlet
5.8	engine diffuser exit
6.0	transition section exit
6.5	straight-through diverter valve exit
6.5	diverted flow valve exit
8.0	exhaust system throat station

1. INTRODUCTION

The objective of this program is to conduct a conceptual design study of developing an engine flow diverter system to supply engine exhaust gases to airframe mounted lift ejectors for V/STOL type operation. The conceptual design study is to utilize an existing large scale wind tunnel model equipped with two General Electric turbo jet YJ97 engines. The system is to be designed for minimum effects on the engine operating characteristics for minimum thrust loss and to fit within the contours of the existing large scale model shown in Figure 1-1. In addition a computer program is to be developed to analyze the effects on the engine operating characteristics, the pressure losses, the nozzle flow area, the nozzle total pressure and temperature, nozzle flow rate, and nozzle thrust for different flow diverter modes of operation.

The conceptual design study was accomplished by first determining the limitations and constraints to the existing 3/4 scale NASA/Ames model shown on Figure 1-1. Various model structural modification options were evaluated. General Electric, subcontractor to General Dynamics, conducted the conceptual design study for the engine flow diverter valve along with providing the engine operating characteristics for the YJ-97 engine. General Dynamics accomplished the conceptual design for the flow diverter system ducting and integrated the complete system into the existing model with modifications. A number of structural modifications in the conceptual design study were developed to determine the trade-off options that would best accommodate the lift ejectors and the engine flow diverter-duct system into the model. The selected configuration concept modified the existing 3/4 scale model by relocating the nacelles outboard, moving the engine forward, and extending the VEO nozzles aft. These model modifications are shown in Figure 1-2.

In addition General Dynamics developed a computer program that provides a means for analyzing the flow diverter/ejector performance by varying parameters, such as mode of operation, change in engine operating characteristics, pressure drop losses, flow coefficients, and changes in ejector nozzle areas. The computer accommodates three modes of operation for evaluation of the engine flow diverter and lift ejector system. The first mode of operation provides performance evaluation with all engine exhaust flow out the VEO nozzle and none through the ejectors. The second mode of operation provides split flow to the lift ejectors and through the VEO nozzle. The third mode of operation provides all flow to the lift ejectors with ejector bleed nozzle flow.



FIGURE I-1. LARGE SCALE WIND TUNNEL MODEL

MODIFICATION DESIGN CONCEPT
FOR BASELINE CONFIGURATION

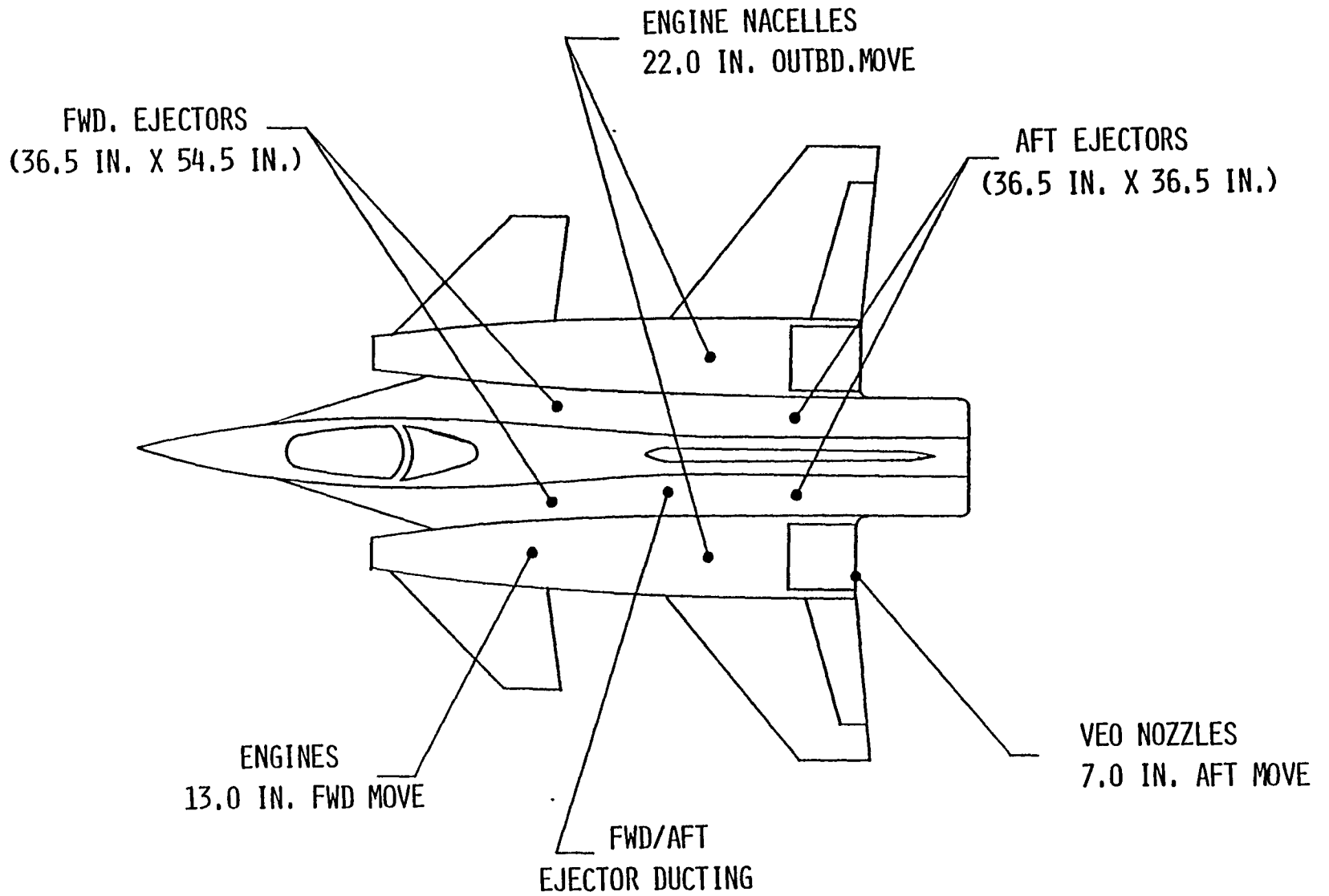


FIGURE 1-2

2. MODIFICATION OPTIONS TO EXISTING MODEL

Modifications necessary to install an engine flow diverter system, as shown in Figure 2-1, into the existing 3/4 scale model located at NASA/Ames have been determined through progressive design concepts. Care has been taken to evaluate the design on the basis of material availability, fabrication effort and cost effectiveness.

Initially a 1/10 scale drawing (GD3616-R001) was made of the model with full-scale sections taken of the strake area at various critical locations such as the cross section of the torque-box support as shown on sheet 2 of the drawing. This highlighted the structural areas of most concern.

A second scale drawing (GD3616-R002) was made with a close approximation of properly sized Alperin ejectors overlaid onto the strake area. Ejector envelope dimensions were obtained from the 7 x 10 model drawing, reference 2-3. The proportions of the ejectors to the 3/4 scale model clearly showed the need to alter either the model or ejectors or both for a workable arrangement.

The third drawing (GD3616-R003) represented only a slight modification by moving the engine nacelles outboard 17.00 in. to widen the strake for the ejectors and by shortening the ejectors to avoid moving the primary attachment fittings. No attempt was made to coordinate the sizing of the ejector with the performance of the engine.

In order to satisfy performance and physical requirements, the fourth drawing (GD3616-R004) shows the engine nacelle moved outboard 17.00 in. and an extension section of 58.95 in. added to the airframe. This would allow the fit of a sized ejector

TYPICAL DUCTING AND EJECTOR
ARRANGEMENT

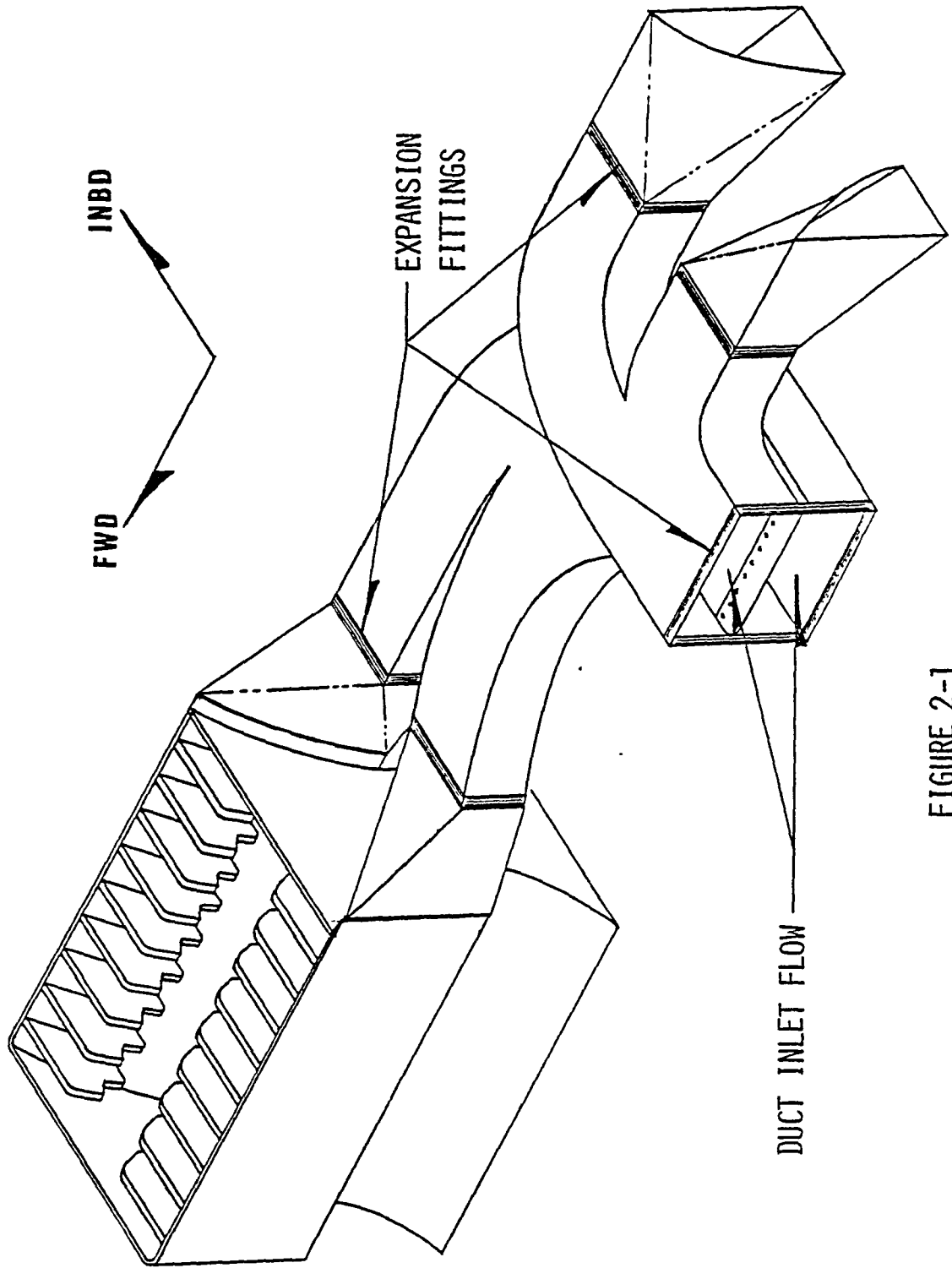
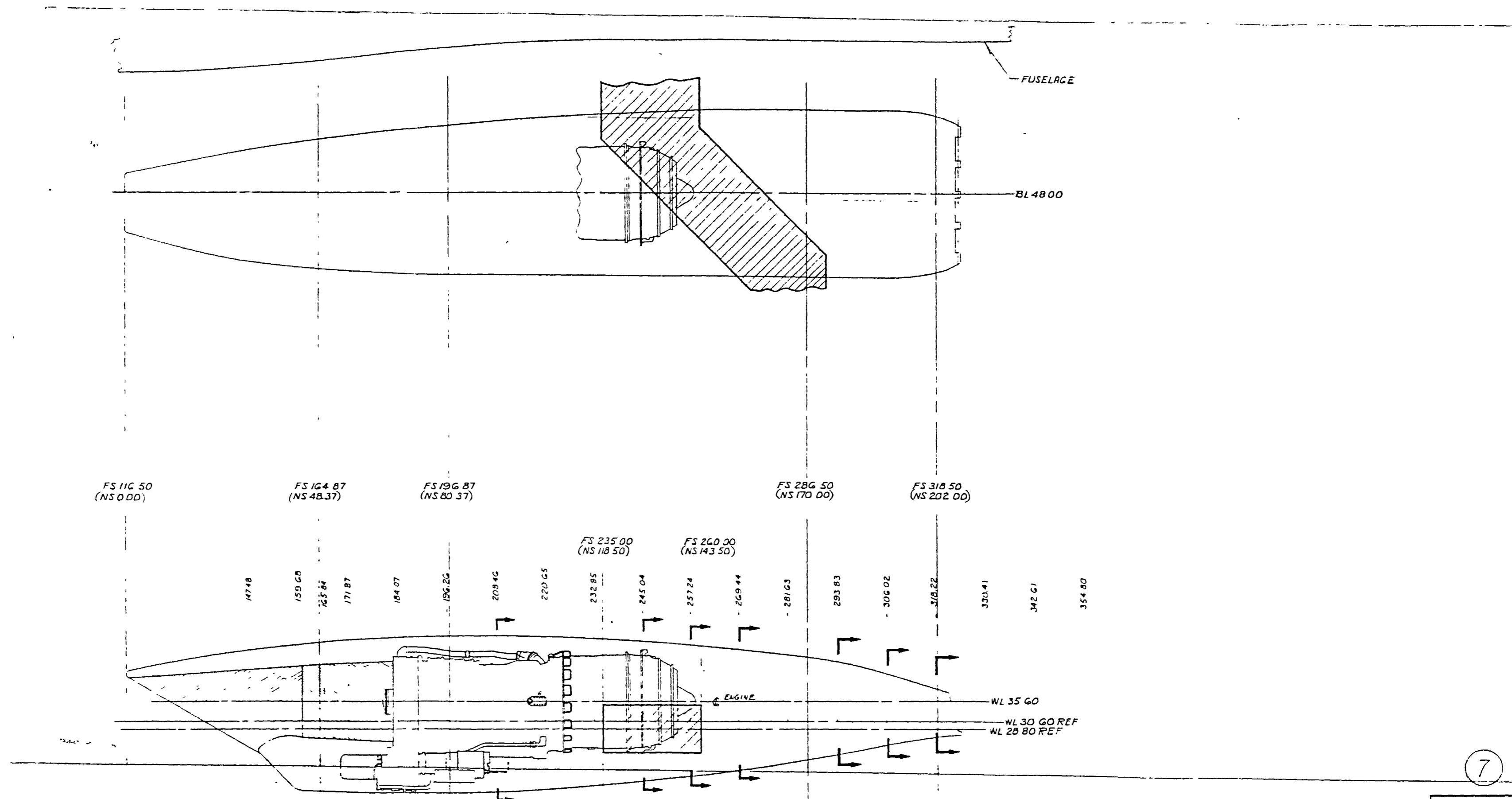


FIGURE 2-1



FS 116.50
(NS 000)

FS 164.87
(NS 48.37)

FS 196.87
(NS 80.37)

FS 286.50
(NS 170.00)

FS 318.50
(NS 202.00)

FS 235.00
(NS 118.50)

FS 260.00
(NS 143.50)

147.48

159.68

165.84

171.87

184.07

196.26

209.46

220.65

232.85

245.04

257.24

269.44

281.63

293.83

306.02

318.22

330.41

342.61

354.80

WL 35.60

WL 30.60 REF

WL 28.80 REF

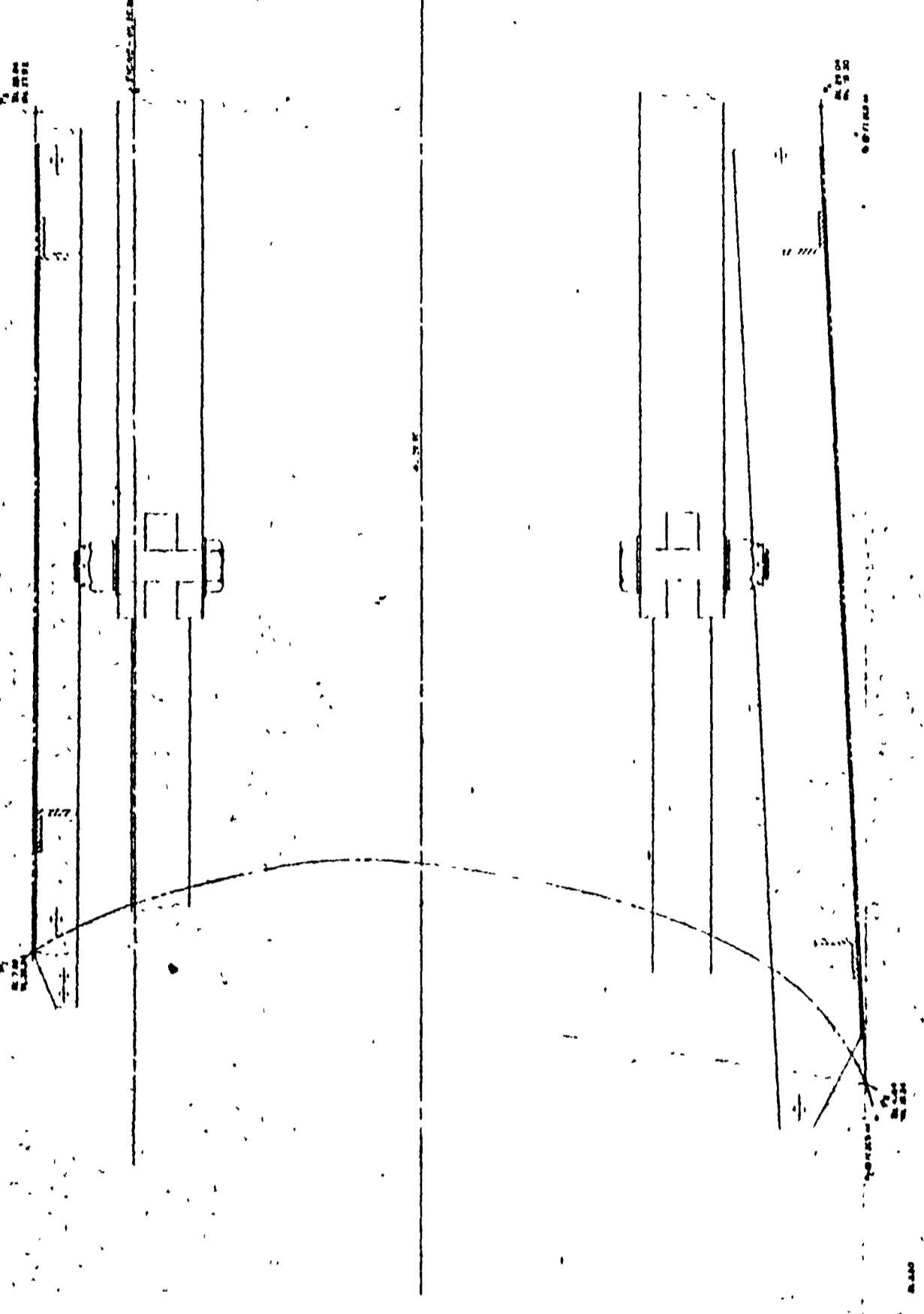
ENGINE NACELLE - LH SIDE
SCALE 1/10

NAS-2-10690

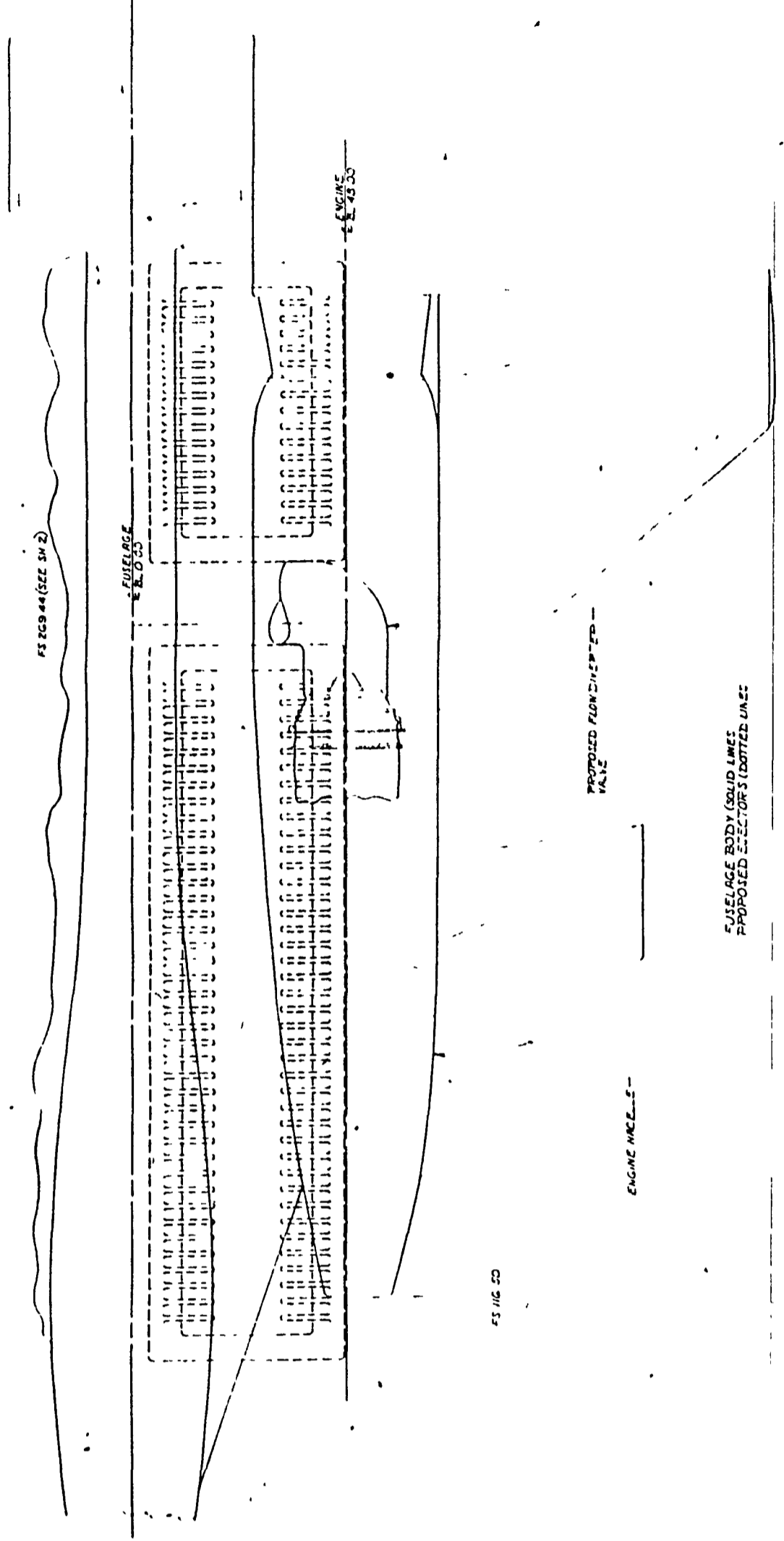
PROJ ENGR		STUDY-NASA ENG FLOW DIVERTER SYS	GENERAL DYNAMICS Fort Worth Division
SR GR ENGR			
GR ENGR			
WEIGHTS			
STRESS			
CHECK			
DESIGN	A. J. ...	DWG GD3616-R001	
DRAFT		SCALE 1/10 DEPARTMENT 88	

PROJECT	100-100000
DATE	10/1/54
SCALE	AS SHOWN
DESIGNED BY	W. J. B. / J. S. B.
CHECKED BY	
APPROVED BY	
STATION AREA ENG. FLOW SHEET NO. 5	

(8)

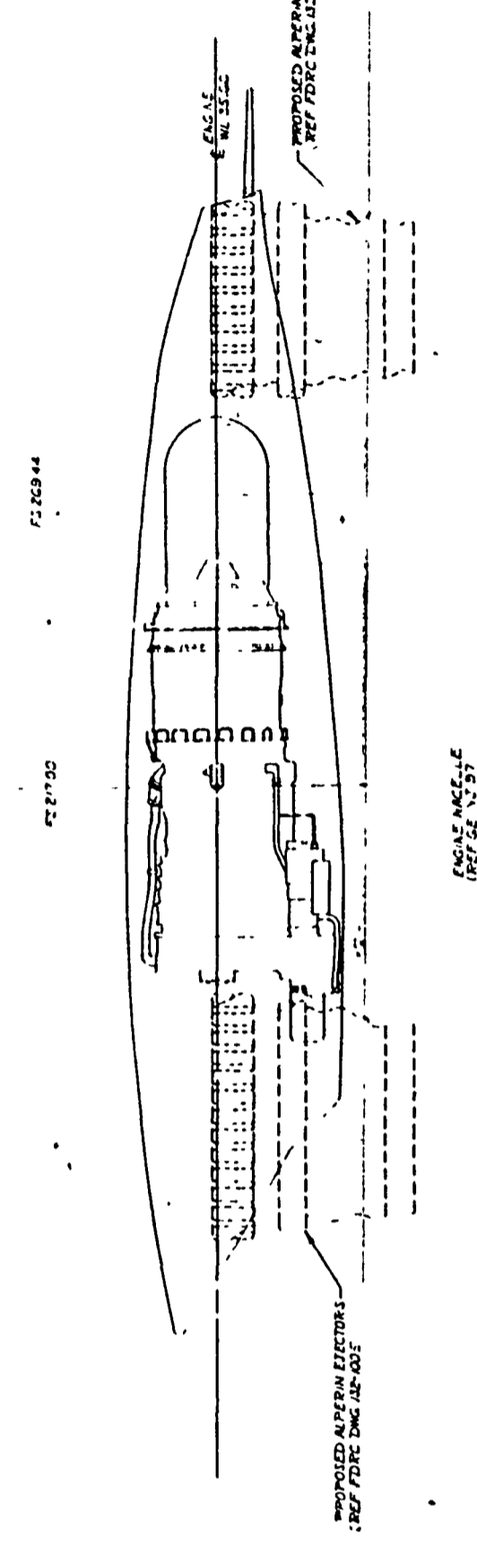


1/2" = 1'-0"



5. OVERALL SIZE OF MODEL SHOWN IS APPROX. 2 FT X 3/4 FT
4. EJECTOR THROAT AREA VS NET EFFECTIVE ENGINE EXHAUST AREA IS A RATIO OF 25:15 TO 1
3. EJECTOR - SHOWN ARE FROM FLIGHT DYNAMICS RESEARCH CORP SYSTEM REF DWG 116-100
2. NO CONSIDERATION HAS BEEN GIVEN TO MODIFY EITHER EJECTOR OR EXHAUST TO PROVIDE COMPATIBILITY
1. 3/4 SCALE MODEL - SHOWN - NASA INLET FIGHTER - NO MODIFICATION

NOTES

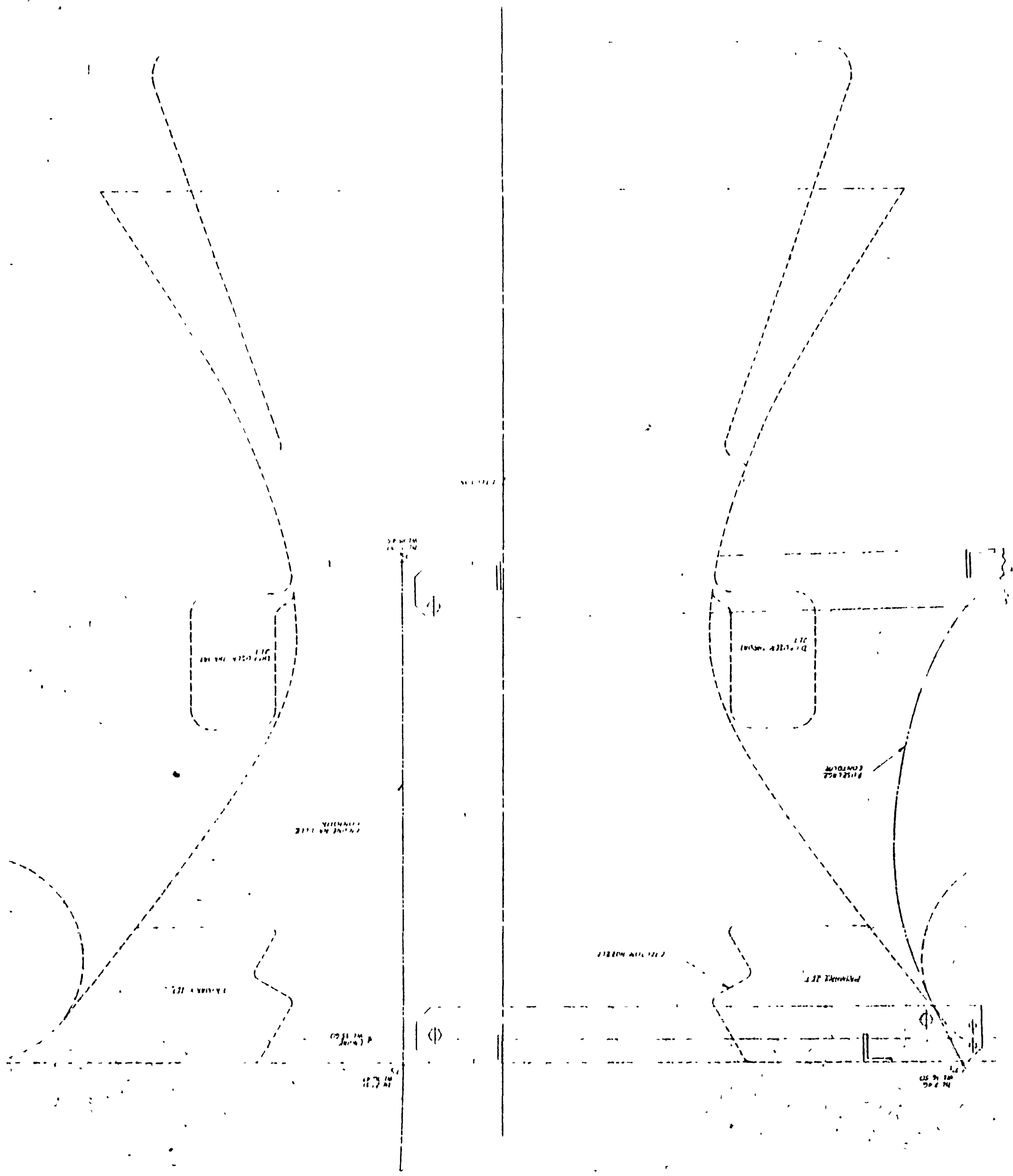


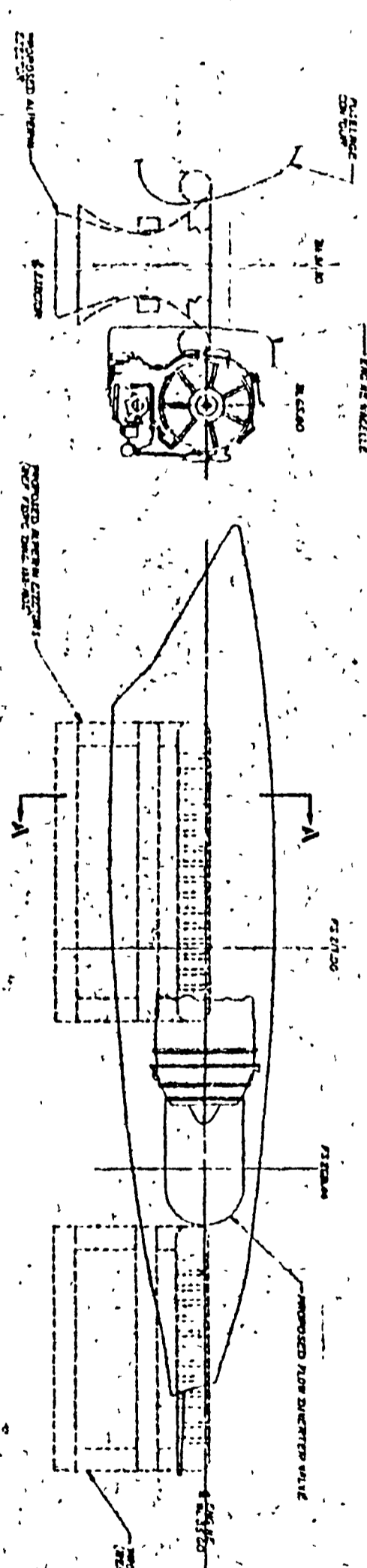
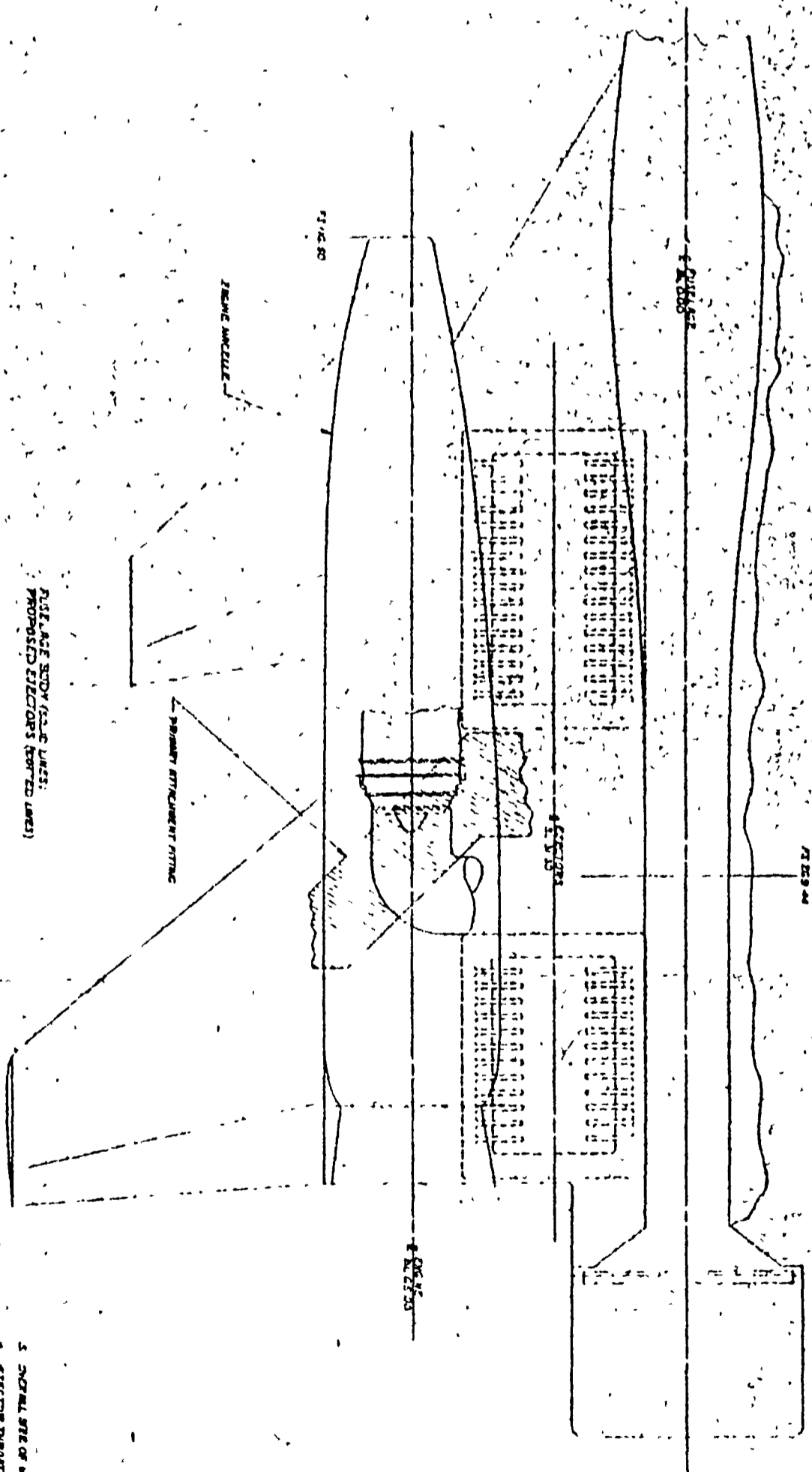
PROJECT	STUDY-NASA
NO. OF SHEETS	1 OF 1
DATE	1963
DESIGNED BY	...
CHECKED BY	...
APPROVED BY	...
SCALE	...
TITLE	ENGINE NOZZLE

(C)

STUDY NO. 11
DATE
BY
REVISIONS
1
2
3
4
5
6
7
8
9
10

STANDARD
 DRAWING
 NO. 11-11-11
 DATE 11-11-11





PASSAGE BODY (SEE LINES)
PROPOSED SELECTOR (DOTTED LINES)

1. DETAIL VIEW OF NOZZLE BODY IS APPROX. 8777 1.4477
2. ELECTOR THROAT AREA IS NOT EXACTLY BEING EXAMINED
3. SELECTOR BODY ARE FROM FUTURE DESIGN RELATIONS. EACH SELECTOR WILL BE DESIGNED FOR A LENGTH OF 1.5 INCHES. PRIMARY ATTACHMENT FITTINGS WITHOUT APPROPRIATE MODIFICATIONS
4. ENGINE NOZZLE AND SELECTOR BODY SHOULD BE DESIGNED FOR PROPOSED WIDER STABLE AREA
5. ALL SCALE ANGLES, SHOW-UP-VALUES, SIZE, PAPER, LIMITED SURVIVAL AND PROTECTION

NOTES

NO. 1	NO. 2	NO. 3	NO. 4	NO. 5	NO. 6	NO. 7	NO. 8	NO. 9	NO. 10
NASA/JSC/ASD STUDY-NASA ENG FLOW DIVERTER SYS R 20200 2023									

more closely matched to the engine characteristics. However, the overall height of the ejector far exceeded the height of the existing strake.

As a logical progressive variation, drawing No. 5 (GD3616-R005) indicated a maximum outboard movement of 24.50 in. for the engine nacelle and continued with the 58.95 in. extension section concept. In addition the strake area was thickened to accept the extra depth without leaving the ejector projected into the airstream.

A final design concept which would provide suitable test data and still be cost effective is shown on drawing GD3616-R006. The engine nacelles were moved outboard 22.00 in. and the strake raised to house the ejectors. The engines were moved 13.00 in. forward and the VEO nozzle moved 7.00 in. aft to accommodate the diverter valve and ejector ducting. The different conceptual designs studies and the selected configuration concept (Study No. 6) are shown in Table 2-1.

2.1 EXISTING LIMITATIONS AND CONSTRAINTS

There were several limitations and constraints to be considered not only in the existing scale model but also with the primary design items such as the ejectors, engine and the VEO nozzle.

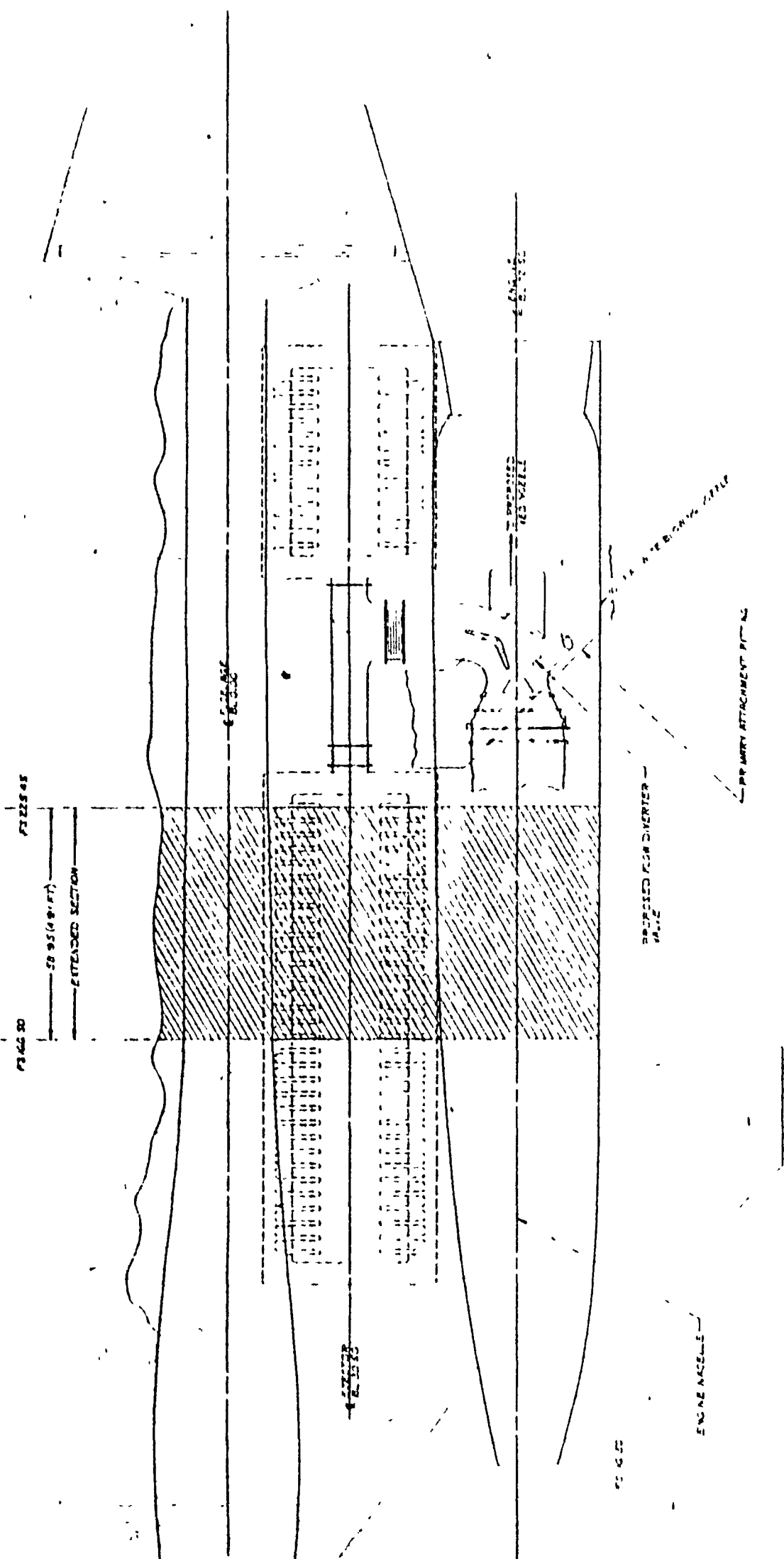
After careful review of NASA furnished drawings of the model, it was determined to retain two major pieces of structure. The forward primary attachment ring and the torque box primary attachment fitting which supports the engine nacelle and wings would remain unaltered except for a widening section. The forward ring and the torque box limit the length of ejectors and the torque box further constrains any ducting to a maximum of 9.00 in. equivalent diameter and dictates the waterline level of the ducts, as shown in Dwg. GD3616-R001, Sheet 2.

TABLE 2-1

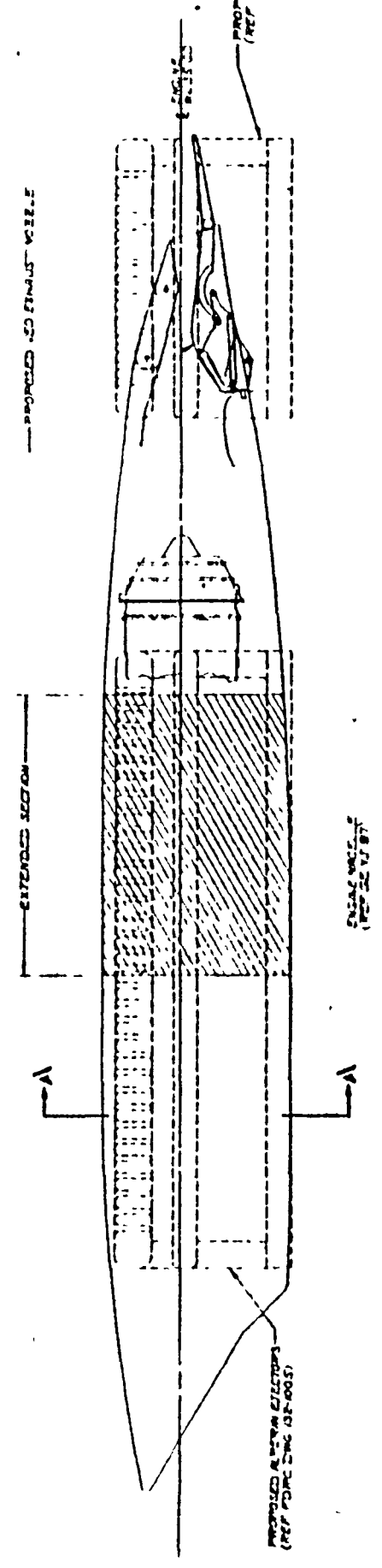
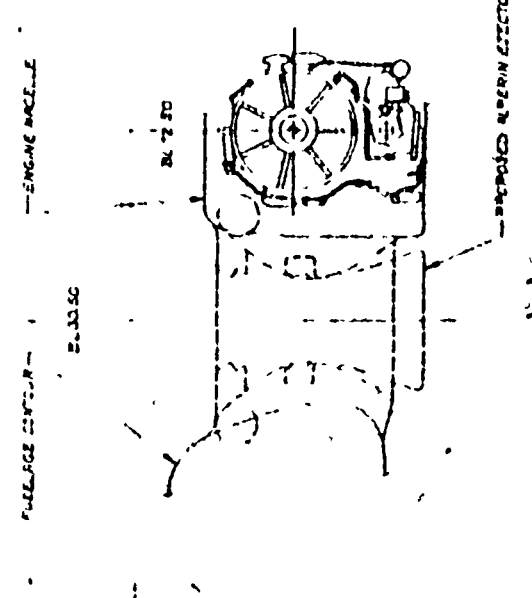
STRUCTURAL MODIFICATION STUDY					
MOD STUDY NO.	GD DRAWING	ENGINE B.L.	INLET F.S.	VEO NOZZLE F.S.	STRAKE THICKNESS (INCHES)
1 (Existing)	GD3516-R001	48.0	116.5	170.8	Varies 15.0-21.0
2	GD3616-R002	48.0	116.5	170.8	15.0-21.0
3	GD3616-R003	65.0	116.5	170.8	15.0-21.0
4	GD3616-R004	65.0	116.5	170.8	Varies 15.0-21.0 (1)
5	GD3616-R005	72.5	116.5	170.8	31.5 (1) (Constant)
6	GD3616-R006	70.0	116.5	177.8	15.35 (2) (Constant)

(1) Adds 58.95 inch extension starting at F.S. 166.5.

(2) Engine moved forward 13.0 inches.

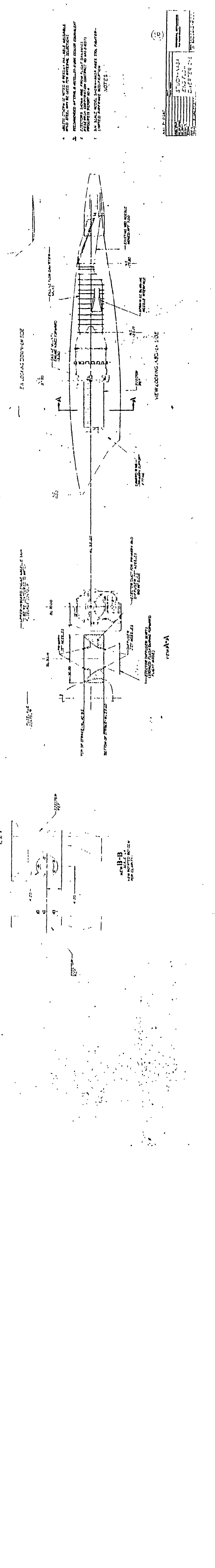
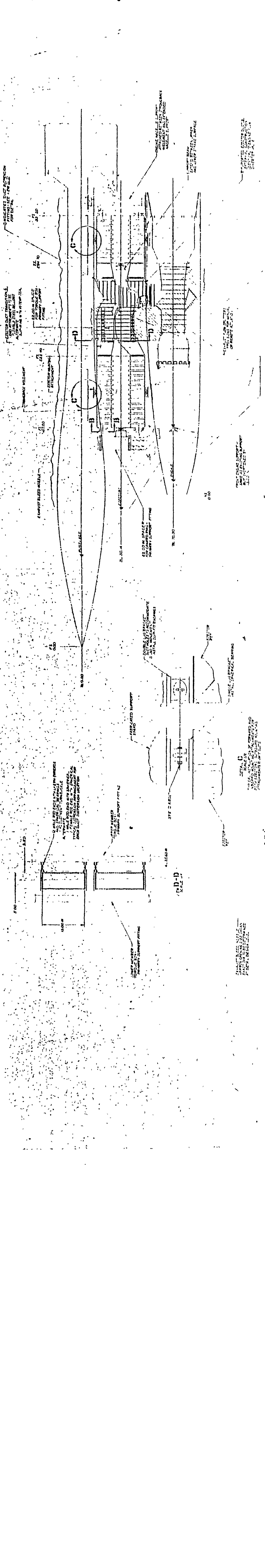


- 1 OVERALL SIZE 3/4 SCALE, SHOWS APPROXIMATE WEIGHT
- 2 EXTERIOR THROAT AREA VS NET EFFECTIVE ENGINE DIAMETER AREA (1.4 & 1.4 x 0.75)
- 3 EXTERIOR THROAT AREA FROM FLIGHT DYNAMICS PERSPECTIVE CORP SYSTEM PER FIG 31-6005
- 4 ENGINE NACELLE AND WINGS MOVED OUTWARD IN 1/2" FROM 24" WIDER THROAT AREA IN EXTENSION SECTION OF 30" BY 1/2" HAS BEEN FOLDED IN WITHIN THE STRIKE AREA BEEN THICKENED TO ALLOW EXTERIOR TO BE RAISED
- 5 3/4 SCALE MODEL, SHOWS AIRFRAME MODIFICATION EXTENDS TO AIRFRAME MODIFICATION



(5)

DATE	10/1/54
BY	W. J. B. / J. S. B.
CHECKED	W. J. B. / J. S. B.
APPROVED	W. J. B. / J. S. B.
TITLE	PROPOSED AIRFRAME MODIFICATION
PROJECT	PROPOSED AIRFRAME MODIFICATION
DESIGN OFFICE	PROPOSED AIRFRAME MODIFICATION
SCALE	PROPOSED AIRFRAME MODIFICATION
FIG. NO.	PROPOSED AIRFRAME MODIFICATION
REV.	PROPOSED AIRFRAME MODIFICATION



- NOTES:
1. ALL DIMENSIONS ARE IN FEET AND INCHES UNLESS OTHERWISE SPECIFIED.
 2. ALL DIMENSIONS ARE TO CENTERLINE UNLESS OTHERWISE SPECIFIED.
 3. ALL DIMENSIONS ARE TO THE OUTSIDE UNLESS OTHERWISE SPECIFIED.
 4. ALL DIMENSIONS ARE TO THE INSIDE UNLESS OTHERWISE SPECIFIED.
 5. ALL DIMENSIONS ARE TO THE CENTERLINE UNLESS OTHERWISE SPECIFIED.
 6. ALL DIMENSIONS ARE TO THE OUTSIDE UNLESS OTHERWISE SPECIFIED.
 7. ALL DIMENSIONS ARE TO THE INSIDE UNLESS OTHERWISE SPECIFIED.
 8. ALL DIMENSIONS ARE TO THE CENTERLINE UNLESS OTHERWISE SPECIFIED.
 9. ALL DIMENSIONS ARE TO THE OUTSIDE UNLESS OTHERWISE SPECIFIED.
 10. ALL DIMENSIONS ARE TO THE INSIDE UNLESS OTHERWISE SPECIFIED.

PROJECT	ST-207-1-1-54
DATE	5-10-54
DESIGNER	W. J. B. G. S.
CHECKER	W. J. B. G. S.
APPROVED	W. J. B. G. S.
SCALE	AS SHOWN

The strake level and thickness were also factors in the envelope size of the ejectors. For obvious reasons of aerodynamics, the strake thickness needed to be identical to the ejector height.

The ejectors were given definition through a series of inputs from Flights Dynamics Research Corp. (FDRC), NASA/Ames and General Dynamics. The diffuser skirts, as described by FDRC, would fold up during forward flight mode creating a relatively smooth lower strake area. As a refinement to the design concept of the ejector per FDRC, the inlet ducts on each side have been reshaped thereby confining the ejector to a 36.50 in. width giving a rectangular overall cross section. This is best shown in VIEW A-A, dwg. GD 3616-R006.

3. ENGINE FLOW DIVERTER VALVE STUDY

3.1 INTRODUCTION

The effective application of the ejector lift system requires that the engine exhaust flow be routed from its normal path to the ejector bays with a minimum loss in total pressure. With this consideration, the task at hand is to design a high performance engine flow diverter valve system which can be installed within the hardware constraints of the existing model. The following sections discuss the procedure and results of this study. The formulation of a set of design requirements is presented in Section 3.2. The selection of an acceptable design concept and the evolution of its performance and integration into the model is discussed in Section 3.3. Section 3.4 covers the analytical investigation into the flow characteristics of the diverter valve system. The results of using the diverter valve in an off-design flow-splitting mode is presented in Section 3.5. The conceptual mechanical design including design criteria and details of the non-flight weight diverter valve design are discussed in Sections 3.6 and 3.7. Section 3 concludes with a discussion of a flight weight type diverter valve design.

3.2 DESIGN REQUIREMENTS

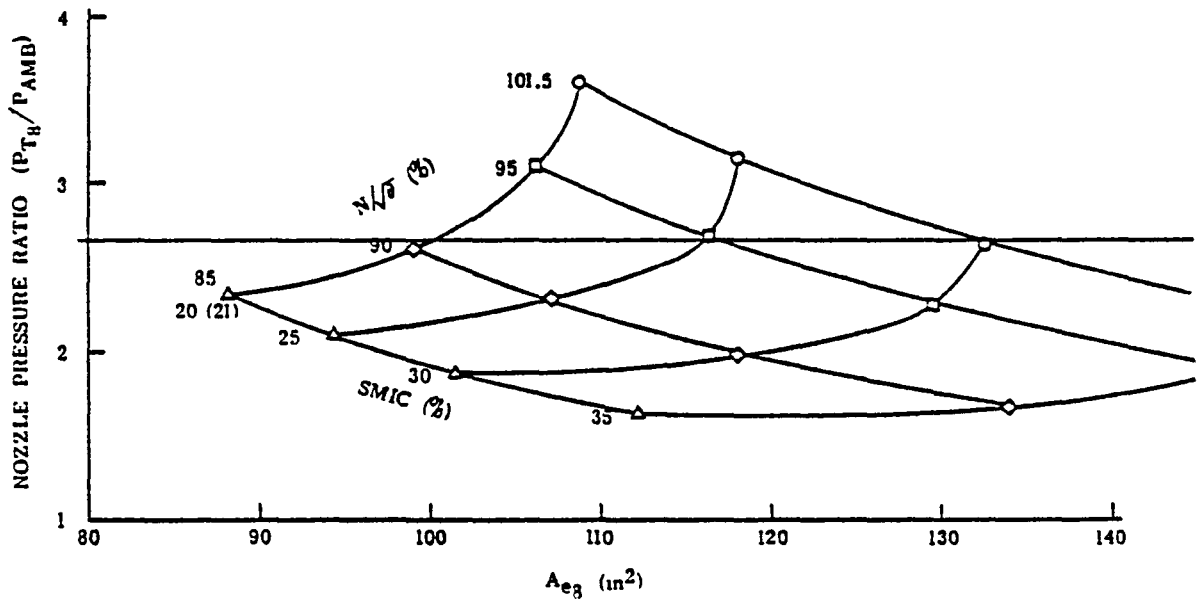
Design requirements were generated from two sources. NASA established the operating requirement while the existing model presented the physical constraints.

3.2.1 Performance Requirement

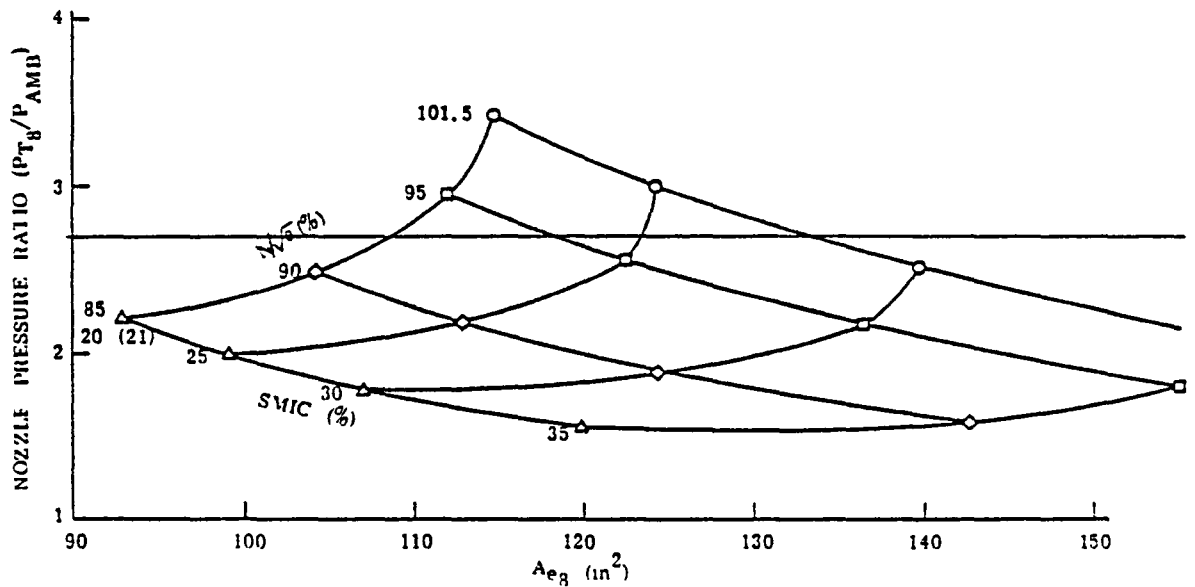
The ejector system performance requirement was simply stated. The diverter valve and ejector ducting system losses shall be small enough to allow the ejectors to attain a

nozzle pressure ratio (NPR) of at least 2.7. As losses in ducts are normally expressed in terms of total pressure loss, this NPR requirement must be related to total pressure loss. This can be accomplished by examining the YJ-97 gas generator cycle data plotted in Figure 3-1. Each of the plots represents the nozzle pressure ratio behavior of an exhaust system with a different total pressure loss between the turbine exit (Station 5.1) and the exhaust system throat (Station 8). In this case, Station 8 may be thought of as the ejector nozzle exit. Figure 3-1a represents the ideal case when there is no pressure loss in the exhaust system. Successively, then, Figures 3-1b, c, and d represent exhaust systems that have a 5%, 10% and finally 15% total pressure loss between Stations 5.1 and 8. Consider the no loss case plotted in Figure 3-1a. Nozzle pressure ratio is plotted versus the Station 8 effective exhaust area as a function of the corrected rotor speed ($N/\sqrt{\theta}$ in percent) and compressor stall margin (SMIC, in percent). (The effective area is equal to the physical area times the discharge coefficient.) The horizontal line at NPR = 2.7 is the NASA performance requirement. Any operating point above this line, a NPR of 2.7 or higher can be attained. In fact, with $A_{eg} = 109 \text{ in.}^2$, $N/\sqrt{\theta} = 101.5\%$ and SMIC = 21%, the system would attain NPR = 3.6. Note also that this plot indicates that A_{eg} must be between 100.7 in.^2 and 131.2 in.^2 to attain an NPR = 2.7. At 101.5% speed a T5.1 temperature limit allows a minimum stall margin of only 21%.

Move now to Figure 3-1d and examine the effect on attainable NPR of a 15% loss in total pressure through the exhaust system. Here, the highest attainable NPR is 3.06 occurring at the same engine operating point as in Figure 3-1a. However, the required A_{eg} is now 128 in.^2 . With lower total pressure at the exit, the exhaust flow requires a larger area for the same mass flow and total temperature. Note that the required NPR of 2.7 can only be attained over a much smaller portion of the engine operating envelope. The result is a limited capability system with a small envelope for experimentation.

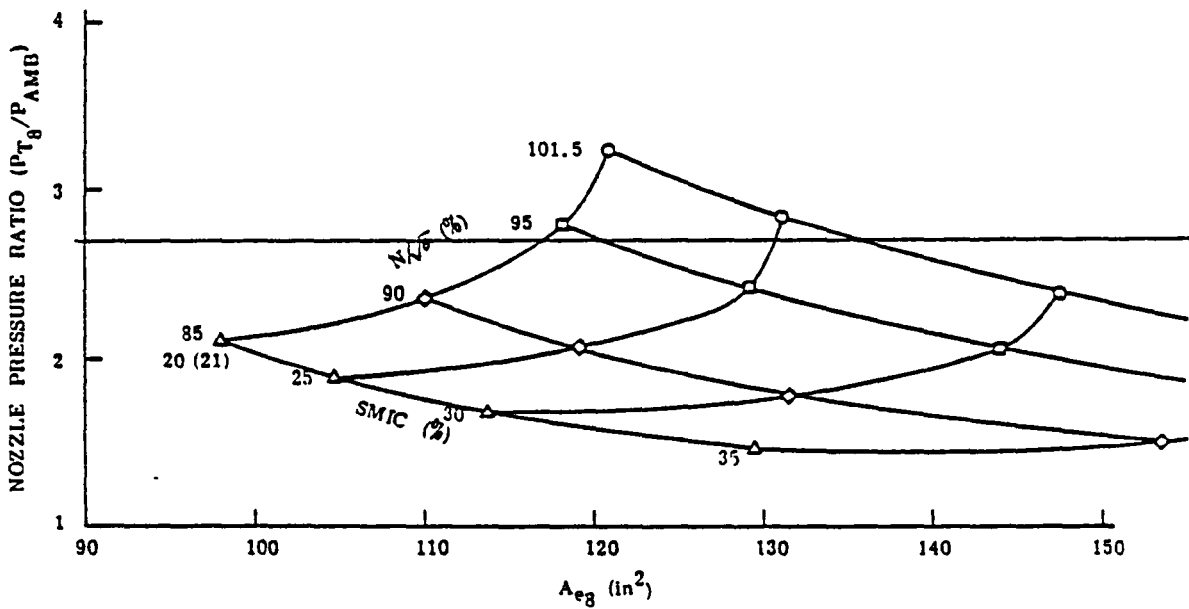


(a) $(P_{T51} - P_{T8}) / P_{T51} = 0$

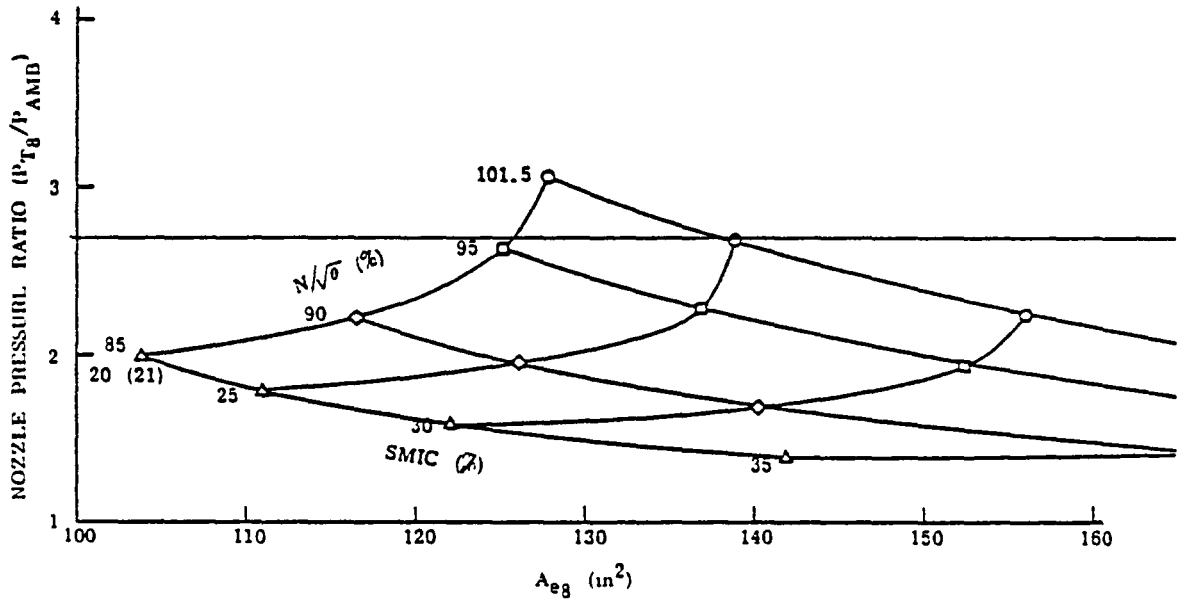


(b) $(P_{T51} - P_{T8}) / P_{T51} = 0.05$

FIGURE 3-1. YJ-97 GAS GENERATOR/NOZZLE PRESSURE RATIO BEHAVIOR (SEA LEVEL STATIC STANDARD DAY)



(c) $(P_{T51} - P_{T8}) / P_{T51} = 0.10$



(d) $(P_{T51} - P_{T8}) / P_{T51} = 0.15$

FIGURE 3-1 (Concluded)

With these data in mind, a target exhaust system total pressure loss of no more than 10% was selected. Available data on the Alperin ejector design estimates the total pressure loss through it alone is about 7%. This leaves only about 3% for the remainder of the exhaust system which includes the engine diffuser, diverter valve, and ducting from the diverter valve to the ejector bay. The operating characteristics of a system with this target loss are plotted in Figure 3-1c. To attain a NPR of 2.7, A_{eg} will be between 117 in.² and 136 in.² with a rotor speed above 94% and stall margin below 26%.

3.2.2 Physical Constraints

The requirement to install the diverter valve within the existing nacelle hardware placed severe physical constraints on the design. A top and side view diagram of the nacelle/diverter valve area is presented in Figure 3-2. In the top view, the diverter valve envelope is seen to be 33 inches long running from nacelle Stations 137.8 to 170.8. The valve must turn the flow inboard with the inner turning radius just aft of the bulkhead at NS 143.5. The inboard thrust link will have to be re-positioned. The side view (Figure 3-2b) illustrates that in flow-through operation the diverter valve must raise the centerline of the flow 4.4 inches from waterlines 35.6 to 40.0.

Within this physical size envelope, the diverter valve system must (1) have the capability to divert the entire engine flow to the ejector ducting, pass all of the engine flow straight-through to the VEO nozzle or split the engine flow between the ejector bay ducting and the VEO nozzle, (2) provide accommodation for the thermal growth, (3) provide a port and connecting ducting to the existing spanwise blowing (SWB) nozzle, and (4) transition between circular at NS 137.8 and rectangular at NS 170.8. Another criteria was established several months into the program when it was determined that the ducting downstream of the diverted leg would have to be rectangular. The diverter valve would

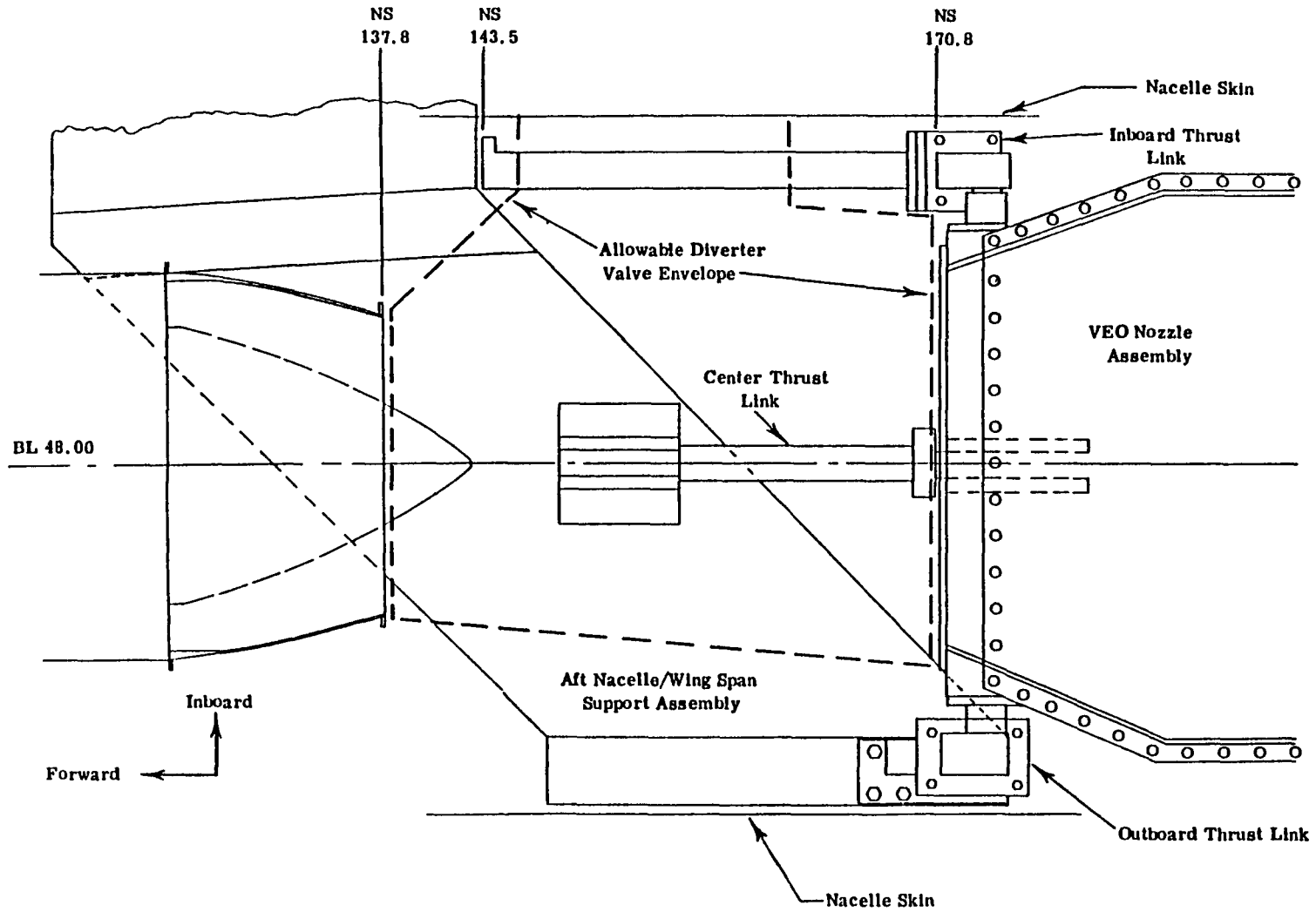


Figure 3-2 a. Left Nacelle (Top View)

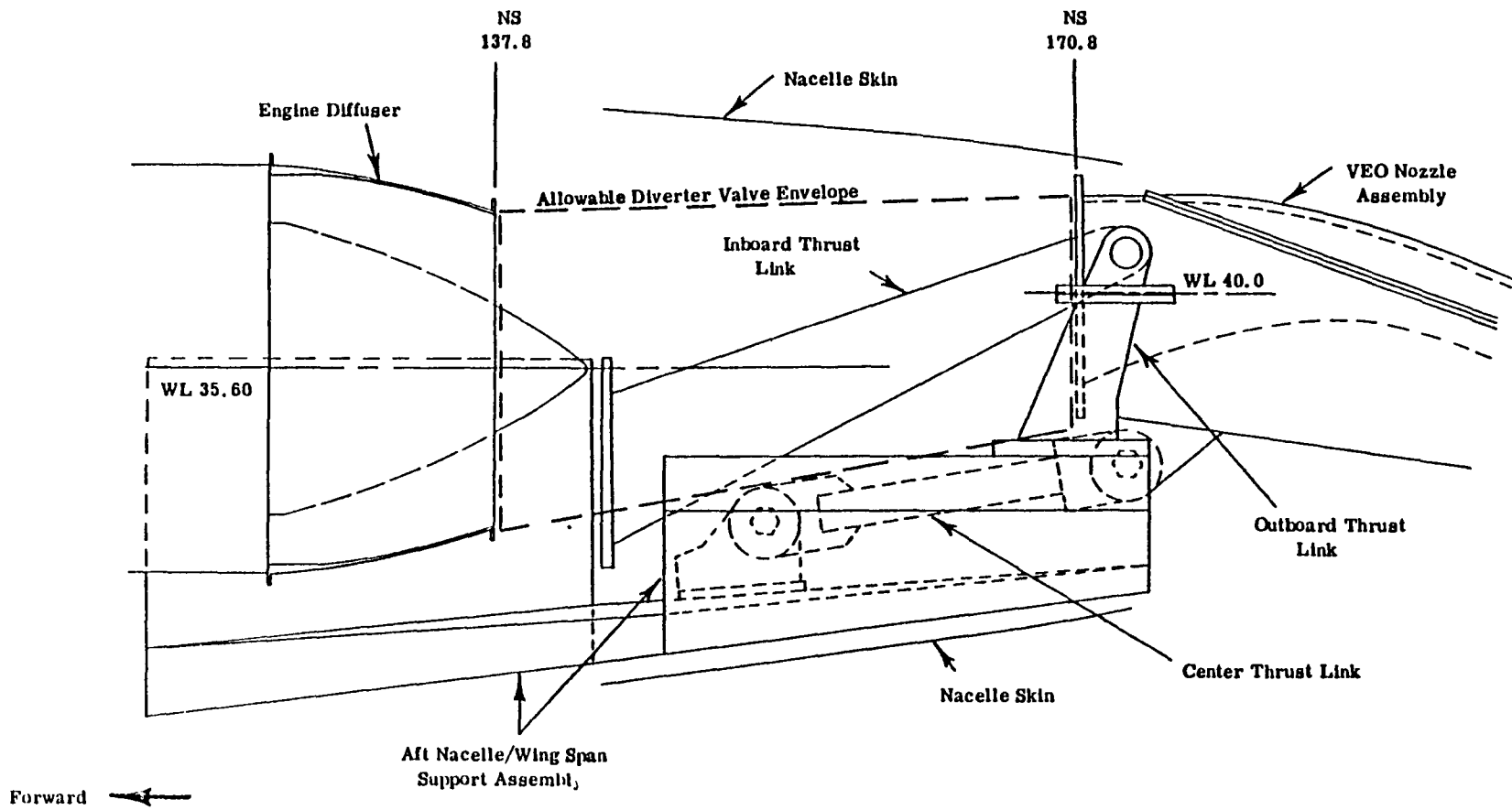


Figure 3-2 b. Left Nacelle (Side View)

therefore have to connect to rectangular ducts at both of its exits. A discussion of the criteria affecting the details of the mechanical design is presented in Section 3.6.

3.3 Concept Design

Three candidate diverter valve concepts were considered and evaluated versus the design requirements outlined in Section 3.2.2. Once a concept was selected the size and integration evolved to meet the performance requirement of Section 3.2.1. For the final configuration, the method of estimating the performance is presented at the end of this section.

3.3.1 Candidate Diverter Valves

Three diverter valve concepts were considered for this study. Two had been previously developed and tested by GE in programs related to the XV5A VTOL aircraft. The third is a new concept derived from variable area bypass technology used in variable cycle engines.

The first previously tested concept is referred to as the "Sugar Scoop" diverter valve (Figure 3-3). The valve consists of a circular section modified "tee" pipe in which a hollow quarter ellipsoid, or "Sugar Scoop" is mounted. The mounting angle of the sugar scoop within the pipe section is such that it may be rotated 180° about its axis of symmetry, giving flow paths in the straight through and diverted directions which approach constant circular section ducts. The data base (reference 3-1) for this concept consists of a 10" diameter cold flow model test.

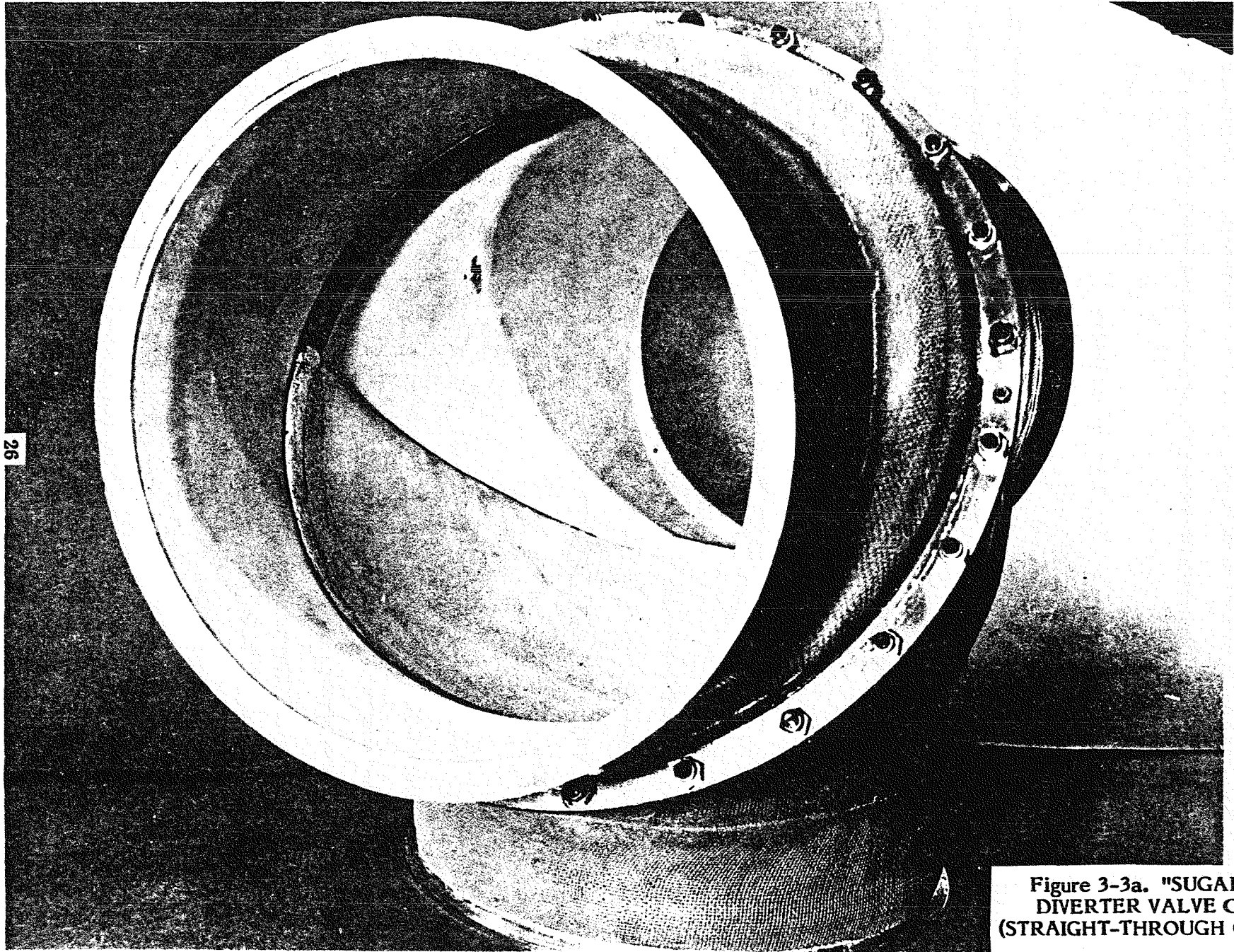
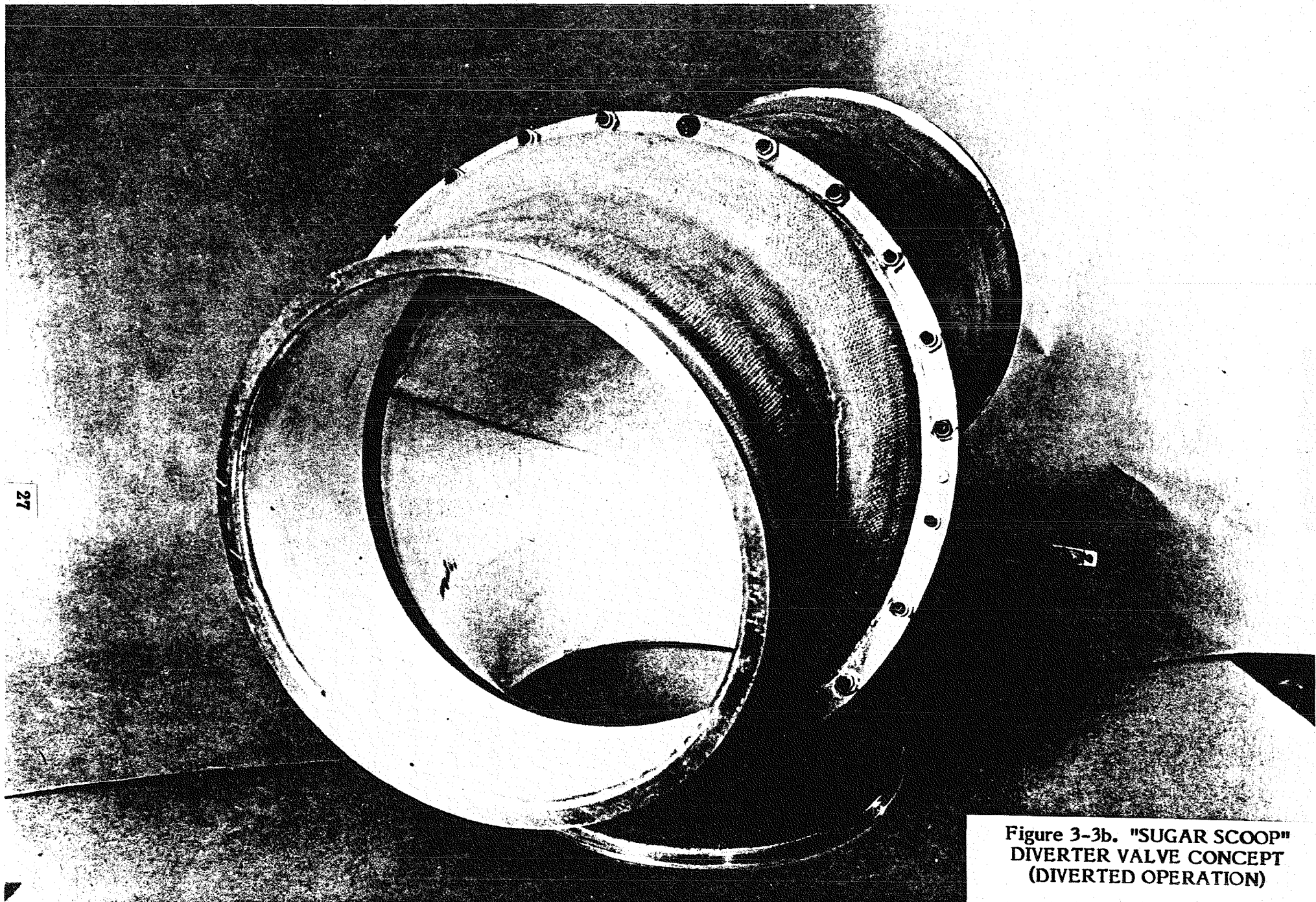


Figure 3-3a. "SUGAR SCOOP"
DIVERTER VALVE CONCEPT
(STRAIGHT-THROUGH OPERATION)



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Figure 3-3b. "SUGAR SCOOP"
DIVERTER VALVE CONCEPT
(DIVERTED OPERATION)

A schematic of the second previously tested concept is shown in Figure 3-4. This two vane valve also is constructed in a modified "tee" form. The flow through this valve may be completely diverted, flow straight-through, or split between the two legs depending on the positioning of the two vanes. This valve may be constructed in either axisymmetric or two-dimensional form. The data base consists of 10" diameter circular section cold flow model tests with two different turn radius ratios. In addition, it was tested in full scale behind a non-afterburning J-85 engine (reference 3-2).

The final candidate is a peripheral port diverter illustrated in Figure 3-5. This concept requires a variable throat area VEO wing nozzle to block the straight-through flow when diverted flow is required. A rotating outer section of the diverter duct controls the area of the diverter ports. The diverter flow is captured in an annular manifold for discharge at the desired circumferential location. No test data exists on this concept.

3.3.2 Concept Selection

The selection of the most acceptable diverter valve concept was based on an evaluation of each candidate against five criteria. A summary of the evaluation is presented in Table 3-1. The first criteria evaluates turning total pressure loss at the common design Mach number of 0.3. The values for candidates 1 and 2 come from test data. It was assumed that the diverted flow for candidate 3 would suffer a plenum loss of its total dynamic head. The "Sugar Scoop" valve did not have a suitable flow splitting capability. The peripheral port diverter required a variable area VEO wing nozzle to provide blockage. The two vane diverter valve was the only concept adaptable to both circular and 2D cross-sections. Finally, the peripheral port design did not lend itself to provisions for SWB operation in the straight-through mode of operation. This evaluation process identifies the two vane design as the best candidate.

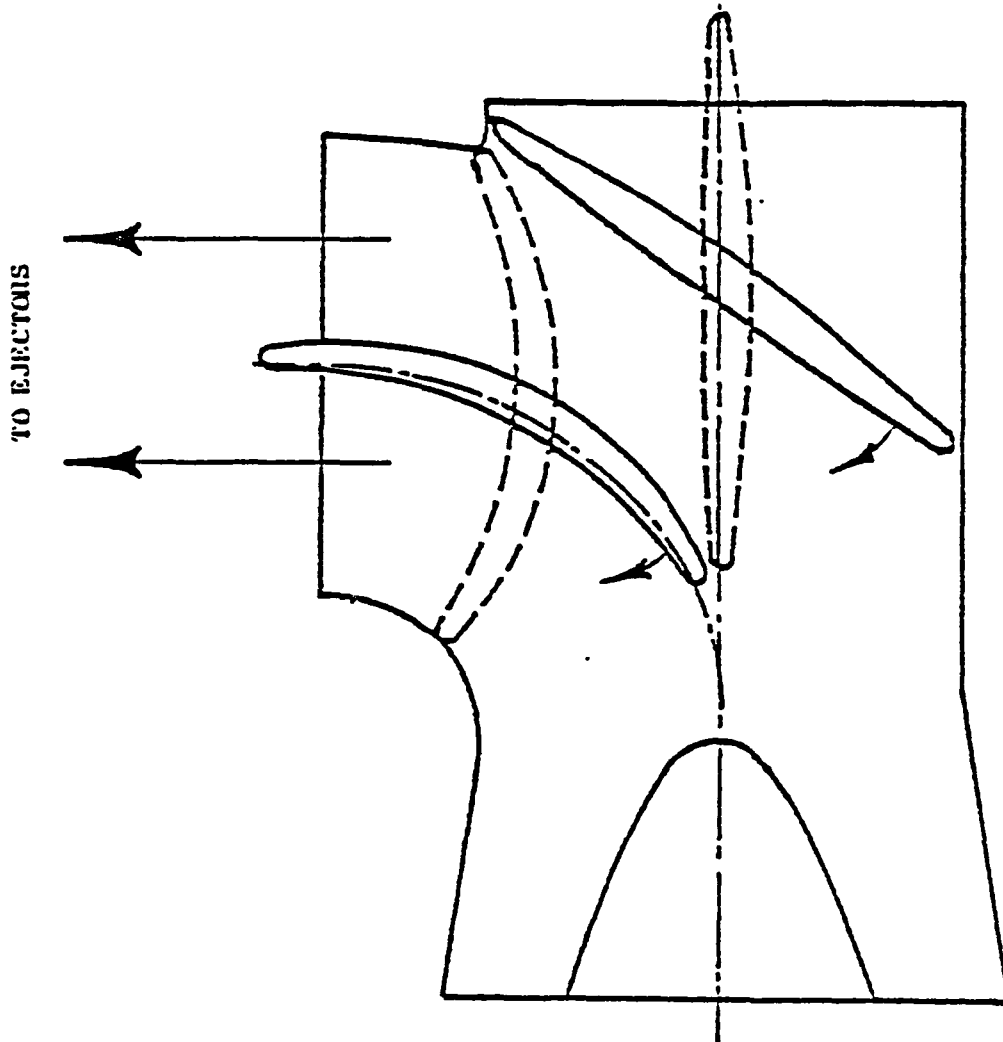


FIGURE 3-4. SCHEMATIC OF TWO VANE DIVERTER VALVE

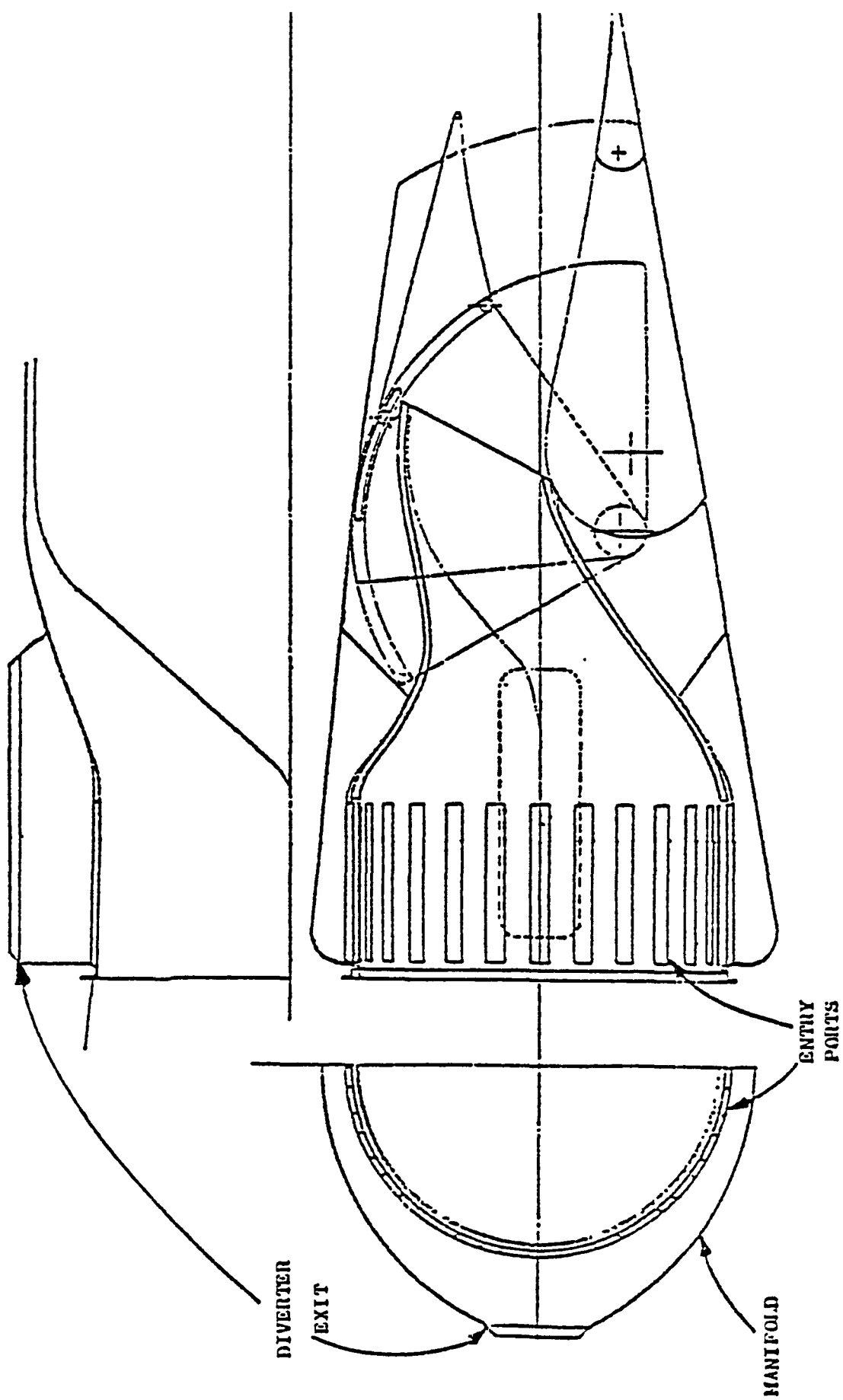


FIGURE 3-5. SCHEMATIC OF PERIPHERAL PORT DIVERTER

TABLE 3-1
CONCEPT SELECTION

CANDIDATE DIVERTER VALVE CONCEPTS			
CRITERIA	(1) SUGAR SCOOP	(2) TWO VANE	(3) PERIPHERAL PORT
P _T loss ($\Delta P_T/q_i$)	.58	.35*-.69**	1.0
Flow Splitting Operation	No	Yes	Yes
Independent Operation	Yes	Yes	No
Axi or 2-D	No	Yes	No
SWB Operation	Yes	Yes	No

* Turning vane radius ratio - 1.0

** Turning vane radius ratio - 0.68

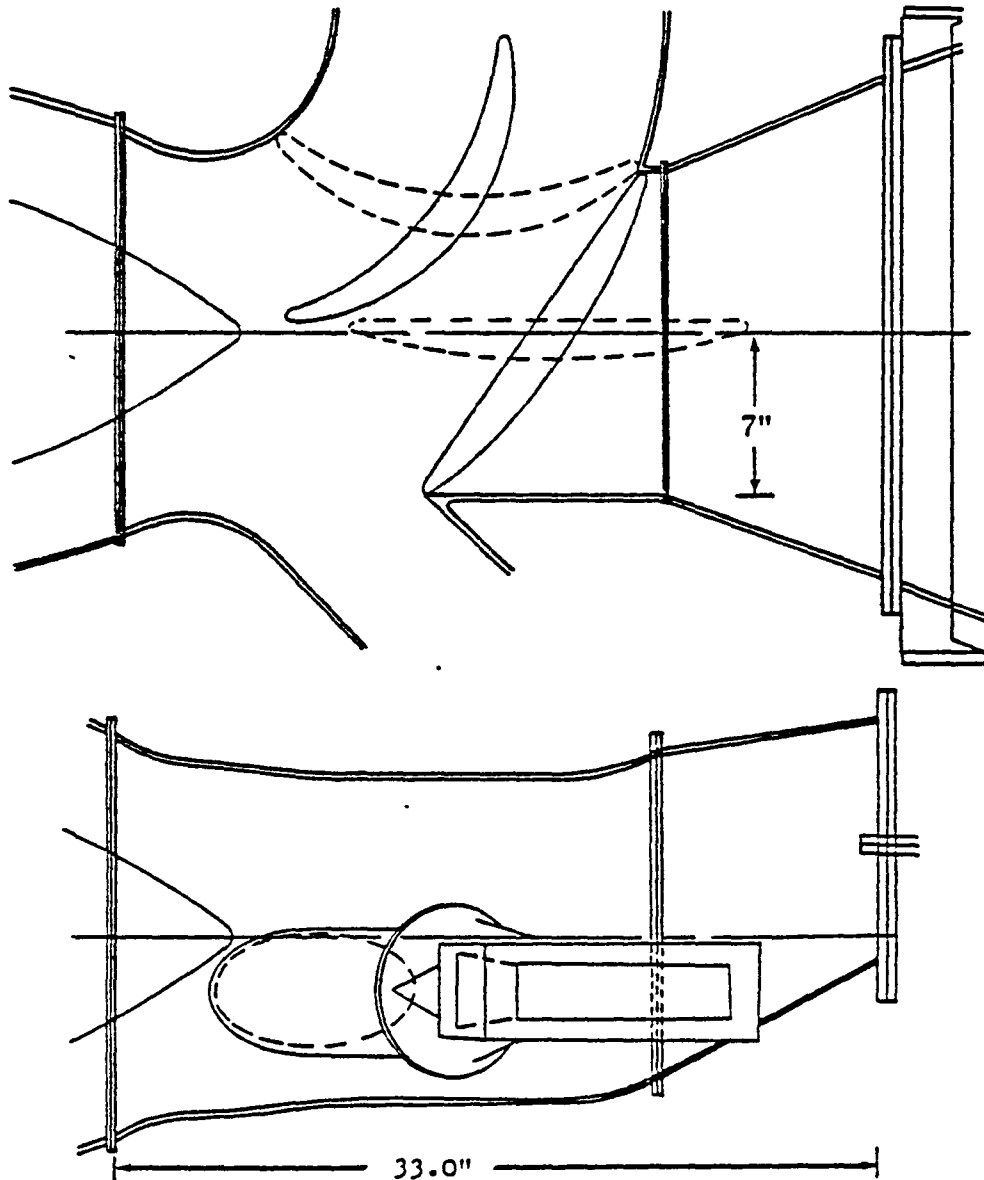
Note: The turning vane radius ratio is defined as the center turning vane radius of the curvature divided by the duct diameter.

3.3.3 Diverter Valve Size, Performance and Integration Evolution

With the two vane diverter valve concept selected, the process of integrating an acceptable performance design could begin. As a first step, a diverter valve which fit within the space allocations called out in Section 3.2.2 was sketched and its performance estimated. Its total pressure losses were found to be too high. An iteration process was then begun which entailed an easing of a physical limit (by moving some structure) and a re-evaluation of performance. The evolution of design which justifies the major structural modifications are presented herein.

A sketch of a design which fits within the existing model structural constraints is presented in Figure 3-6. It has a 14" diameter circular cross-section. The side view shows the orientation to the SWB nozzle. This sketch may not be mechanically feasible as no

- Fits within existing model structural constraints



- May not be mechanically feasible
- Poor aerodynamics performance

FIGURE 3-6. TWO VANE DIVERTER VALVE DESIGN #1

space allowances were made for thermal growth accommodation. In addition, the many curved lines may be difficult to construct. This design requires repositioning of the inboard and center thrust links (as do all subsequent designs). The immediate determining factor is the valve total pressure loss estimate presented in Figure 3-7 which was calculated from the experimental data of reference 3-2. Here, the total pressure loss ratio from the turbine exit to the diverter valve outlet is plotted for each engine operating point. As explained in Section 3.2.1, the probable operating point will be at high rotor speed ($\geq 94\%$) and low stall margin ($\leq 26\%$). This plot, therefore, indicates a least possible loss of 7% at the expected operating point which is more than double the target loss of 3%. This loss is unacceptably high. The design illustrated in Figure 3-6, with its turning radius ratio of 1.0, represents the highest performing diverter valve which will fit in the available space. The high losses of this design are due to its small flow cross-sectional area. The total pressure losses are directly proportional to dynamic pressure, q , which is proportional to M^2 , which is inversely proportional to the flow cross-sectional area. Therefore, to reduce the total pressure losses, the diverter valve cross-sectional area must be increased. Since the length of the diverter valve grows proportionally with the cross-sectional area (diameter), the diverter valve envelope must also grow in length.

As a result of this finding and other requirements established in the ejector installation, the following additional guidelines were established:

1. The diverter valve will connect to the existing engine diffuser.
2. The engine is moved 13 inches forward.
3. The engine/nacelle is moved outboard 22 inches.
4. The existing fixed VEO nozzle is retained.
5. The diverter valve shall be changed to rectangular construction to provide easy connection to the rectangular ejector bay ducting.

NOTE: P_{T51} - TURBINE EXIT TOTAL PRESSURE
 $P_{T65'}$ - DIVERTER VALVE OUTLET TOTAL PRESSURE

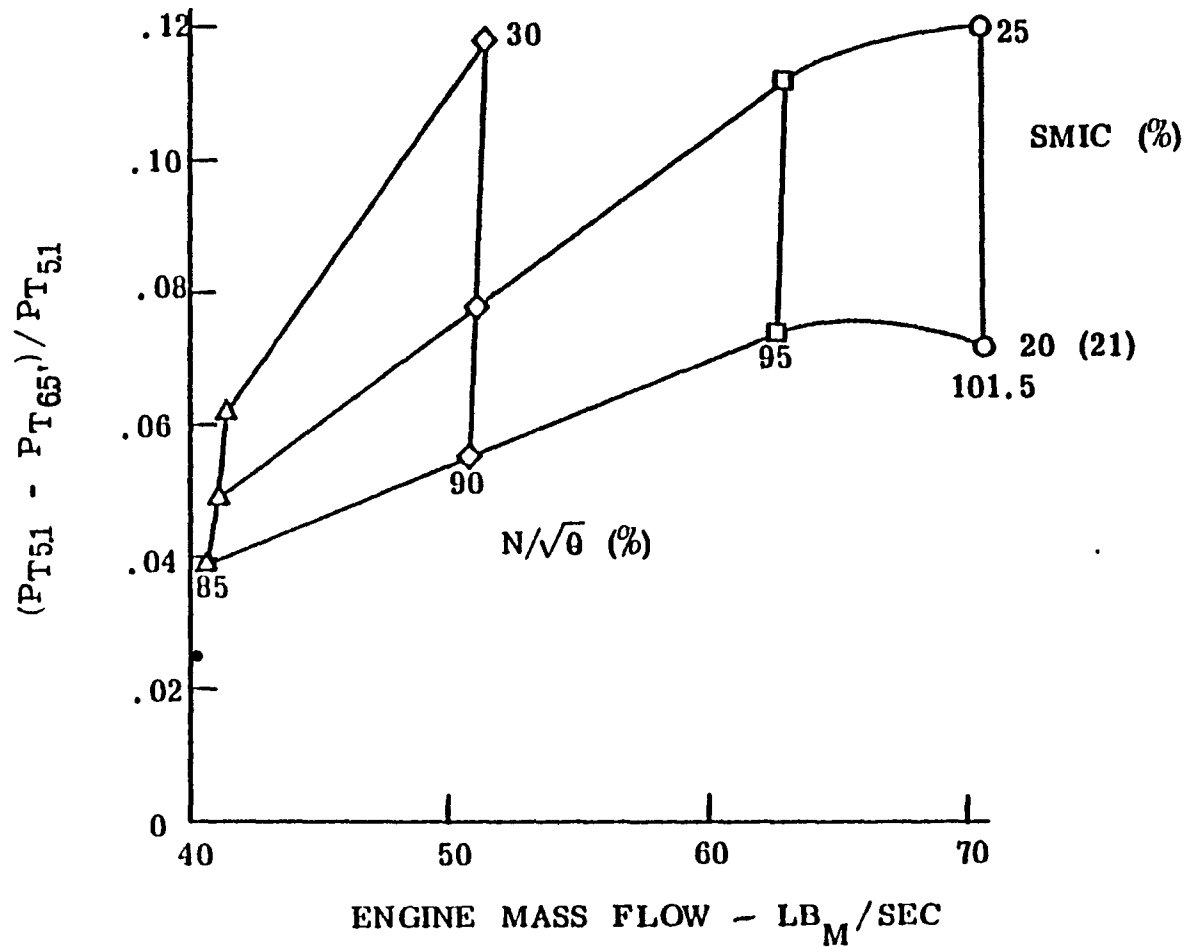


FIGURE 3-7. TWO VANE DESIGN #1 ESTIMATED PERFORMANCE (DIVERTED FLOW)

The design resulting from these new guidelines is presented in Figure 3-8. A circular to square transition piece is inserted between the engine diffuser and the 17.56 inch square diverter valve. In addition, the valve centerline is canted up 5° to allow connection to the VEO wing nozzle at NS 170.8. The estimated total pressure loss of this design was found to be very acceptable 2% - 3% in the probable operating area. However, integration with the ejector bay ducting necessitated one more design iteration.

In the previous design, the 5° cant forced the diverted channel outlet to be rotated 5° . This was determined to be unacceptable for the thermal growth connection to the ejector bay duct. Removing the 5° cant necessitated moving the VEO wing nozzle connect plane aft 7 inches. Without this move, an unacceptably high convergence angle would have existed on the lower aft face of the diverter valve. This final design is illustrated in Figure 3-9. Details of the construction and exact geometry are presented in Section 3.6. The performance estimation methodology and the resulting performance of this final design are present in Section 3.3.4.

3.3.4 Final Diverter Valve Design Performance

Estimating the performance of the final diverter valve design required the combined use of existing experimental data and a standard incompressible duct flow loss technique. A schematic of the method used is presented in Figure 3-10. Reference 3-2 was used extensively as the experimental data source. This reference presents parametric cold flow test results of several engine diffusers and diverter valve designs. The data were, however, for circular cross section diverter valves. A correction was made to a square section by ratioing the appropriate incompressible duct flow loss parameters (from reference 3-3). That is, for the diverted flow channel, the loss parameter of a 90° square elbow was ratioed to the loss parameter for a 90° circular elbow.

- Connects to the existing engine diffuser
- Engine moved forward 13 inches
- Engine and nacelle moved outboard 22 inches
- Existing fixed VEO nozzle retained
- Rectangular construction to allow easy connect to GD's ducting

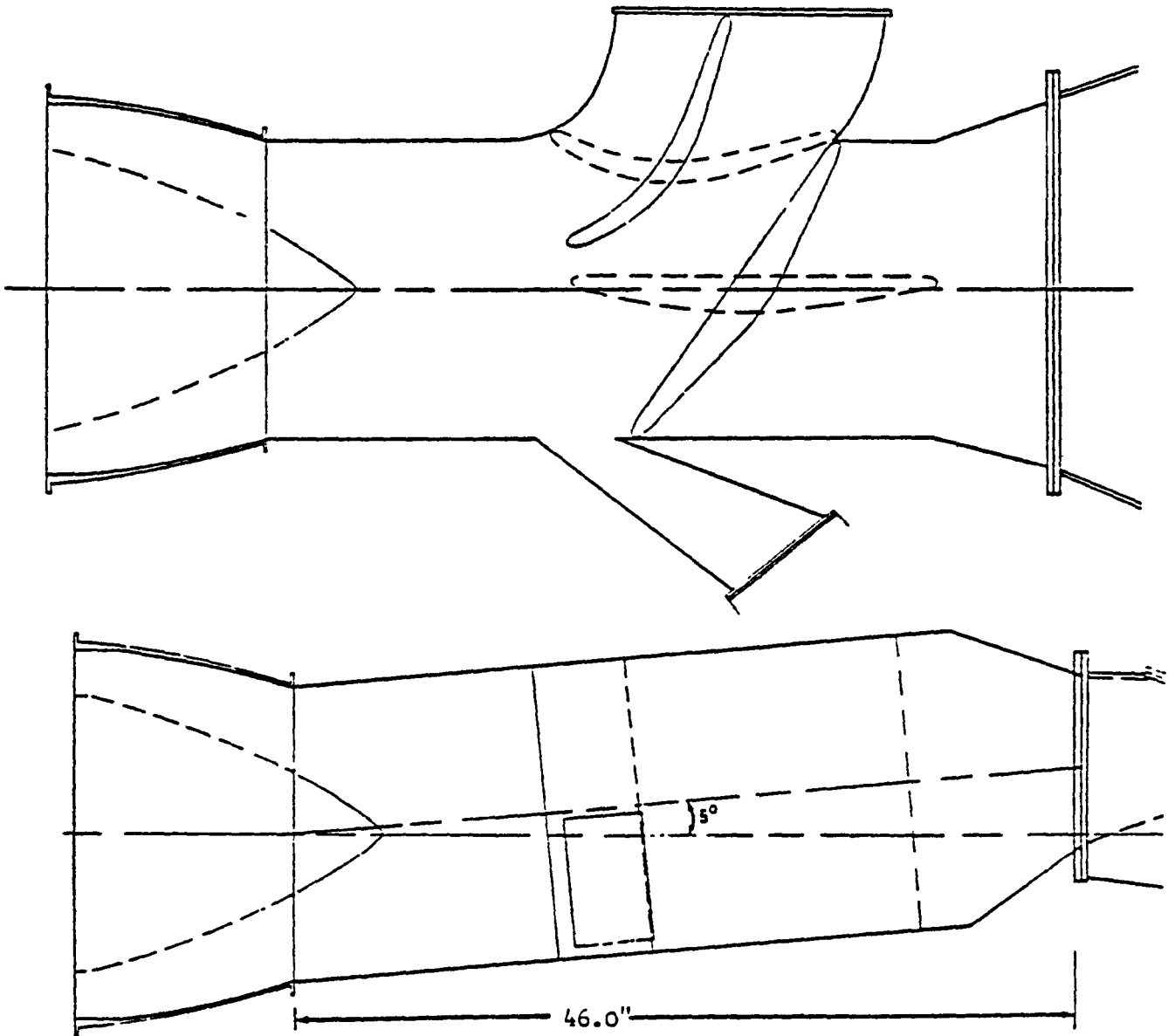


FIGURE 3-8. TWO-VANE DIVERTER VALVE DESIGN #2

- Rectangular construction
- Engine moved 13" forward
- 0° cant
- VEO nozzle structure aft of NS 170.8 moved aft 7".

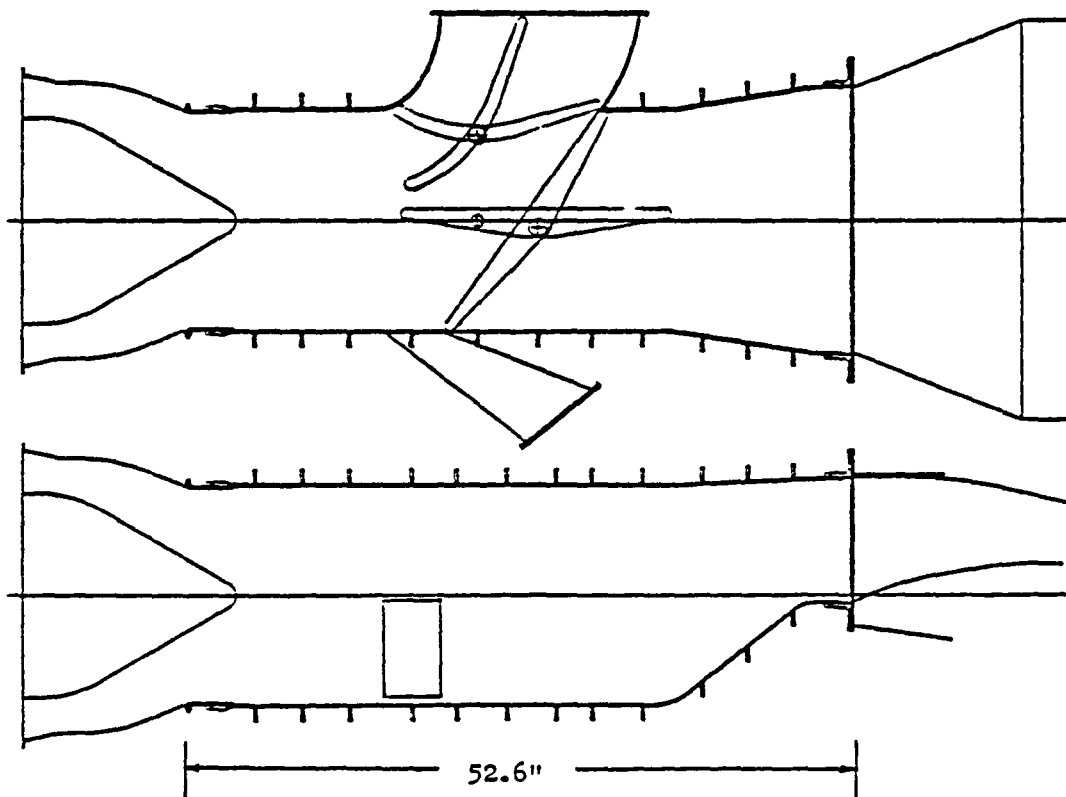
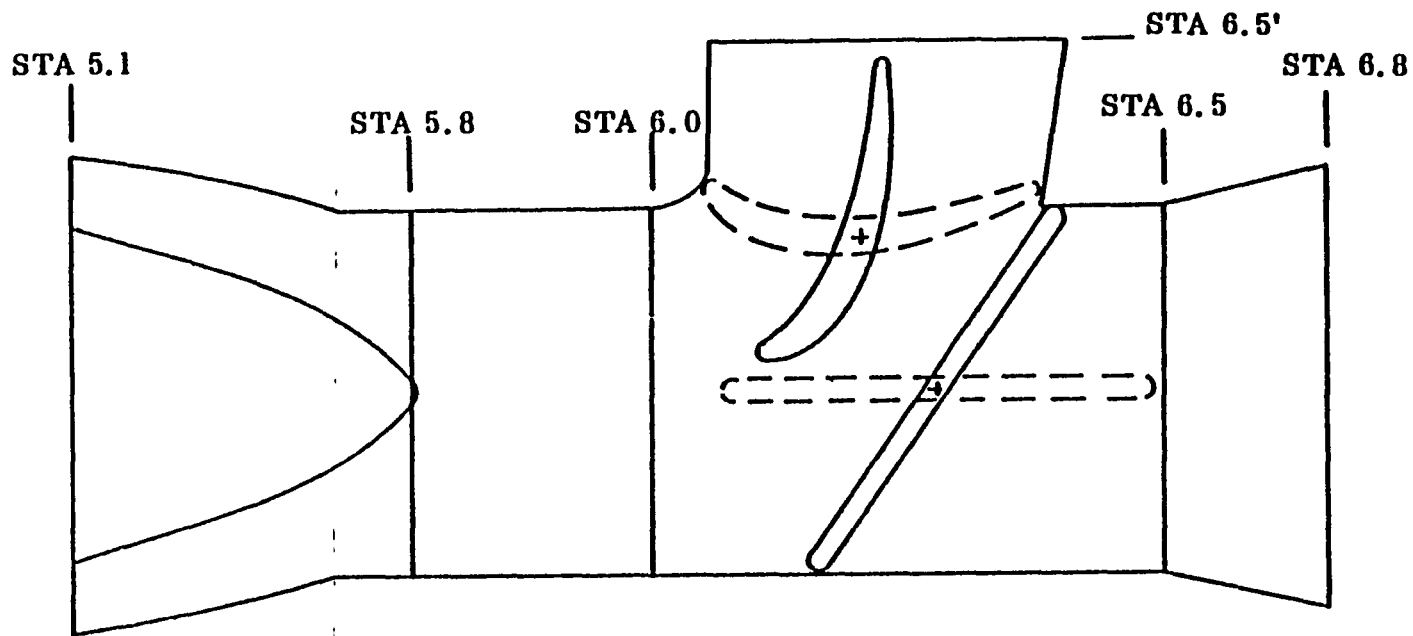


FIGURE 3-9. TWO-VANE DIVERTER VALVE FINAL DESIGN



1. STA 5.1 - TURBINE EXIT. CYCLE DECK OUTPUT.
2. STA 5.8 - ANNULAR DIFFUSER EXIT. COLD FLOW EXPERIMENTAL DATA.
3. STA 6.0 - DIFFUSING CIRCULAR TO SQUARE TRANSITION EXIT. INCOMPRESSIBLE FLOW DUCT LOSS TABLES
4. STA 6.5 - STRAIGHT-THRU DIVERTER VALVE EXIT. CIRCULAR CROSS-SECTION COLD FLOW EXPERIMENTAL DATA. CORRECTED TO SQUARE BY INCOMPRESSIBLE DUCT FLOW LOSS TABLES.
5. STA 6.8 - CONVERGENT SQUARE TO RECTANGULAR TRANSITION EXIT. INCOMPRESSIBLE DUCT FLOW LOSS TABLES.
6. STA 6.5' - DIVERTED FLOW VALVE EXIT. SAME AS 4.

FIGURE 3-10. DIVERTER VALVE SYSTEM TOTAL PRESSURE LOSS ESTIMATION

The resulting estimated performance is presented in Figure 3-11 and Table 3-2 and 3-3. Figure 3-11a presents the total pressure loss suffered by the diverter valve in diverted flow operation. The losses in the probable operating region are between 2% and 3%. This system has only about 35% of the loss suffered by the first design illustrated in Figure 3-6. The loss incurred during straight-through operation is presented in Figure 3-11b. To maintain low loss through the ducting downstream of the diverter valve, it is important that the Mach number is low ($M < 0.3$). Figure 3-11c illustrates that this requirement was accomplished. Finally, tabulations of the diverter valve exit flow conditions are presented in Table 3-2 and 3-3 as functions of engine operating condition.

3.4 ANALYTICAL INVESTIGATION

The performance estimates of the proceeding section are based on the assumption that the flow entering the individual component is free of large areas of separated flow. An analytical study was conducted using General Electric's Streamtube Curvature (STC) compressible, invicid flow computer program (reference 3-4) in combination with the Stratford and Beavers boundary-layer code. The objective of this study were five fold: (1) Analyze any flow separation tendencies in the corners of the circular to square transition section. (2) Optimize the turning vane geometry and orientation in the diverter valve, (3) Analyze the effects of the downstream ducting on the diverter valve. (4) Evaluate the flow separation characteristics entering the ejector bay ducting. (5) Provide pressure loadings for mechanical design. The results of this study are presented in this section.

NOTE: P_{T51} - TURBINE EXIT TOTAL PRESSURE

P_{T65} - DIVERTER VALVE OUTLET TOTAL PRESSURE

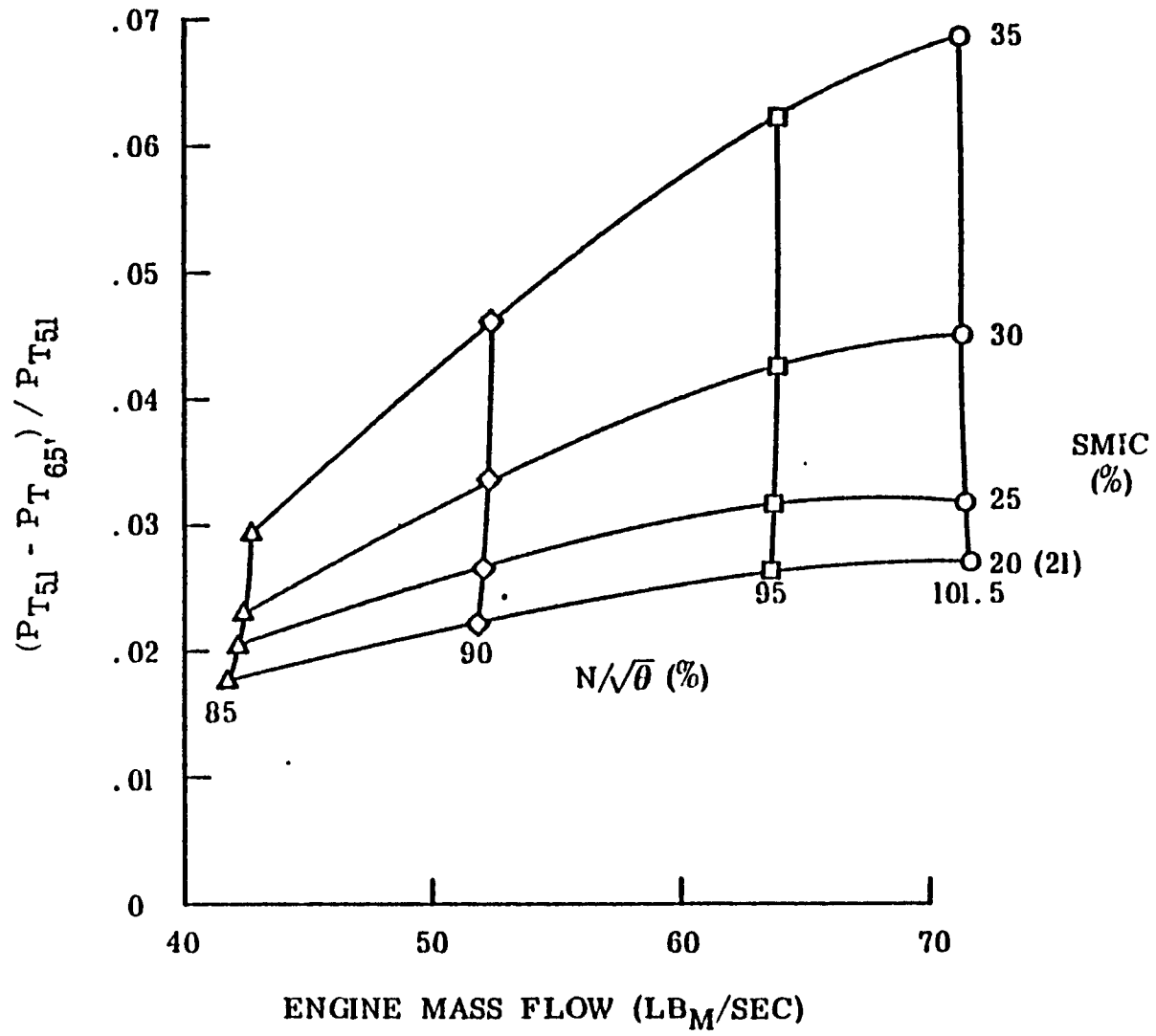


FIGURE 3-11a. TWO VANE FINAL DESIGN ESTIMATED PERFORMANCE (DIVERTED FLOW)

NOTE: P_{T51} - TURBINE EXIT TOTAL PRESSURE

P_{T68} - DIVERTER VALVE OUTLET TOTAL PRESSURE

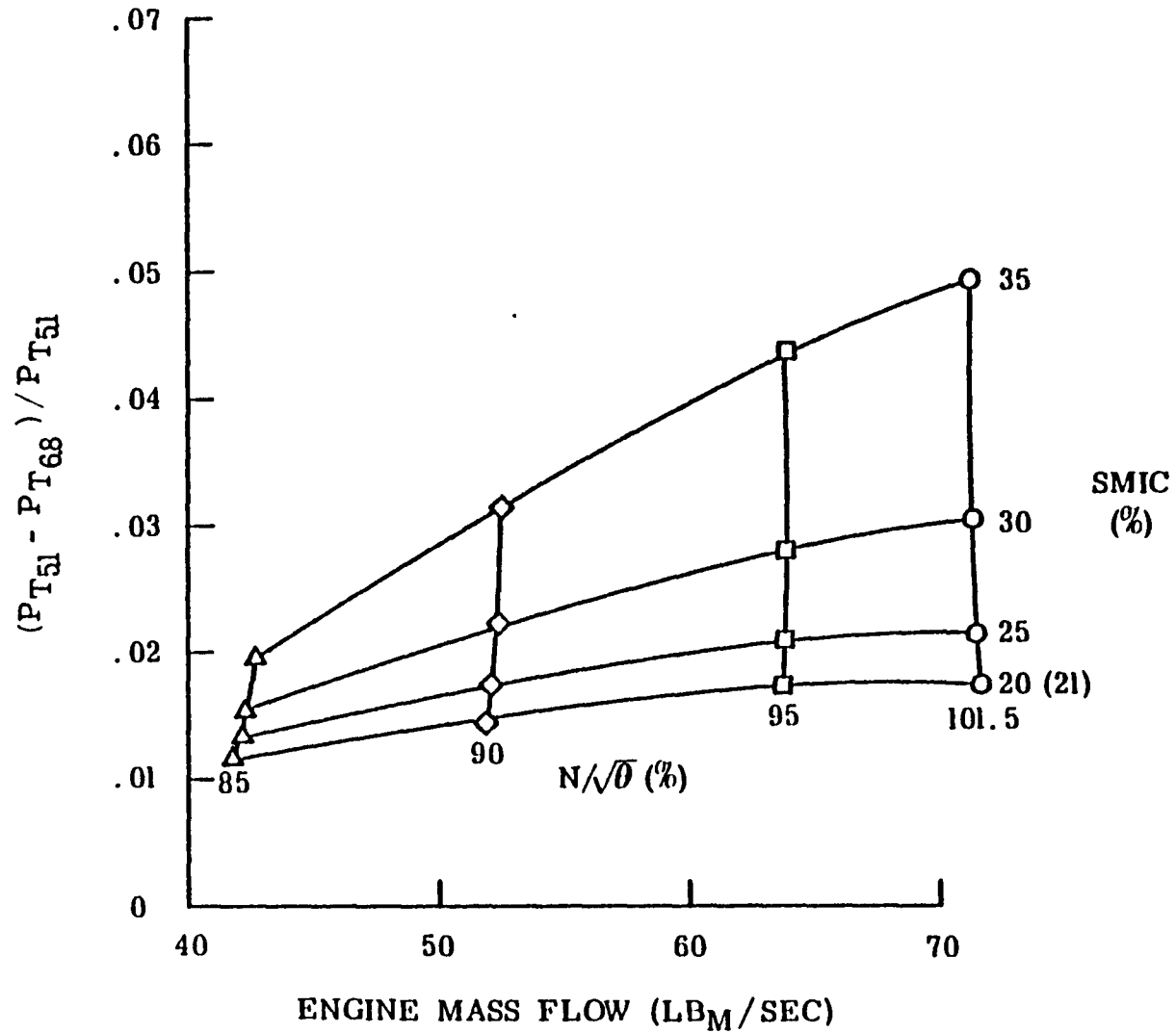


FIGURE 3-11b. TWO VANE FINAL DESIGN ESTIMATED PERFORMANCE (STRAIGHT-THRU FLOW)

NOTE: $M_{65'}$ - DIVERTER VALVE OUTLET AVERAGE MACH NUMBER

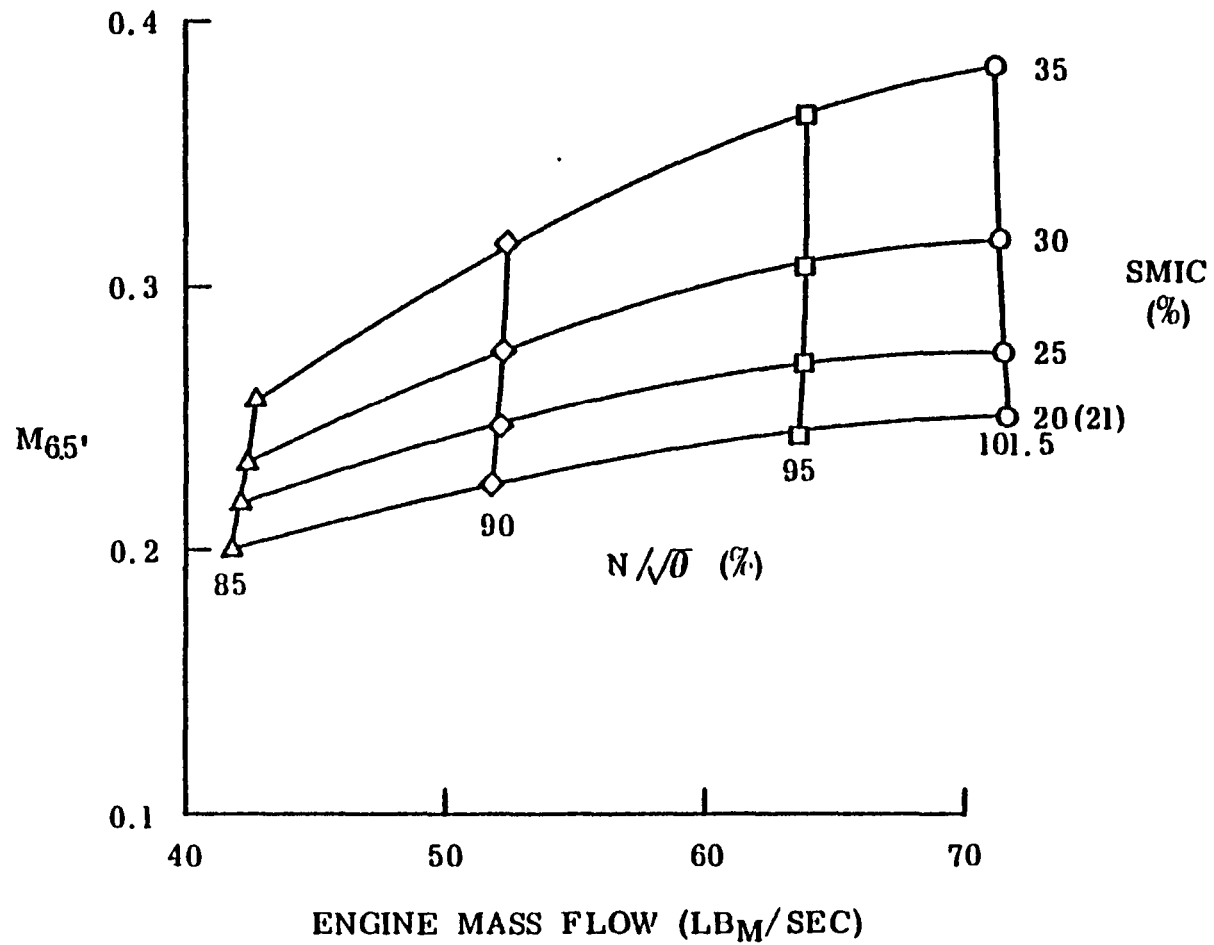


FIGURE 3-11c. TWO VANE FINAL DESIGN DIVERTER VALVE OUTLET MACH NUMBER (DIVERTED FLOW)

TABLE 3-2
YJ-97 GAS GENERATOR/DIVERTER VALVE SYSTEM
ESTIMATED DIVERTED FLOW PERFORMANCE

CASE	SMIC %	N _{0-1/2} %	W lbm/sec	T oR	PT ₅₁ psi	Diverter Valve Outlet Properties (Sta. 6.5')			
						PT psi	M	A in. ²	
2	21	101.5	71.59	1835	53.00	51.57	.250	1.32	276.6
3	20	95.0	63.65	1660	45.68	44.48	.243	1.33	
4	↓	90.0	51.82	1561	38.51	37.66	.225	1.34	
5	↓	85.0	41.74	1544	34.44	33.83	.200	1.34	
6	25	101.5	71.42	1677	46.51	45.03	.274	1.33	
7	↓	95.0	63.76	1491	39.53	38.28	.270	1.34	
8	↓	90.0	52.09	1403	33.84	32.94	.246	1.35	
9	↓	85.0	42.09	1397	30.87	30.24	.217	1.35	
10	30	101.5	71.23	1498	38.88	37.13	.317	1.34	
11	↓	95.0	63.82	1340	33.60	32.18	.307	1.35	
12	↓	90.0	52.30	1257	29.11	28.13	.275	1.36	
13	↓	85.0	42.40	1265	27.44	26.81	.232	1.36	
14	35	101.5	71.06	1334	31.76	29.58	.382	1.35	
15	↓	95.0	63.89	1201	27.97	26.24	.364	1.36	
16	↓	90.0	52.48	1124	24.58	23.45	.316	1.37	
17	↓	85.0	42.68	1142	24.05	23.35	.256	1.37	

PT₅₁ - Turbine Exit Total Pressure

TABLE 3-3
YJ-97 GAS GENERATOR/DIVERTER VALVE SYSTEM
ESTIMATED STRAIGHT THROUGH FLOW PERFORMANCE

CASE	SMIC %	NG-½ %	W lbm/sec	T oR	PT51 psi	Diverter Valve Outlet Properties (Sta. 6.8)				
						PT psi	M	A in. ²		
2	21	101.5	71.59	1835	53.00	52.08	.329	1.32	213.9	
3	20	95.0	63.65	1660	45.68	44.89	.321	1.33		
4	↓	90.0	51.82	1561	38.51	37.96	.294	1.34		
5	↓	85.0	41.74	1544	34.44	34.04	.261	1.34		
6	25	101.5	71.42	1677	46.51	45.51	.363	1.33		
7	↓	95.0	63.76	1491	39.53	38.70	.356	1.34		
8	↓	90.0	52.09	1403	33.84	33.25	.324	1.35		
9	↓	85.0	42.09	1397	30.87	30.46	.280	1.35		
10	30	101.5	71.23	1498	38.88	37.69	.421	1.34		
11	↓	95.0	63.82	1340	33.60	32.66	.408	1.35		
12	↓	90.0	52.30	1257	29.11	28.46	.363	1.36		
13	↓	85.0	42.40	1265	27.44	27.02	.304	1.36		
14	35	101.5	71.06	1334	31.76	29.93	.525	1.36		
15	↓	95.0	63.89	1201	27.97	26.60	.493	1.37		
16	↓	90.0	52.48	1124	24.58	23.81	.422	1.37		
17	↓	85.0	42.68	1142	24.05	23.58	.337	1.37		7

PT₅₁ - Turbine Exit Total Pressure

3.4.1 Circular-to-Square Transition Section

The transition section converts the flow from circular to nearly square while diffusing the flow by a ratio of 1.53. A study was undertaken to analyze the potential for flow separation in the diagonal corners of the transition section. The STC program was used to determine the wall static pressure distribution along the diagonal. The calculated streamlines and wall pressure distributions are presented in Figure 3-12. The boundary layer analysis indicates that separation becomes probable at NS 132.5. However, downstream of NS 140 the flow encounters a favorable pressure gradient which should insure reattachment. This favorable pressure gradient is caused by the converging flow channel through the diverter valve.

3.4.2 Isolation Diverter Valve

Prior to the definition of the ejector bay ducting downstream of the diverter valve, an STC analysis of the isolated diverter valve was undertaken to configure the valve for minimum flow separation and to provide pressure loadings for the mechanical design analysis. Figure 3-13 presents an optimized flowpath based on a simplified planar STC solution. The basic size and layout of the diverter valve system was dictated by geometric constraints and the desire for minimum flow velocity at the diverter valve outlet (inlet of the ejector bay ducting). Therefore, the shape and orientation of the turning vane was the only remaining variable to affect the flow quality in the diverter valve. The vane analyzed in Figure 3-13 illustrates a low separation flowpath. There is no separation on the vane and only two small pockets on the lower boundary. However, a separated area does exist on the upper boundary starting at the diverter valve outlet and continuing to grow in the streamwise direction. The cause of this separated region may be seen in Figure 3-14. Here the wall static pressure (ratioed to 14.7) are plotted versus X. By

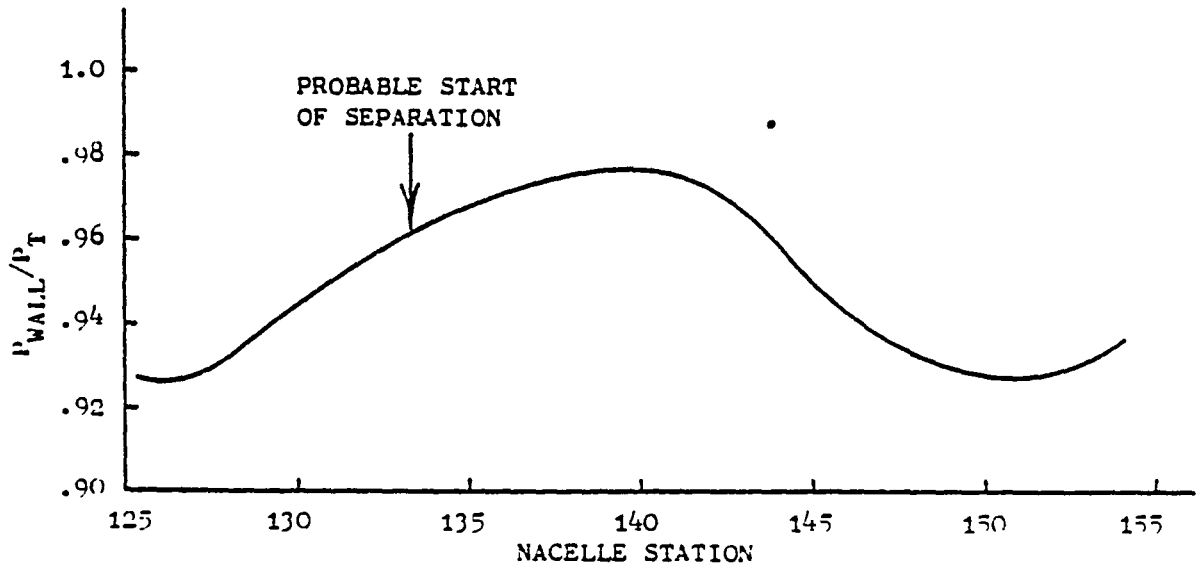
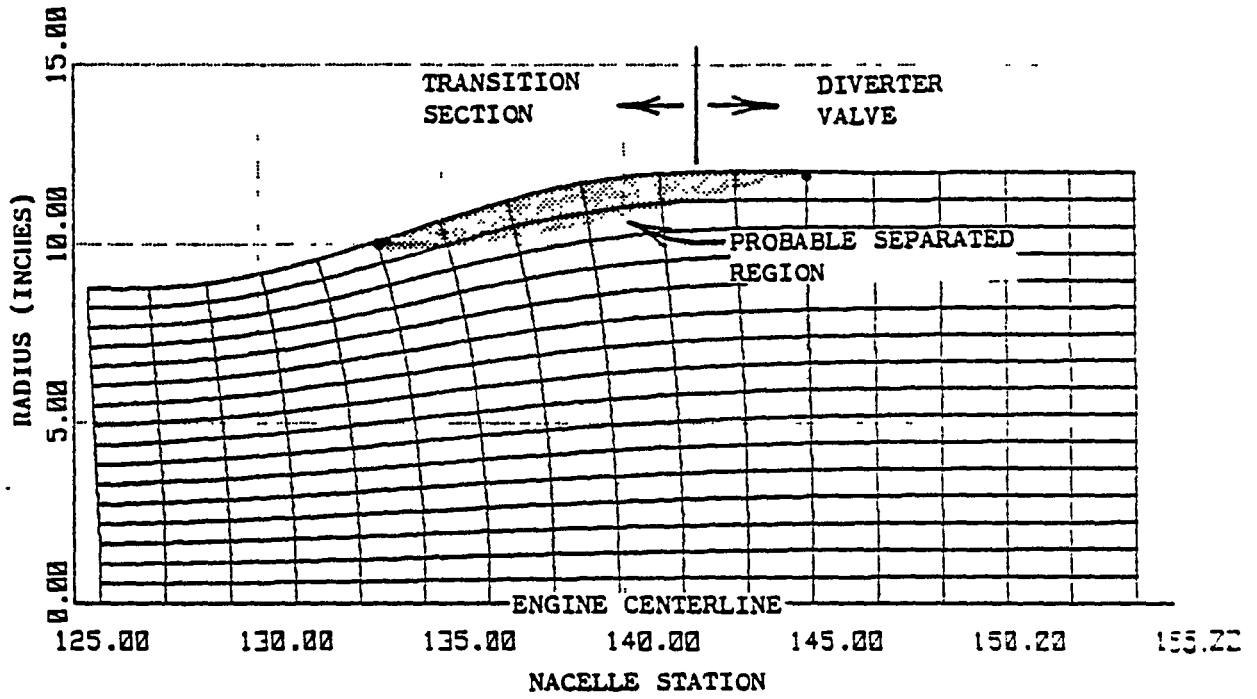



FIGURE 3-12. TRANSITION SECTION CORNER FLOW ANALYSIS

STREAMTUBE CURVATURE PROGRAM FLOWFIELD SOLUTION
ENGINE CONDITIONS: CASE 2 ($N/\theta^{1/2}=101.5\%$, $SMIC=21\%$, $P_T=52.4$ PSI)

 INDICATES PROBABLE SEPARATED FLOW AREA

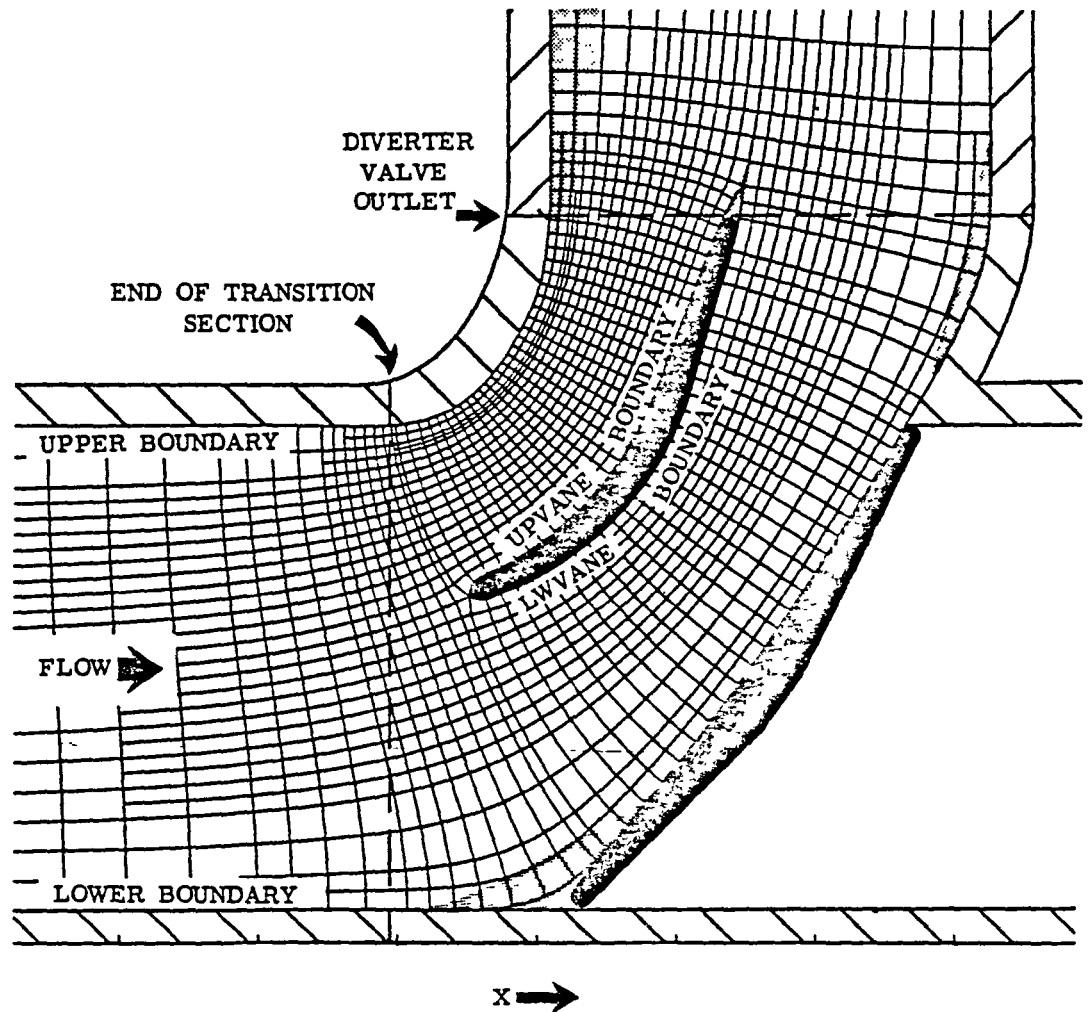


FIGURE 3-13. ISOLATED DIVERTER VALVE FLOW PATH

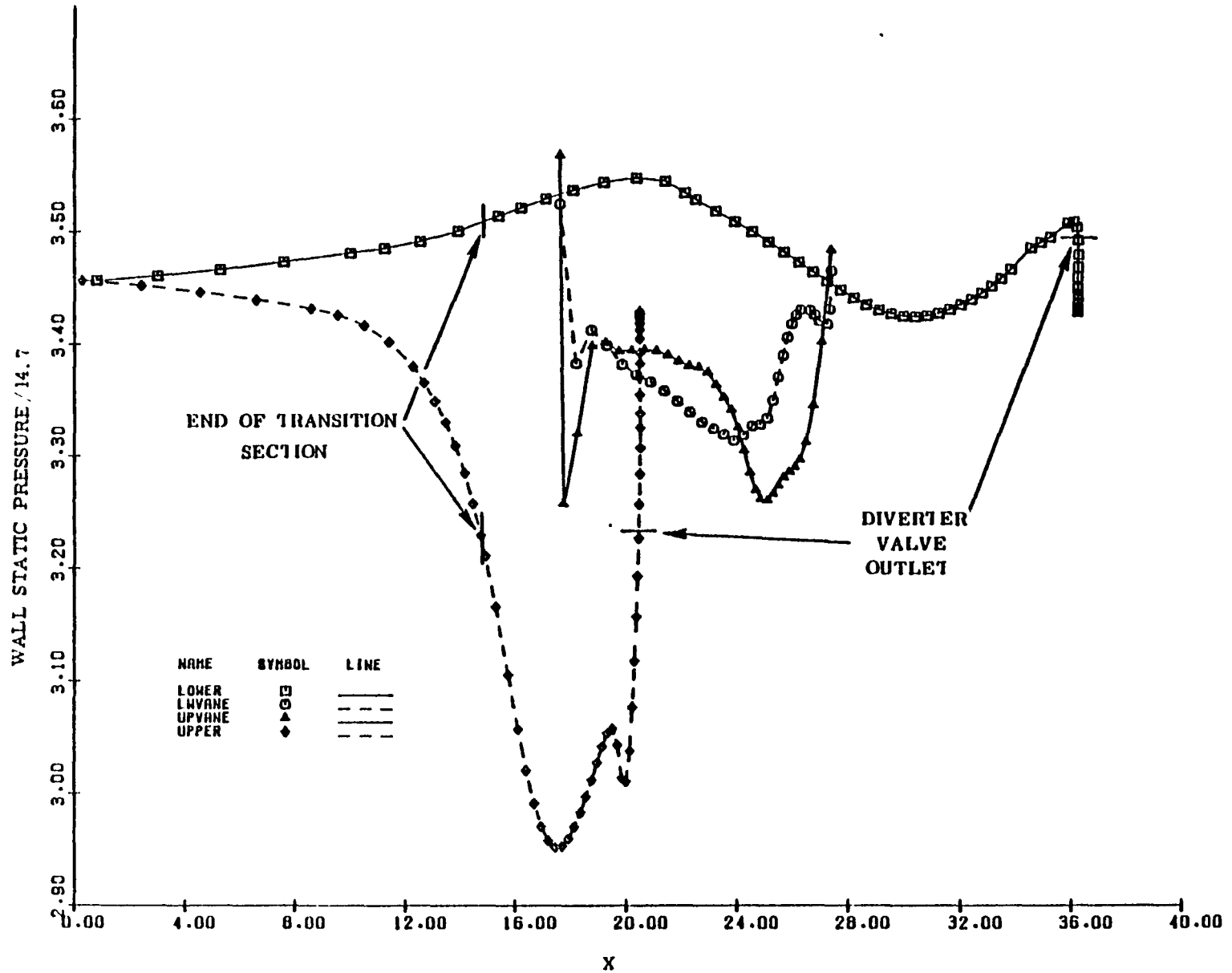


FIGURE 3-14. ISOLATED DIVERTER VALVE WALL PRESSURES

examining the upper boundary pressure data, a strong adverse pressure gradient can be seen for X greater than 20. This is due to flow acceleration around the corner and then diffusion near the diverter valve outlet. This separated area may cause flow turning problems for the flow in the ejector bay ducting downstream of the diverter valve.

Several other turning vane shapes and orientations were examined. All other vane shapes produced more separation in the diverter valve and were discarded. Reorientating the vane of Figure 3-13 by a 5° counter-clockwise rotation alleviated the separation tendency on the UPPER boundary but did not eliminate it. However, it caused separation to occur on the lower (right) side of the turning vane which then propagates into the ducting.

3.4.3 Diverter Valve in Combination with Ejector Ducting

The STC analysis of the diverter valve was extended to include the aft ejector bay ducting to study the combined effect on flow through the diverter valve and to identify any potential flow separation problems in the ejector ducting.

The diverter valve/aft ejector bay ducting inviscid flowpath is illustrated in Figure 3-15. All dimensions are in inches. The engine centerline is represented as $R = 0$. The flow around the turning vane has changed slightly from that observed for the isolated diverter valve due to the influence of the non-uniform flow downstream. However, the flow separation areas are very nearly the same. The solution indicates that the flow in the ducting is plagued by possible flow separation. The thickness of the shaded areas are only an estimate of the separated boundary-layer thickness. However, the indicated start of the separated areas are dependable. These separated flow areas reflect the adverse pressure gradients illustrated in Figure 3-16. Here, the wall static pressures for each boundary are plotted versus the path length along each boundary. This separated flow

ENGINE CONDITIONS: $N/\theta^{1/2} = 101.5\%$ & $SMIC = 21\%$

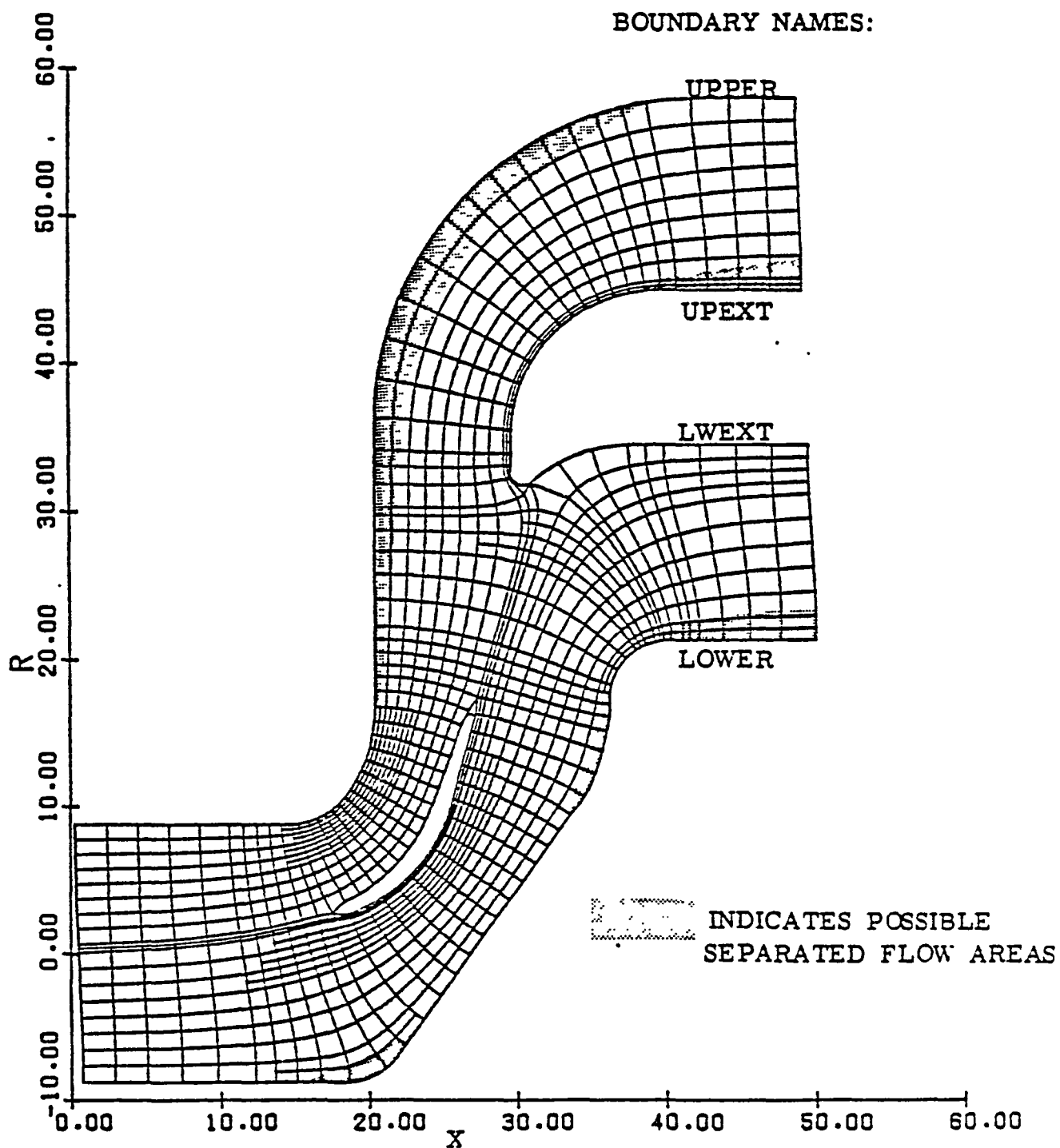


FIGURE 3-15. DIVERTER VALVE/AFT EJECTOR BAY DUCTING
INVISCID FLOW PATH

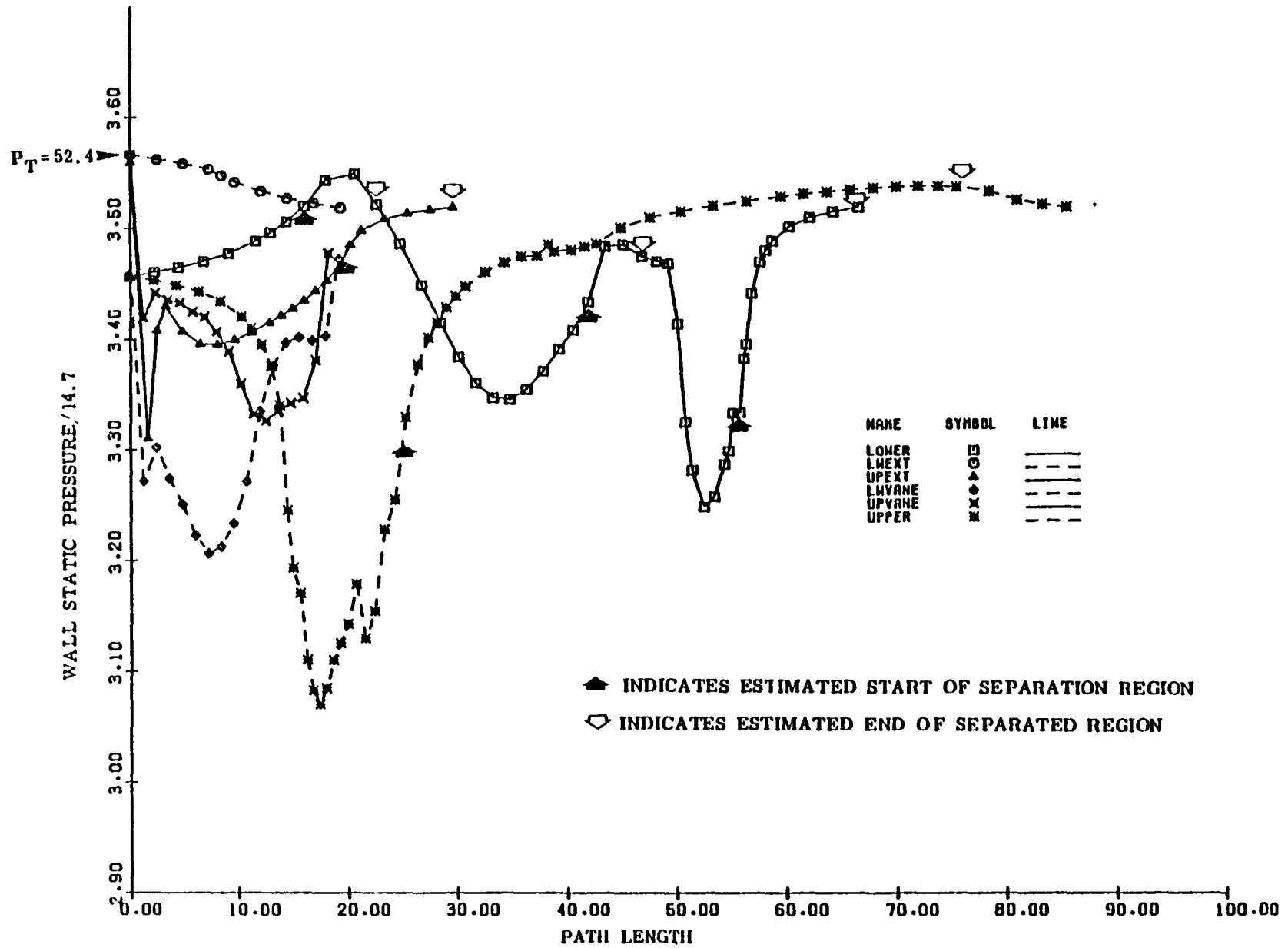


FIGURE 3-16. DIVERTER VALVE/AFT EJECTOR BAY DUCTING WALL PRESSURES

entering the ducting downstream of the diverter valve can have a detrimental effect on the duct total pressure losses as well as making any duct pressure loss estimates optimistic. Most standard duct pressure loss estimate methods depend on non-separated flow approaching the turn or bend. Reshaping of the ejector bay ducting and/or the addition of turning vanes in the ducting may alleviate this problem.

3.5 DIVERTER VALVE PERFORMANCE IN THE FLOW-SPLITTING MODE

The diverter valve was designed to handle the entire engine flow in either the diverted or straight-through modes. If, however, a variable area VEO wing nozzle replaces the fixed area VEO wing nozzle, the diverter valve may be operated in a flow-splitting mode. In such a case, only the engine mass flow required by the ejector nozzles would be routed through the diverted leg. The remaining engine mass flow would be routed straight-through the diverter valve and exhausted through the variable VEO wing nozzle. This section provides a recommended setting for the diverter valve vanes and the resulting ejector nozzle pressure ratio performance and VEO wing nozzle area required as a function of engine operating condition for this type of operation.

Ideally, the diverter valve vanes should be oriented so that the flow path area split through the diverter valve is proportional to the mass flow split through the two legs. However, even with the ejector nozzle effective area fixed at 62.07 in.^2 , the mass flow split is a function of engine operating point. As a compromise the vane position which maximizes the total flow area and provides a near equal area split between the two legs was selected. This recommended setting is illustrated in Figure 3-17. This configuration provides a minimum flow area through the diverter valve of 280 in.^2 with 46% of this area dedicated to the diverted channel.

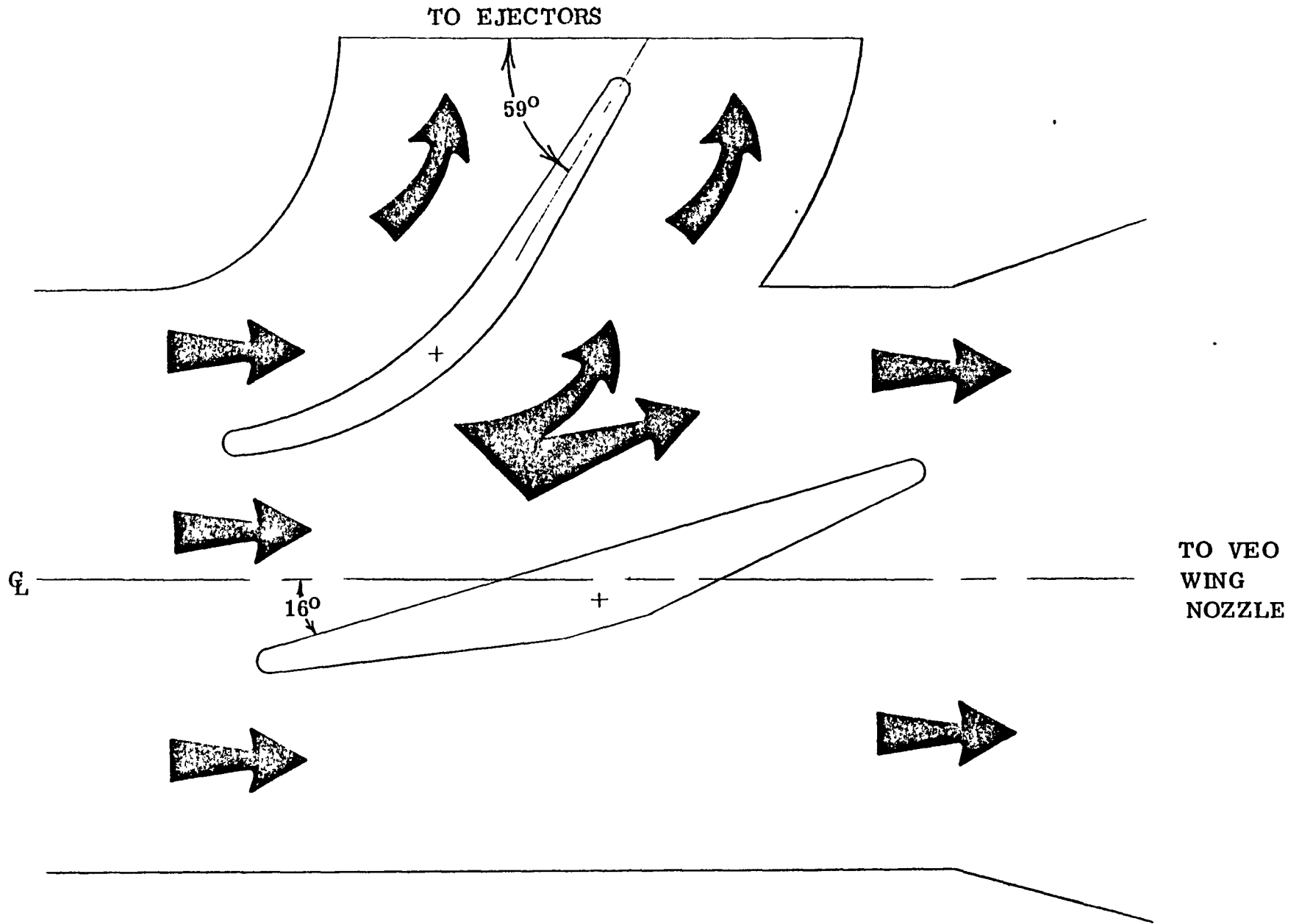


FIGURE 3-17. RECOMMENDED DIVERTER VALVE VANE SETTINGS FOR FLOW-SPLITTING MODE OF OPERATION (TOP VIEW)

The estimated performance of the diverter valve/ejector system functioning in this type operation is based on the following assumptions.

- o An additional flow expansion loss for an area ratio of two (2) is charged to each diverter valve leg.
- o The straight-through leg is charged with a butterfly valve loss.
- o The ejector bay ducting loss is set at a constant 1% of total pressure.
- o The ejector bay loss is set at a constant 7% of total pressure.

The estimated performance of the ejector system with the excess engine mass flow dumped through the VEO wing nozzle is presented in Figure 3-18. For each engine operating condition (combination of rotor speed and stall margin) the ejector nozzle pressure ratio may be read on the ordinate and the required VEO wing nozzle effective area may be read on the abscissa. Conversely, for a given fixed VEO wing effective nozzle area, the maximum available ejector nozzle pressure ratio may be determined. As an example, with $A_{eVEO} = 60$, an ejector nozzle pressure ratio of 3.15 may be obtained with the engine operating at 101.5% corrected rotor speed and about 21% compressor stall margin.

The intent of this section is to provide an estimate of the ejector system performance with the diverter valve operating in an off design flow-splitting mode. If this method of operation is selected as the primary one, a redesign of the diverter valve might provide as much as a 1% reduction in the total pressure loss. However, as long as the ejector bay total pressure loss estimate continues near 7%, it will be the driving factor in total system performance.

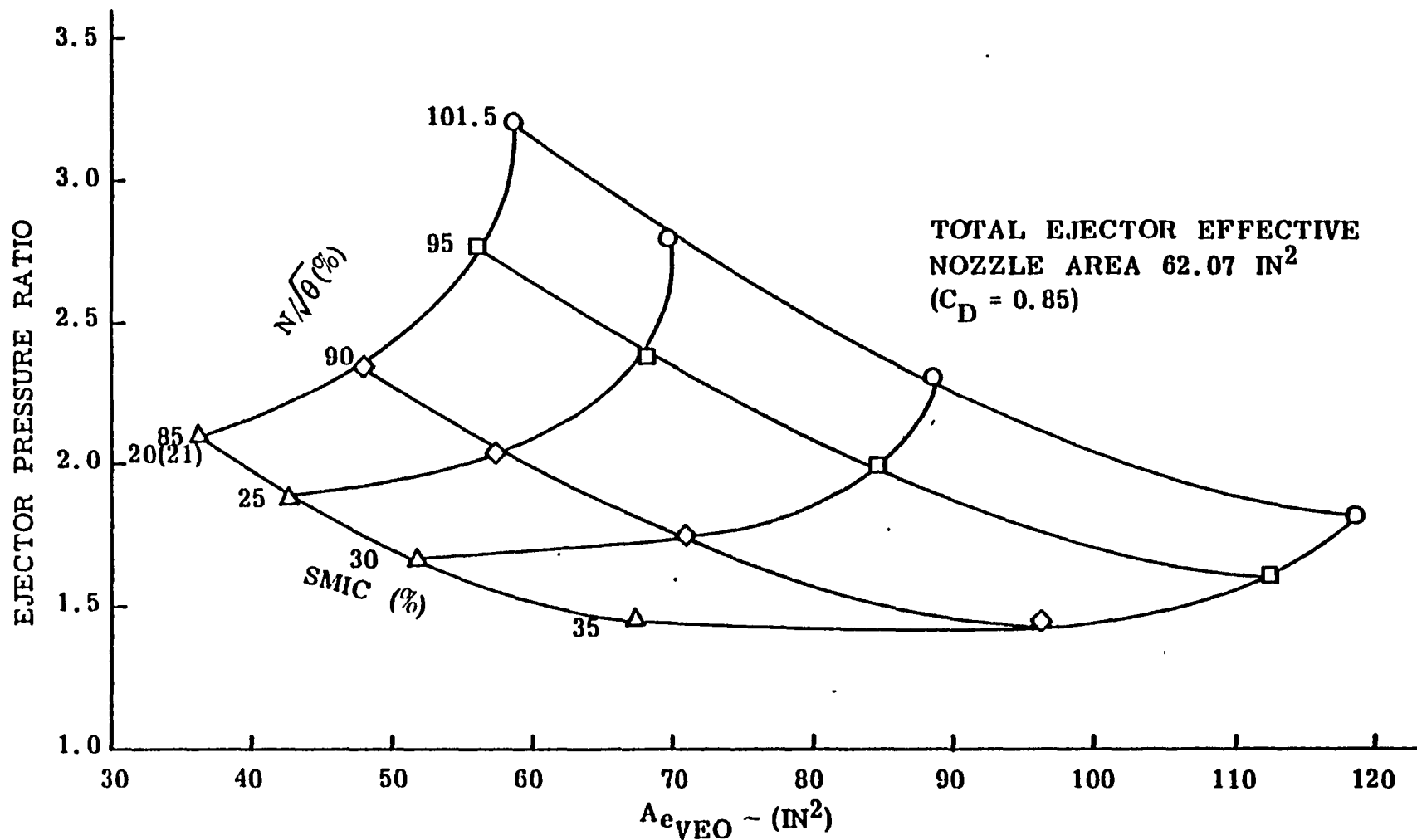


FIGURE 3-18. ESTIMATED EJECTOR SYSTEM PERFORMANCE WITH EXCESS ENGINE MASS FLOW DUMPED THROUGH VEO-WING NOZZLE

3.6 MECHANICAL DESIGN CRITERIA

The mechanical design effort of this study was to define the basic body structure, the mount system and the actuation system for a non-flight weight diverter valve for the YJ-97 engine. The study objective was to complete the preliminary design analysis to assure the feasibility of the selected conceptual design based on the flow-path defined by aerodynamic considerations and to be compatible with the modified aircraft structure as delineated in Section 3.3.3.

The primary design considerations are as follows:

1. The diverter valve will be sized to the core gas flow of the YJ-97 engine and be capable of diverting all or part of the flow into the ejector nozzle duct.
2. The valve design will minimize changes to the existing model structure.
3. A span-wise blowing port will be provided to connect to the existing SWB nozzle.
4. The diverter valve internal construction will be designed for minimum pressure loss, flow distortion and gas leakage.
5. A slip joint at both the forward and aft flanges will be incorporated into the valve body to accommodate the axial thermal growth of the engine and exhaust nozzle.

- YJ-97 EXHAUST PRESSURE AND TEMPERATURES
1400°F. 50 PSI Δ P
- NON-FLIGHT WEIGHT
- UNCOOLED STRUCTURE
- MOUNT DESIGN FOR NORMAL AND DIVERTED OPERATION
- EJECTOR PORT COMPATIBLE WITH G. D. REQUIREMENTS
- ACCOMMODATE AXIAL THERMAL EXPANSION
- COMPONENT LIFE REQUIREMENTS
 - LOW CYCLE FATIGUE LIFE > 1000 CYCLES
 - STRESS LIMIT (-3 σ VALUES)
 - .2% YIELD STRENGTH
 - 2/3 ULTIMATE STRENGTH

FIGURE 3-19. DESIGN CRITERIA

6. The diverter valve mounting system will be designed to react the axial and side thrust components with the vanes in the normal through or diverted flow position.

3.7 NON-FLIGHT WEIGHT MECHANICAL DESIGN

3.7.1 Introduction

The layout of the YJ-97 non-flight weight diverter valve is shown in Figures 3.20, 3.21 and 3.22. The valve consists of a reinforced two-dimensional shell with a forward and aft vane that can be operated independently or in tandem with the appropriate connecting linkage. In the straight through position, the aft vane is in the open position, parallel to the core flow stream, the forward vane is in the close position blocking the air flow from the ejector duct. In the diverter mode, the aft vane is rotated to the closed or blocker position and the forward vane is rotated to the open position to allow the core gas to enter the ejector duct. The aft and forward vanes serve as turning vanes when in the diverted mode to minimize turning losses.

3.7.2 Valve Body Construction

The valve body as shown in Figure 3.21 is a reinforced sheet metal shell fabrication. The forward or inlet section of the body transitions from the circular YJ-97 diffuser duct to a rectangular cross section in the area of the vanes and the valve outlet. In addition to the circular inlet and rectangular outlets, a flanged rectangular diverter leg for the ejector duct and a second opening on the opposite side for span-wise flow are provided. On each side of the valve body is a one-half inch thick trunnion mounting pad which is welded into the casing. The pad also supports the forward and aft vanes bearing pads.

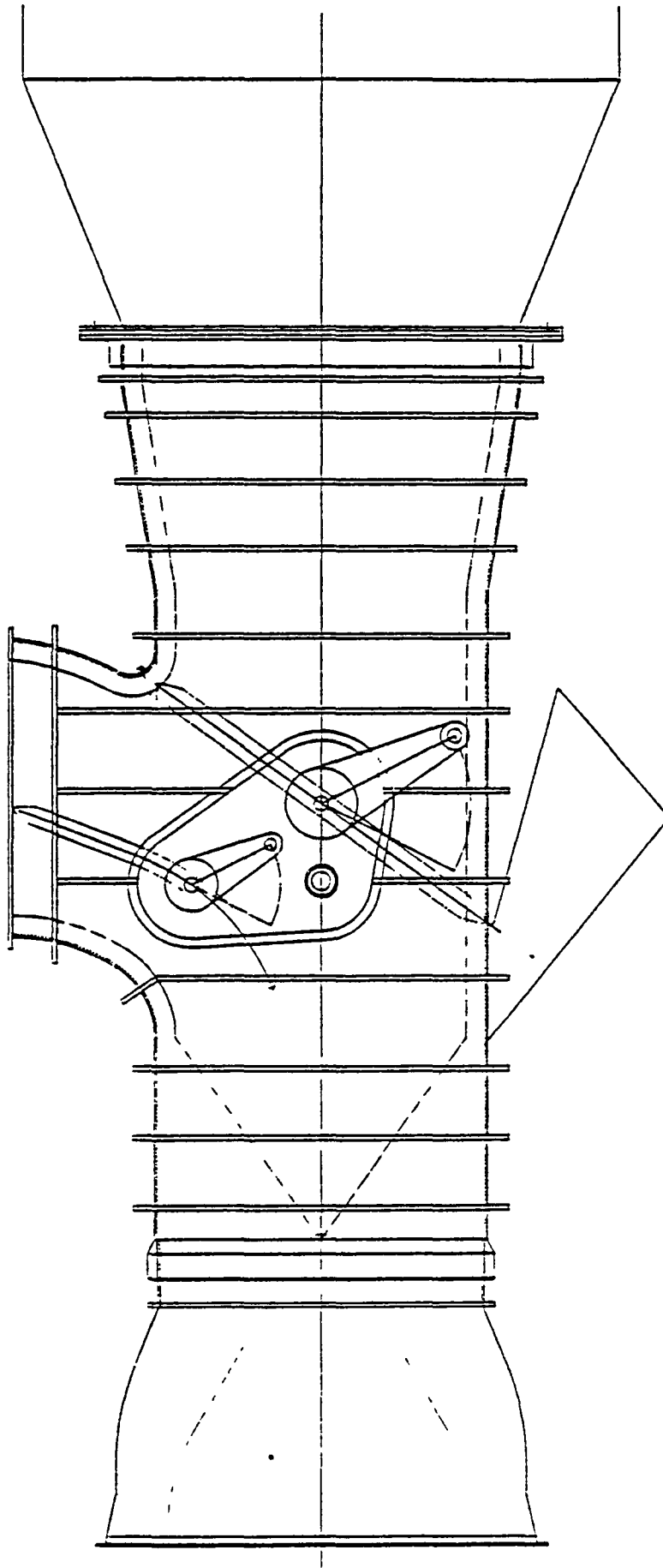


FIGURE 3-20. YJ-97 DIVERTER VALVE - NON FLIGHT WEIGHT

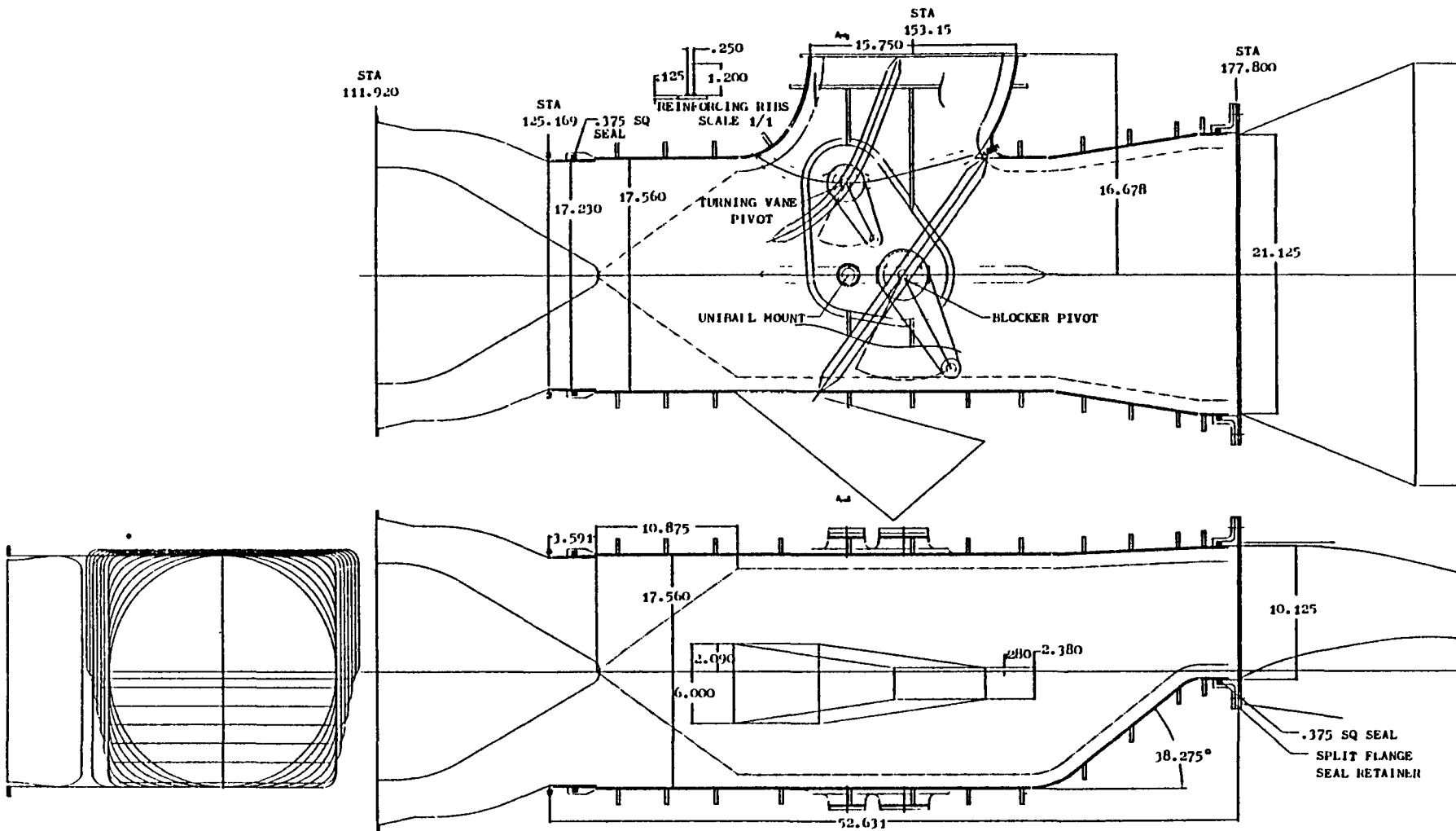


FIGURE 3-21 YJ 97 DIVERTER VALVE

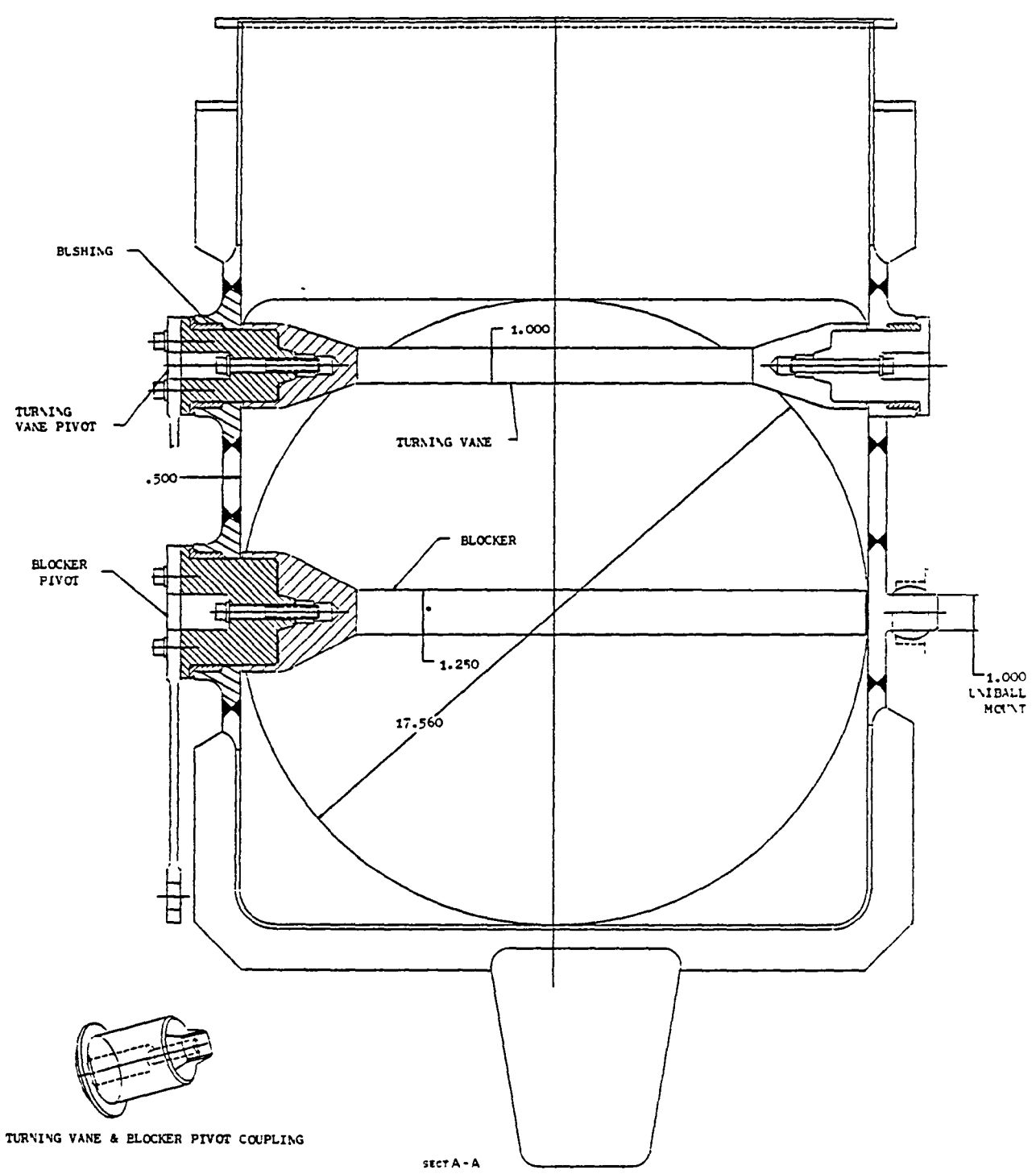


FIGURE 3-22. YJ-97 DIVERTER VALVE

3.7.3 Mount Design

The axial and side thrust loads of the diverter valve for both normal and diverted modes are reacted by two trunnion mounts. The preferred location of the mounts would be at the intersection of the axial centerline of the valve and the centerline of the ejector port. However, the aft vane bearing position requires the mount to be located upstream of the ejector duct centerline and will result in a turning moment about the mounts that must be reacted at the forward and aft thermal expansion joints.

3.7.4 Vane Design and Construction

The forward and aft vanes are subjected to a combination of pressure induced loads. The primary load on the vane is the differential pressure load when the vanes are used in the blocker position.

A cross-section of the vane construction is shown in Figure 3-22. The vanes also carry a transverse tension load since the vanes are used as "tie rods" in supporting the valve body sides from distorting under pressure loads in the area of the trunnion mount pad where the reinforcing ribs are interrupted. The "tie rod" feature insures that the casing will not deflect along the sides of the vanes that could result in excessive leakage unless an expensive, conforming and flexible seal is used. During operation, the vanes will also be subjected to a torque load due to the non-uniform pressure differential across the vanes and the offset in the location of the rotating center of the forward vane.

In the non-flight weight design, no seals will be used since the diverter valve is a one-of-a-kind fabrication and the vane perimeter can be cut to size at assembly to minimize leakage.

3.7.5 Vane Bearing and Actuation Mechanism

The vane bearings consist of hard Stellite #6 bushings press-fit into the bearing pads located on the trunnion mount pad. The bushings are flanged so that they can take both radial and axial loads which allows the vanes to be used as "tie rods" to minimize the shell deflection under the internal pressure load. The bearing clearance will be designed to accommodate the differential thermal expansion between the bearing and the stub shaft during transient operations to prevent bearing seizure. The bearings can operate unlubricated to an operating temperature of 1400°F.

3.7.6 Stress Analysis of Transition Section and Main Diverter Valve Structure

A preliminary stress analysis was made of the diverter valve body to assure that the basic two-dimensional reinforced shell design was feasible and that no obvious mechanical design limitations were present due to the pressure loading on the flat sided valve body. In the analysis, the valve body was assumed to consist of a .125 inch thick HASTELLOY-X shell and reinforced with .25 inch thick by 1.2 inch high ribs. The valve body computer model consisting of plates and beams is shown in Figure 3.23. Effective stresses in both the plates and beams were calculated using the Mechanical Analysis of Space Structures (MASS) computer program which is a three-dimensional elastic stress program using the finite element method. The effective stresses in the plates and beams for a differential pressure of 50 PSI are shown in Figures 3.24, 3.25, and 3.26. The results of this preliminary stress analysis demonstrates the feasibility of the design although some rearrangement of the beams and the local strengthening of the beams will be required to reduce the stress values to acceptable design values.

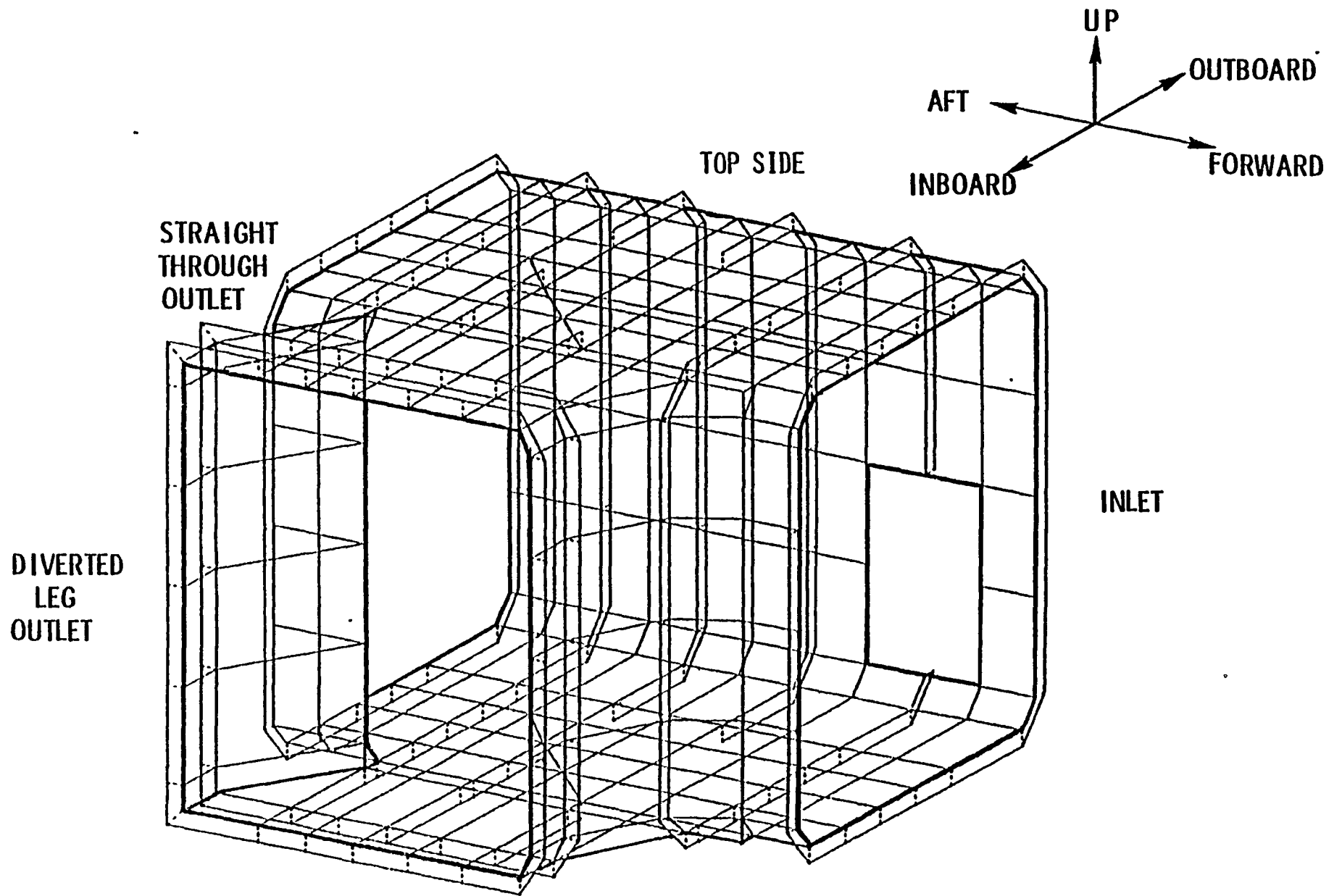


FIG. 3-23. DIVERTER VALVE (MID-SECTION) FINITE ELEMENT MODEL

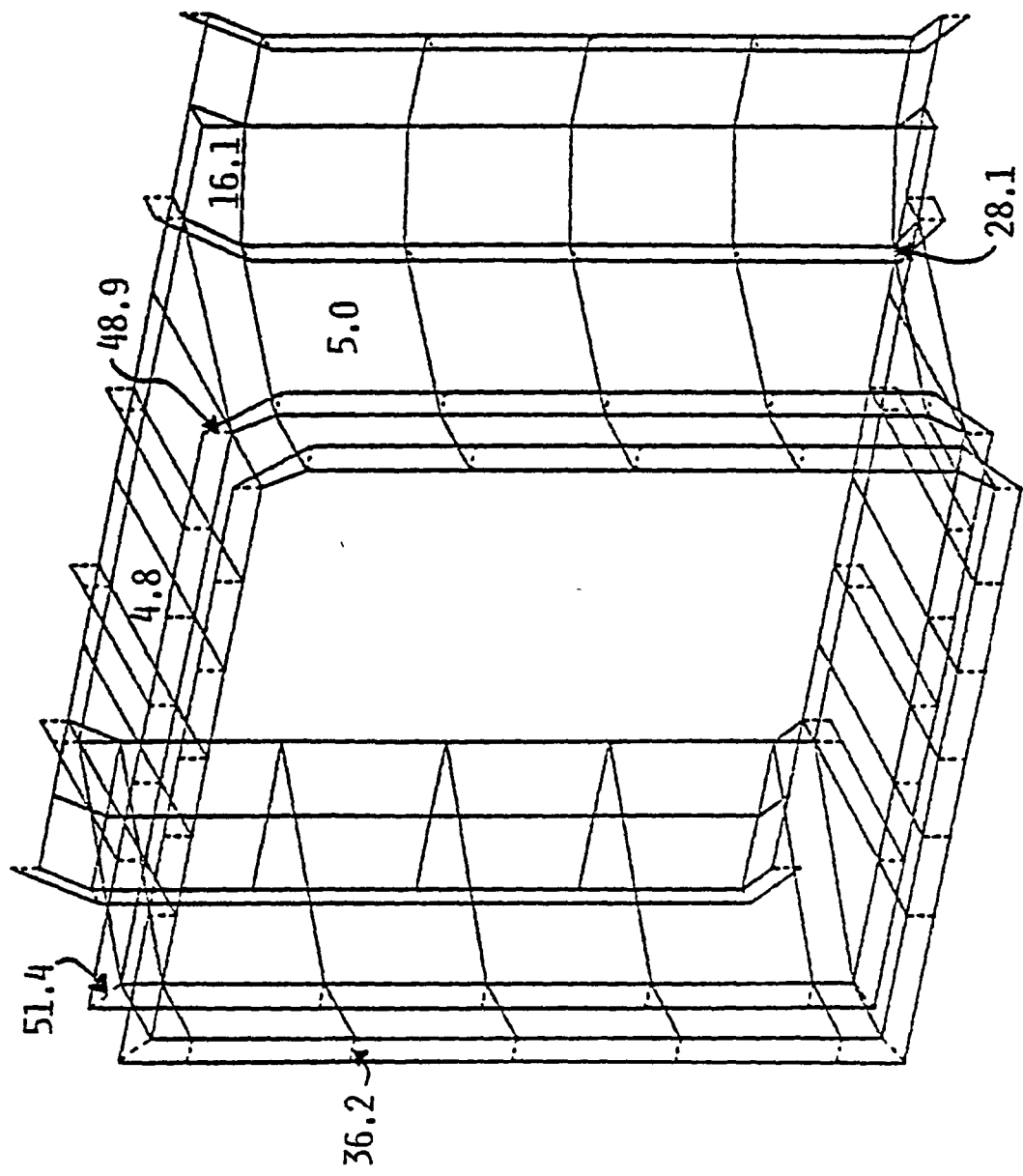


FIG. 3-24. EFFECTIVE STRESSES ON DIVERTER LEG OUTLET (KSI)

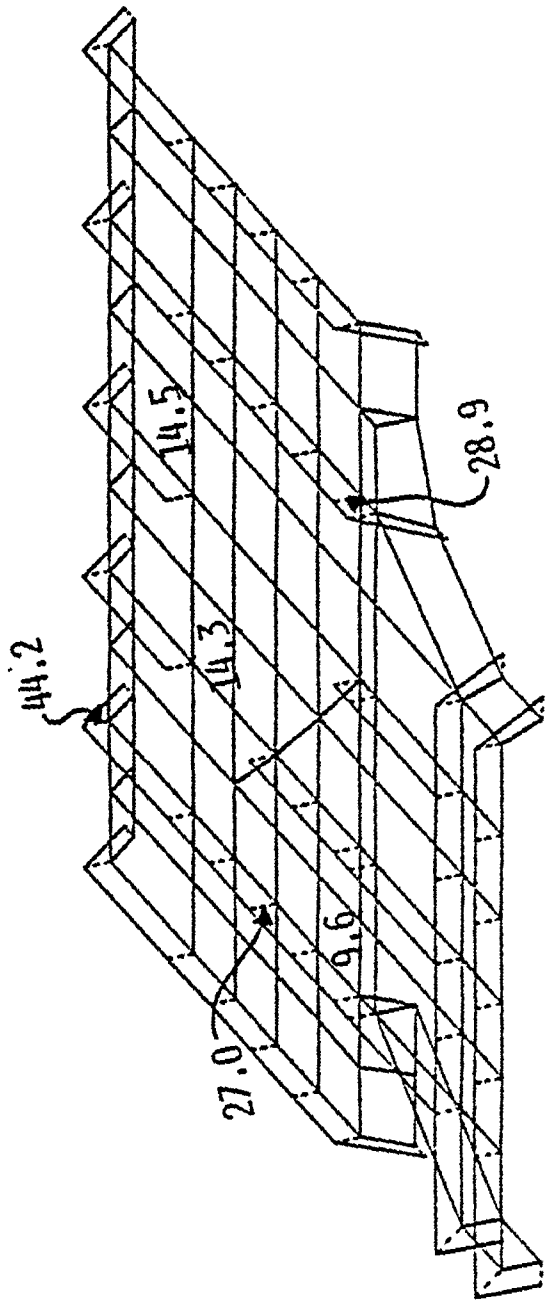


FIG. 3-25. EFFECTIVE STRESSES ON TOP SIDE (KSI)

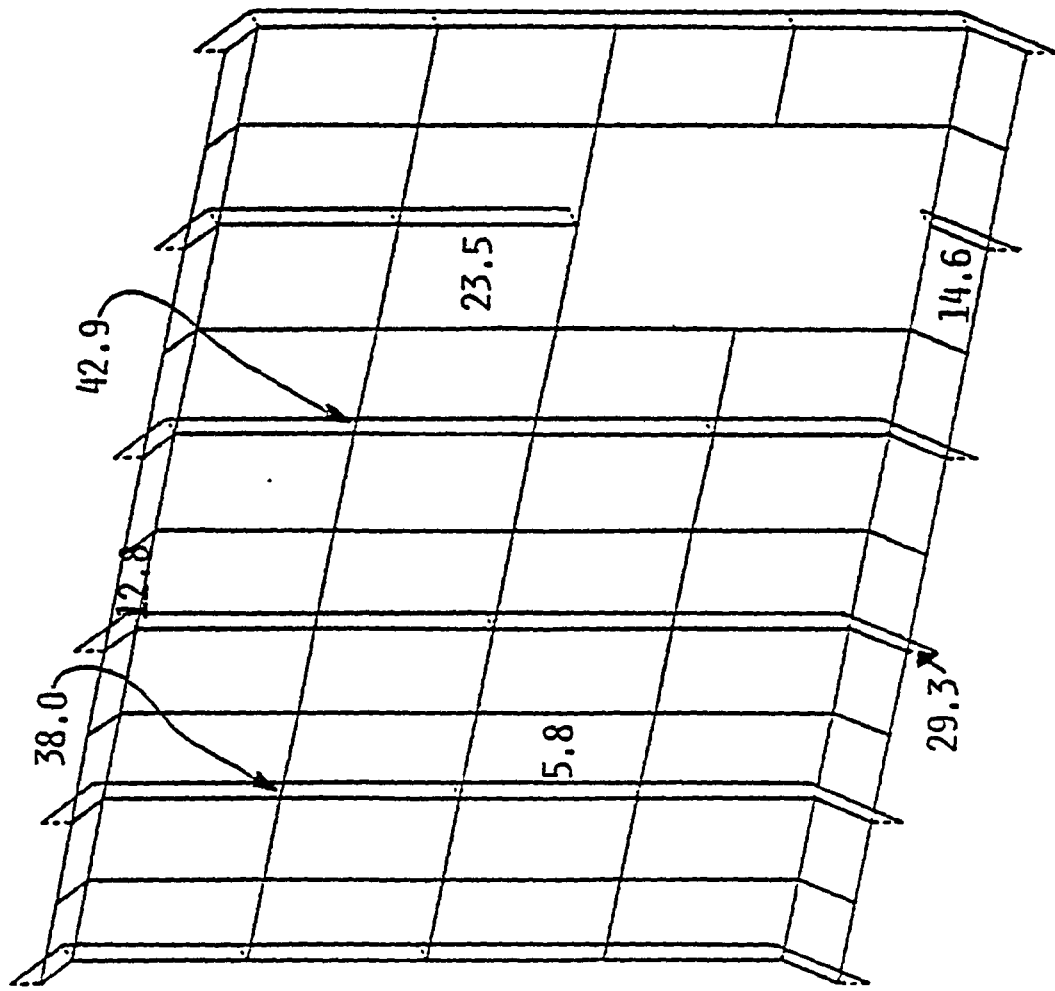


FIG. 3-26. EFFECTIVE STRESSES ON OUTBOARD SIDE (KSI)

3.8 Flight-Type Mechanical Design Considerations

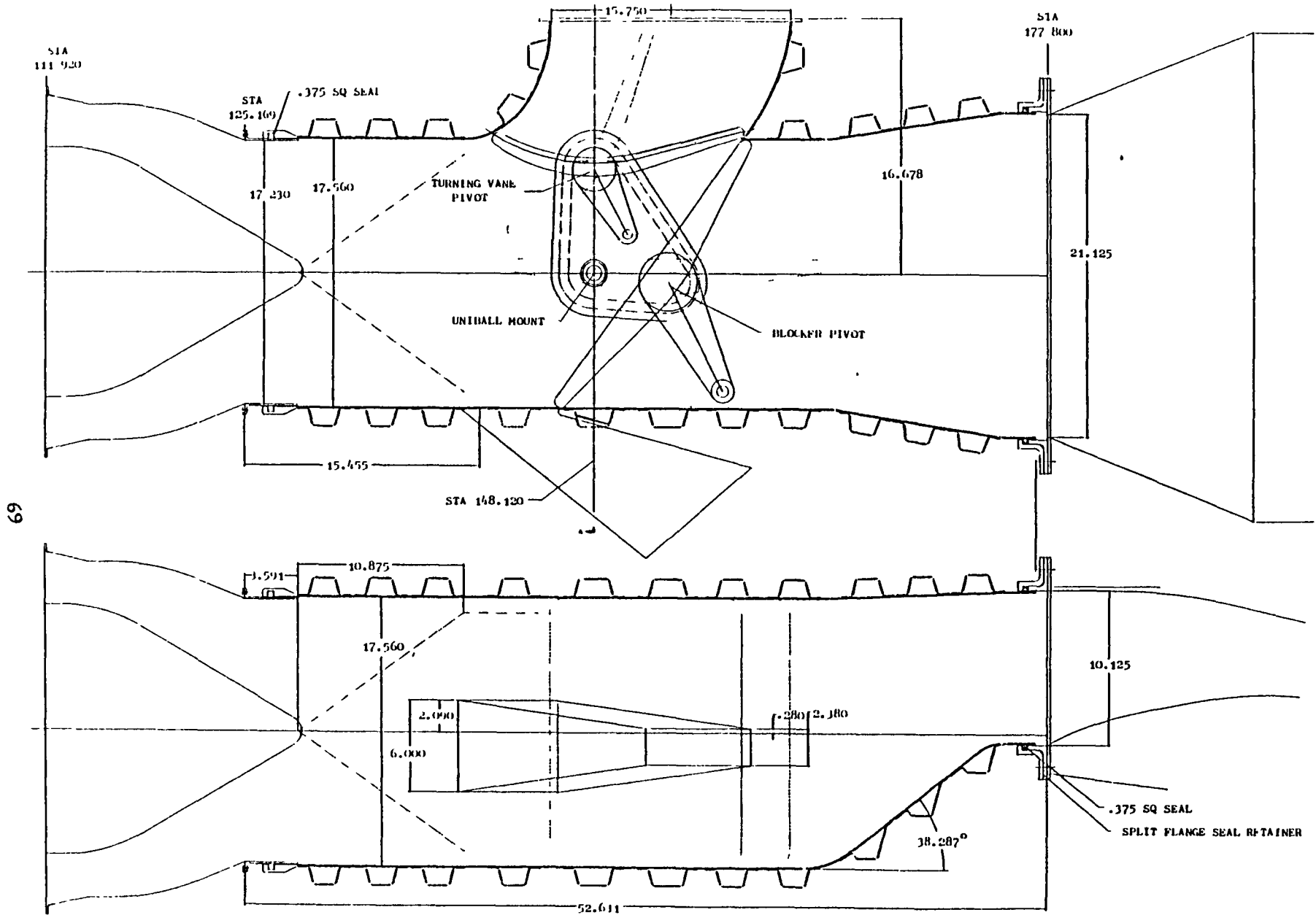
3.8.1 Alternate Duct Reinforcement

The YJ-97 Diverter Valve with its non-axisymmetric geometry can be fabricated using the materials and processes used in the fabrication of current high temperature two-dimensional exhaust nozzles and augmentors for a cost effective, light-weight design. As an example, chemical milling could be used to provide weight effective material distribution throughout the structure. This method of varying thickness in sheet metal structures is preferable to the use of attached reinforcements since stress concentrations at the attachment welds can lead to fatigue failure.

In a flight weight design, the valve body would be fabricated from thin sheet metal with formed ribs for added stiffness as shown in Figure 3.27. The ribs or hat sections would be attached to the sheet by resistance welding, rivets or bolts. This type of construction is preferred over sandwich construction in high temperature augmentors or exhaust nozzles since this type of construction has been shown to be more thermal fatigue resistant than sandwich construction and is substantially lower in cost.

3.8.2 Flight Weight Vanes and Seal Construction

The vanes would also be fabricated as a basic sheet and reinforced box beam type construction rather than the solid metal vanes used in the non-flight weight design. Thermal gradients across the vane thickness during transient flight conditions will require a floating face sheet and thermal shields separate from the load bearing structure as shown in Figure 3.28.



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FIGURE 3-27 YJ-97 DIVERTER VALVE - FLIGHT WEIGHT

High excursion, conformable seals will be required around the vane perimeter to minimize the gas leakage past the closed vanes. The seals must also be capable of resisting vibration or flutter in the high velocity air stream when the vanes are in the open position. An effective seal used in a previous flight type diverter valve for a J-85 engine is shown in Figure 3.29.

3.8.3 Material Considerations

Material selection for a light weight, flight type diverter valve is based on cost, formability, weldability and thermal fatigue properties in addition to its strength characteristics. In general, the diverter valve would be designed and fabricated using conventional turbojet engine exhaust nozzle and augmentor construction techniques to ensure lightweight and long service life with reasonable manufacturing costs.

The primary sheet metal candidate for the diverter valve housing and vanes would be Rene'41 - a vacuum melted, precipitation hardening Nickel based alloy especially designed for severely stressed, high temperature applications and is considered one of the most versatile, high temperature alloys available. High solutioning temperatures result in high rupture strength at elevated temperatures while lower solutioning temperatures give high tensile properties. Rene '41 can be inert-arc welded with or without filler material. At 1400°F, the .2% yield strength of Rene '41 sheet is over 120,000 PSI.

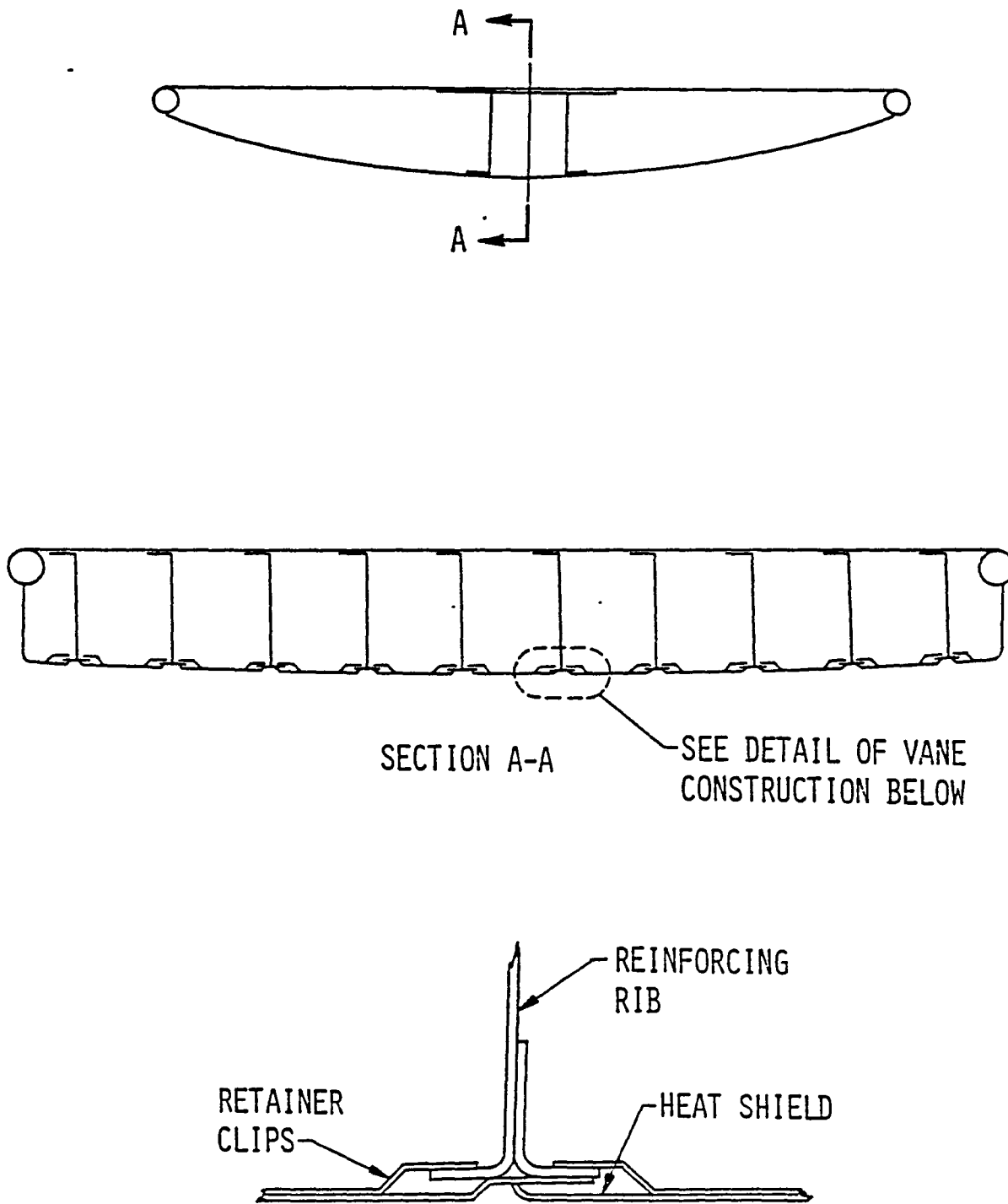


FIGURE 3-28 CROSS SECTION OF VANE STRUCTURE AND DETAIL OF HEAT SHIELD SUPPORTS

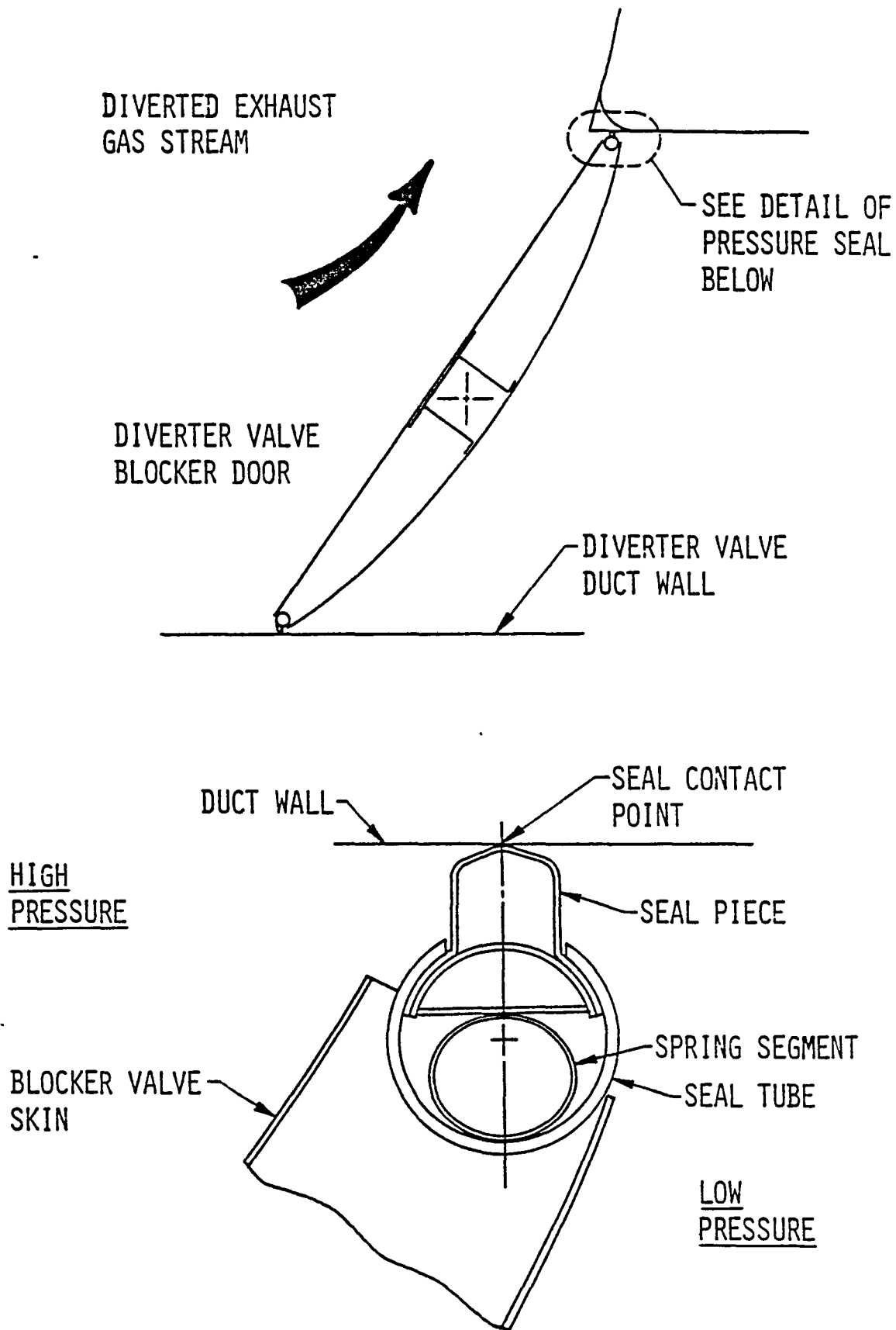


FIGURE 3-29 DIVERTER VALVE VANE SEAL CONSTRUCTION

4.0 ENGINE FLOW DIVERTER DUCT DESIGN STUDY

The duct design is actually a conclusion of the constraints and limitations placed upon it by the engine, flow diverter valve, ejector and model structure. The envelope formed by these other items dictates the majority of the physical features of the duct system.

4.1 ENGINE RELOCATION

In order to provide sufficient clearance for the installation of the flow diverter valve and to allow return bends in the ducting, the engines have been moved forward 13.00 in. as shown in VIEW LKG. DOWN, dwg. GD 3616-R006, Page 16. The engine is supported by two side mounts and one front mount. The two side mounts should be moved forward at the existing waterline level and restructured within the engine nacelle identical to existing structure. The forward mount would remain at the same location and be of similar construction but would be forshortened by 13.00 in.

Engine hydraulics and electrical wiring harnesses will not be researched in this concept design study but will be examined at a later contracted detail design level.

4.2 ENGINE NACELLE RELOCATION

To move the engine nacelle outboard the strake skin and sub-structure should be removed except for the forward primary support ring and the torque-box primary support fitting. A 22.00 in. spacer, similar in construction to the present support ring and having matching bolt arrangements, would be inserted to increase the span. The torque-box primary support fitting would be treated likewise. A 22.00 in. splice, identical to the

existing upper and lower sections of the torque box, would be bolted into form an extension.

To stabilize the engine nacelle when the aft ejector is installed, an engine nacelle support should be located aft of the rear ejector between the strongback weldment and an aft extension of the inboard side of the nacelle. The support could be constructed of either rectangular or square tubing with welded bases.

The upper inboard side of the engine nacelle should be re-shaped to a contour similar to the fuselage as indicated in VIEW A-A, DWG. GD 3616-R006. This would provide a more efficient entry ramp into the ejector throat than the existing vertical side.

To cover the remaining strake surface, a network of secondary structural ties can be fabricated between the fuselage and engine nacelle. These can be simple mild steel angles which can also support the strake skin.

4.3 EJECTORS

A basic configuration of the ejectors was required before the ejectors could be installed. Their physical characteristics were imposed by testing methods or established constraints. Figure 4-1 shows the approximate conceptual shape. The overall size of the forward ejector is 54.60 in. long and 36.50 in. wide. The aft ejector is 36.50 in. long and 36.50 in. wide. Both ejectors are 15.35 in. deep which is also the thickness of the strake. The strake has been moved upward from the existing model and has been maintained at a constant thickness except for the leading and trailing edges. The top of the strake was set at WL 40.95 and the bottom at WL 25.60. The forward support ring and the torque-box support remain at the same level which would expose them into the lower airstream by

ALPERIN EJECTOR

PRIMARY JET NOZZLES
(3.5 IN. SPACING)
 $A_{\infty} = .8722 \text{ SQ. IN.}$

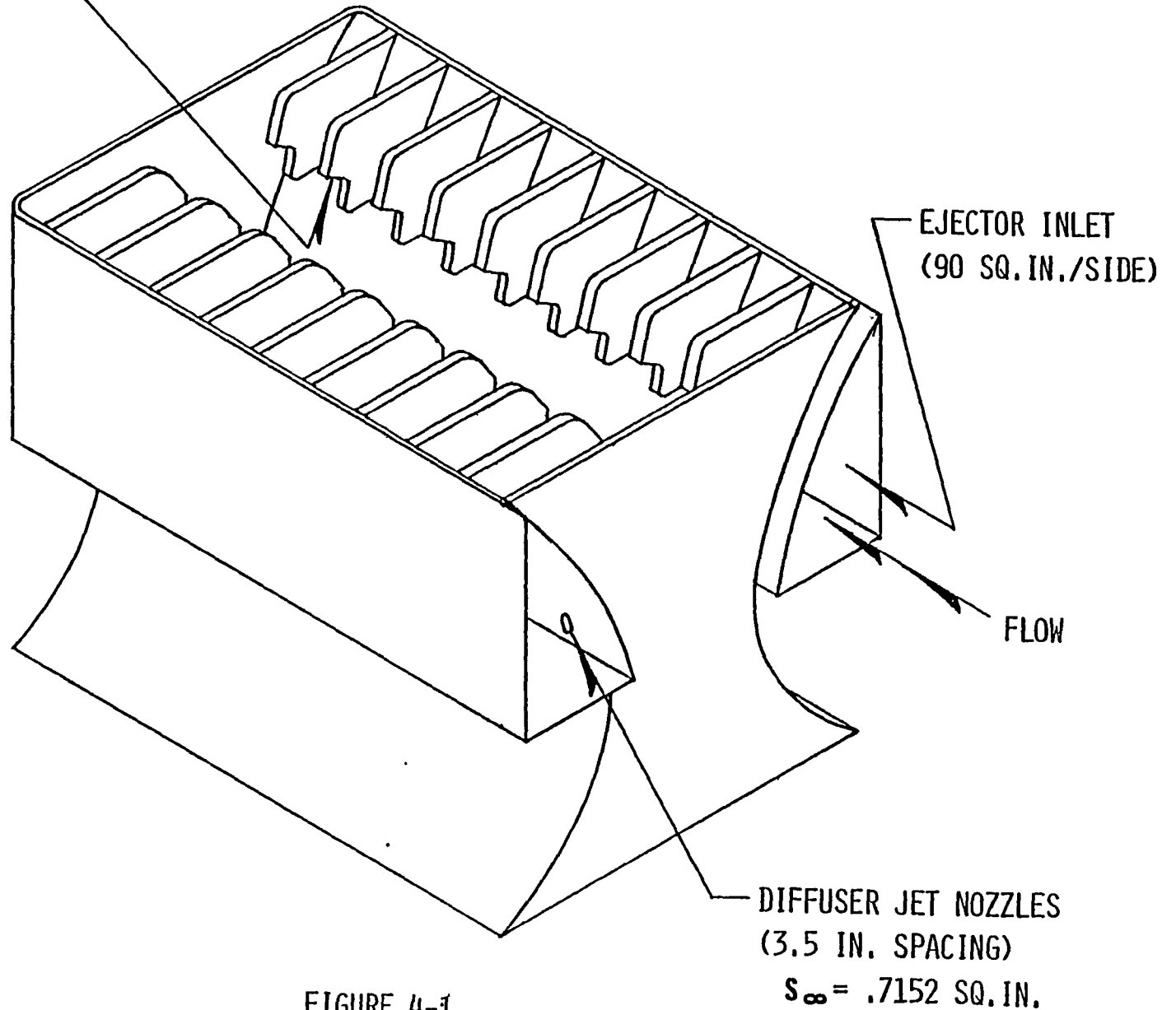


FIGURE 4-1

about 3 to 4 in. Direction was given that the finished ejectors will contain folding diffuser skirts. Therefore, no consideration was given to the aerodynamics of the lower ejector surface. The common ejector ducting for both the primary jet nozzles and the diffuser jet nozzles as defined by the progress report, reference 2-2, was refined to include equal area ducts of approximately 90 in.² and of a shape easily integrated into a rectangular ejector.

A mounting system very similar to one used for engines should be used for the ejectors and is shown in DETAIL C, DWG GD 3616-R006. A hot engine exhaust forced through the ejectors (in the 1300°F range) makes it mandatory to design for thermo-expansion and to be selective of construction materials. The inboard, outboard and forward mounting attachment would be a simple clevis bracket arrangement. It would use spherical bearings in the single-lug brackets and slip-fit bushings in the double-lug brackets. The forward and inboard attachments would have slotted holes in the double-lug brackets to accommodate the thermo movement while the outboard fittings would have only a diameter hole to prevent any outboard expansion.

A new support must be installed to supply an attachment location for the forward ejector mount on the aft ejector. It should be a vertical beam arrangement attached between the upper and lower strake surfaces. Additional framework would be needed in the area to securely tie in the beam.

Because excess exhaust flow must be bled from the ejectors, exhaust bleed nozzles are used on the ejectors as the most expedient and cost-effective method to balance and trim the system. The nozzles as shown in VIEW B-B, DWG. GD 3616-R006, would consist of flat plates with a calculated hole size and bolted to flanges which in turn are attached to each ejector duct exit. Consideration will be given for a more flight-worthy bleed system later in this report.

The materials for the ejectors, bleed valves and attachment fittings should be of a strength and quality equivalent to or in excess of Hastelloy-X (AMS 5536).

4.4 EJECTOR DUCTING

The configuration for the ejector ducting consists of a two-level bifurcated ducting system as shown in Figure 4-2. Ducting begins at the exit interface of the flow diverter valve. It carries the engine exhaust gases inboard and then diverts them both forward and aft into the ejector inlets. The tight constraints of surrounding structure severely limit the size of the ducts and their bend radii. The ducting has been designed with a rectangular cross section. All of the ducts would have a constant dimension of 13.00 in. wide by 5.00 in. high measured normal to centerline. The forward ducts interface with the diverter valve at the lower level, make a 90° turn and then pass through the opening in the torque box support. The aft ducts are located at the upper level. Both ducts eventually empty into the ejector inlets at the same level.

A total of three internal flow splitters are used within the ducting at each of the bifurcated areas to balance the exhaust flow to the ejectors. The first one is located at the interface of the diverter valve to direct the flow to the upper and lower ducts. The second splitter is in the upper ducts and the third in the lower ducts. Both of these are to balance right and left ejector inlet flow. The splitters should be a simple structural airfoil section mounted to a rotating axis. All of the splitters would be able to be adjusted manually or by remote actuation if so desired.

To mount the duct assembly into the model, a suspension system would be best. Readily available rod ends with spherical bearings and right and left-hand threads would be used in conjunction with an adjusting turnbuckle. These are shown in VIEW D-D, DWG.

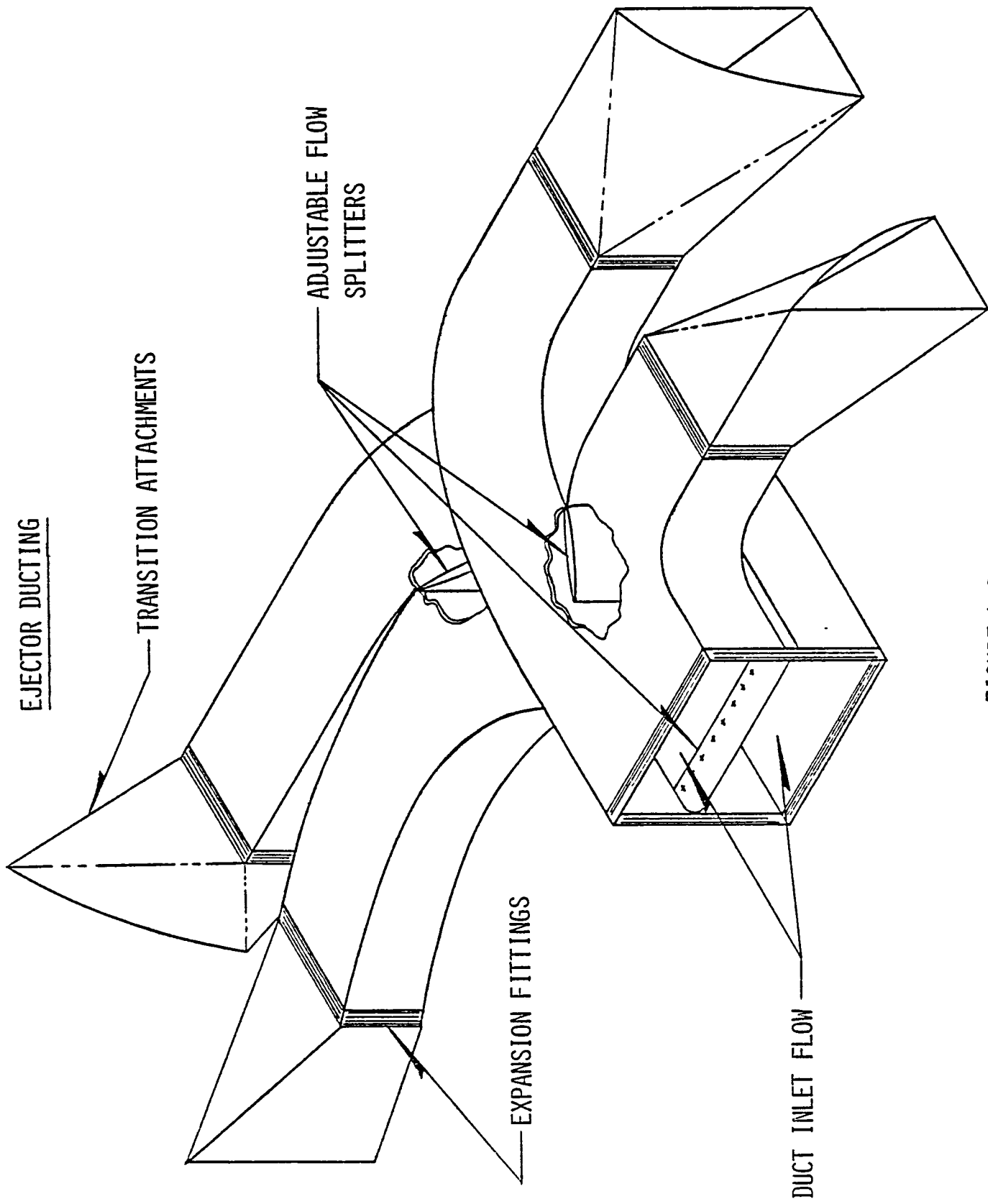


FIGURE 4-2

GD 3616-R006. The rod ends would be attached to the model and the ducts by fabricated brackets. This arrangement would give the duct suspension the flexibility needed for thermo expansion, operational vibrations and installation tolerances.

To connect the ducts to the ejector openings a transition duct should be used. This would be necessary because of differences in cross-sections. The transition ducts would also have a stainless steel bellows on each end to dampen the thermo expansion and vibration. An alternate to the bellows would be a slip-joint with seal similar to the engine exhaust diffuser and flow diverter valve connection. The slip-joint would have less susceptibility to blow out but would offer less flexibility.

Construction of the ejector ducts and transitions would be identical with the flow diverter valve since the temperatures and the stress loads are essentially the same. The material for the ducts, transitions and associated hardware should be of a strength and quality equivalent to or in excess of Hastelloy-X (AMS 5536).

4.5 SPAN-WISE BLOWING/ROLL CONTROL

Provisions have been made for span-wise blowing ducting should there be any later requirements for its use. A transition duct has been integrated into the flow diverter valve immediately forward of the turning vanes and then capped off. It is envisioned that should there be a need for roll control, it would be taken from the span-wise blowing duct and run outboard to a roll control nozzle.

5.0 ENGINE FLOW DIVERTER SYSTEM

PERFORMANCE COMPUTER PROGRAM

5.1 ANALYTIC MODEL

The computer program developed for the purpose of evaluating duct flows and pressures in the engine exhaust diverter valve system has been designed to analyze flow in the duct system shown in Figure 5-1. Details of program are shown in Appendix A. This duct system was chosen to provide the capability of evaluating overall exhaust system performance, including consideration of spanwise blowing and roll control, for cases wherein all or part of the engine exhaust flow is diverted to the ejector primary nozzles. The program is capable of evaluating the flow balance in a system having any number of duct sections downstream of station 4. The program functions in two modes: Mode 1 considers the case where part of the flow is diverted to the ejector primary nozzles and the remainder of the flow discharges through the VEO nozzle. In this mode, the program computes the VEO nozzle throat area required to match the specified engine power level and stall margin. The second mode of operation considers the case wherein all of the flow is diverted toward the ejector primary nozzles. Operating in this mode, the computer program will select the flow balance bleed orifice sizes such that the pressure at each of the ejector primary nozzles is the same value and the total flow is matched to the engine operating characteristic.

5.2 COMPUTER PROGRAM INPUT DATA

The input data to the program is comprised of the engine performance characteristic data, the pressure loss data and the nozzle area data.

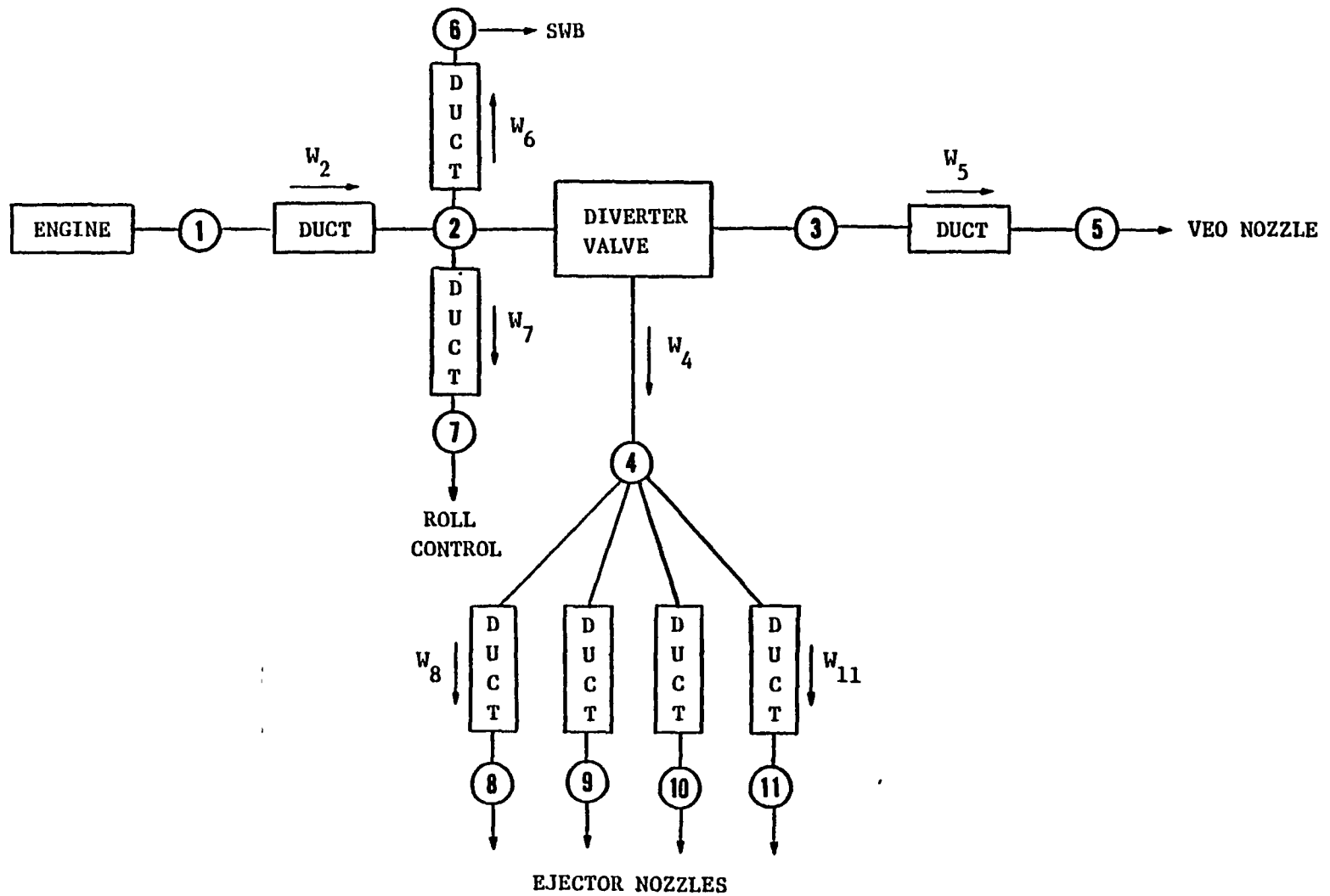


Figure 5-1. Computer Program Flow System Schematic

5.2.1 Engine Performance Characteristics

The engine performance characteristics required by the computer program are definitions of the exhaust flow rate, total pressure, and temperature as functions of engine corrected speed ($N/\sqrt{\theta}$) and stall margin (SMIC) for the YJ-97 engine. These data were supplied by GE and are presented in Figure 5-2 thru 5-4 in the form for input to the computer program.

5.2.2 Pressure Loss Characteristics

The pressure loss characteristic data for each of the duct sections shown in Figure 5-1 are defined to the computer program as curves of the total pressure loss, $\Delta P/P$, as a function of corrected flow, $W\sqrt{T}/P$. For the diverter valve block, the pressure losses from station 2 to station 3 and from station 2 to station 4 are considered to be functions of valve position as well as corrected flow. The pressure loss characteristics of the four duct sections from the diverter valve to the ejector primary plenum chambers are shown in Figure 5-5. The station numbers shown on the figure are those of Figure 5-1. These pressure loss values were evaluated as described in Appendix A. The pressure loss characteristics of the duct from station 1 to station 2 (referred to as stations 5.1 and 6.0, respectively, in section 3) and the pressure loss of the diverter valve in its fully diverted position, station 2 to station 4 (stations 6.0 and 6.5 in section 3), were supplied by GE and are shown in Figure 5-6 in the form for input to the computer program.

Since the computer program has been designed to consider cases beyond the scope of the current study, the pressure loss in the ducts leading to the VEO nozzle, the spanwise blowing nozzle, and the roll control nozzle were defined to the computer program as being zero. Also, since the diverter valve pressure loss characteristic has been evaluated only in the fully non-diverted and diverted positions, arbitrary pressure loss data were loaded

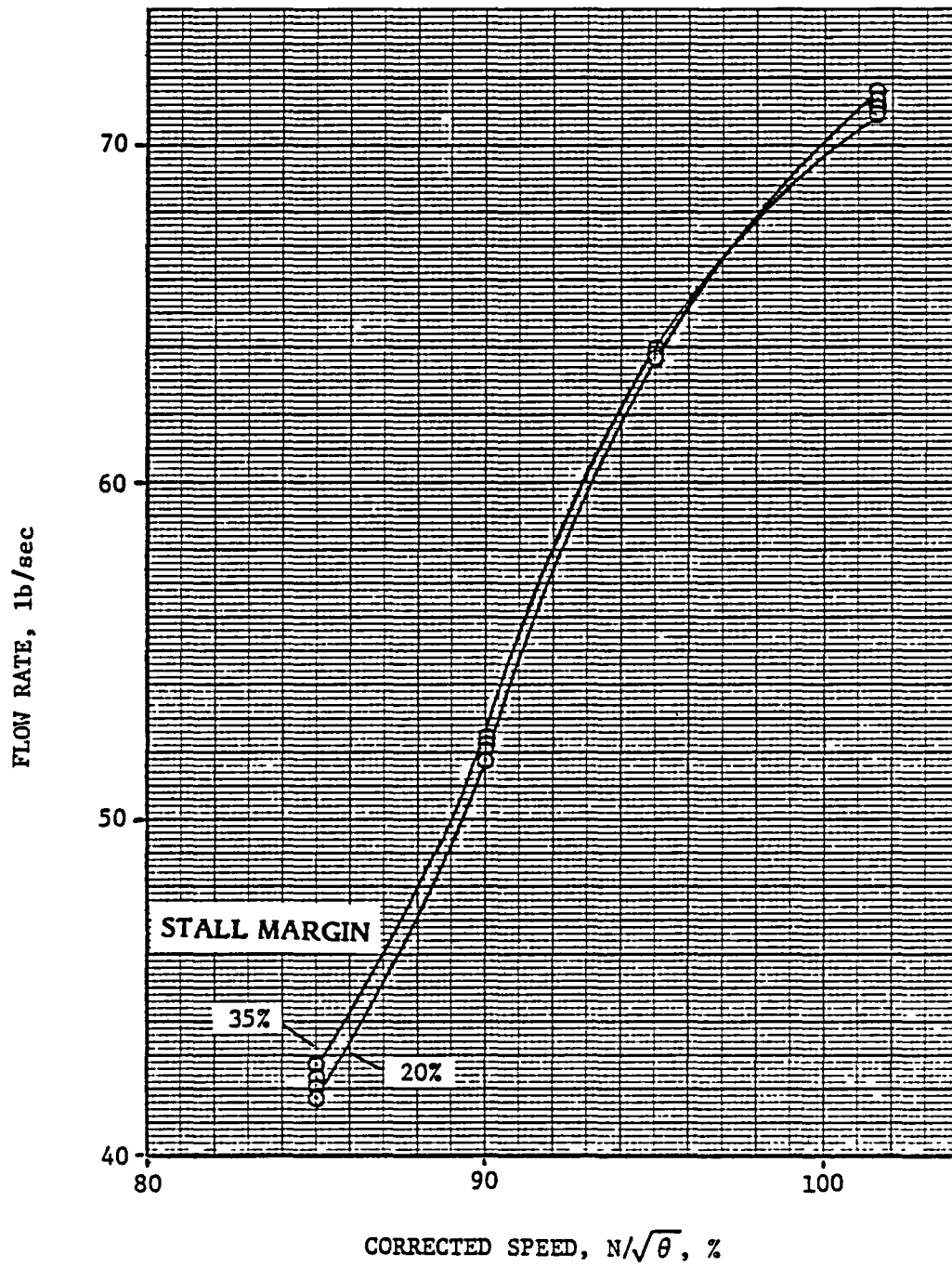


Figure 5-2. Engine Exhaust Flow Rate

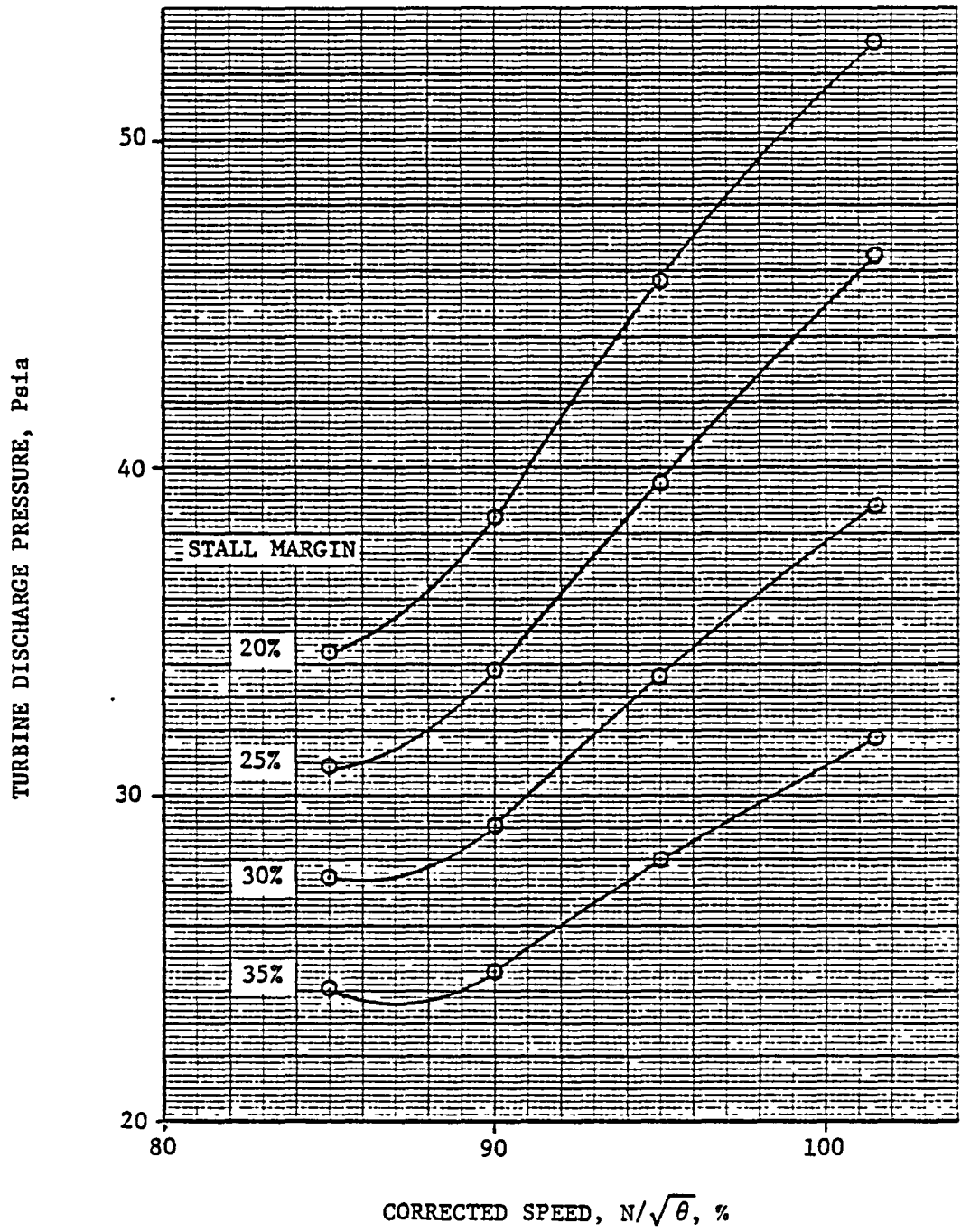


Figure 5-3. Engine Turbine Discharge Pressure

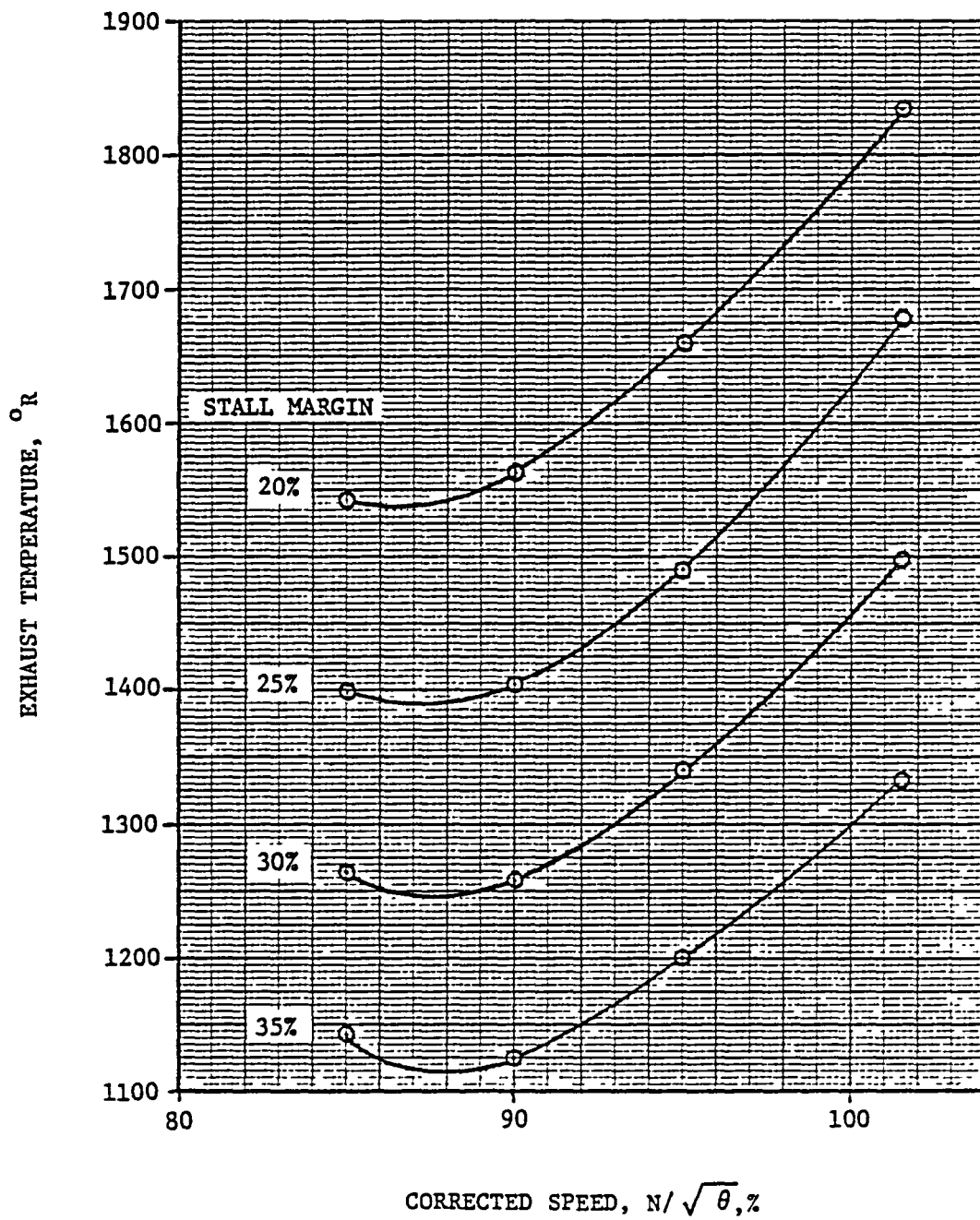


Figure 5-4. Engine Exhaust Total Temperature

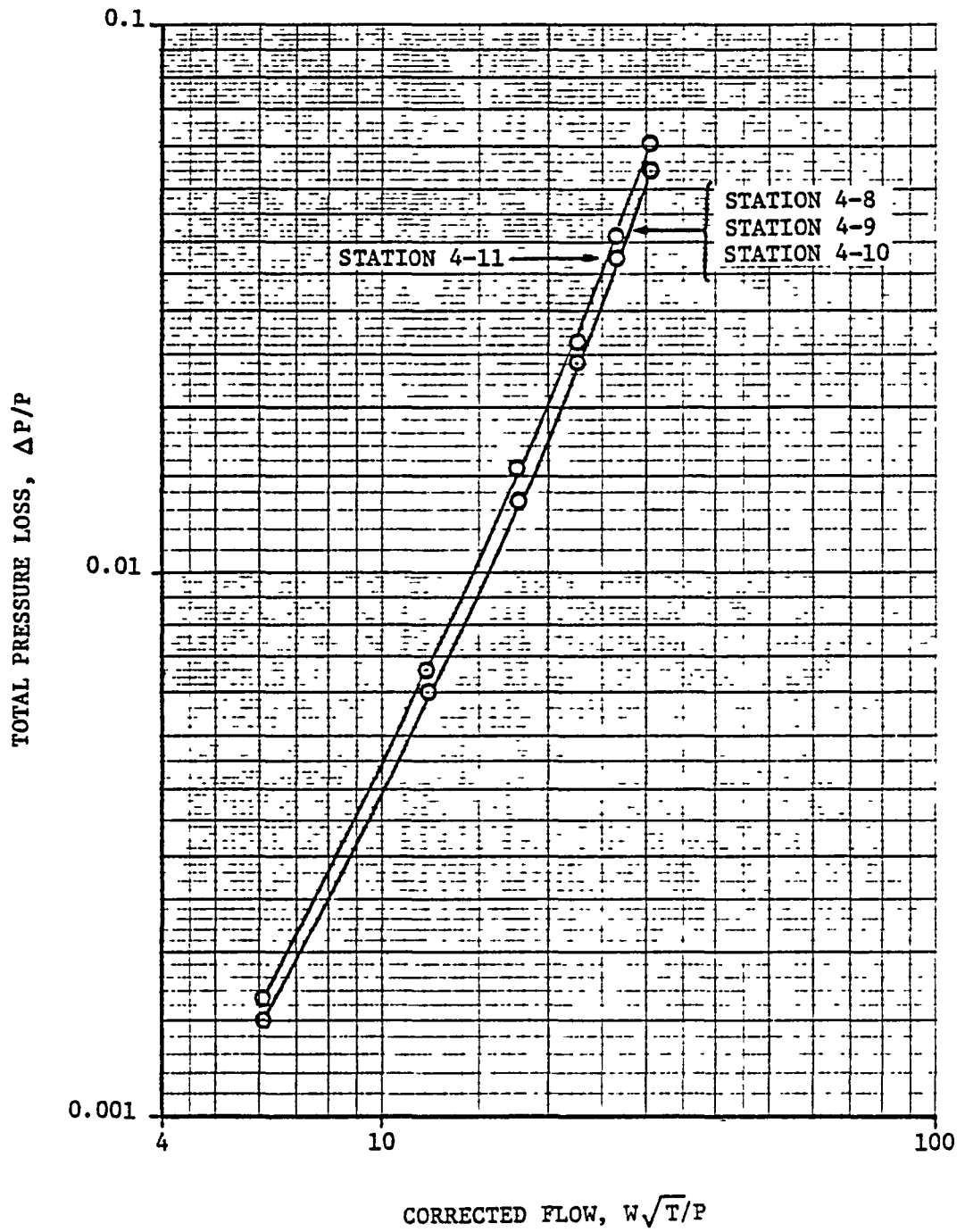


Figure 5-5. Ejector Duct Pressure Loss Characteristics

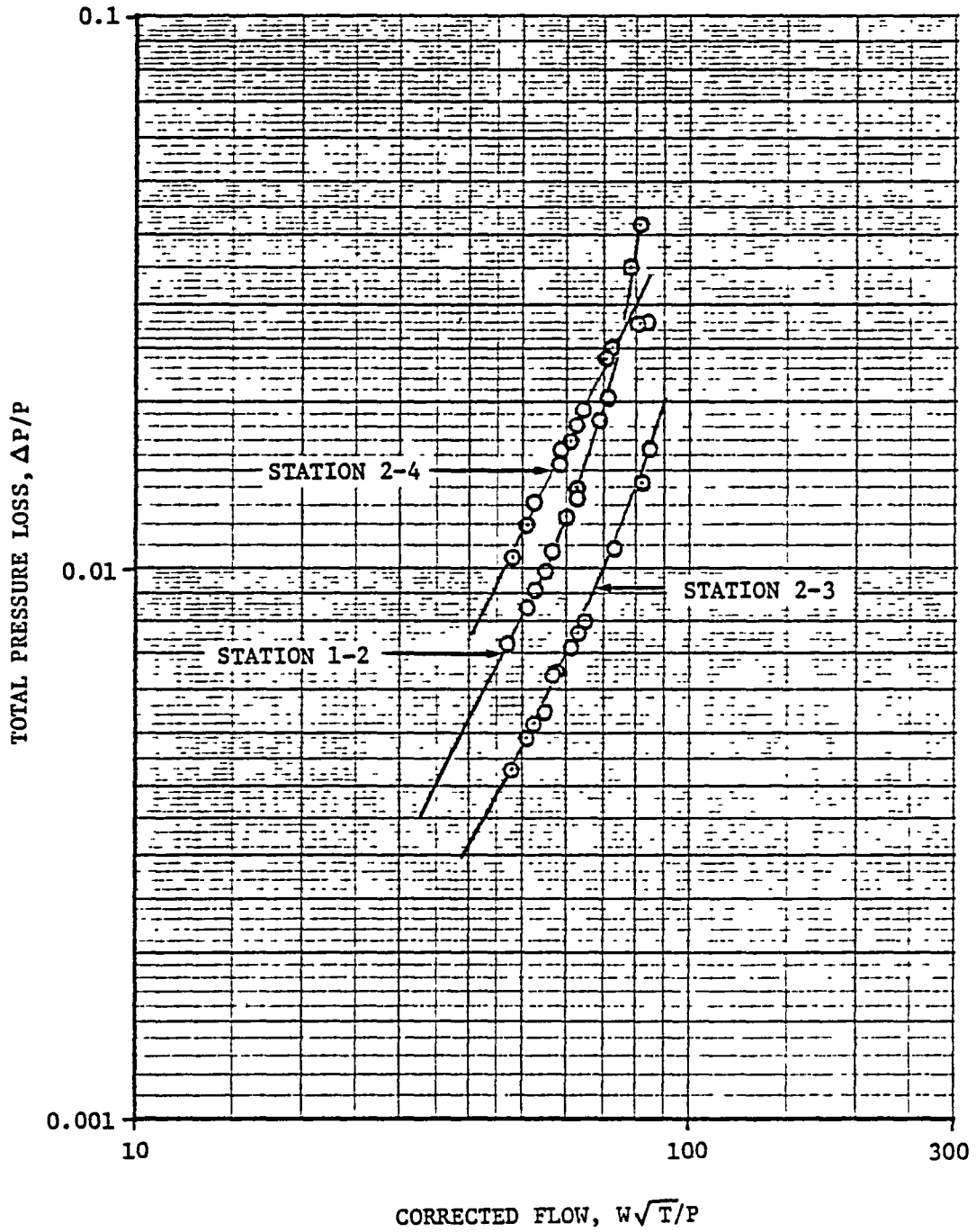


Figure 5-6. Diverter Valve and Engine Duct Pressure Loss Characteristics

for other diverter valve positions. These steps were taken in order to facilitate development of a computer program with expanded capability and do not represent a limitation of the computer program. The computer program will accept realistic values when they are available.

5.2.3 Nozzle Areas

The computer program requires as input a definition of the ejector primary nozzle flow areas, the spanwise blowing nozzle area, the roll control nozzle area and their respective discharge coefficients.

5.3 SAMPLE OUTPUT

The computer program provides one page of printed output for each engine operating point evaluated. Figure 5-7 is an example of the output produced by the program when functioning in Mode 2.

NASA FLOW DIVERTER SYSTEM PERFORMANCE
CORRECTED SPEED = 95.0 PERCENT
STALL MARGIN = 25 PERCENT

STATION	PRESSURE, PSIA	NPR	AREA, SQIN	FLOW, LB/SEC
1 ENGINE OUT	39.53	2.69	0.00	63.76
2 DIVERTER IN	38.98	2.65	0.00	59.00
3 DIVERTER OUT	0.00	0.00	0.00	0.00
4 DIVERTER OUT	38.36	2.61	0.00	59.00
5 VEO NOZZLE	0.00	0.00	0.00	0.00
6 SWB NOZZLE	38.98	2.65	5.00	2.51
7 ROLL NOZZLE	38.98	2.65	5.00	2.25
8 EJECTOR NOZZLE	38.00	2.59	14.29	15.01
9 EJECTOR NOZZLE	38.00	2.59	14.29	15.01
10 EJECTOR NOZZLE	38.00	2.59	22.23	15.01
11 EJECTOR NOZZLE	38.00	2.59	22.23	13.97

EJECTOR BLEED NOZZLE DATA

STATION	EJECTOR FLOW, LB/SEC	BLEED FLOW, LB/SEC	BLEED AREA, SQIN
8	6.2	8.8	20.4
9	6.2	8.8	20.4
10	9.6	5.4	12.4
11	9.6	4.3	10.0

Figure 5-7. Sample Computer Program Output

6.0 CONCLUSIONS AND RECOMMENDATIONS

1. Limitations of extensive structural modifications prevent the lift ejector sizing to be compatible with the engine operating characteristics. However, ejector performance can be evaluated by diverting excess engine exhaust flow overboard.
2. Updated ejector design criteria should be utilized in the final sizing and fabrication of the ejectors.
3. A two-vane diverter valve concept was found to satisfy the performance and system installation requirements for successful operation.
4. An acceptable performance diverter valve and ejector system could not be fitted within the existing nacelle structure. A 13 inch forward relocation of the engine in the nacelle structure, a 7 inch aft movement of the VEO nozzle and a 22 inch outboard movement of the nacelle was required for the ejectors and an acceptably high performance diverter valve and ducting system.
5. A flow analysis of the diverter valve found it to be free of large areas of separated flow. However, the flowpath downstream of the diverted leg of the valve may be subject to large areas of flow separation. A water-table study would help to identify any flow problems and allow definition of additional useful turning vanes.
6. The diverter valve may be operated in a flow splitting mode with apparently satisfactory performance. It is difficult to make an accurate estimation of the

diverter valve performance in this operating mode without experimental data. If this type of operation is chosen as the primary method, it is recommended that a cold flow scale model experiment be conducted to accurately determine the total pressure losses.

7. The preliminary mechanical design study defined the basic body structure for a non-flight weight diverter valve for the YJ-97 engine. The design can be fabricated as a one-of-a kind structure using low cost tooling and conventional construction techniques. Prior to fabrication, however, detail drawings will be required and a more comprehensive stress analysis including thermal effects must be completed.
8. A stress and thermal analysis should be accomplished to include considerations for the model structural modifications, the diverter valve, and the ducting system when the final sizing and design of the lift ejectors are completed.
9. Use of the exhaust flow splitting mode of operation will require a variable area VEO nozzle to balance and trim the flow.
10. Provisions for supplying exhaust gas flow for spanwise blowing and roll control have been included. However, additional ducting will have to be added for operational use.

REFERENCES

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- 2-3 Wu, J. J.; "V/STOL Fighter (7x10 Model, Version II) Ejector Deployed"; Drawing Flight Dynamics Research Corporation, Dwg. No. 132-1005
- 3-1 Kallin, I. N.; "Preliminary Data Report Cold Air Testing of Bell Diverter Valve"; GE Report R59AGT130, January 1959
- 3-2 Downer, G.T., Smith, E.G., Alderson, E.D.; "Cold Air Scale Model Aerodynamic Investigations of Several Diffuser-Diverter Valve Design Parameters"; GE Report TIS R60FPD576, November, 1960.
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- A-1 SAE Committee AC-9; "SAE Aerospace Applied Thermodynamics Manual"; October 1969.
- A-2 Meriwether, R. F.; "Additional Mach Number Tables for Internal Ramjet Flow Analysis"; FZA-279, January 1958.

APPENDIX A

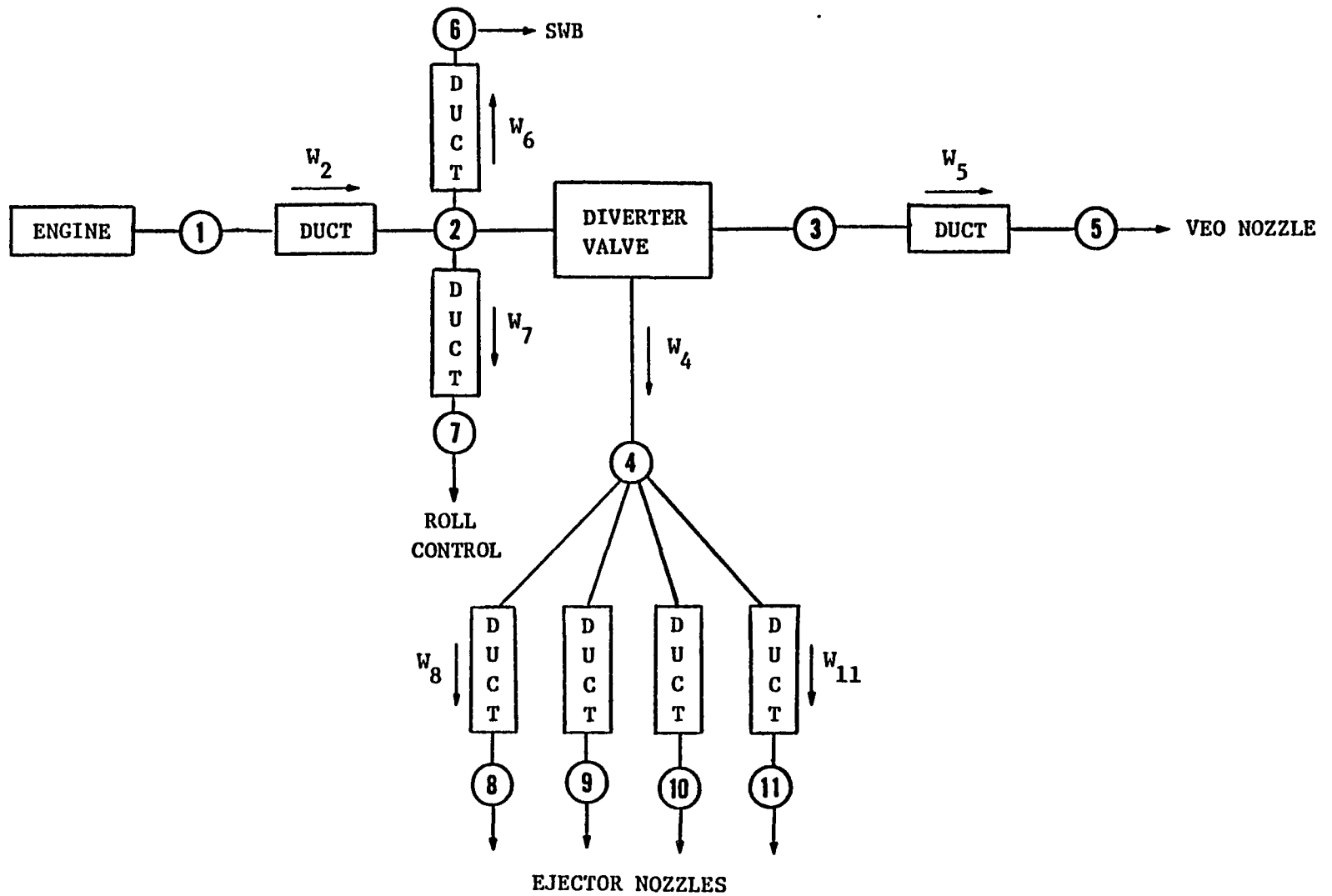
Computer Program Users' Manual

This appendix describes, in detail, the input data required by the computer program. Sample input and output are included. The input data are divided into three types of data decks. The computer program is organized such that any number of input decks of types 1 and 2 may be input to define a library of pressure loss characteristics and engine performance characteristics. This library of data will be accessed as indicated by the type 3 data deck when the program is executed. The type 1 and type 2 decks are general in form in that they are used to input single and double interpolation data sets respectively. The type 1 data sets are numerical representations of curves of y versus x . The type 2 data sets are maps of y versus x and z .

1. Preparation of Data for Input

The computer program has been structured so that it will compute the flow balance in the duct system shown in Figure A-1. The program requires as input data a definition of the pressure loss characteristics of each of the duct sections and the diverter valve. Input decks of type 1 are used to input the duct pressure loss data. Type 2 decks are used to input the diverter valve data and the engine performance data.

When preparing the data for input to the computer program, one first assigns curve index numbers to the curves of $\Delta P/P$ versus $W\sqrt{T}/P$ for each of the duct sections of Figure A-1. He also assigns index numbers to each of the maps which define the engine performance characteristics and the diverter valve pressure loss data. The following list shows the index numbers as used in the sample input shown in Section 5:



A2

Figure A-1. Computer Program Flow System Schematic

Curve - Dependent variable

- 3 - pressure loss from station 2 to 6, 2 to 7 and 3 to 5
- 4 - pressure loss from station 1 to 2
- 5 - pressure loss from station 4 to 8, 4 to 9, 4 to 10
- 6 - pressure loss from station 4 to 11

Map - Dependent variable

- 1 - pressure loss from station 2 to 4
- 2 - pressure loss from station 2 to 3
- 7 - engine exhaust flow rate
- 8 - engine exhaust total pressure
- 9 - engine exhaust total temperature

Note that the assignment of these index numbers is arbitrary. Any number of curves and/or maps may be loaded as input data. The data loaded into the program using types 1 and 2 data decks become a library of data which will be accessed as per the instructions of the type 3 deck, which will be discussed later.

After assignment of the curve and map index numbers, the data is loaded for computer input as described in the following paragraphs which describe input of curves of the form $y = f(x)$ and maps of the form $y = f(x,z)$. When loading the data, load the dependent variable as the y value and the independent variable as the x value. For the pressure loss data the independent variable (x) is $W\sqrt{T}/P$. For the diverter valve pressure loss data the second independent variable (z) is the valve position (VPOS). For the case when all the flow goes to the VEO nozzle, VPOS = 0. For the case where all the flow is diverted to the ejector ducts, VPOS = 1.0. VPOS values between 0 and 1 refer to intermediate positions

of the diverter valve. When defining the engine flow characteristics, the x variable is corrected speed and the z variable is the stall margin.

2. Type 1 Data Decks, $y = f(x)$

The first card of a type 1 deck contains a 1 in column 5. In columns 6 thru 10, enter the number of curves to be entered in the type 1 deck. In columns 11 thru 15, enter the deck number. This deck number will be referred to by the program if an input error is detected in the data.

Following the first card, a type 1 deck contains any number (as specified in columns 6-10 on first card) of groups of data; each group defines one of the curves. The curves may be entered in any order, and there may be any number of points (x-y pairs) on each curve. There may be as many as 100 curves (the curve ID number must be between 1 and 100). Data for each curve is entered as follows:

First Card of each data group (3I5,5X,2E10.0)

- Cols. 1-5: The curve ID number
- Cols. 6-10: The number of points (X-Y pairs) on the curve
- Cols. 11-15: Enter 0 if the plot is linear; enter 1 if the plot is log-log
- Cols. 21-30: Scale factor for the X coordinate
- Cols 31-40: Scale factor for the Y coordinate

Note: The scale factors need be entered only when they are not unity. The scale factor is the ratio of the value entered in the library deck to the value to be used in the calculations.

Other cards of each data group (6E10.0):

Enter the points on the curve in the following order:

$X_1, Y_1; X_2, Y_2; X_3, Y_3$: etc. Enter the points on the curve such that

$X_1 < X_2 < X_3$, etc. Use as many cards as required to enter the curve.

3. **Type 2 Data Decks, $y = f(x,z)$**

The first card of a type 2 data deck contains a 2 in column 5. In columns 6 thru 10, enter the number of maps to be entered in the deck. In columns 11 thru 15 enter the deck reference number.

Following this first card, a type 2 deck contains any number (as specified in columns 6 through 10 on first card) of groups of data; each group defines one of the maps. These maps may be entered in any desired order. Each curve (constant Z value) in the map is entered without regard to the values of X used to enter the other curves; each curve may have any number of points (X-Y pairs). The curves must be entered in the order of increasing values of Z. There may be as many as 50 maps. (The map ID number must be between 1 and 50). Data for each map are entered as follows:

First card of each data group (3I5, 5X, 3E10.0)

Cols. 1-5: The map ID number

Cols. 6-10: The number of Z values

Cols. 11-15: Enter 0 if the map is linear;

enter 1 if the map is log-log

NOTE: A linear interpolation with respect to the Z values is used for both linear and log-log domains.

Cols. 21-30: Scale factor for the X coordinate

Cols. 31-40: Scale factor for the Y coordinate

Cols. 41-50: Scale factor for the Z coordinate

NOTE: The scale factors need be entered only when they are not unity. The scale factor is the ratio of the value entered in the map to the value to be used in the calculations.

Card group for each value of Z:

First card of group (E10.0,I5):

Cols. 1-10: The value of Z

Cols. 11-15: The number of points on the curve of Y vs X for the above value of Z

Other cards (6E10.0):

Enter the points on the curve (X-Y pairs) in the following order: $X_1, Y_1; X_2, Y_2; X_3, Y_3;$ etc. Use as many cards as required to enter the curve.

NOTE: Enter the above group of cards for each value of Z in the order of increasing Z.

4. Type 3 data decks

The first card of a type three deck contains a 3 in column 5. In column 10 enter the operating mode: enter 1 for the case wherein part of the flow is diverted to the ejectors and part of the flow is discharged through the VEO nozzle; enter 2 for the case wherein all of the flow is diverted to the ejector ducts. In column 15 enter the deck reference number.

On the second card of the type 3 deck, enter the total pressure loss, $\Delta P/P$, from the ejector plenum to the primary nozzle if this loss is included in the pressure loss characteristic for the ducts downstream of station 4, for which case stations 8, 9, 10, etc. are at the primary ejector nozzles. The value entered on this card will be used to evaluate the bleed orifice total pressure for each duct. If stations 8, 9, 10, etc. were chosen to be the ejector plenum pressures (as is the case for the examples contained in this report) this value should be entered as being zero.

It should be noted that the ejector primary nozzle discharge coefficients used in the sample input contained herein are from reference 2-1 wherein the discharge coefficient is based on the nozzle plenum pressure, and, therefore, stations 8, 9, 10 and 11 were chosen to be the ejector plenum.

On the third card enter, in column 5, the number of duct sections downstream of station 4.

On the fourth card enter, in cols 5, 10, 15, etc., the curve index numbers to identify the following duct pressure loss data sets:

Col. 5:	From station	1	to station	2
10:		2		3
15:		2		4
20:		3		5
25:		2		6
30:		2		7
35:		4		8
40:		4		9
.		.		.
.		.		.
.		.		.
$30+5(N)$:		4		$7+N$

where N is the number of duct sections downstream of station 4.

On card number 5 enter, in cols 5, 10, and 15, the index numbers to identify the engine operating characteristic data sets for definition of flow rate, pressure, and temperature, respectively.

Beginning on card number 6, enter in six successive fields of 10 columns per card, and in the following order, nozzle geometric areas for the VEO nozzle, the spanwise blowing nozzle, the roll control nozzle, and the ejector nozzles at stations 8, 9, 10, etc. If there are more than 3 duct sections downstream of station 4, continue on the next card with the nozzle area at station 11 in the first field of 10 cols.

The next data group to be entered is the nozzle discharge coefficient for each of the nozzles. Enter these discharge coefficient values in the same manner as the nozzle areas were entered.

The remaining cards of the type 3 deck are a definition of the engine operating points for which the flow balance is to be evaluated. Each of these cards contain in successive fields of 10 columns, and in the following order, these values: 1) the ratio of specific heats for the exhaust gas, 2) the diverter valve position, 3) the engine operating corrected speed, and 4) the stall margin at which the engine operates.

5. Sample Input Listing

The following page is a listing of the input data used to produce the output presented in section 6. Note that the comments identifying the station numbers may begin in column 41 for type 1 decks and column 51 for type 2 decks. These comments, if used, must be on the card containing the curve or map index number.

6. Sample output

The following pages present the computer output produced by the input data shown in Section 5.

NASA FLOW DIVERTER SYSTEM PERFORMANCE
CORRECTED SPEED = 101.5 PERCENT
STALL MARGIN = 20 PERCENT

STATION	PRESSURE, PSIA	NPR	AREA, SQIN	FLOW, LB/SEC
1 ENGINE OUT	53.00	3.61	0.00	71.59
2 DIVERTER IN	52.37	3.56	0.00	65.83
3 DIVERTER OUT	0.00	0.00	0.00	0.00
4 DIVERTER OUT	51.66	3.52	0.00	65.83
5 VEC NOZZLE	0.00	0.00	0.00	0.00
6 SWC NOZZLE	52.37	3.56	5.00	3.04
7 ROLL NOZZLE	52.37	3.56	5.00	2.72
8 EJECTOR NOZZLE	51.25	3.49	14.29	16.75
9 EJECTOR NOZZLE	51.25	3.49	14.29	16.75
10 EJECTOR NOZZLE	51.25	3.49	22.23	16.75
11 EJECTOR NOZZLE	51.25	3.49	22.23	15.63

EJECTOR BLEED NOZZLE DATA

STATION	EJECTOR FLOW, LB/SEC	BLEED FLOW, LB/SEC	BLEED AREA, SQIN
8	7.5	9.2	17.5
9	7.5	9.2	17.5
10	11.7	5.0	9.6
11	11.7	3.9	7.5

NASA FLOW DIVERTER SYSTEM PERFORMANCE
CORRECTED SPEED = 95.0 PERCENT
STALL MARGIN = 25 PERCENT

STATION	PRESSURE, PSIA	NPR	AREA, SQIN	FLOW, LB/SEC
1 ENGINE OUT	39.53	2.69	0.00	63.76
2 DIVERTER IN	38.98	2.65	0.00	59.00
3 DIVERTER OUT	0.00	0.00	0.00	0.00
4 DIVERTER OUT	38.36	2.61	0.00	59.00
5 VEC NOZZLE	0.00	0.00	0.00	0.00
6 SWB NOZZLE	38.98	2.65	5.00	2.51
7 ROLL NOZZLE	38.98	2.65	5.00	2.25
8 EJECTOR NOZZLE	38.00	2.59	14.29	15.01
9 EJECTOR NOZZLE	38.00	2.59	14.29	15.01
10 EJECTOR NOZZLE	38.00	2.59	22.23	15.01
11 EJECTOR NOZZLE	38.00	2.59	22.23	13.97

EJECTOR BLEED NOZZLE DATA

STATION	EJECTOR FLOW, LB/SEC	BLEED FLOW, LB/SEC	BLEED AREA, SQIN
8	6.2	8.8	20.4
9	6.2	8.8	20.4
10	9.6	5.4	12.4
11	9.6	4.3	10.0

NASA FLOW DIVERTER SYSTEM PERFORMANCE
CORRECTED SPEED = 85.0 PERCENT
STALL MARGIN = 30 PERCENT

STATION	PRESSURE, PSIA	NPR	AREA, SQIN	FLOW, LB/SEC
1 ENGINE OUT	27.44	1.87	0.00	42.40
2 DIVERTER IN	27.15	1.85	0.00	38.80
3 DIVERTER OUT	0.00	0.00	0.00	0.00
4 DIVERTER CUT	26.82	1.83	0.00	38.80
5 VEC NOZZLE	0.00	0.00	0.00	0.00
6 SWB NOZZLE	27.15	1.85	5.00	1.90
7 ROLL NOZZLE	27.15	1.85	5.00	1.70
8 EJECTOR NOZZLE	26.63	1.81	14.29	9.87
9 EJECTOR NOZZLE	26.63	1.81	14.29	9.87
10 EJECTOR NOZZLE	26.63	1.81	22.23	9.87
11 EJECTOR NOZZLE	26.63	1.81	22.23	9.23

EJECTOR BLEED NOZZLE DATA

STATION	EJECTOR FLOW, LB/SEC	BLEED FLOW, LB/SEC	BLEED AREA, SQIN
8	4.7	5.2	15.7
9	4.7	5.2	15.7
10	7.3	2.5	7.7
11	7.3	1.9	5.8

NASA FLOW DIVERTER SYSTEM PERFORMANCE
CORRECTED SPEED = 80.0 PERCENT
STALL MARGIN = 27 PERCENT

STATION	PRESSURE, PSIA	NPR	AREA, SQIN	FLOW, LB/SEC
1 ENGINE OUT	27.05	1.84	0.00	32.25
2 DIVERTER IN	26.87	1.83	0.00	28.80
3 DIVERTER OUT	0.00	0.00	0.00	0.00
4 DIVERTER OUT	26.68	1.82	0.00	28.80
5 VEC NOZZLE	0.00	0.00	0.00	0.00
6 SWB NOZZLE	26.87	1.83	5.00	1.82
7 ROLL NOZZLE	26.87	1.83	5.00	1.63
8 EJECTOR NOZZLE	26.57	1.81	14.29	7.31
9 EJECTOR NOZZLE	26.57	1.81	14.29	7.31
10 EJECTOR NOZZLE	26.57	1.81	22.23	7.31
11 EJECTOR NOZZLE	26.57	1.81	22.23	6.90

EJECTOR BLEED NOZZLE DATA

STATION	EJECTOR FLOW, LB/SEC	BLEED FLOW, LB/SEC	BLEED AREA, SQIN
8	4.6	2.8	8.6
9	4.6	2.8	8.6
10	7.1	.2	.7
11	7.1	-.2	-.6

7. Fortran Listing of Computer Program

This section contains a complete listing of the computer program. The program is comprised of 5 parts. The function performed by each of the five parts is outlined in the following paragraphs.

Program Ames is the program control or executive routine. It contains all of the solution algorithm which consists of several iterative loops. The convergence tolerance for each of these loops has been set at 0.1%.

Subroutine Single is a subroutine which provides single interpolations of tabular data. It is used to read the pressure loss data to provide P/P as a function of $W T/P$.

Subroutine Double is a double interpolation routine which is used to provide the engine operating characteristics and the pressure loss of the diverter valve as functions of valve position and corrected flow.

The Block Data subroutine initializes the point counter indices used by subroutines single, double, and read.

Subroutine Read performs the function of reading from the input stream all of the input defining the pressure loss data and engine performance characteristics. These data are read into the X, Y, and Z arrays and origin pointers for each of the curves are set at this time the data is read.

```

PROGRAM AMES (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT) 1
LOGICAL LTST
REAL NPR
COMMON A(20),P(20),W(20),N(20),WE(15),WB(15),AB(15),CD(20),AG(20) 2
COMMON /COM/ N1,N2,N3,IV,IW,IX,IER 3
COMMON /TABLE/ X(1000),Y(1000),Z(500),IXY(100),LL(100),LJ(100), 4
X NP(100),IXYP(50),LLM(50),LJM(500),NPZ(500),LJZ(50),NZ(50),IZ(50) 5
COMMON /SF/ SFC(2,100),SFH(3,50) 6
DIMENSION ISTA(16) 7
DATA ISTA /1CHENGINE OUT, 1CH , 10HDIVERTER I, 8
X 1CHN , 10HDIVERTER O, 10HUT , 9
X 10HDIVERTER O, 10HUT , 10HVEO NOZZLE, 10
X 10H , 10HSWB NOZZLE, 10H , 11
X 1CHROLL NOZZL, 1CHE , 10CHEJECTOR NO, 12
X 1CHZZLE /
C READ INPUT DECK IDENTIFICATION INFORMATION 131
LTST=.FALSE.
10 READ (5,20) N1,N2,N3 14
20 FORMAT (12I5) 15
C IF DECK TYPE IS 1 OR 2, CALL READ TO INPUT ENGINE CHARACTERISTICS 151
C AND PRESSURE LOSS CHARACTERISTIC DATA 152
IF (N1.GT.2) GO TO 30 16
CALL READ (N1,N2,N3,IV,IW,IX,IER) 17
GO TO 10 18
C READ PRESSURE LOSS INDEX INFORMATION 181
C N(1)=NUMBER OF DUCTS DOWNSTREAM OF STATION 4 182
C N(2)=INDEX NO. FOR DUCT LOSS FROM STA 1 TO STA 2 183
C N(3)=INDEX NO. FOR DUCT LOSS FROM STA 2 TO STA 3 184
C N(4)=INDEX NO. FOR DUCT LOSS FROM STA 2 TO STA 4 185
C N(5)=INDEX NO. FOR DUCT LOSS FROM STA 3 TO STA 5 186
C N(6)=INDEX NO. FOR DUCT LOSS FROM STA 2 TO STA 6 187
C N(7)=INDEX NO. FOR DUCT LOSS FROM STA 2 TO STA 7 188
C N(I)=INDEX NO. FOR DUCT LOSS FROM STA 4 TO STA I 189
30 READ (5,40) CPEJ
READ (5,20) LM
NS=LM+7
READ (5,20) (N(I),I=2,NS)
N(1)=LM
C READ ENGINE PERFORMANCE CHARACTERISTIC INDEX NUMBERS 211
READ (5,20) K1,K2,K3 22
C READ NOZZLE AND EJECTOR PRIMARY NOZZLE AREAS 221
READ (5,40) (AG(I),I=5,NS)
40 FORMAT (6F10.0) 24
READ (5,40) (CD(I),I=5,NS)
DO 31 I=5,NS
31 A(I)=AG(I)*CD(I)
DO 42 I=1,4
AG(I)=0.
42 A(I)=0.
C READ RATIO OF SPECIFIC HEATS, DIVERTER VALVE POSITION, ENGINE 241
C POWER LEVEL, AND STALL MARGIN 242
41 READ (5,40) GAM,VPOS,PWR,SMIC 25
IF (EOF(5).NE.0) GOTO 240
C CALL SUBROUTINE DOUBLE TO EVALUATE FLOW, PRESSURE, AND TEMPERATURE 251
C AT STATION 1 252
CALL DOUBLE (PWR,SMIC,W(1),K1,IER) 26
CALL DOUBLE (PWR,SMIC,P(1),K2,IER) 27

```

	CALL DOUBLE (PWR,SMIC,T,K3,IER)	28
	SQT=SQRT(T)	29
	WC1=W(1)*SQT/P(1)	30
C	CALL SUBROUTINE SINGLE TO EVALUATE PRESSURE DROP FROM STATION 1	301
C	TO STATION 2	302
	CALL SINGLE (WC1,DP2,N(2),IER)	31
	P(2)=P(1)*(1.-DP2)	32
	F=.7766148+SQRT(GAM)*(2./(1.+GAM))*((1.+GAM)/2./(GAM-1.))	33
C	LOOP ENDING AT STATEMENT 60 WILL EVALUATE FLOW TO THE SUB NOZZLE	331
C	AND THE ROLL CONTROL NOZZLE AS FUNCTIONS OF NOZZLE AREA AND DUCT	332
C	LOSS	333
	DO 60 K=6,7	34
	WC0=F*A(K)	35
	WC=WC0	36
	NCT=0	
50	CALL SINGLE (WC,DP,N(K),IER)	37
	P(K)=P(2)*(1.-DP)	38
	W(K)=WC0*P(K)/SQT	39
	WC1=W(K)*SQT/P(2)	40
	IF (ABS(WC-WC1).LE..001*WC1) GO TO 60	41
	WC=(WC+WC1)/2.	42
	NCT=NCT+1	
	IF(NCT.LT.50) GO TO 50	
	WRITE (6,51)	
51	FORMAT(*0LOOP AT 50 DID NOT CONVERGE*)	
60	CONTINUE	44
	W(2)=W(1)-W(6)-W(7)	45
C	BRANCH TO 120 IS FOR CASE WHERE EJECTORS HAVE BLEED NOZZLES AND	451
C	FLOW TO THE VEO NOZZLE IS ZERO	452
	IF (N2.EQ.2) GO TO 120	46
	P(4)=0.	
	W(4)=0.	
	WCE=0.	47
C	LOOP ENDING AT 70 SUPPLIES FIRST TRIAL VALUE OF FLOW THROUGH THE	471
C	DIVERTER VALVE TO THE EJECTOR NOZZLES	472
	DO 70 K=8,NS	48
	WC0=F*A(K)	49
	P(K)=0.	
	W(K)=0.	
70	WCE=WC0+WCE	50
	NCTT=0	
80	IF (VPOS.EQ.0.) GO TO 110	
	CALL DOUBLE (WCE,VPOS,DP,N(4),IER)	51
	P(4)=P(2)*(1.-DP)	52
	W(4)=0.	53
C	LOOP ENDING AT 100 WILL EVALUATE EJECTOR FLOWS AND PRESSURES	531
	DO 100 K=8,NS	54
	WC0=F*A(K)	55
	WC=WC0	56
	NCT=0	
90	CALL SINGLE (WC,DP,N(K),IER)	57
	P(K)=P(4)*(1.-DP)	58
	W(K)=WC0*P(K)/SQT	59
	WC1=W(K)*SQT/P(4)	60
	IF (ABS(WC-WC1).LT..001*WC1) GO TO 100	61
	WC=(WC+WC1)/2.	62
	NCT=NCT+1	

```

      IF (NCT.LT.50) GO TO 90
      WRITE (6,91)
91  FORMAT(+0LOOP AT 90 DID NOT CONVERGE+)
100 W(4)=W(4)+W(K)
      WCE1=W(4)+SQT/P(2)
C   THE FOLLOWING TEST CHECKS FOR CONVERGENCE OF THE TRIAL VALUE OF
C   CORRECTED FLOW USED AT 80 TO EVALUATE P(4)
      IF (ABS(WCE-WCE1).LT..001*WCE1) GO TO 110
      WCE=(WCE+WCE1)/2.
      NCTT=NCTT+1
      IF (NCTT.LT.50) GO TO 80
      WRITE (6,101)
101 FORMAT(+0LOOP AT 80 DID NOT CONVERGE+)
110 W(3)=W(2)-W(4)
      W(5)=W(3)
      WC=W(3)+SQT/P(2)
      CALL DOUBLE (WC,VPOS,DP,N(3),IER)
      P(3)=P(2)*(1.-DP)
      WC=W(3)+SQT/P(3)
      CALL SINGLE (WC,DP,N(5),IER)
      P(5)=P(3)*(1.-DP)
      A(5)=W(5)+SQT/P(5)/F
      AG(5)=A(5)/CC(5)
      GO TO 160
C   THE FOLLOWING IS FOR CASE WHERE FLOW TO VED NOZZLE IS ZERO
120 WCE=W(2)+SQT/P(2)
      CALL DOUBLE (WCE,1.,DP,N(4),IER)
      F(4)=P(2)*(1.-DP)
      WCD=WCE+P(2)/P(4)
C   THE LOOP ENDING AT 130 EXCHANGES X AND Y VALUES FOR THE CURVES
C   DEFINING THE PRESSURE LOSS CHARACTERISTICS FOR EACH OF THE DUCTS
C   DOWNSTREAM OF STATION 4.
      IF (LTST) GO TO 132
      LTST=.TRUE.
      DO 130 K=8,NS
      NC=N(K)
      IF (K.EQ.8) GO TO 122
      KZ=K-1
      DO 121 J=8,KZ
      IF (NC.EQ.N(J)) GO TO 130
121 CONTINUE
122 SS=SFC(1,NC)
      SFC(1,NC)=SFC(2,NC)
      SFC(2,NC)=SS
      NPT=NP(NC)
      IOR=IXY(NC)-1
      DO 123 J=1,NPT
      XS=Y(IOR+J)
      Y(IOR+J)=X(IOR+J)
123 X(IOR+J)=XS
130 CONTINUE
132 CP=.02
      W(5)=0.
      A(5)=0.
      F(3)=0.
      P(5)=0.
      W(3)=0.

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        W(4)=W(2)
        NCT=0
140  WD=0.
        DO 150 K=8,NS
C     THIS CALL TO SINGLE EVALUATES THE FLOW THROUGH THE DUCT AS A
C     FUNCTION OF TRIAL VALUE OF PRESSURE LOSS
        CALL SINGLE (DP,WC,N(K),IER)
        W(K)=WC*P(4)/SQT
        P(K)=P(4)*(1.-DP)
        WE(K-7)=F*P(K)*A(K)/SQT
        WB(K-7)=W(K)-WE(K-7)
        AB(K-7)=WB(K-7)*SQT/P(K)/F/CD(K)*(1.-DPEJ)
150  WD=WD+WC
C     THE FOLLOWING CHECKS FOR CONVERGENCE OF THE TOTAL FLOW TO THE
C     EJECTORS
        IF (ABS(WD-WCD).LT..001*WD) GO TO 160
        DP=DP*(WCD/WD)**2
        NCT=NCT+1
        IF (NCT.LT.50) GO TO 140
        WRITE(6,151)
151  FORMAT(=0LOOP AT 140 DID NOT CONVERGE=)
160  ISTALL=SMIC+.5
        WRITE (6,170) PWR,ISTALL
170  FORMAT (1H1/21X,=NASA FLOW DIVERTER SYSTEM PERFORMANCE= /
X 24X,=CORRECTED SPEED =*,F6.1,= PERCENT= /
X 27X,=STALL MARGIN = *,I2,1X,=PERCENT=)
        WRITE (6,180)
180  FORMAT (=0 STATION*,T22,=PRESSURE, PSIA*,T42,=NPR*,T54,
X =AREA, SQIN*,T68,=FLOW, LB/SEC= /)
        DO 190 I=1,NS
        K=2*I-1
        IF (K.GT.15) K=15.
        NPR=P(I)/14.696
190  WRITE (6,200) I,ISTA(K),ISTA(K+1),P(I),NPR,AG(I),W(I)
200  FORMAT (I3,1X,2A10,T25,F6.2,T40,F6.2,T55,F6.2,T70,F6.2)
        IF (N2.EQ.1) GO TO 41
        WRITE (6,210)
210  FORMAT (////T27,=EJECTOR BLEED NOZZLE DATA=//T7*STATION*,T20,
X =EJECTOR FLOW, LB/SEC*,T42,=BLEED FLOW, LB/SEC*,T63
X ,=BLEED AREA, SQIN= /)
        CO 220 I=8,NS
220  WRITE (6,230) I,WE(I-7),WB(I-7),AB(I-7)
230  FORMAT (I11,T26,F6.1,T46,F6.1,T66,F6.1)
        GO TO 41
240  WRITE (6,250)
250  FORMAT (=1THIS JOB IS COMPLETE.=)
        END

```

```

SUBROUTINE SINGLE (XT,YO,NUM,IER)                                001
CCMPON /SF/SFC(2,100),SFM(3,50)                                002
CCMPON /TABLE/ X(1000),Y(1000),Z(500),IXY(100),LL(100),LJ(100), 003
X NF(100),IXYP(50),LLM(50),LJM(50),NPZ(50),LJZ(50),NZ(50),I2(50) 004
C IXY= ORIGIN IN X AND Y ARRAYS                                005
C LL = 1 - LOG-LOG CURVES , =0 - LINEAR CURVES                 006
C LJ = FCINT COUNTER MEMORY                                    007
C NP = NUMBER OF FCINTS ON CURVE                               008
C NUM= CURVE NUMBER                                           009
C IER= ERROR FLAG                                             010
  XI=XT*SFC(1,NUM)                                             011
  I=IXY(NUM)-1                                                 012
  L=LL(NUM)                                                     013
10  IF (L.GT.1.AND.L.LE.NP(NUM)) GO TO 30                       014
  IER=1                                                         015
  IF (L.EQ.1) L=2                                              016
  IF (L.GT.NP(NUM)) L=NP(NUM)                                  017
  GO TO 50                                                       018
30  K=L+I                                                       019
  IF (XI.GE.X(K-1)) GO TO 40                                    020
  L=L-1                                                         021
  GO TO 10                                                       022
40  IF (XI.LE.X(K)) GO TO 50                                    023
  L=L+1                                                         024
  GO TO 10                                                       025
50  L.(NUM)=L                                                  026
  IF (LL(NUM).GT.0) GO TO 60                                    027
  YC=(Y(K-1)*(X(K)-XI)-Y(K)*(X(K-1)-XI))/(X(K)-X(K-1))/SFC(2,NUM) 028
  RETRN                                                         029
60  XIL=ALOG(XI)                                               030
  Y1=ALOG(Y(K-1))                                             031
  Y2=ALOG(Y(K))                                               032
  X1=ALOG(X(K-1))                                             033
  X2=ALOG(X(K))                                               034
  YO=EXP((Y1*(X2-XIL)-Y2*(X1-XIL))/(X2-X1))/SFC(2,NUM)      035
  RETRN                                                         036
ENC                                                             037

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SUBROUTINE CCUBLE (XT,ZT,YO,NUM,IER)                                038
  COMMON /SF/SFC(2,100),SFM(3,50)                                  039
  COMMON /TABLE/ X(1000),Y(1000),Z(500),IXY(100),LL(100),LJ(100),  040
  X NP(100),IXYP(50),LLP(50),LJP(500),NPZ(50),LJZ(50),NZ(50),IZ(50) 041
C  IXYP = CRIGIN IA X & Y ARRAYS                                    042
C  IZ = OFIGIN IN Z ARRAY                                          043
C  LLP = 1 - LOG-LOG CURVES , =0 LINEAR CURVES (ALLAYS LINEAR IN Z ) 044
C  LJP = FCINT COUNTER MEMCRY - X & Y ARRAYS                      045
C  NPZ = ALPEER CF X-Y FCINTS FOR EACH Z VALLE                    046
C  LJZ = FCINT COUNTER MEMCRY - Z ARRAY                            047
C  NUM = PNP NUMBER                                               048
C  IER = ERROR FLAG                                               049
C  NZ = NUMBER OF Z VALUES                                       050
  XI=XT+SFM(1,NUM)                                                051
  ZI=ZT+SFM(3,NUM)                                                052
  IZC=IZ(NUM)                                                      053
  LZ=LJZ(NUM)                                                       054
  LZ=LJZ(NUM)                                                       055
10  IF (LZ.GT.1.ANC.LZ.LE.NZ(NUM)) GO TO 30                       056
  IER=1                                                             057
  IF (LZ.EQ.1) LZ=2                                               058
  IF (LZ.GT.NZ(NUM)) LZ=NZ(NUM)                                    059
  GO TO 50                                                           060
30  KZ=IZC+LZ                                                       061
  IF (ZI.GE.Z(KZ-1)) GC TC 40                                       062
  LZ=LZ-1                                                           063
  GO TO 10                                                           064
40  IF (ZI.LE.Z(KZ)) GO TO 50                                       065
  LZ=LZ+1                                                           066
  GC TO 10                                                           067
50  L,Z(NLM)=LZ.                                                    068
  LIM=KZ-1                                                          069
  IXYC=IXYP(NLM)-1.                                               070
  DO 60 I=IZC,LIM.                                                 071
60  IXYC=IXYO+NPZ(I)                                               072
  L=LJM(KZ)                                                         073
70  IF (L.GT.1.ANC.L.LE.NPZ(KZ)) GO TC 80                          074
  IF (L.EQ.1) L=2                                                 075
  IF (L.GT.NPZ(KZ)) L=NPZ(KZ)                                     076
  IER=1                                                             077
  GO TO 100                                                         078
80  K=IXYO+L                                                        079
  IF (XI.GE.X(K-1)) GC TO 90                                       080
  L=L-1                                                             081
  GO TO 70                                                           082
90  IF (XI.LE.X(K)) GO TO 100                                       083
  L=L+1                                                             084
  GO TC 70                                                           085
100 L,L(KZ)=L                                                       086
  IF (LLM(NUM).GT.0) GC TO 110                                       087
  YC2=(Y(K-1)+(X(K)-XI)-Y(K)+(X(K-1)-XI))/(X(K)-X(K-1))          088
  GO TO 120                                                         089
110 XIL=ALOG(XI)                                                   090
  Y1=ALOG(Y(K-1))                                                  091
  X1=ALOG(X(K-1))                                                  092
  Y2=ALOG(Y(K))                                                    093
  X2=ALOG(X(K))                                                    094

```

	YC2=(Y1*(X2-XIL)-Y2*(X1-XIL))/(X2-X1)	095
120	IXYC=IXY0-NPZ(LIM)	096
	L=L+M(KZ-1)	097
130	IF (L.GT.1.AND.L.LE.NPZ(KZ-1)) GO TO 140	098
	IF (L.EQ.1) L=2	099
	IF (L.GT.NPZ(KZ-1)) L=NPZ(KZ-1)	100
	IER=1	101
	GO TO 160	102
140	K=IXY0+L	103
	IF (XI.EE.X(K-1)) GO TO 150	104
	L=L-1	105
	GO TO 130	106
150	IF (XI.LE.X(K)) GO TO 160	107
	L=L+1	108
	GO TO 130	109
160	LJM(KZ-1)=L	110
	IF (LLM(NUM).GT.0) GO TO 170	111
	YC1=(Y(K-1)*(X(K)-XI)-Y(K)*(X(K-1)-XI))/(X(K)-X(K-1))	112
	GO TO 180	113
170	Y1=ALOG(Y(K-1))	114
	X1=ALCG(X(K-1))	115
	Y2=ALCG(Y(K))	116
	X2=ALOG(X(K))	117
	Y01=(Y1*(X2-XIL)-Y2*(X1-XIL))/(X2-X1)	118
180	YC=(YC1*(Z(KZ)-Z1)-YC2*(Z(KZ-1)-Z1))/(Z(KZ)-Z(KZ-1))	119
	IF (LLP(NUM).GT.0) YC=EXP(YC)	120
	YC=Y0/SFM(Z,NUM)	121
	RETURN	122
	END	123

BLCK DATA GD	124
CCMCA /TABLE/ X(1000),Y(1000),Z(500),IXY(100),LL(100),LJ(100),	125
X NP(100),IXYM(50),LLM(50),LJM(500),NPZ(500),LJZ(50),NZ(50),IZ(50)	126
COMMON /COM/ N1,N2,N3,IV,IW,IX,IER	127
CATA LJ,LJM,LJZ/650*2/,IXY,NP,IXYM,IZ/300*0/	128
DATA IV,IW,IER/1,1,0/	129
END	130

	SLERCUTINE READ (N1,A2,A3,IV,IW,IX,IER)	131
	CCPPON /TABLE/ X(1000),Y(1000),Z(500),IXY(100),LL(100),LJ(100),	132
	X NF(100),IXYF(50),LLM(50),LJF(500),NPZ(500),LJZ(50),NZ(50),IZ(50)	133
	CCPPON /SF/SFC(2,100),SFM(3,50)	134
	NC=A3	135
	GO TO (10,170),A1	136
10	IF (A2.GT.0.AND.A2.LE.100) GO TO 40	137
	WRITE (6,20) ND	138
20	FORMAT (*OTPE NUMBER OF CURVES SPECIFIED IN DECK NUMBER*,I3,* IS	139
	XINCORRECT.*)	140
30	IER=1	141
C	CALL SKIPPR	
	RETURN	143
40	CO 160 ACT=1,N2	144
	READ (5,50) ALM,NPTS,LDUM,SF1,SF2	145
	IF (SF1.EQ.(.)) SF1=1.	146
	IF (SF2.EQ.(.)) SF2=1.	147
50	FCRPAI (3I5,5X,3E10.0)	148
	IF (NUM.GT.(.AND.NUM.LE.100) GO TO 70	149
	WRITE (6,60) ND	150
60	FORMAT (*OAN INVALID CURVE IC NUMBER WAS SPECIFIED IN DECK NUMBER	151
	X *,I3,*,*)	152
	IER=1	153
70	IF (LDUM.EQ.0.OR.LDUM.EQ.1) GO TO 90	154
	WRITE (6,80) NUP	155
80	FCRPAI (*OCLRVE NUMEER*,I3,* WAS NOT SPECIFIED TO BE LINEAR OR LO	156
	XEARITHMIC.*)	157
	IER=1	158
90	IF (NLM.LE.(.OR.NUM.GT.100) GO TO 91	159
	LL(NUM)=LDUM	160
	NP(NUM)=NPTS	161
	IXY(NUM)=IV	162
	SFC(1,NUM)=SF1	163
	SFC(2,NUM)=SF2	164
91	IF (NPTS.GT.1) GO TO 105	165
	WRITE (6,100) NLP	166
100	FORMAT (*OTPE ALPBER OF POINTS ON CURVE NUMBER*,I3,* WAS INCORREC	167
	X TLY SPECIFIED.*)	168
	GO TO 30	169
105	IX=IV-1+NPTS	170
	IF (IX.LE.1000) GO TO 120	171
	WRITE (6,110)	172
110	FORMAT (*OTPE ARRAYS FOR STORAGE OF X AND Y VALLES FOR CURVES AND	173
	X MAPS HAVE BECOME TOO LARGE.*/* IT WILL BE NECESSARY TO REMOVE ANY	174
	X UNUSEC CURVES AND/OR MAPS FROM THE DATA* / * OR OTHERWISE REDUCE	175
	X THE NUMBER OF X AND Y VALUES TO BE STORED.*)	176
	GO TO 30	177
120	READ (5,130) (X(I),Y(I),I=IV,IX)	178
130	FCRPAI (6E10.0)	179
	IV=IV+1	180
	GO 150 I=IV,IX	181
	IF (X(I).GE.X(I-1)) GO TO 150	182
	WRITE (6,140) NUM	183
140	FORMAT (*OTPE PCINTS ON CURVE NUMEER*,I3,* ARE NOT IN ORDER OF IN	184
	XCREASING VALLES OF X.*)	185
	IER=1	186
	GO TO 160	187

150	CONTINUE	188
160	IV=IX+1	189
	RETLRN	190
170	IF (A2.GT.C.AND.A2.LE.50) GC TO 190	191
	WRITE (6,18C) AC	192
180	FCRPMAT (*GT-E NUMBER OF MAPS SPECIFIED IN DECK NUMBER*,I3,* IS IN	193
	XCORRECT.*)	194
	GC TC 30	195
190	DC 31C ACT=1,A2	196
	REAC (5,50) NUM,LZ,LCUM,SF1,SF2,SF3	197
	IF (SF1.EQ.0.) SF1=1.	198
	IF (SF2.EQ.0.) SF2=1.	199
	IF (SF3.EQ.0.) SF3=1.	200
	IF (NLM.GT.C.AND.NUM.LE.50) GO TO 210	201
	WRITE (6,20C) AD	202
200	FCRPMAT (*OIA INVALID MAP ID NUMBER WAS SPECIFIED IN DECK NUMBER*,	203
	X I3,*,*)	204
	IER=1	205
210	IF (LZ.GT.1) GC TO 230	206
	WRITE (6,22C) NUM	207
220	FORMAT (*GT-E NUMBER OF Z VALUES SPECIFIED FOR MAP NUMBER*,I3,* I	208
	XS INCORRECT.*)	209
	IER=1	210
230	IF (LCUM.EQ.0.OR.LDLM.EQ.1) GO TO 250	211
	WRITE (6,24C) NUM	212
240	FCRPMAT (*OIA MAP NUMBER*,I3,* WAS NOT SPECIFIED TO BE LINEAR OR LOGA	213
	XRITHMIC.*)	214
	IER=1	215
250	IF (NLM.LE.C.CR.NLM.GT.50) GO TO 251	216
	LLM(NLM)=LDLM	217
	IZ(NUM)=IV	218
	IXYM(NUM)=IV	219
	NZ(NLM)=LZ	220
	SFM(1,NUM)=SF1	221
	SFM(2,NUM)=SF2	222
	SFM(3,NLM)=SF3	223
251	DO 310 N=1,LZ	224
	REAC (5,260) Z(IV),NPTS	225
260	FORMAT (E10.0,I5)	226
	IF (N.EQ.1) GC TO 261	227
	IF (Z(IV).GT.Z(IV-1)) GC TO 261	228
	WRITE (6,262) NUM	229
262	FORMAT (*OIA MAP NUMBER*,I3,*, THE CURVES ARE NOT ENTERED IN ORDE	230
	X OF INCREASING VALUES OF Z.*)	231
	IER=1	232
261	IF (NPTS.GT.1) GC TO 280	233
	WRITE (6,27C) NLM,Z(IV)	234
270	FORMAT (*OIA MAP NUMBER*,I3,*, THE NUMBER OF POINTS ON THE CURVE	235
	XCF Y VS X FOR Z =*,E12.5,* IS INCORRECT.*)	236
	GO TO 30	237
280	NPZ(IV)=NPTS	238
	IX=IV+NPTS-1	239
	IF (IX.LE.1000) GO TO 290.	240
	WRITE (6,11C)	241
	GC TC 30	242
290	REAC (5,130) (X(I),Y(I),I=IV,IX)	243
	IV=IV+1	244

DO 291 I=IV,IX	245
IF (X(I).GT.X(I-1)) GO TO 291	246
WRITE (6,252) NUF,Z(IW)	247
252 FCRPAT ('OIA MAP NUMBER',I3,' THE CURVE FOR Z=',E12.5,' HAS NOT B	248
XEN ENTERED IN ORDER OF INCREASING X. *)	249
IER=1	250
GO TO 253	251
251 CCATIAUE	252
253 IV=IX+1	253
IW=IW+1	254
IF (IW.LE.501) GO TO 310	255
WRITE (6,300)	256
300 FORMAT ('THE ARRAY FOR STORAGE OF THE VALUES OF Z FOR MAPS HAS B	257
XECOME TOO LARGE.*/' IT WILL BE NECESSARY TO REMOVE ANY UNUSED MAPS	258
X FROM THE DATA*/' OR OTHERWISE REDUCE THE NUMBER OF Z VALUES TO BE	259
X STCFEC.*)	260
GO TO 30	261
310 CONTINUE	262
RETRN	263
ENC	264

8. Example Computation of Duct Loss Characteristics

The duct pressure loss characteristics which are input to the computer program in the form of $\Delta P/P$ versus $W\sqrt{T}/P$ are evaluated as outlined in this section. The evaluation of the duct loss characteristics for the four duct sections downstream of the diverter valve to the ejector primary nozzle plenum chamber are shown in detail, making use of the curves contained in the SAE Aerospace Applied Thermodynamics Manual (Reference A-1), and the Mach function tables of Reference A-2.

Figure A-2 is a sketch of the duct system for which the pressure loss characteristics are evaluated. The four duct sections are identified by the corresponding station numbers of Figure A-1. Consider the duct section from station 4 to station 8. The pressure loss in this duct section is the sum of three parts: 1) friction loss, 2) bend loss, and 3) an expansion loss. The pressure loss in the duct is, then

$$\Delta P/P = (4fL/D + K_B + K_E) q/P$$

where $4fL/D$ is the friction loss coefficient, K_B is the bend loss coefficient and K_E is the expansion loss coefficient. L/D is the length/diameter ratio for the duct. The friction factor, $4f$, is evaluated from Figure 1A-5 of reference A-1 as a function of Reynolds number at a surface roughness ratio of 0.00001. The equivalent diameter of the rectangular duct is given by

$$D_e = 2ab/(a+b) = 2(8.78)(7.785)/(8.78+7.785) = 8.25 \text{ in.}$$

The Reynolds number is given by the following:

$$R_e = (720)(W)(D_e)/[(\mu)(A)]$$

where W is the flow rate, lb/min, D_e is the equivalent diameter, inches, μ is to viscosity in lb/ft.hr, and A is area in in^2 . The viscosity may be considered to be the following function of temperature ($^{\circ}\text{F}$).

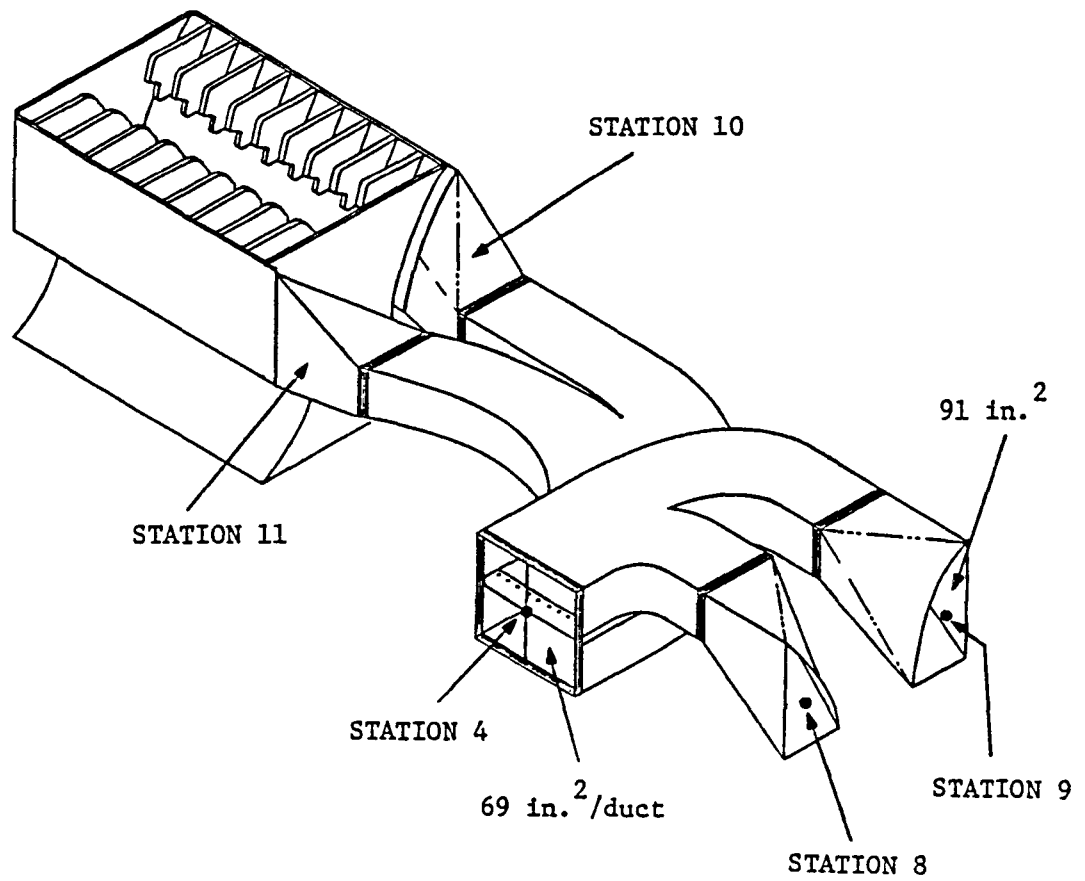


Figure A-2. Duct System Downstream of Diverter Valve

$$\mu = .04 + (6.05 \times 10^{-5})T$$

The "design point" flow conditions were taken to be the engine operating point of 101.5% RPM and 21% stall margin for which $W = 71.6$ lb/sec and $T = 1375$ °F. Each duct is considered to flow 1/4 of the total engine flow. The design point Reynolds number is then 0.76×10^6 . From Figure 1A-5 of Reference 1, the friction factor is then:

$$4f = .012$$

The duct length is taken to be the total length from the diverter valve exit to the exit of the expansion section (ejector primary nozzle plenum). The friction loss coefficient is, then:

$$4fL/D = (.012)(30/8.25) = .0437$$

The bend coefficient was evaluated from Figure 1A-20 of Reference A-1 at an aspect ratio of 1.1 and a radius ratio of 1.28. The bend loss coefficient is 0.15. The expansion loss coefficient was evaluated from Figures 1A-38 and 1A-41 of Reference A-1. A_1/A_2 is 69/91 and Figure 1A-38 yields .062 for the sudden expansion loss coefficient. Since data for expansion factors for a transition from a rectangular diffuser inlet to a triangular exit are not available, it was approximated to be 0.5 using Figure 1A-41 as a guide. The expansion loss coefficient is then .031.

The total loss coefficient for the duct section is, then

$$K_T = 4fL/D + K_B + K_e = .0437 + .15 + .031 = .2247$$

When the above analysis was done for all 4 ducts, the following were obtained:

	Sta. 4-8	Sta. 4-9	Sta. 4-10	Sta. 4-11
Friction Loss	.0437	.0727	.0872	.0727
Bend Loss	.1500	.1300	.1100	.1452
Expansion Loss	.0310	.0310	.0310	.0310
Total	.2247	.2337	.2282	.2489

The characteristics plotted in Figure A-3 were obtained by use of the Mach function tables of Reference A-2 for a ratio of specific heats of 1.34. For example, at a mach number of .1, the flow function ($W\sqrt{T}/PA$) is .08938 and the q/p is .0067. The parameter $W\sqrt{T}/P$ is

$$W\sqrt{T}/P = (W\sqrt{T}/PA)(A) = 6.167$$

and $P/P = K_T q/P = (.2247)(.0067) = .00151$ (sta. 4-8)

The above was repeated for several duct mach numbers and the results shown in Figure A-3 were obtained.

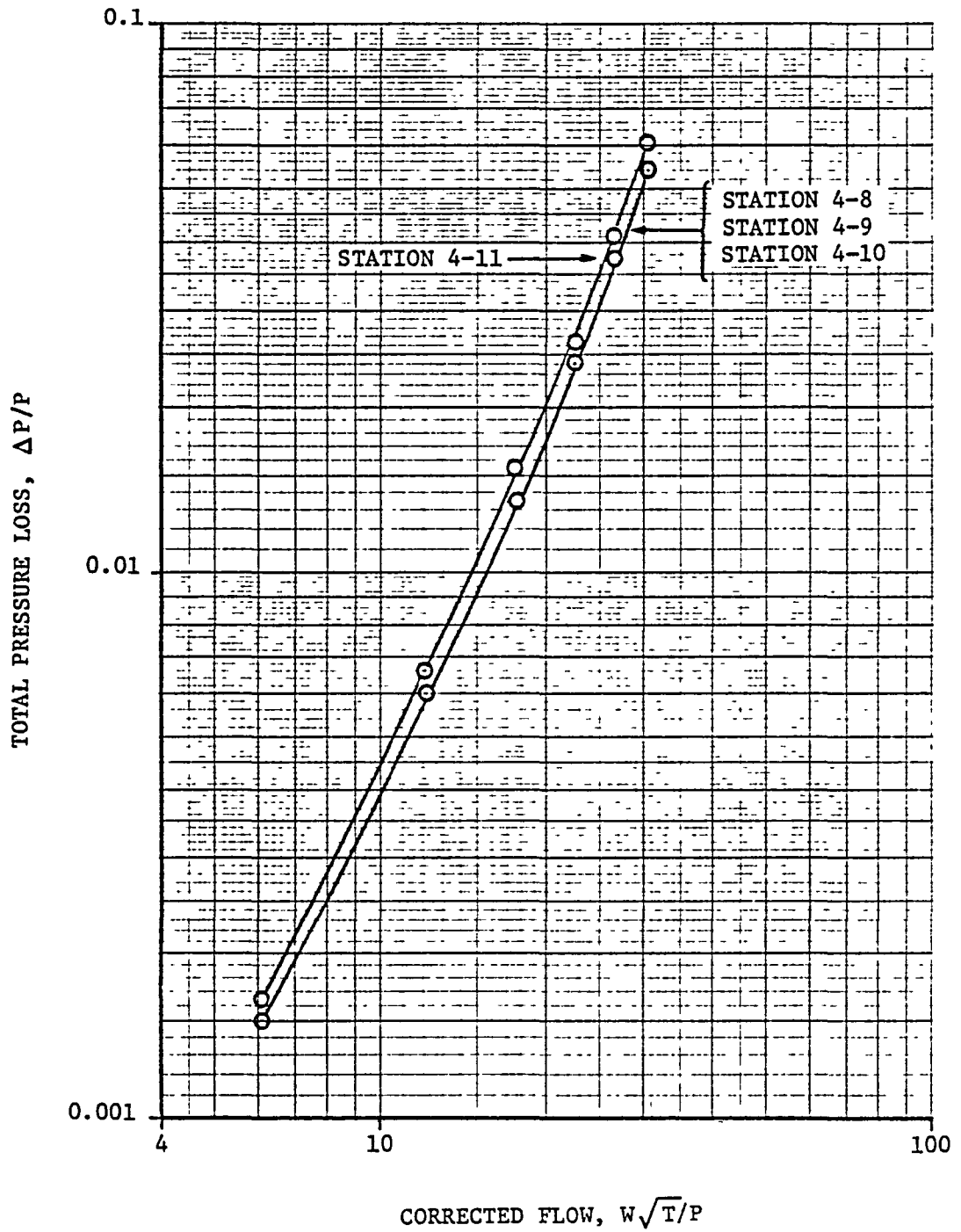


Figure A-3. Ejector Duct Pressure Loss Characteristics

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16. Abstract Requirements were established for a conceptual design study to analyze and design an engine flow diverter system and to include accommodations for an ejector system in an existing 3/4 scale fighter model equipped with YJ-79 engines. Model constraints were identified and cost-effective limited modification was proposed to accept the ejectors, ducting and flow diverter valve. General Electric furnished conceptual design for the diverter valve and its operating characteristics. General Dynamics calculated complete system performance and provided a versatile computer program capable of analyzing any ejector system.					
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