

AD-A104 072

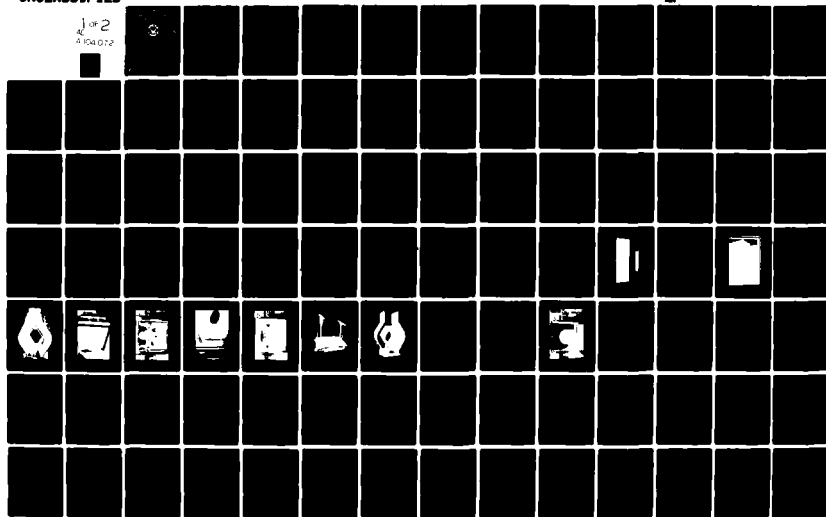
NAVAL POSTGRADUATE SCHOOL MONTEREY CA
FLOW CHARACTERISTICS OF A MULTIPLE NOZZLE EXHAUST GAS EDUCTOR S--ETC(U)
MAR 81 D L RYAN

F/8 21/2

UNCLASSIFIED

MI

1 of 2
A 104 072



AD A104072

LEVEL 1

2

NAVAL POSTGRADUATE SCHOOL
Monterey, California



DTIC
ELECTE
SEP 11 1981
H

THESIS

FLOW CHARACTERISTICS OF A MULTIPLE NOZZLE
EXHAUST GAS EDUCTOR SYSTEM

by

Dennis Leo Ryan III

March 1981

Thesis Advisor:

P.F. Pucci

Approved for public release; distribution unlimited.

DTIC FILE COPY

81 9 11 018

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
	AD-A104 072	
4. TITLE (and Subtitle)		5. TYPE OF REPORT & PERIOD COVERED
Flow Characteristics of a Multiple Nozzle Exhaust Gas Eductor System.		Master's Thesis March 1981
6. PERFORMING ORG. REPORT NUMBER		
7. AUTHOR(s)		8. CONTRACT OR GRANT NUMBER(s)
Dennis Leo/Ryan, III		
9. PERFORMING ORGANIZATION NAME AND ADDRESS		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
Naval Postgraduate School Monterey, California 93940		
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE
Naval Postgraduate School Monterey, California 93940		March 1981
13. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		14. NUMBER OF PAGES
		167
		15. SECURITY CLASS. (of this report)
		Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report)		
Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
Multiple nozzle eductor system, cold flow tests		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)		
Cold flow tests of a four nozzle eductor system were conducted to evaluate the flow characteristics of several mixing stack configurations. A previously tested mixing stack design used a plug to shield the primary flow nozzles from view. Flow visualization was used to determine the flow pattern in the stack. The results of the visualization runs were then used to modify the mixing stack geometry. The eductor system flow characteristics were evaluated		

DD FORM 1473
1 JAN 73EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Item 20: continued.

in terms of non-dimensional parameters governing the flow phenomena from a one dimensional analysis of a simple eductor system. The eductor system's pumping capacity was improved over that of the previously tested unmodified mixing stack.

Accession For	
DTIC ST/61	☒
DTIC T R	☐
Unprocessed	☐
Justification	
Revised	
Discontinued	
Available	
Unpublished	
Unpublished	
A	

Approved for public release; distribution unlimited

Flow Characteristics of a Multiple Nozzle
Exhaust Gas Eductor System

by

Dennis Leo Ryan III
Lieutenant Commander, United States Navy
B.S., United States Naval Academy, 1970

Submitted in partial fulfillment for the
requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
March 1981

Author

Dennis L. Ryan III

Approved by:

Paul J. [Signature]

Thesis Advisor

L. J. [Signature]

Second Reader

J. J. [Signature]

Chairman, Department of Mechanical Engineering

William M. [Signature]

Dean of Science and Engineering

ABSTRACT

Cold flow tests of a four nozzle eductor system were conducted to evaluate the flow characteristics of several mixing stack configurations. A previously tested mixing stack design used a plug to shield the primary flow nozzles from view. Flow visualization was used to determine the flow pattern in the stack. The results of the visualization runs were then used to modify the mixing stack geometry. The eductor system flow characteristics were evaluated in terms of non-dimensional parameters governing the flow phenomena from a one dimensional analysis of a simple eductor system. The eductor system's pumping capacity was improved over that of the previously tested unmodified mixing stack.

TABLE OF CONTENTS

I.	INTRODUCTION -----	14
II.	EDUCTOR ANALYSIS -----	19
III.	EXPERIMENTAL CORRELATION -----	20
IV.	MODEL GEOMETRIES -----	21
	A. MIXING STACK WITH PORTED AND SHROUDED PLUG -----	21
	B. CUSP MODIFICATION OF THE PLUG -----	22
	C. MIXING STACK SIDE MODIFICATION -----	23
V.	EXPERIMENTAL FACILITY -----	24
	A. PRIMARY AIR SYSTEM -----	24
	B. SECONDARY AIR PLENUM -----	26
	C. TERTIARY AIR PLENUM -----	27
	D. ALIGNMENT -----	29
	E. INSTRUMENTATION -----	29
VI.	EXPERIMENTAL METHOD -----	32
	A. PUMPING COEFFICIENTS -----	32
	B. INDUCED AIR FLOW -----	33
	C. PRESSURE DISTRIBUTIONS -----	34
	D. EXIT VELOCITY PROFILES -----	34
	E. FLOW VISUALIZATION -----	35
VII.	DISCUSSION OF EXPERIMENTAL RESULTS -----	37
VIII.	CONCLUSIONS -----	42
IX.	RECOMMENDATIONS FOR FURTHER STUDY -----	43

LIST OF REFERENCES -----	44
FIGURES -----	45
TABLES -----	99
APPENDIX A: ONE DIMENSIONAL ANALYSIS OF A SIMPLE EDUCTOR -----	140
APPENDIX B: FORMULA -----	152
APPENDIX C: DATA ACQUISITION AUTOMATION -----	155
APPENDIX D: UNCERTAINTY ANALYSIS -----	164
INITIAL DISTRIBUTION LIST -----	166

LIST OF FIGURES

FIGURE 1	Eductor Model Testing Facility -----	45
FIGURE 2	Eductor Model Testing Facility, Secondary and Tertiary Air Plenums -----	46
FIGURE 3	Schematic of Mixing Stack Eductor -----	47
FIGURE 4	Dimensional Illustration of Mixing Stack with Symmetric Plug -----	48
FIGURE 5	Schematic of Mixing Stack With Ported and Shrouded Plug -----	49
FIGURE 6	Schematic of Plug Porting Arrangement -----	50
FIGURE 7	Cusp Illustration -----	51
FIGURE 8	Dimensional Illustration of Mixing Stack With Cusp -----	52
FIGURE 9	Mixing Stack with Cusp Installed -----	53
FIGURE 10	Dimensional Illustration of Mixing Stack With Cusp and Side Modification -----	54
FIGURE 11	Mixing Stack With Cusp and Side Modification -----	55
FIGURE 12	Secondary and Tertiary Air Plenums -----	56
FIGURE 13	Tertiary Air Plenum -----	57
FIGURE 14	Mixing Stack Entrance With Air Seal -----	58
FIGURE 15	Mixing Stack Exit With Air Seal -----	59
FIGURE 16	Mixing Stack Mounting Stand -----	60
FIGURE 17	Mixing Stack With Ported Shroud -----	61
FIGURE 18	Schematic of Instrumentation -----	62
FIGURE 19	Schematic of Instrumentation for Primary Air Flow Measurement -----	63

FIGURE 20	Velocity Profile Apparatus -----	64
FIGURE 21	Example Plot of Pumping Coefficient -----	65
FIGURE 22	Schematic of Velocity Traverse Directions -----	66
FIGURE 23	Schematic of Flow Visualization Results ----	67
FIGURES 24	Experimental Pumping Coefficient a, b, c Comparisons -----	68
FIGURES 25	Experimental Film Pumping a-g Coefficient Comparisons -----	71
FIGURES 26	Axial Pressure Distribution a-1 Comparisons -----	78
FIGURES 27	Velocity Traverses -----	90
	a-i	
FIGURE A-I	Simple Single Nozzle Eductor System -----	151
FIGURE C-I	Schematic of Data Acquisition System -----	161
FIGURES C-II	Illustration of Data Acquisition -----	162
	a, b	

LIST OF TABLES

TABLES I through XVIII	Computer Output of Experimental Data -----	99
TABLE C-I	Sample Calibration Program -----	160

NOMENCLATURE

English Letter Symbols

A	- Area, in. ²
c	- Sonic velocity, ft/sec
C	- Coefficient of discharge
D	- Diameter, in.
F _a	- Thermal expansion factor
F _{fr}	- Wall skin-friction force, lbf
g _c	- Proportionality factor in Newton's Second Law, g _c = 32.174 lbm-ft/lbf-sec ²
h	- Enthalpy, Btu/lbm
k	- Ratio of specific heats
L	- Length, in.
P	- Pressure, in. H ₂ O
P _a	- Atmospheric pressure, in. Hg
P _v	- Velocity head, in. H ₂ O
PMS	- Static pressure along length of mixing stack in. H ₂ O
R	- Gas constant for air, 53.34 ft-lbf/lbm-R
s	- Entropy, Btu/lbm-R
S	- Primary dimension of mixing stack
T	- Absolute temperature, R
u	- Internal energy, Btu/lbm
U	- Velocity, ft/sec

v	- Specific volume, ft^3/lbm
W	- Mass flow rate, lbm/sec
D	- Distance from primary nozzle exit to mixing stack, in.
Y	- Expansion factor

Dimensionless Groupings

A^*	- Secondary flow area to primary flow area ratio
AR	- Area ratio
f	- Friction factor
K	- Flow coefficient
K_e	- Kinetic energy correction factor
K_m	- Momentum correction factor at the mixing stack exit
K_p	- Momentum correction factor at the primary nozzle exit
M	- Mach number
$\Delta P^* = p^*$	- Pressure coefficient
PMS^*	- Mixing stack pressure coefficient
Re	- Reynolds number
D/S	- Standoff; Ratio of distance from primary nozzles to entrance of mixing stack, (D) to primary dimension of mixing stack (S)
T^*	- Absolute temperature ratio of the secondary flow to primary flow
$T_t^* = TT^*$	- Absolute temperature ratio of the tertiary flow to primary flow
$W^* = W^*$	- Secondary mass flow rate to primary mass flow rate ratio

- $W_t^* = WT^*$ - Tertiary mass flow rate to primary mass flow rate ratio
 L/S - Ratio of distance from entrance of mixing stack to diameter of mixing stack
 σ^* - Induced flow density to primary flow density

Greek Letter Symbols

- μ - Absolute viscosity, lbf-sec/ft²
 ρ - Density, lbm/ft³

Subscripts

- 0 - Section within secondary air plenum
 1 - Section at primary nozzle exit
 2 - Section at mixing stack exit
 f - Film or wall cooling
 m - Mixed flow or mixing stack
 or - Orifice
 p - Primary
 s - Secondary
 t - Tertiary (Cooling)
 u - Uptake
 w - Mixing stack inside wall

Computer Tabulated Data and Illustrative Plots

- UPTMACH - Uptake Mach number
 PA-PS - Static pressure at mixing stack entrance,
 in. H₂O
 PA-PT - Static pressure in tertiary air plenum,
 in. H₂O

I. INTRODUCTION

With gas turbines becoming a more popular means of powering naval vessels, special considerations need to be given to their particular air breathing and exhausting characteristics. With air-fuel ratios of four to five times that of conventional steam plants and the requirement for a relatively large amount of combustion air, a large quantity of hot exhaust gas is generated. Due to gas turbine design, these exhaust gases are at temperatures significantly above those of conventionally powered ships. A few of the problems caused by these high temperatures are thermal damage to electronic equipment located on the masts of these ships, hot gas corrosion of masts and other superstructures located in the hot gas wake, and a significant infrared radiation signature created by the hot gas plume and hot external surfaces of the stack.

This thesis is an extension of research done by Ellin [Ref. 1], Moss [Ref. 2], Lemke and Staehli [Ref. 7], and Shaw [Ref. 8] to determine better geometric designs for the exhaust plenum and mixing stack system of gas turbine powered naval ships.

Ellin initiated the work by constructing an eductor model testing facility consisting of an uptake, primary flow nozzle, mixing stack, a means to control and measure the primary air flow, and a means to measure the secondary air flow; see

Figures 1 and 2. The primary air flow in the testing facility represents a gas turbine's hot exhaust gas. The secondary air flow is ambient air induced into the entrance of the mixing stack by the primary air flow; see Figure 3. From Ellin's study of multiple nozzle flow systems consisting of several identical round nozzles, it was determined that four primary flow nozzles were preferable to either three or five, and that nozzle length has little or no effect on the eductor system's overall performance. Ellin then verified the independence of the one-dimensional model correlation parameters used on flow rate or Mach number. He determined that for Mach numbers from 50% to 145% of the design Mach number of 0.064, the correlation parameters suggested in the one-dimensional analysis did in fact provide a good correlation of the data.

Moss' work followed, and it initially consisted of verifying the one-dimensional analysis as did Ellin. He then tested the effect of the stand-off distance (that distance between the exit plane of the primary flow nozzles and the entrance plane of the mixing stack). For the primary flow nozzles he tested, Moss determined that the optimum stand-off distance for maximum eductor pumping was a distance equal to 0.5 diameters ($0.5D_m$) of the mixing stack. An independent investigation of this, conducted by Harrel [Ref. 3], confirmed Moss' findings. Moss then investigated the effects of a conical transition placed on the entrance to the mixing stack.

He concluded that a straight mixing stack without an entrance transition provided a better system performance.

The study conducted by Lemke and Staehli [Ref. 7] investigated the effects on the eductor system's overall performance of varying the geometric configuration of the mixing stack and changing the area of the primary flow nozzles. Their work showed that a decrease in the ratio of the area of the mixing stack to primary flow nozzles from 3.0 to 2.5 decreased uptake back pressure but reduced the pumping coefficient of the eductor. Lemke and Staehli then investigated the effects of a solid diffuser, a two-ring and a three-ring diffuser. The results of these tests showed a decrease in uptake back pressure and a improvement in the eductor's pumping capacity. They then performed tests on a ported mixing stack. Their work determined that significant air flow through the ports could provide film cooling on the inside of the mixing stack. To enhance the film cooling provided by the ported mixing stack, Lemke and Staehli placed a shroud around the mixing stack. This shroud did not degrade the pumping or mixing characteristics, yet it provided thermal shielding of the mixing stack. Their final configuration was a combination of the ported mixing stack with flow through shroud and diffuser. Lemke and Staehli concluded that this geometric configuration, combined with a ratio of the area of the mixing stack to the primary flow nozzles 3.0, provided the best system overall performance.

The work done by Shaw [Ref. 8] concentrated on a method to further reduce the infrared signature of the mixing stack. Of particular concern was the concealment of the hot primary flow nozzles from an overhead view. Using the results of Lemke and Staehli, Shaw designed a rectangular mixing stack with an internal symmetric plug, Figure 4. The internal plug, which shields the primary nozzles from direct view, is cooled by two means. The plug was ported, to provide film cooling along the exhaust gas side of the device. Also, the plug was shrouded (on the non-exhaust gas side) to direct the flow of cooling air to the ports and provide a means of convectively cooling the downstream half of the plug, see Figure 5. Shaw found that the rectangular mixing stack with plug increased the system back pressure and reduced the pumping capacity of the eductor. He also determined that the design and placement of the plug improved mixing of the exhaust gases with the secondary cooling air and that the plug provided a potential means of presenting a cool surface to view.

Based upon the conclusions and recommendations of Shaw, it was decided that geometric changes in the eductor should be investigated in order to lessen the penalties involved with plug installation. These changes will be described in detail in Section IV.

Evaluation of eductor system performance was measured in four areas: the amount of secondary air flow induced by the primary air flow, the degree of mixing of primary and induced

air flows within the mixing stack system, the amount of uptake back pressure impressed upon the turbine exhaust by the eductor system, and the amount of wall cooling air available to reduce the exterior stack temperature of the eductor system. Additionally, a qualitative indication of the flow patterns in the mixing stack was obtained through flow visualization.

The key factor which allows cold flow testing to predict the effects of a hot gas eductor system is the similarity of the momentum and energy transfer mechanisms in turbulent flows.

II. EDUCTOR ANALYSIS

This investigation, being an extension of the work of Shaw [Ref. 8], and others [Ref. 1, 2, and 7]; uses the same one-dimensional analysis to model the eductor system. This one-dimensional analysis is given in Appendix A. As a result of this analysis, dimensionless parameters controlling the phenomena are obtained which are then used in the correlation of experimental data. Three such dimensionless groups used are:

$$\Delta P^* = \frac{\frac{P_a - P_{os}}{\rho_s}}{\frac{U_p^2}{2g_c}}$$

a pressure coefficient which compares the pumped head $P_a - P_{os}$ to the driving head U_p^2 of the primary flow

$$W^* = \frac{W_s}{W_p}$$

a flow rate ratio, secondary to primary mass flow rate

$$T^* = \frac{T_s}{T_p}$$

an absolute temperature ratio, secondary to primary

III. EXPERIMENTAL CORRELATION

For the geometries and flow rates investigated, it was confirmed by Ellin and Moss that a satisfactory correlation of the variables P^* , T^* , and W^* takes the form

$$\frac{\Delta P^*}{T^*} = \phi(W^* T^{*n}) \quad (1)$$

where the exponent n is determined to be equal to 0.44. The details of the determination of 0.44 as the correlating exponent for the geometric parameters of the models tested is given in Reference [1]. To obtain an eductor model's pumping characteristic curve, the experimental data is correlated and analyzed using equation (1) that is P^*/T^* is plotted as a function of $W^* T^{*0.44}$. This correlation is used to predict the open to the environment operating point. Variations in the eductor model's geometry will change the appearance of the pumping ability between models. For ease of discussion, $W^* T^{*0.44}$ will henceforth be referred to as the pumping coefficient. Similarly, $W^* T^* T^{*0.44}$ will be referred to as the film cooling or tertiary pumping coefficient.

IV. MODEL GEOMETRIES

The multiple nozzle eductor systems studied here are designed specifically for service onboard gas turbine powered ships. The model consisted of a single primary uptake, a single cluster of four primary nozzles of constant cross section, and a mixing stack.

A. MIXING STACK WITH PORTED AND SHROUDED PLUG

The eductor mixing stack as designed by Shaw with its tertiary air flow cooling ports and associated plug shrouding provided the base design for the initiation of this study. Shaw's design utilized a symmetric plug to shield the hot primary exhaust nozzles from direct view. The initial design by Shaw is illustrated in Figure 4. He then provided two means of cooling the surfaces of the plug that were exposed to direct view. The first method provides film cooling along both sides of the downstream half of the plug. The film cooling air is induced through three sets of ports located as illustrated in Figure 5. The dimensional configuration of the ports is shown in Figure 6. The second means of cooling the plug provides an air flow to convectively cool the downstream half of the plug. This is accomplished with a shroud that directs a flow of air along the backside of the plug before it is pulled through the ports to be used

for film cooling. This flow of air is called tertiary air flow and is illustrated in Figure 5.

B. CUSP MODIFICATION OF THE PLUG

The symmetric design of the plug was modified by the addition of a cusp on the exhaust gas inlet side in order to provide a more uniform and gradual direction of the gas flow about the plug and to physically separate the flow into two symmetric parts. The cusp addition is picture in Figures 7 and 9 and dimensionally illustrated in Figure 8. The cusp was manufactured from 0.102 cm (0.04 in) thick sheet aluminum. Each side of the cusp was formed to a concave shape with a 24.77 cm (9.75 in) radius of curvature. Axial supports were soldered on the inside of the cusp to prevent warpage. The cusp was then glued over the inlet end of the plug. The apex of the cusp was aligned on the cross-sectional centerline of the mixing stack to maintain symmetry of the flow about each half of the mixing stack. The apex of the cusp extended upstream toward the entrance of mixing stack 7.11 cm (2.8 in) along the axial centerline from the end of the plug. The lip formed where the edges of the cusp met the plug was filled in with putty to provide a smooth surface. The corners between the cusp and the sides of the mixing stack were sealed with silicone epoxy to minimize leakage.

C. MIXING STACK SIDE MODIFICATION

The second geometric modification to Shaw's design changed the shape of the curved sides of the mixing stack. In Shaw's original design, at the position where the two air flows around the plug reconverged, the sides of the mixing stack had a 137 degree angle bend into the final exit duct portion (see Figure 5). This point was 48.59 cm (19.13 in) from the entrance of the stack. This sharp corner was removed from the stack by installing a curved side beginning at a point 43.18 cm (17.0 in) from the stack entrance. The radius of curvature of the new piece was 43.18 cm (17 in). The new sides were also made of .102 cm (.04 in) sheet aluminum. Edges formed where the new section was fitted into the mixing stack were filled in with putty to maintain a smooth surface. The mixing stack with the side modification is dimensionally shown in Figure 10. The picture in Figure 11 highlights the area changed by the side modification and cusp addition.

V. EXPERIMENTAL FACILITY

Air is supplied to the primary nozzles by means of a centrifugal compressor and associated ducting schematically illustrated in Figure 1. The mixing stack configuration being tested is placed inside an air plenum containing an airtight partition so that two separate air flows, secondary and tertiary, may be measured. The air plenum facilitates the accurate measurement of secondary and tertiary air flows by using ASME long radius flow nozzles.

A. PRIMARY AIR SYSTEM

The circled numbers found in this section refer to locations on Figure 1. The primary air ducting is constructed of 16-gage steel with 0.635 cm (0.25 in) thick steel flanges. The ducting sections were assembled using 0.635 cm (0.25 in) bolts with air drying silicone rubber seals between the flanges of adjacent sections. Entrance to the inlet ducting ① is from the exterior of the building through a 91.44 cm (3.0 ft) square to a 30.48 cm (1.0 ft) square reducer, each side of which has the curvature of a quarter ellipse. A transition section ② then changes the 30.48 cm (1.0 ft) square section to a 35.31 cm (13.90 in) diameter circular section ③. This circular section runs approximately 9.14 m (30 ft) to the centrifugal compressor inlet.

A standard ASME square edged orifice (4) is located 15 diameters downstream of the entrance reducer and 11 diameters upstream of the centrifugal compressor inlet, thus insuring stability of flow at both the orifice and compressor inlet. Piezometer rings (5) are located one diameter upstream and one-half diameter downstream of the orifice. The duct section also contains a thermocouple just downstream of the orifice. Primary flow is measured by means of the standard ASME square edged orifice designed to the specifications given in the ASME power test code [Ref. 5]. The 17.55 cm (6.902 in) diameter orifice used was constructed out of 304 stainless steel 0.635 cm (0.25 in) thick. The inside diameter of the duct at the orifice is 35.31 cm (13.90 in) which yields a beta ($\beta = d/D$) of 0.497. The orifice diameter was chosen to give the best performance in regard to pressure drop and pressure loss across the orifice for the primary air flow rate used (1.71 Kg/sec (3.77 lbm/sec)).

The centrifugal compressor 7 used to provide primary air to the system is a Spencer Turbo Compressor, catalogue number 25100-H, rated at 6000 cfm at 2.5 psi back pressure. The compressor is driven by a three phase, 440 volt, 100 horsepower motor.

A manually operated sliding plate variable orifice (6) was designed to constrict the flow symmetrically and facilitate fine control of the primary air flow. During operation, the butterfly valve (8), located at the compressor's

discharge, provided adequate regulation of primary air flow, eliminating the necessity of using the sliding plate valve. The sliding plate valve was positioned in the wide-open position for all data runs.

On the compressor discharge side, immediately downstream of the butterfly valve, is a round to square transition (9) followed by a 90 degree elbow (10) and a straight section of duct. All ducting to this point is considered part of the fixed primary air supply system. A transition section is fitted to this last square section which reduces the duct cross section to a circular section 29.72 cm (11.17 in) in diameter. This circular ducting tapers down to a diameter of 26.30 cm (11.5 in) to provide the primary air inlet to the eductor system being tested. The transition is located far enough upstream of the model to insure that the flow reaching the model is fully developed.

B. SECONDARY AIR PLENUM

The secondary air plenum, pictured in Figure 1 and 2, is constructed of 1.905 cm (0.75 in) plywood and measures 1.22 m by 1.22 m by 1.88 m (4 ft by 4 ft by 6.17 ft). It serves as an enclosure that can contain all or only part of the eductor model and still allow the exit plane of the mixing stack to protrude. The purpose of the secondary air plenum is to serve as a boundary through which secondary air for the eductor system must flow. Long radius ASME flow nozzles,

designed in accordance with ASME power test codes [Ref. 5] and constructed of fiberglass, penetrate the secondary air plenum, thereby providing the sole means for metering the secondary air reaching the eductor. Appendix D of Reference [1] outlines the design and construction of the secondary air flow nozzles. By measuring the temperature of the air entering and the pressure differential across the ASME flow nozzles, the mass flow rate of secondary air can be determined. Flexibility is provided in measurement of the mass flow rate of secondary air by employing flow nozzles with three different throat diameters: 20.32 cm (8 in), 10.16 cm (4 in), and 5.08 cm (2 in). By using a combination of flow nozzles, a wide variety of secondary cross sectional areas can be obtained.

A secondary air flow straightener, shown in Figures 1 and 2, consisting of a double screen is installed 1.22 m (4 ft) from the open end of the secondary air plenum, between the ASME long radius nozzles and the primary air flow nozzles. The purpose of the straightener is to reduce any swirl effect that could result when only a small secondary air flow area exists.

C. TERTIARY AIR PLENUM

The tertiary air plenum, pictured in Figures 12 and 13, is constructed of 1.90 cm (0.75 in) plywood and measure 1.22 m by 1.22 m by 1.22 m (4ft by 4 ft by 4 ft). It serves as

an enclosure that completely surrounds the mixing stack and allows the exit and entrance regions to protrude. An airtight rubber diaphragm type seal, schematically illustrated in Figure 2 and pictured in Figures 14 and 15, is located at each end of the enclosure. This allows measurement of a tertiary air flow independent of the secondary air flow. Tertiary air flow is measured with the use of long radius ASME flow nozzles designed in accordance with ASME test codes [Ref. 5] and constructed of fiberglass. These nozzles are located so that they penetrate the airtight tertiary air plenum, thereby providing the sole means for metering the tertiary air reaching the eductor. By measuring the temperature of the air entering and the pressure differential across the ASME flow nozzles, the mass flow rate of tertiary air can easily be obtained. Flexibility in measuring the tertiary flow is provided by employing different size flow nozzles: two of 20.32 cm (8 in) throat diameter, three of 10.16 cm (4 in) throat diameter, and two of 5.08 cm (2 in) throat diameter. By using various combinations of these flow nozzles, a wide variety of tertiary cross section flow areas can be obtained.

The interior of the tertiary air plenum is pictured in Figure 13. The stand which holds the mixing stack can be seen mounted inside the plenum. Figure 15 shows the diaphragm air seal at the exit plane of the mixing stack. As can be seen, removable sections were located in the exit plane

door to allow for adjustments to the mixing stack and instrumentation without removing the diaphragms.

D. ALIGNMENT

The alignment of the mixing stack with the primary air flow nozzles was accomplished using a level, a 30.78 (12.0 in) rule graduated in 0.25 mm (0.01 in) and 45.72 x 30.48 cm (18.0 x 12.0 in) square. The graduated rule and square were to establish the stand-off distance (D/S) and to center the primary flow nozzles within the entrance area of the mixing stack. The geometric alignment was checked for accuracy using pressure readings at symmetric points on the model. Additional verification was obtained by subsequent symmetric exit velocity profiles measurements. The three axis mounting stand, pictured in Figure 16 allowed alignment adjustments to be performed easily.

E. INSTRUMENTATION

Pressure taps for measuring gage pressures are located inside the primary air uptakes just prior to the primary nozzles, inside the secondary air plenum, inside the tertiary air plenum, and at various points on the model. A variety of manometers, pictured in Figure 17, were used to indicate the pressure differentials. A schematic representation of the pressure measuring instrumentation is illustrated in Figures 18 and 19. Monitoring of each of the various pressures was facilitated by the use of a scanivalve and a

multiple valve manifold. The scanivalve was used to select the pressure tap to be read, while the multiple valve manifold allowed selection of the optimum manometer for the pressure being recorded. A vent was included in the multiple valve manifold which provided a means of venting the manometers between pressure readings. When taking readings of the pressure distribution in the mixing stack, it was necessary to manually change the tubing from one end of the manometer to the other in order to get the negative pressure readings. The valve manifold provided a selection of a 15.24 cm (6.0 in) inclined water manometer, a 5.08 cm (2.0 in) inclined water manometer, and a 1.27 cm (0.5 in) inclined oil manometer (specific gravity 0.827). In addition, the following dedicated manometers were used in the system: a 50.80 cm (20 in) single column water manometer connected to the primary air flow just prior to the primary nozzles, a 1.27 cm (50 in) U-tube water manometer with each leg connected to a piezometric ring on either side of the orifice plate in the air inlet duct, and a 2.54 cm (1.0 in) inclined water manometer connected to the upstream piezometric ring.

Primary air temperatures, measured at the orifice outlet and just prior to the primary nozzles, are measured with copper-constantan thermocouples. The thermocouples are in assemblies manufactured by Honeywell under the trade name Megapak. Polyvinyl covered 20 gage copper-constantan extension wire is used to connect the thermocouples to a

Newport Digital Pyrometer, model number 267, which provides a digital display of the measured temperature in degrees Fahrenheit. The Newport Digital Pyrometer failed in use and was replaced by an Omega Digital Thermometer, Model Number 2176A. Secondary/tertiary ambient air temperature is measured with a mercury-glass thermometer and recorded in degrees Fahrenheit.

Velocity profiles at the mixing stack exit plane are obtained by using a pitot tube, pictured in Figure 20. The tube is affixed to a mounting template which allows accurate determination of the major axis, minor axis, minor and diagonal positions and distances. Alignment pins allow changes in velocity traverse directions to be made fast and accurately. The pitot tube is used in conjunction with the 15.24 cm (6 in) inclined water manometer for obtaining the velocity pressure head.

An additional objective of this research was to assemble an automated data acquisition system. The data which was used in this thesis was taken "manually", i.e., pressure and temperature values visually acquired from manometer and thermometer. Each piece of data was then inputted into a computer for reduction. Although equipment limitation prevented full automation, "semi-automatic" data acquisition now exists and is described in Appendix B.

VI. EXPERIMENTAL METHOD

Evaluation of the eductor model requires the experimental determination of pressure differentials across the ASME long radius flow nozzles, temperature of primary and induced air flows, internal mixing stack pressures, and mixing stack exit velocities. These experimentally determined quantities are then reduced to obtain pumping coefficients, induced air flow rates, pressure distributions within the mixing stack, and mixing stack exit velocity profiles. In addition an indication of flow behavior in the stack was accomplished by flow visualization. The performance characteristics of the eductor model are then evaluated to determine the model's relative effectiveness.

The following discussion addresses the individual performance characteristics of the eductor model and how they were determined.

A. PUMPING COEFFICIENTS

The secondary pumping coefficient and the tertiary pumping coefficient provide the basis for analysis of the eductor model's pumping performance. Thus, changes in eductor model parameters which affect pumping can be noted by a change in pumping coefficient. The pumping coefficient(s) is desired at the operating point corresponding to that of the ship-board prototype. At this point there is no restriction of

the secondary (or tertiary) air flow. In the model, this is simulated by completely opening the air plenum(s) to the environment. However, at this condition, the secondary (or tertiary) air flow rate cannot be measured. Therefore, the eductor's characteristics are determined, plotted, and then extrapolated to find the operating point, see Figure 21.

The pumping characteristics of the eductor model are established by varying the associated induced air flow rate, either secondary or tertiary, from zero to its maximum measurable rate. This rate is determined by sequentially opening the ASME flow nozzles mounted in the appropriate plenum and recording the pressure drop across the nozzles. Values for nozzle cross sectional area, pressure drop, and induced air temperature are then used to calculate the dimensionless parameters P^*/T^* and $W^*T^{*0.44}$ or PT^*/TT^* and $WT^*TT^{*0.44}$ as described in Appendix A. The dimensionless parameters are then plotted as illustrated in Figure 21. Extrapolation of the pumping characteristics curve to intersect with the zero pressure/temperature coefficient abscissa locates the appropriate operating point coefficient of the model.

B. INDUCED AIR FLOWS

Two induced air flows are identified in this study: secondary and tertiary.

The secondary air flow is the amount of air induced by the primary nozzles which mixed with the primary air flow to reduce the exhaust gas temperature.

The tertiary air flow indicates the amount of air induced by the stack pressure distribution to provide cooling air through the ports in the stack plug. In addition to the method of metering tertiary air flow as described in Section III, the effect on the tertiary pumping coefficient by varying the number of rows of cooling ports open, see Figure 6, was investigated.

C. PRESSURE DISTRIBUTIONS

The mixing stack axial static pressure was obtained using a series of pressure taps fixed to the mixing stack. These taps were placed in two axial rows, the rows being along the centerline of the flow. Along each row the taps were axially spaced in increments of one quarter primary dimension. The exact location of the pressure taps is indicated on Figure 2 and 4. The non-dimensional stack pressure, PMS^* , (see Appendix A) is plotted versus X/S to obtain a mixing stack pressure distribution, see Figures 26a through 26l.

D. EXIT VELOCITY PROFILES

Velocity profiles at the mixing stack exit were calculated from the pressures measured using the pitot tube pictured in Figure 20. Since it was impractical to obtain a complete three-dimensional plot of velocities at the exit plane of

the mixing stack, advantage was taken of the symmetry of the velocity surface resulting from the arrangement of the primary nozzles. Only three traverses were made. The first traverse passes vertically along the centerline down the mixing stack exit, the second traverse passes horizontally across the mixing stack. This traverse, along the centerline, passes across the top of the plug. The third traverse passes diagonally through the intersection of the centerlines. Figure 22 illustrates the orientation and identification of the three velocity traverses, while Figures 27a through i, show plots of the velocity traverses.

E. FLOW VISUALIZATION

Based upon Shaw's results it was felt necessary to obtain a visual indication of the flow patterns in the mixing stack. Visualization of flow was accomplished by using string or yarn placed in the flow stream. Two procedures were used. The first utilized a string the length of the mixing stack. With this string the shape of the air stream flow throughout the entire mixing stack could be seen. The second procedure involved the insertion of a probe with a small string attached to the end of it into the mixing stack. With this procedure it was very easy to investigate specific location within the stack for flow action, particularly for transition regions from positive to negative pressure. In order to record the flow visualizations it was necessary to

use a 16 mm motion picture camera set for a speed of 60 frames per second.

VII. DISCUSSION OF EXPERIMENTAL RESULTS

Exhaust eductor systems designed for marine gas turbine applications must substantially cool exhaust gases, present an exterior stack surface temperature which will not give an easily detectable infrared signature, and effectively disburse exhaust gases. In order to quantitatively evaluate the overall eductor model performance, four areas of performance were identified: the amount of secondary air flow induced by the primary air flow, referred to here as pumping; the degree of mixing of primary and induced air flow within the mixing stack system, referred to here as mixing; the amount of uptake back pressure impressed upon the turbine exhaust by the eductor system; and the amount of cooling air available to reduce the exterior stack temperature of the eductor system. A qualitative means of assessing flow patterns in the mixing stack was accomplished by flow visualization with string placed in the gas flow regions.

The eductor model and its modified configurations in this study were designed to shield the primary flow nozzles from an overhead view and to provide cooling to those surfaces which are visible from above.

The initial tests performed were for flow visualization. The tests showed the following condition within the mixing stack. First there appeared to be large scale turbulence

within the stack. This was demonstrated by the wide range of travel of a string running the length of the stack. Secondly, there was evidence of some sort of reverse flow, probably a vortex formation on the downstream sides of the plug. Finally, there was a demonstration of flow oscillatory interaction at the outlet end of the plug. The range of motions of the strings in the flow is shown in Figure 23.

Further model testing was conducted using an eductor model with the addition of a cusp on the inlet end of the symmetric plug. The tests were conducted with a primary flow nozzle area to mixing stack area ratio of 3.0, a mixing stack length L/S of 3.0 and a standoff distance D/S of 0.5. These ratios of mixing stack length, standoff distance and primary nozzle to mixing stack area were used as a result of the previous study by Shaw [Ref. 8]. The results of this first set of eductor system tests are shown in Tables I through XIII.

These tests showed the following results. First, the uptake back pressure, over the variation in secondary and tertiary flows tested, showed a reduction of up to .5 inches of H_2O . However, at the operating point of the eductor system (secondary and tertiary areas wide open) the back pressure was the same as Shaw's 9.85 inches of H_2O . This uptake back pressure may be too high and would impact on the turbine efficiency. Secondly, the eductor model pumping coefficient was improved by approximately sixteen percent

over that of Shaw. Figure 24a demonstrates that with Shaw's design the pumping coefficient at the operating point would be less than 0.3. With the addition of the cusp alone, the pumping coefficient is increased above 0.35. Finally, the velocity profiles in all three direction; vertical, horizontal, and diagonal showed little change from Shaw's data. On the average these profiles were relatively flat. These velocity traverses are depicted in Figures 17a through 27i.

The next mixing stack modification was the replacement of a sharp corner in the sides with a curved section that smoothly transitioned from the ducting over the plug to the exit ducting. The results of the tests performed after this modification are tabulated in Tables XIII through XVIII.

Initial comparisons of data were with the back pressures obtained. Over the ranges of secondary and tertiary flow combinations the back pressures increased over those values recorded for the cusp only addition. However, at the wide open operating point the back pressure was the same as that with the cusp only and with Shaw's data, 9.85 inches of H_2O . With the addition of the side modification the pumping coefficient, over the range of flows used, was reduced from those values obtained without the side modification (see Figure 24c). The pumping coefficients at the operating point without and with the side modification were essentially the same. Finally, the velocity profiles in all three directions showed more variation with the side modification

than previously. However, in the aggregate these profiles were still relatively flat. These traverses are in Figures 27g, h and i.

The following observations were made in comparing the cooling (tertiary) pumping coefficients ($WT*TT^{0.44}$). Concomitant with an increase or decrease in secondary pumping coefficient was an inverse action with the tertiary pumping coefficient. The addition of the cusp decreased the tertiary pumping coefficient from .060, the value obtained by Shaw, by approximately 33% to .040 (see Figure 25c). Over the ranges of flow combinations tested the addition of the side modification improved the tertiary pumping coefficient. At the operating point the values of the tertiary pumping coefficients for with and without the side modification essentially converged. These results are displayed in Figures 25a through 25g.

It was further noted that decreasing the number of tertiary ports open had the effect of increasing the secondary pumping coefficient and consequently decreasing the tertiary pumping coefficient.

The final indicator looked at was the pressure distribution in the mixing stack. The data obtained was essentially unchanged from that of Shaw's. Positive pressures occurred along the exterior curved surface of the mixing stack. As with Shaw, a large negative pressure (PMS^*) = - 0.30, occurs at the junction of the curved surface and

the rectangular mixing stack exit plane. It was noted that with the addition of the cusp only, this large negative pressure (PMS*) increased to a value of -0.35 (Figure 26a). With the further modification of the curved side the large negative pressure was significantly reduced to -.15, a value much less than Shaw's (Figure 26i). No significant pressures were noted along the flat surface of the mixing stack.

VI. CONCLUSIONS

This investigation studied the effects on the eductor system's overall performance of a mixing stack geometry which has a rectangular cross-section and employs a plug placed over the primary flow nozzles. The plug was modified with the addition of a cusp on the inlet end. The sides of the mixing stack was further modified to remove a sharp corner.

The conclusions resulting from this investigation are given here.

1. The addition of the cusp on the plug increased the secondary pumping coefficient and increased a negative pressure at a point within the mixing stack.
2. The addition of the cusp reduced the tertiary cooling pumping coefficient.
3. The modification of the sides of the mixing stack reduced the negative pressure at the specific point within the mixing stack.
4. The modification to the curved side of the mixing stack did not improve the performance of the eductor system and should be removed.

VII. RECOMMENDATIONS FOR FURTHER STUDY

This study showed the effects on a specific eductor system with several geometric configurations. This research adds some information to the overall data base upon which further research can be conducted. Recommendations for further investigation of this eductor system are presented here.

1. Further explore the flow patterns within the stack using tufting or some other flow visualization process.
2. Test the eductor model with the following modifications: remove the side modification, add an exterior shroud to the mixing stack and add a diffuser configuration to the exit plane of the mixing stack.

LIST OF REFERENCES

1. Ellin, C.R., Model Test of Multiple Nozzle Exhaust Gas Eductor Systems for Gas Turbine Powered Ships, Engineer's Thesis, Naval Postgraduate School, June 1977.
2. Moss, C.M., Effects of Several Geometric Parameters on the Performance of A Multiple Nozzle Eductor System, Master's Thesis, Naval Postgraduate School, September 1977.
3. Harrell, J.P. Jr., Experimentally Determined Effects of Eductor Geometry on the Performance of Exhaust Gas Eductors for Gas Turbine Powered Ships, Engineer's Thesis, Naval Postgraduate School, September 1977.
4. Pucci, P.F., Simple Eductor Design Parameters, Ph.D. Thesis, Stanford University, September 1954.
5. American Society of Mechanical Engineers Interim Supplement 19.5 on Instrumentation and Apparatus, Fluid Meters, Sixth edition, 1971.
6. Kline, S.J. and McClintock, F.A., "Describing Uncertainties in Single-Sample Experiments," Mechanical Engineering, p. 3-8, January 1953.
7. Lemke, R.J. and Staehli, C.P., Performance of Multiple Nozzle Eductor Systems with Several Geometric Configurations, Master's Thesis, Naval Postgraduate School, September 1978.
8. Shaw, R.S., Performance of a Multiple Nozzle Exhaust Gas Eductor System for Gas Turbine Powered Ships, Master's Thesis, Naval Postgraduate School, December 1980.

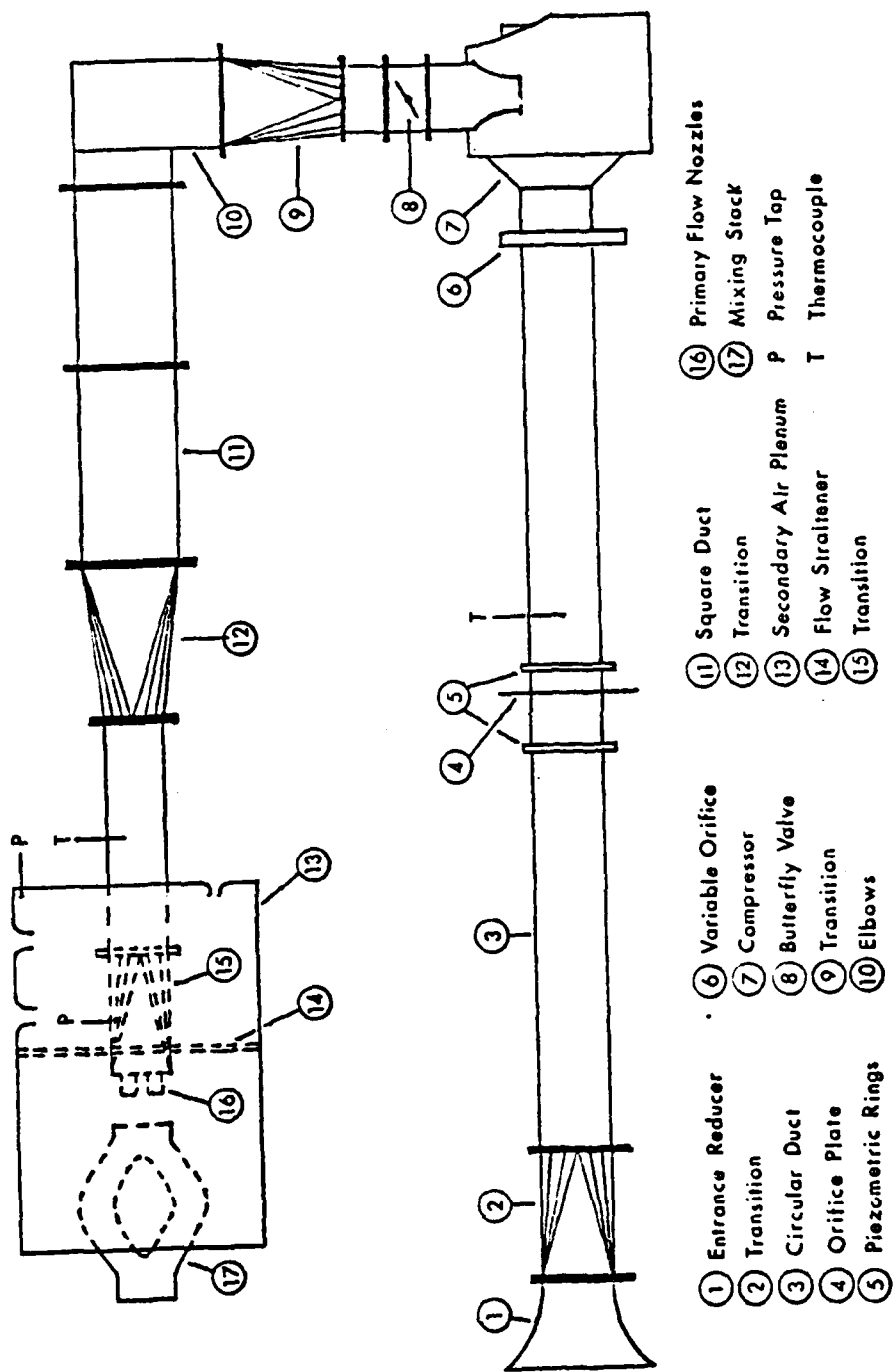


FIGURE 1. EDUCTOR MODEL TESTING FACILITY

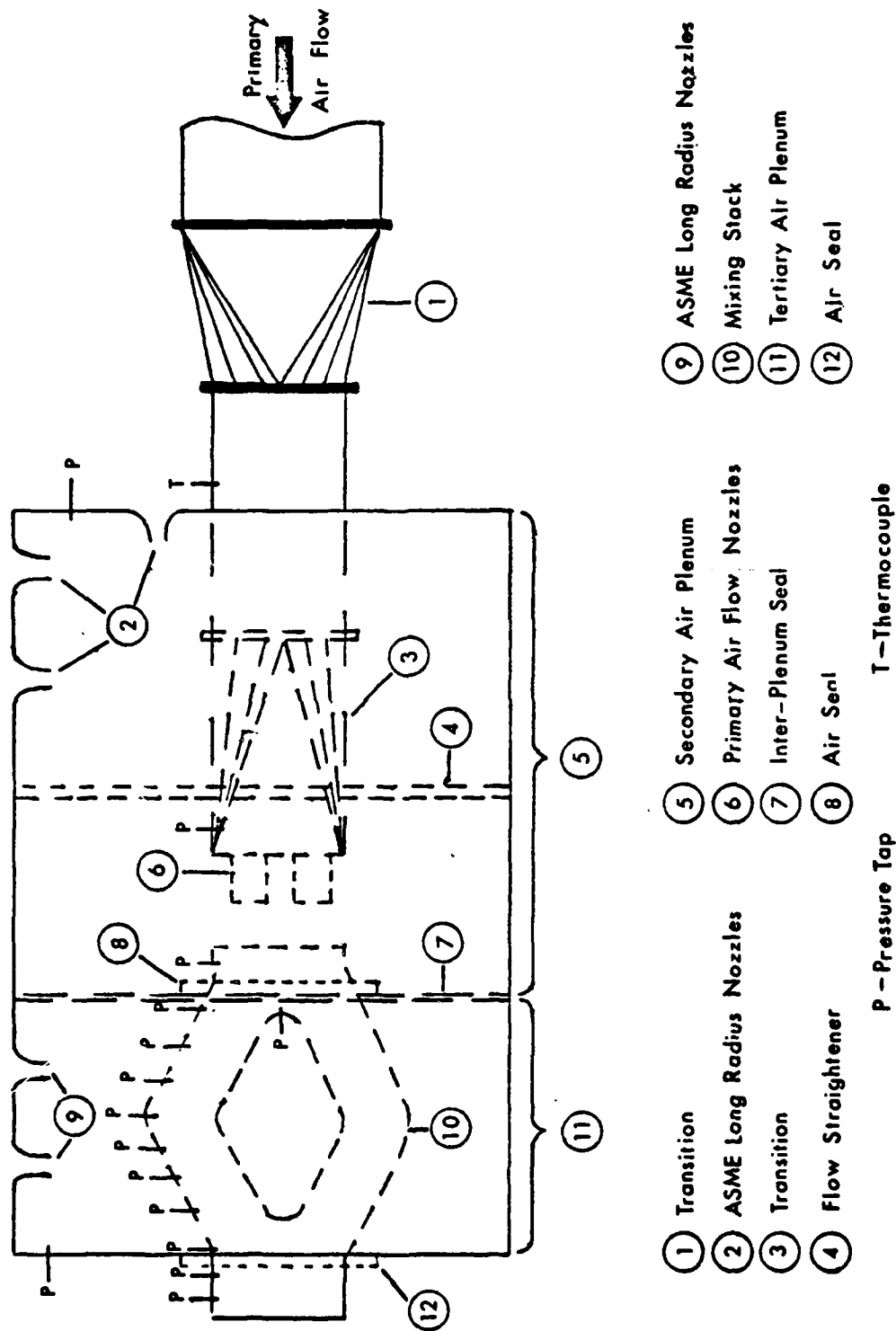


FIGURE 2. EDUCTOR MODEL WITH SECONDARY AND TERTIARY PLENUMS

S - Mixing Stack Primary Dimension

L - Mixing Stack Length

D - Stand Off Distance

l - Nozzle Length

P - Symmetric Plug Length

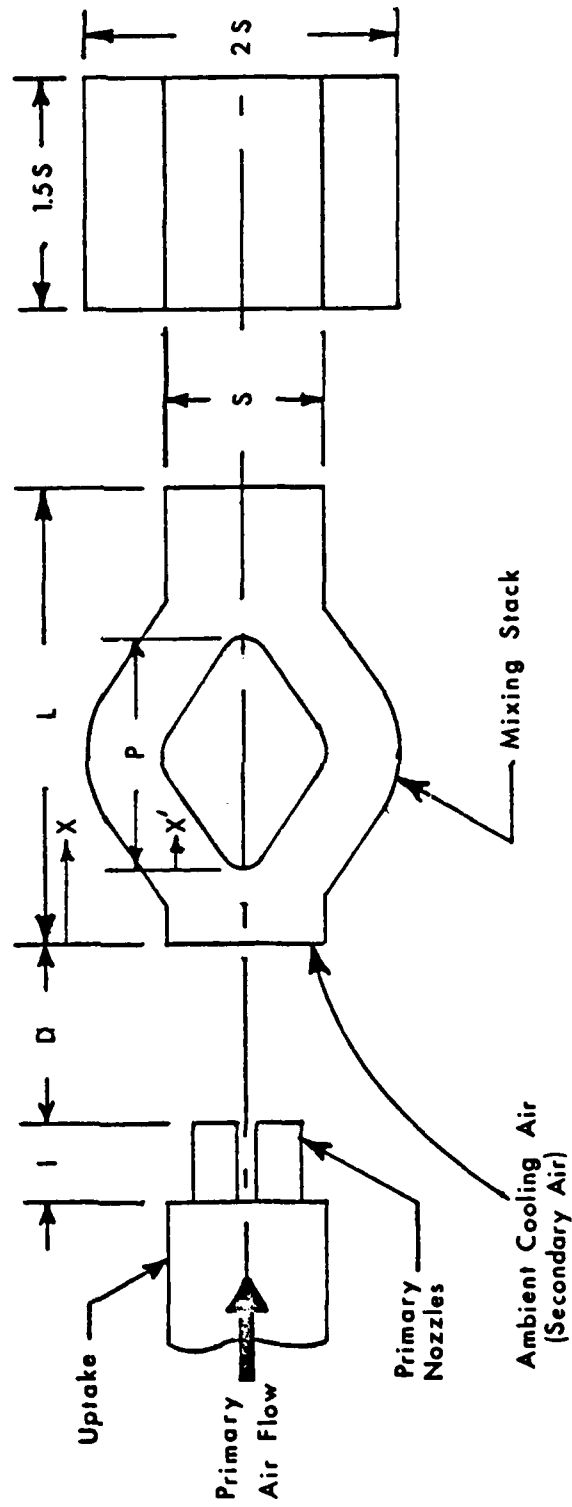


FIGURE 3. SCHEMATIC OF MIXING STACK EDUCTOR

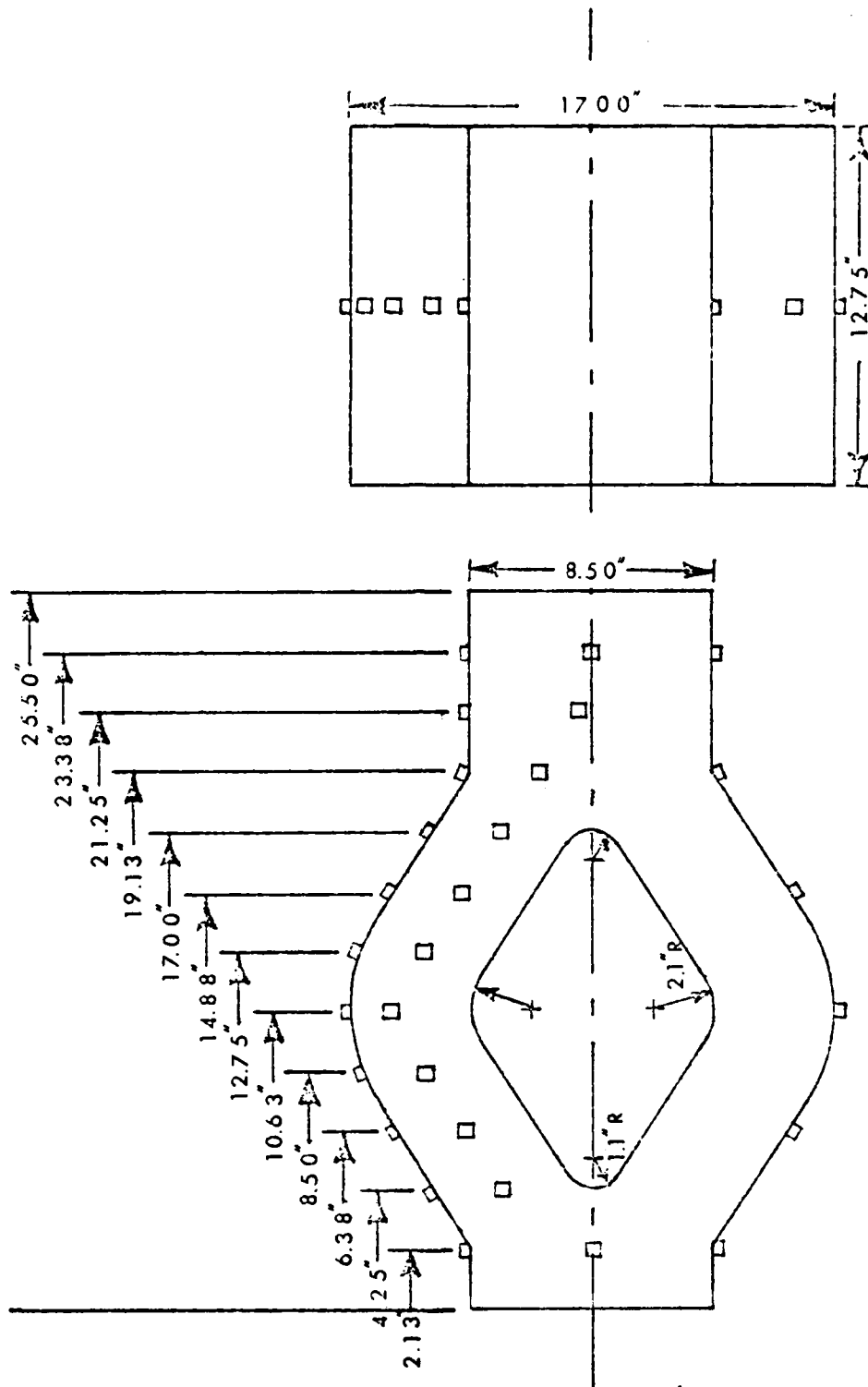


FIGURE 4. MIXING STACK WITH SYMMETRIC PLUG

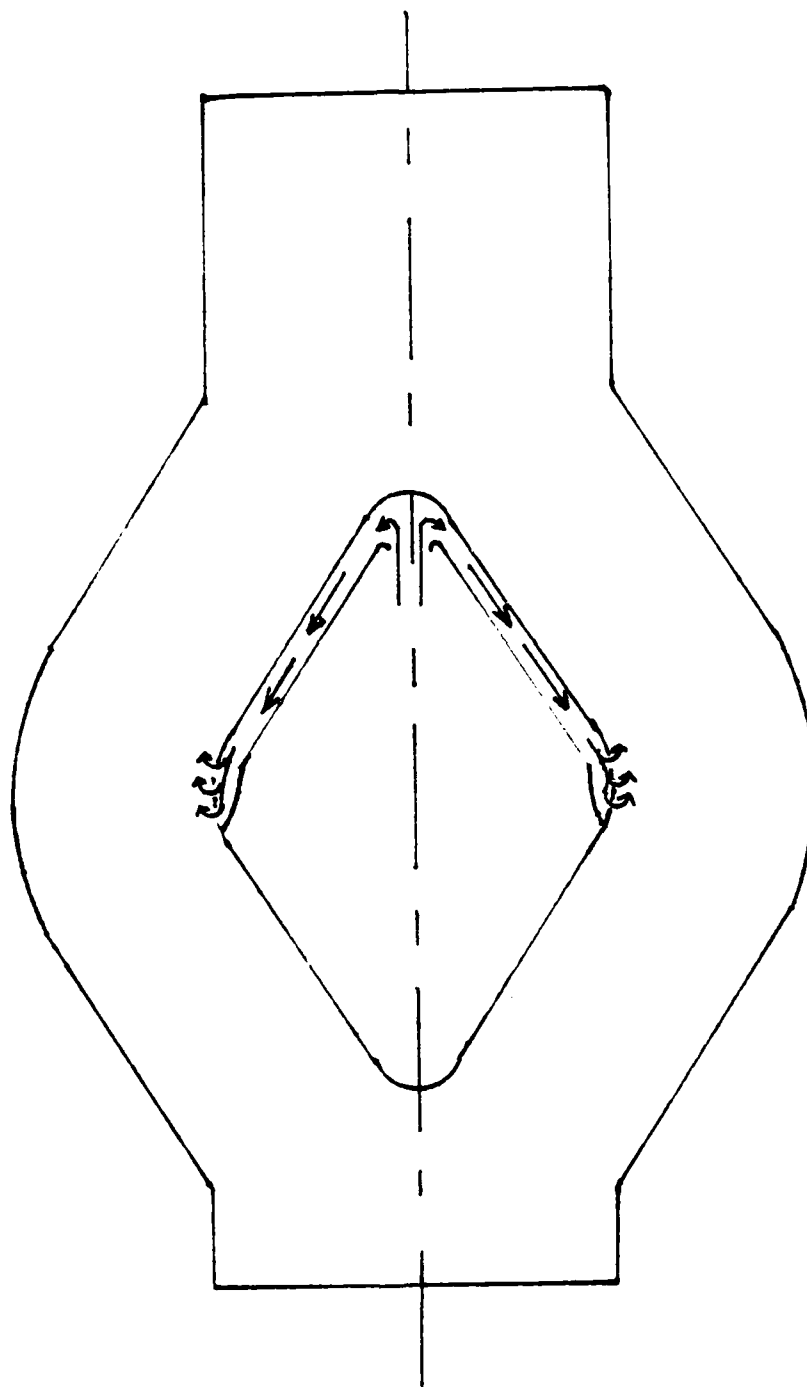


FIGURE 5. MIXING STACK WITH PORTED AND SHROUDED PLUG

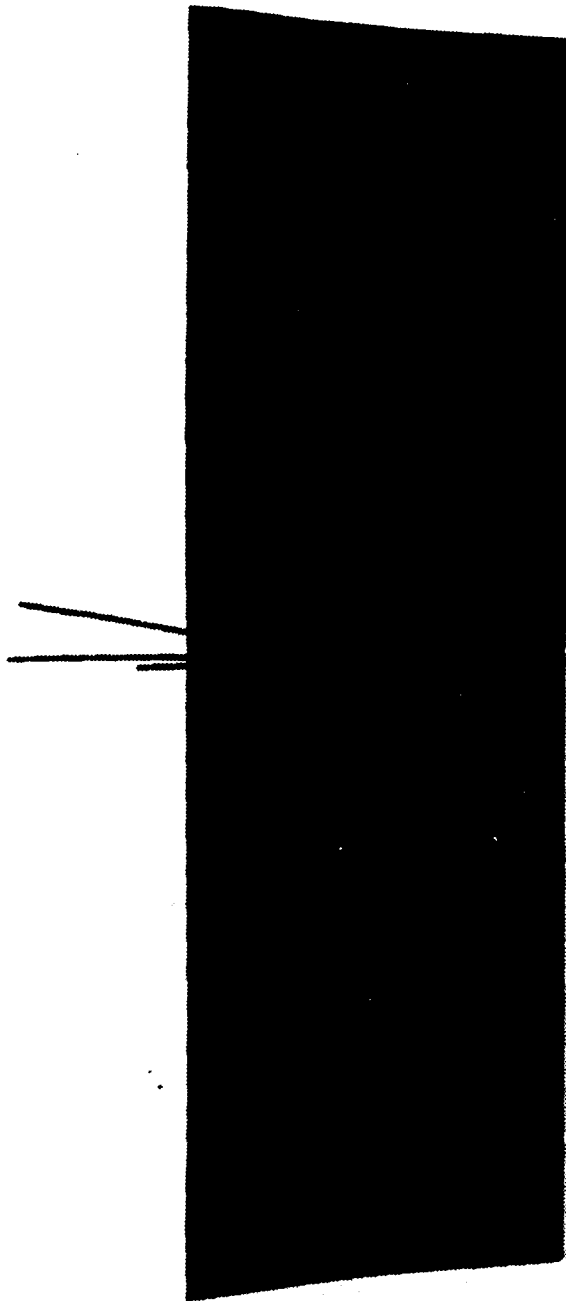


FIGURE 7. CUSP ILLUSTRATION

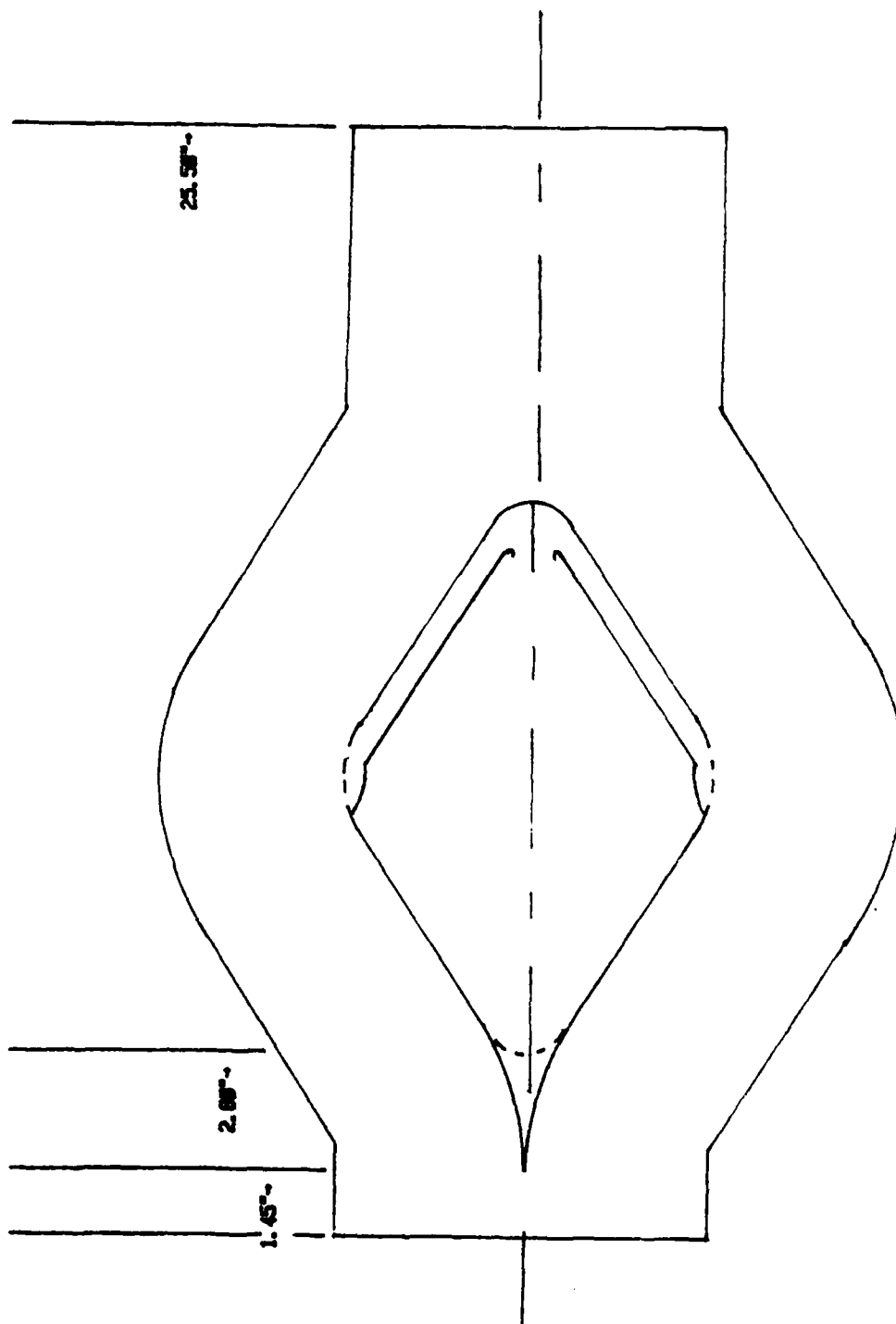


FIGURE 8. DIMENSIONAL ILLUSTRATION OF MIXING STACK WITH CUSP

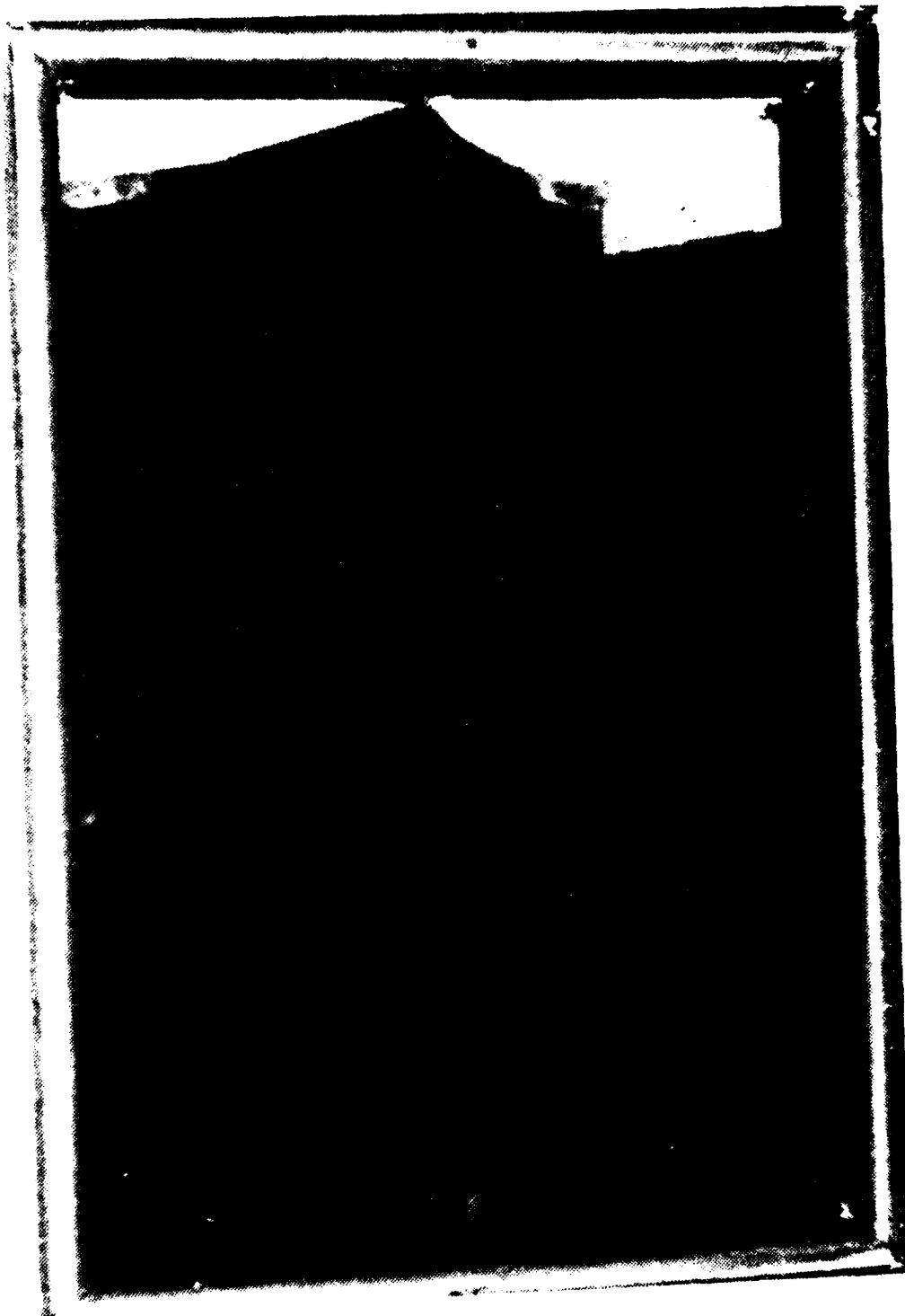


FIGURE 9. MIXING STACK WITH CUSP INSTALLED

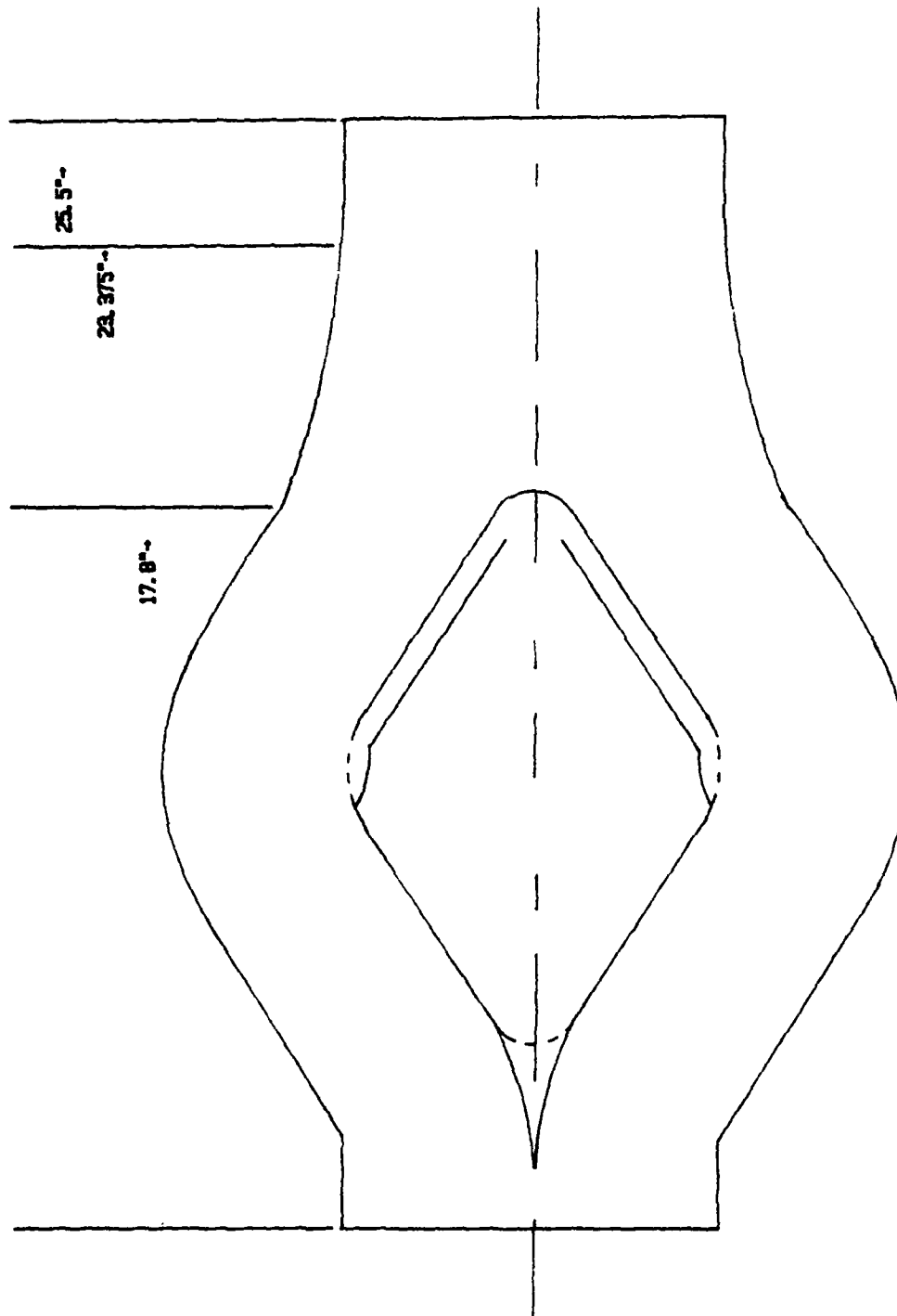


FIGURE 10. DIMENSIONAL ILLUSTRATION OF MIXING STACK WITH CUSP AND SIDE MODIFICATION

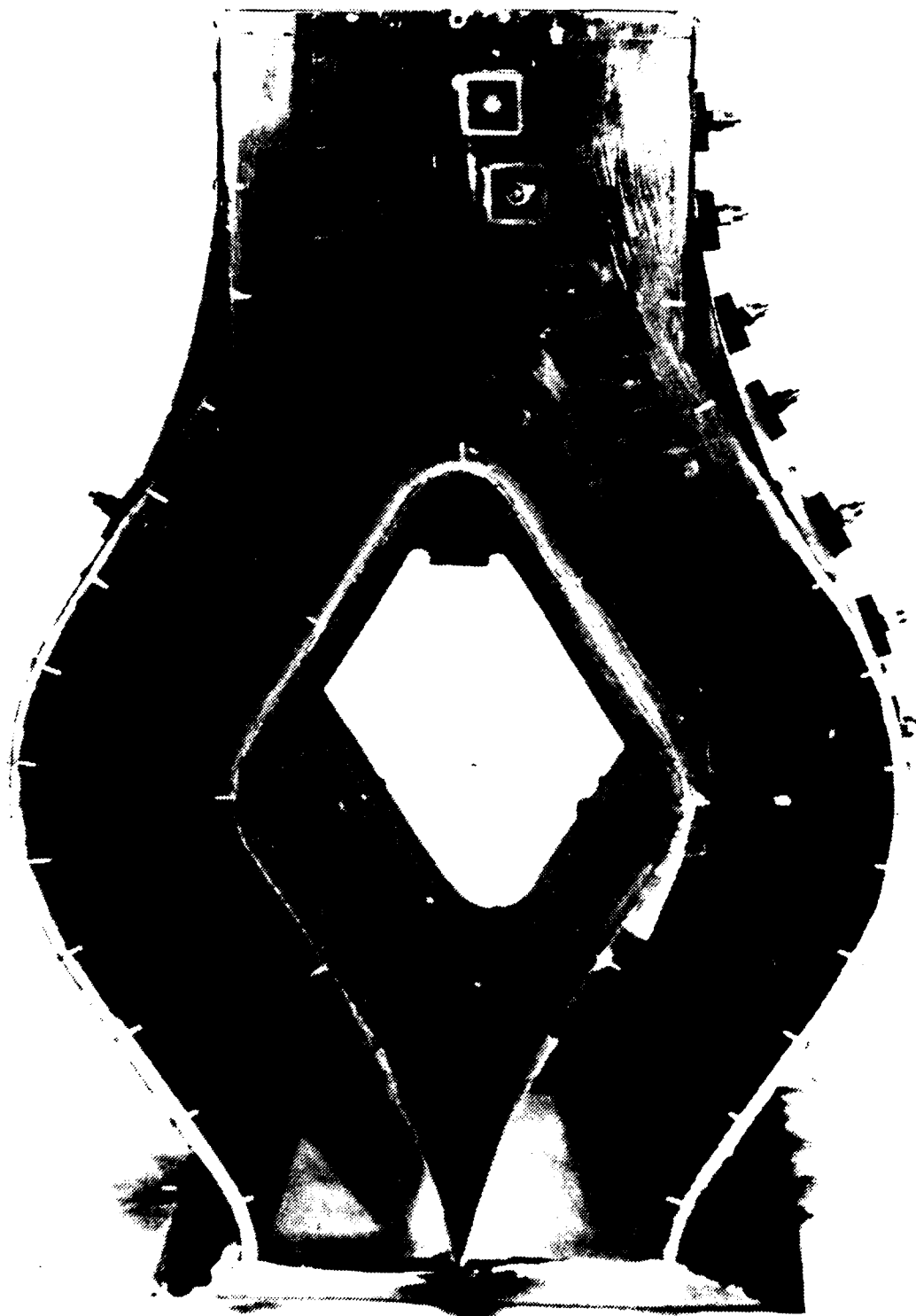


FIGURE 11. MIXING STACK WITH CUSP AND SIDE MODIFICATION



FIGURE 12. SECONDARY AND TERTIARY AIR PLENUMS

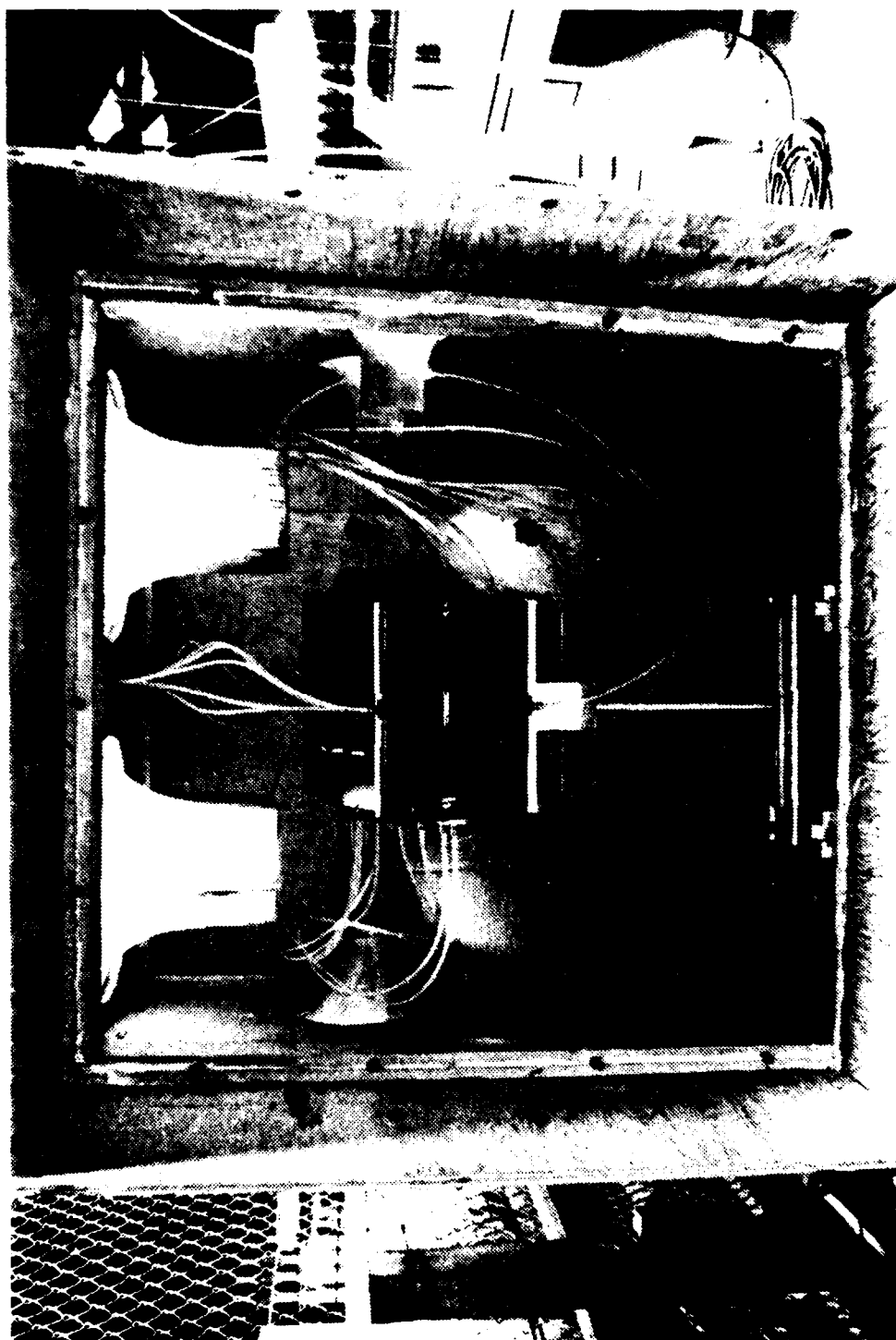


FIGURE 13. TERTIARY AIR PLENUM INTERIOR

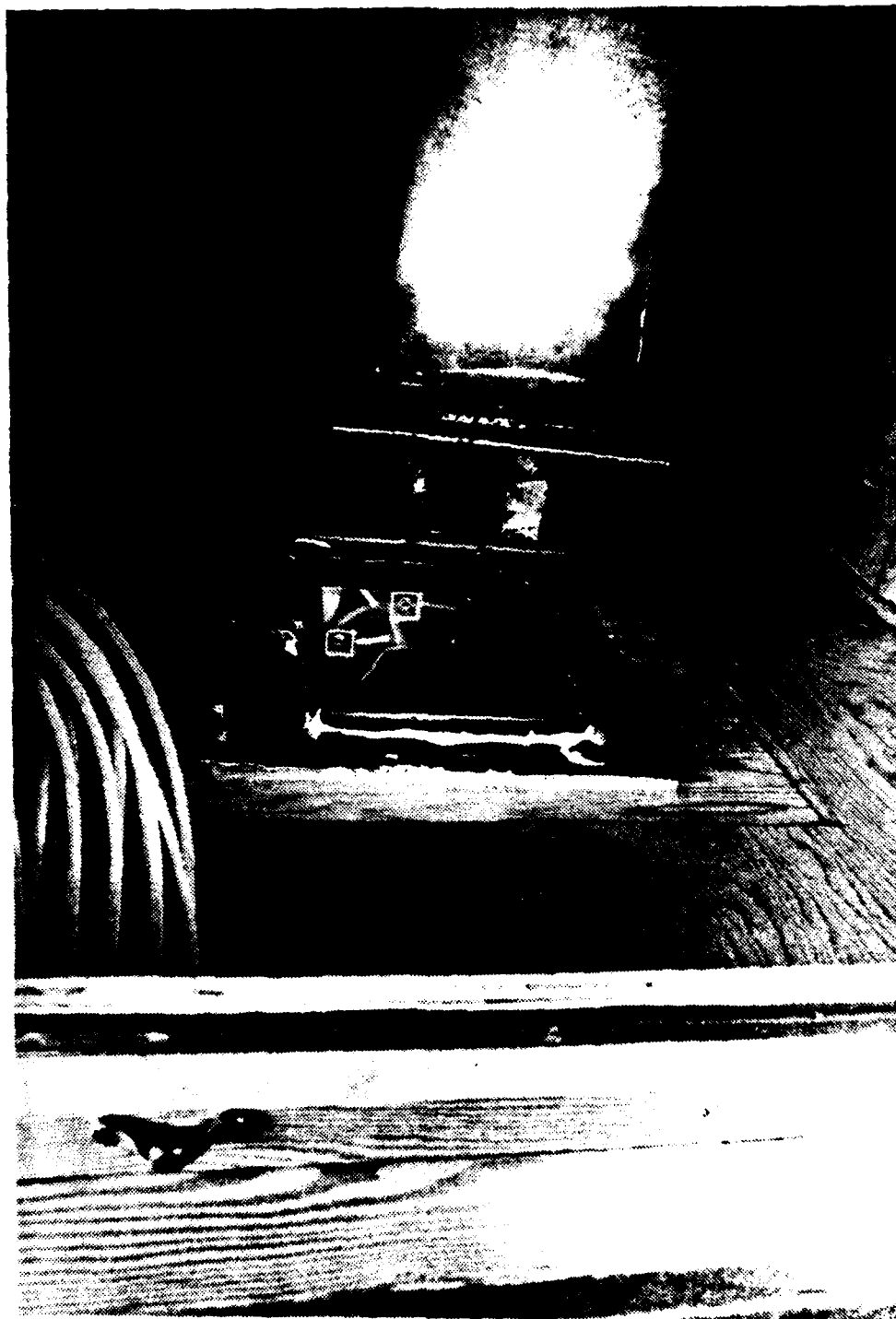


FIGURE 14. MIXING STACK ENTRANCE WITH AIR SEAL

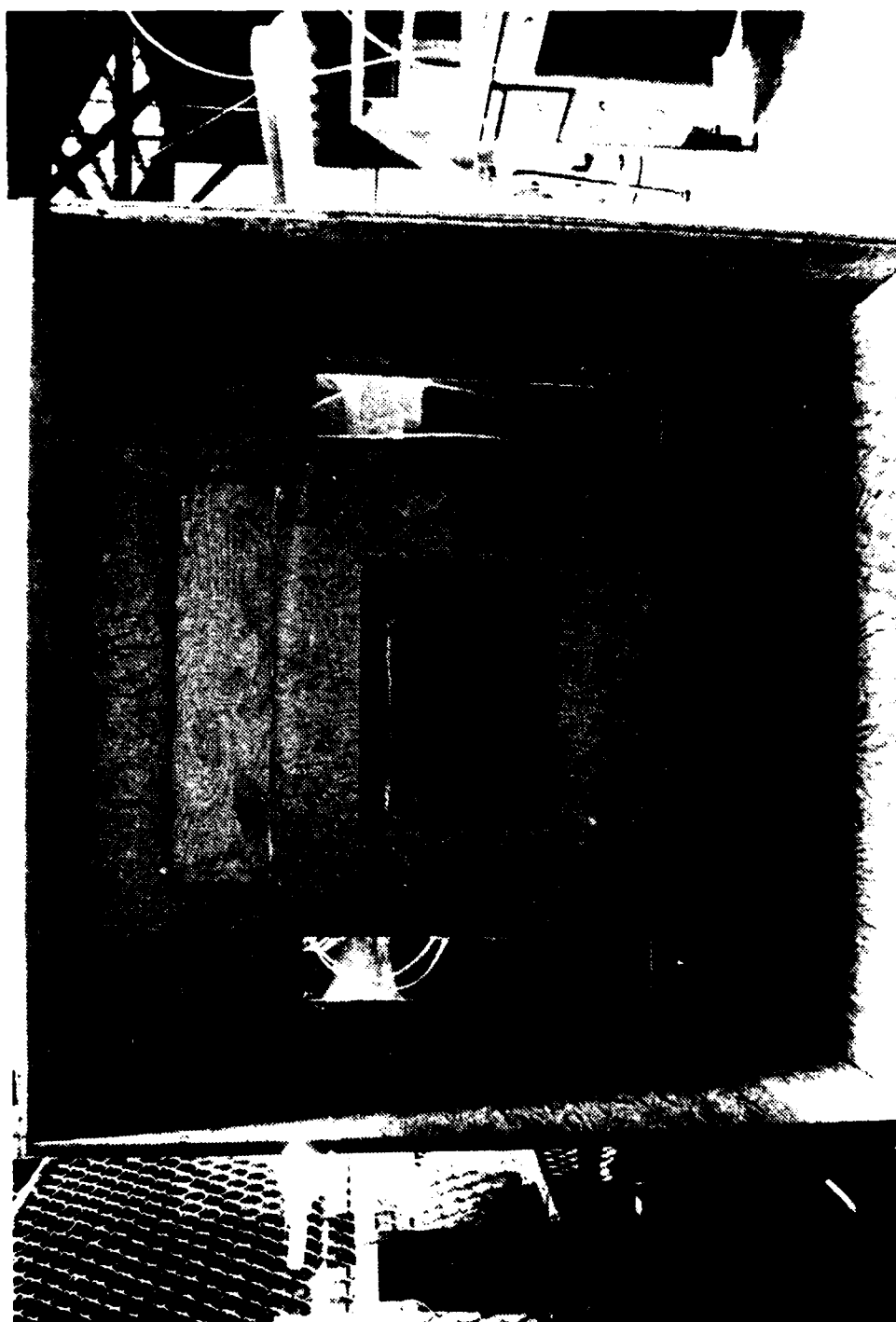


FIGURE 15. MIXING STACK EXIT WITH AIR SEAL

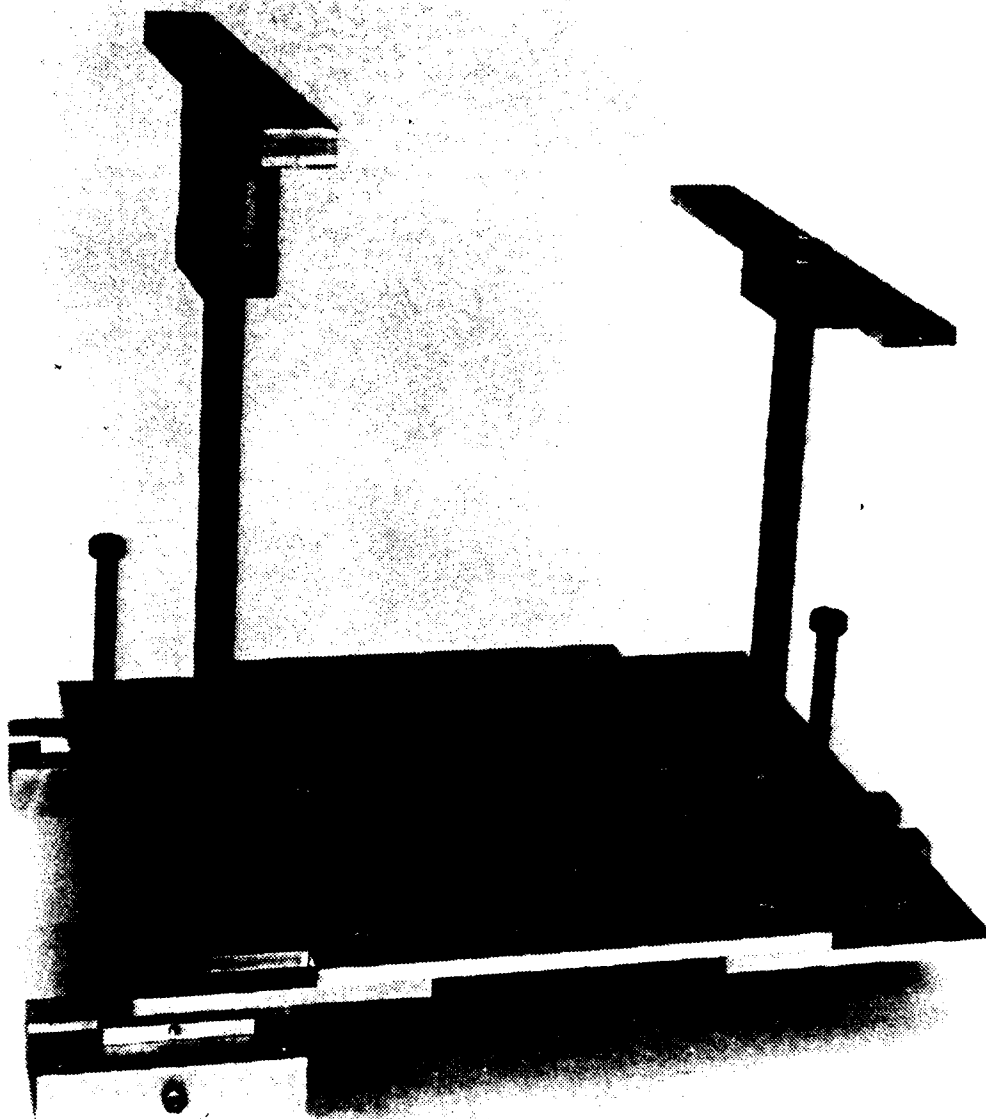


FIGURE 16. MIXING STACK MOUNTING STAND

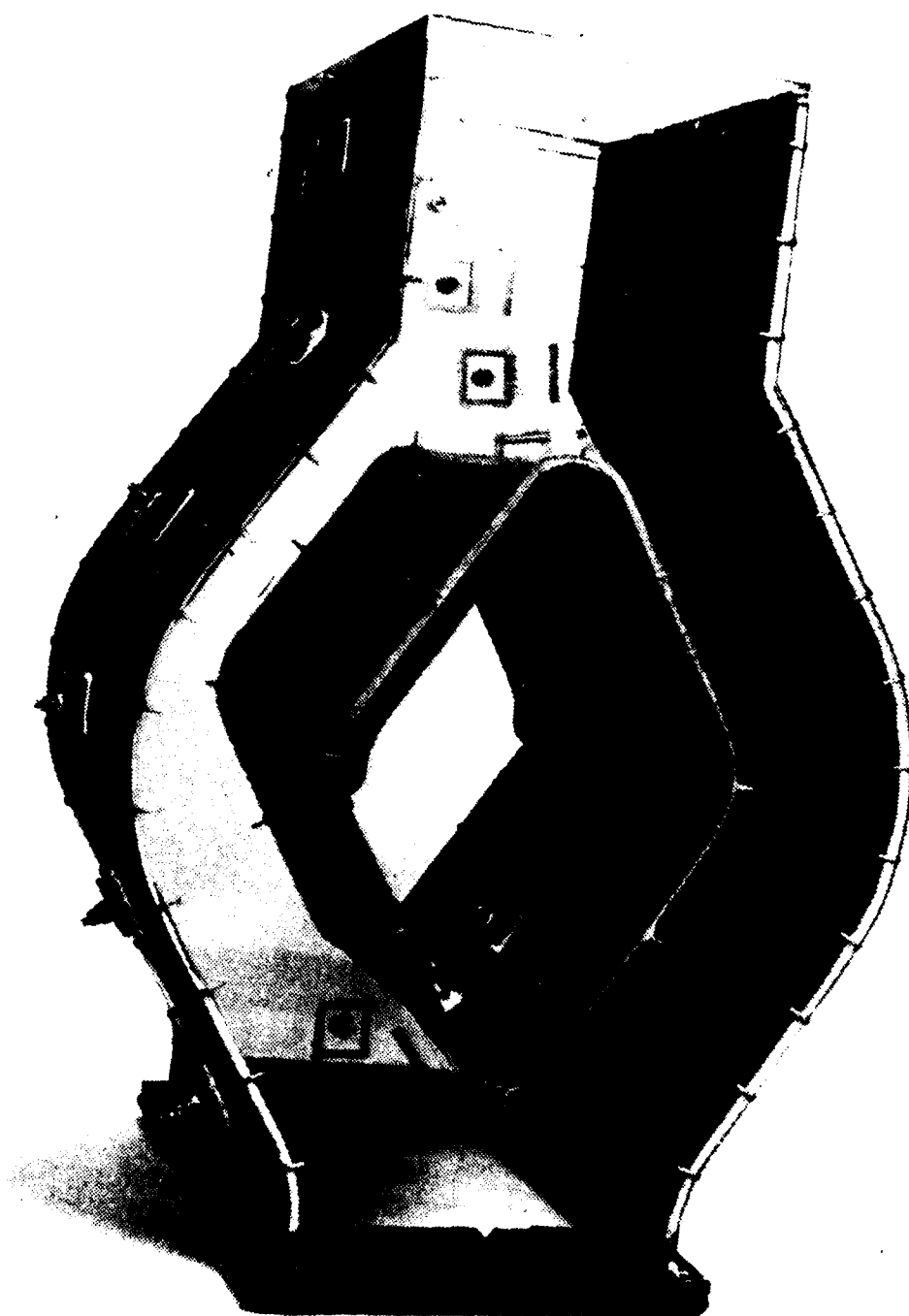


FIGURE 17. MIXING STACK WITH PORTED AND SHROUDED PLUG

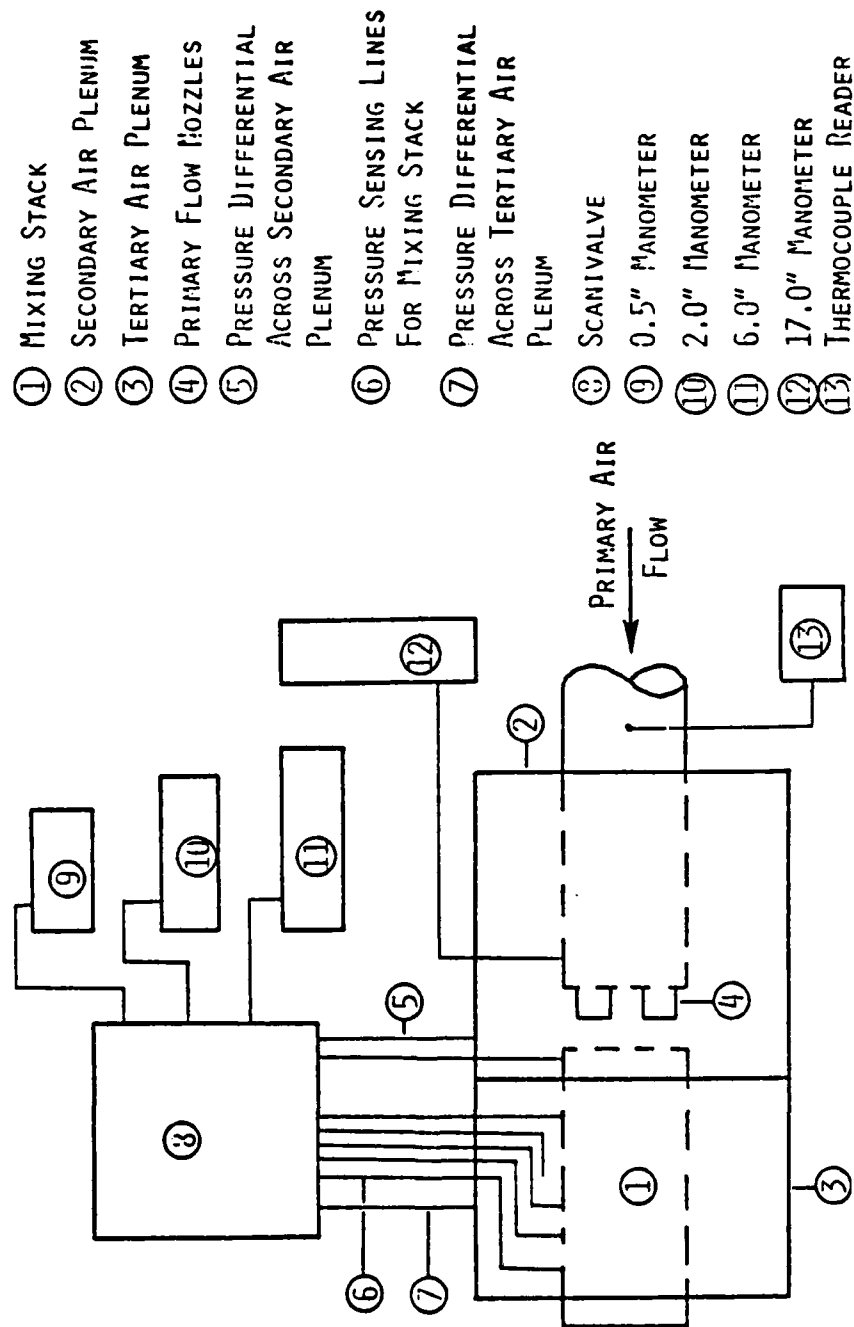


FIGURE 18. SCHEMATIC OF INSTRUMENTATION

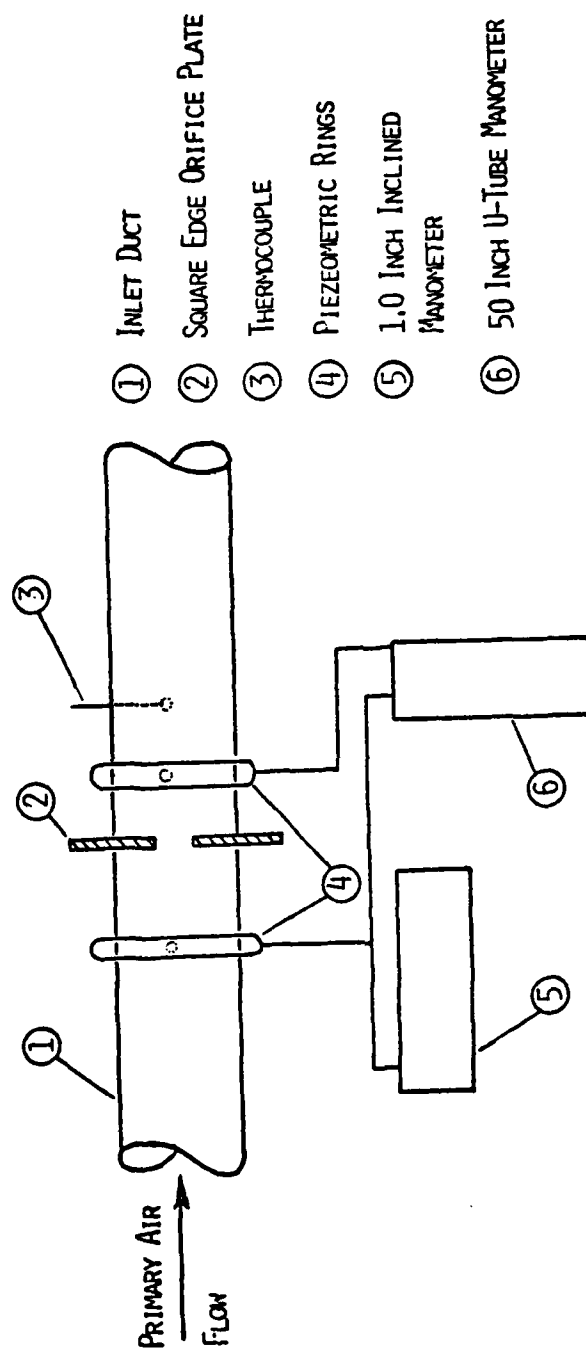


FIGURE 19. SCHEMATIC OF INSTRUMENTATION FOR PRIMARY AIR FLOW MEASUREMENT

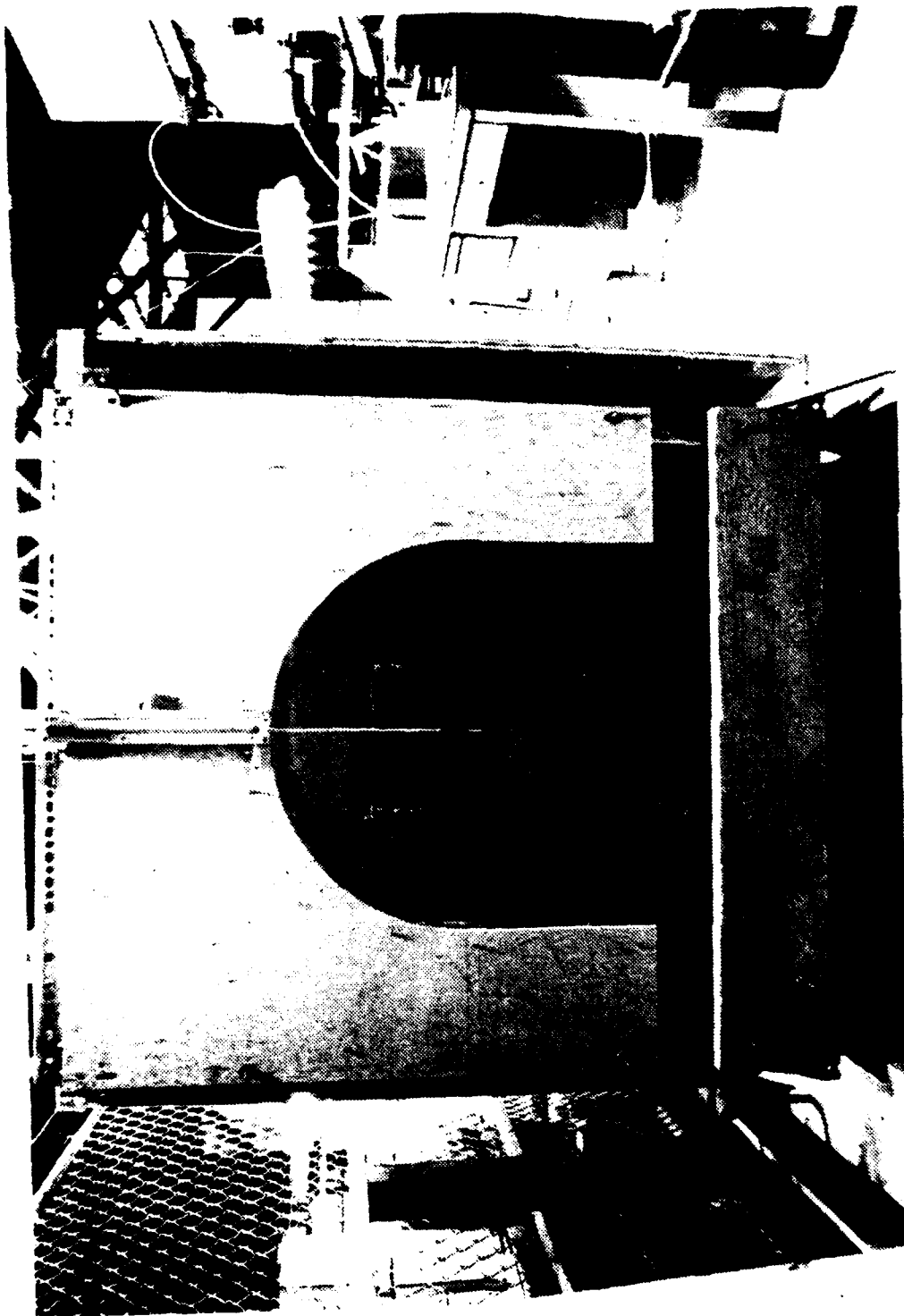
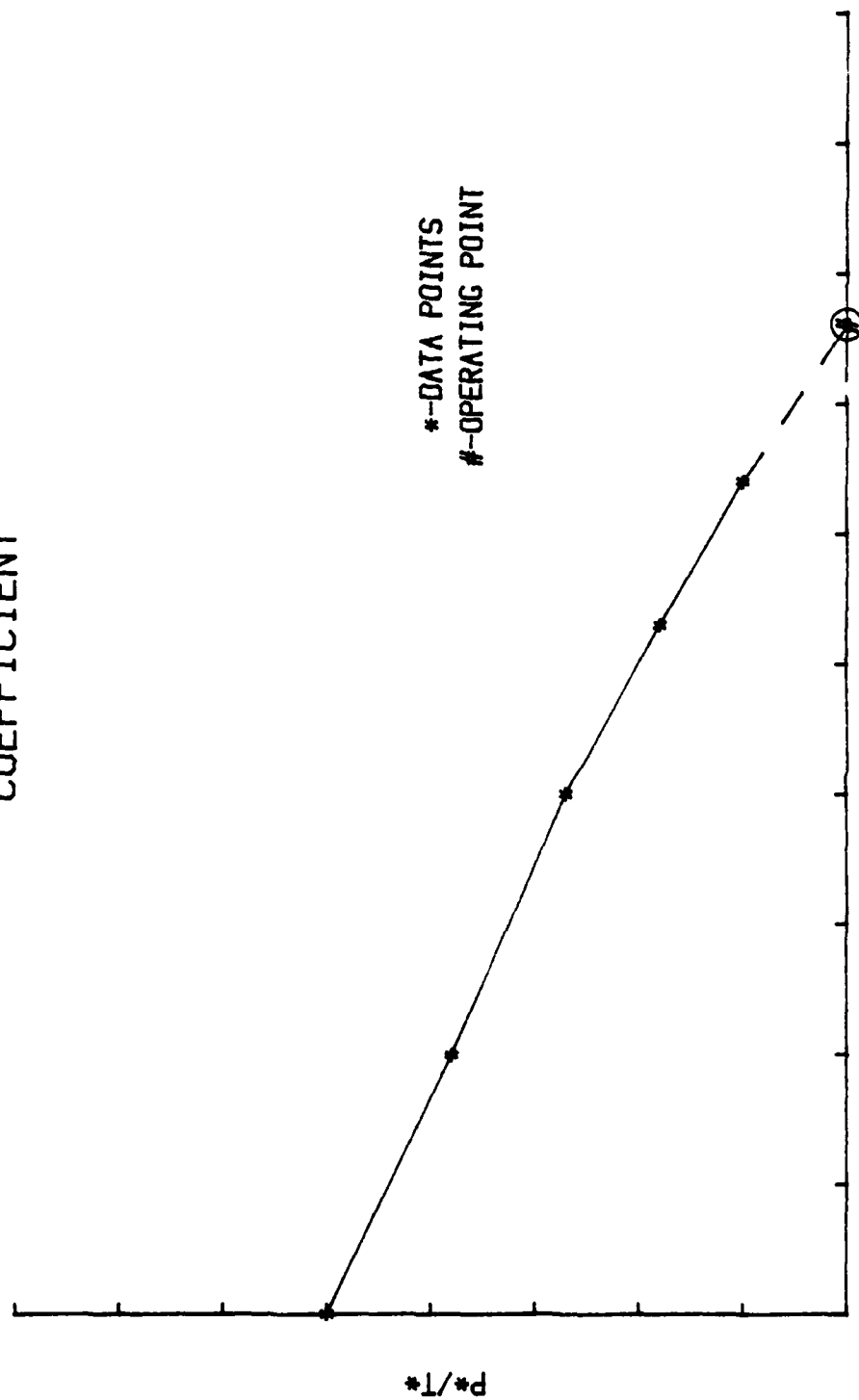


FIGURE 20. VELOCITY PROFILE APPARATUS

EXPERIMENTAL PUMPING COEFFICIENT



W*18*0.44
FIGURE 21. EXAMPLE PLOT OF PUMPING COEFFICIENT

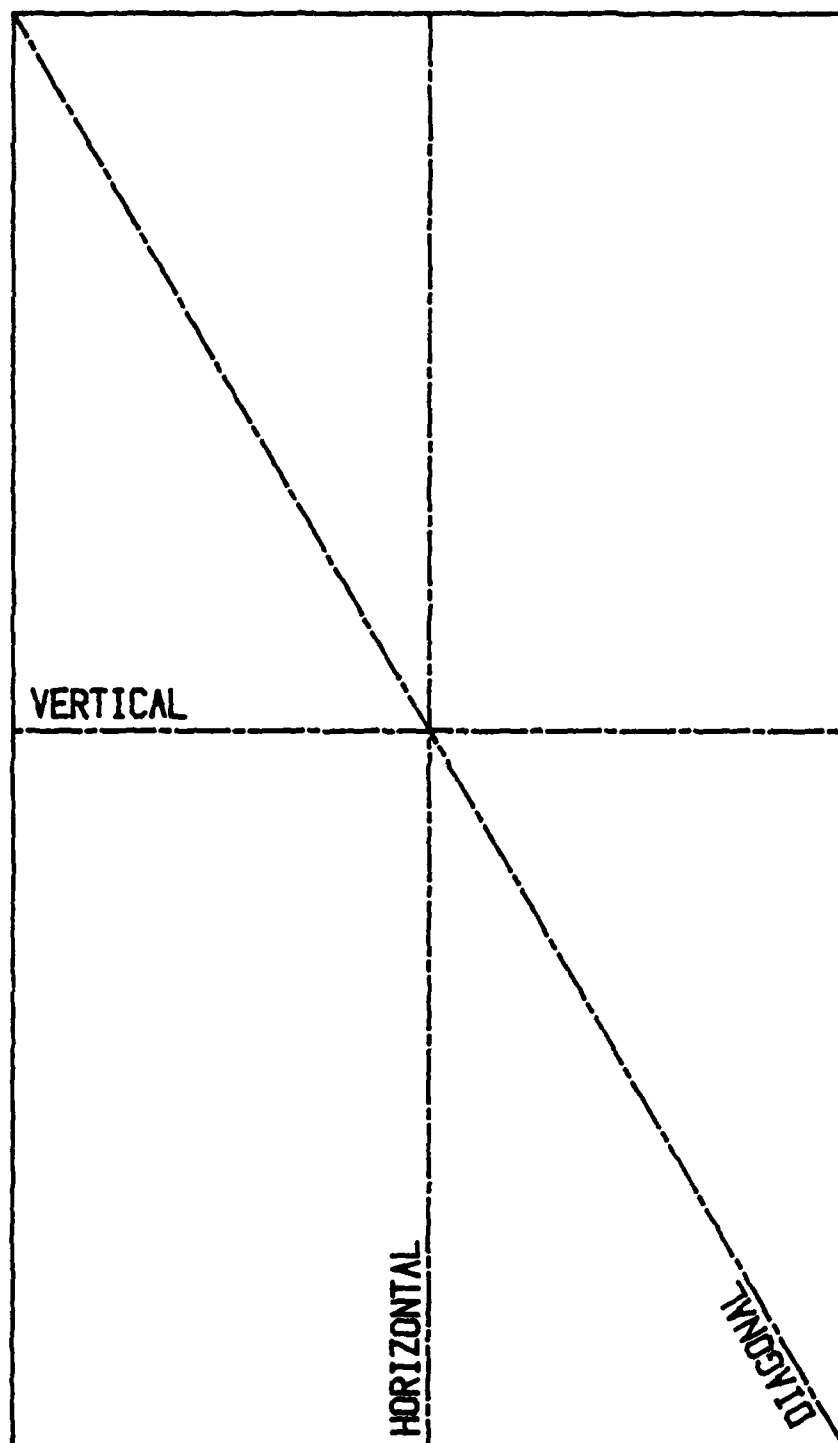


FIGURE 22. VELOCITY TRAVERSE DIRECTIONS

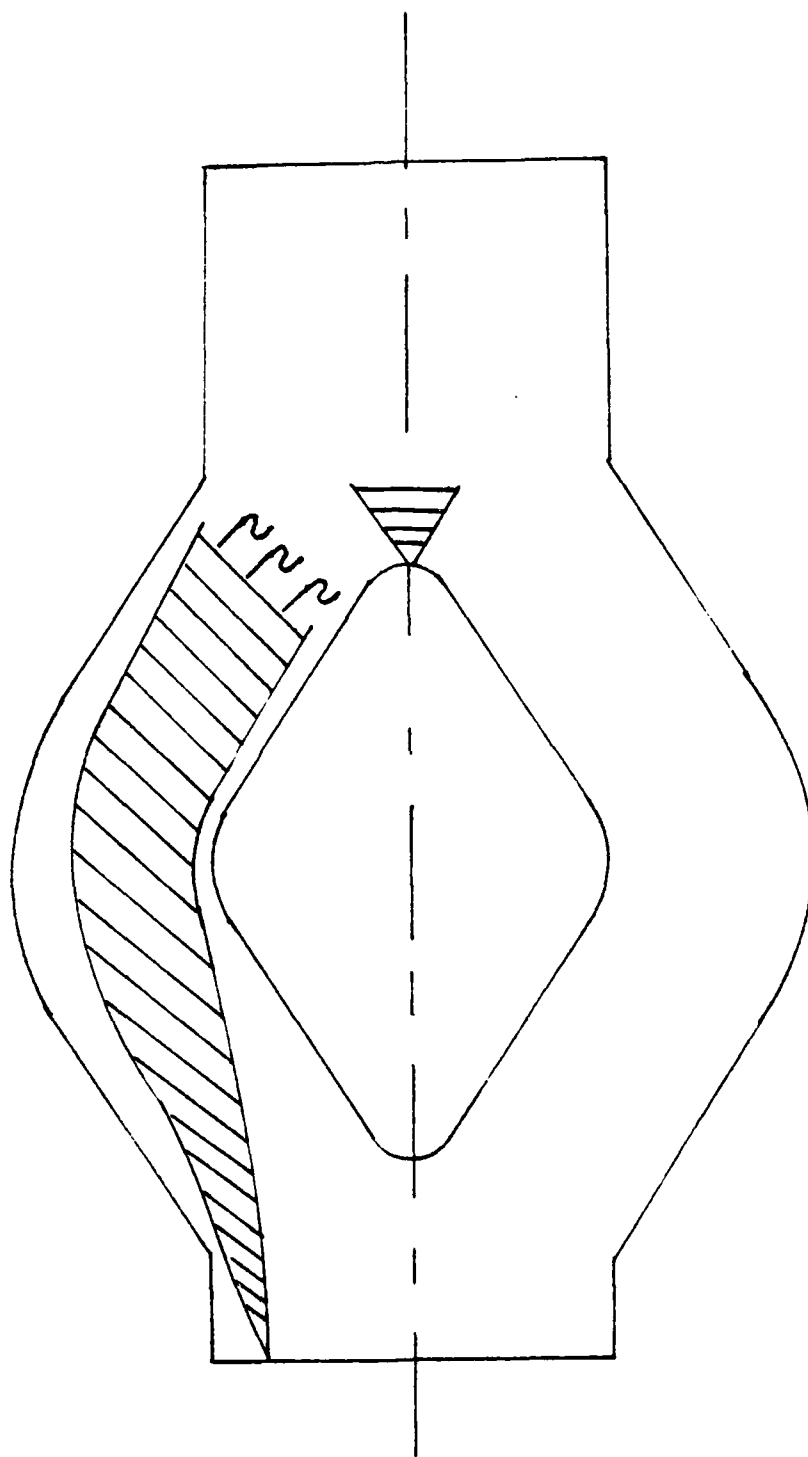


FIGURE 23. SCHEMATIC OF FLOW VISUALIZATION RESULTS

EXPERIMENTAL PUMPING COEFFICIENT COMPARISON

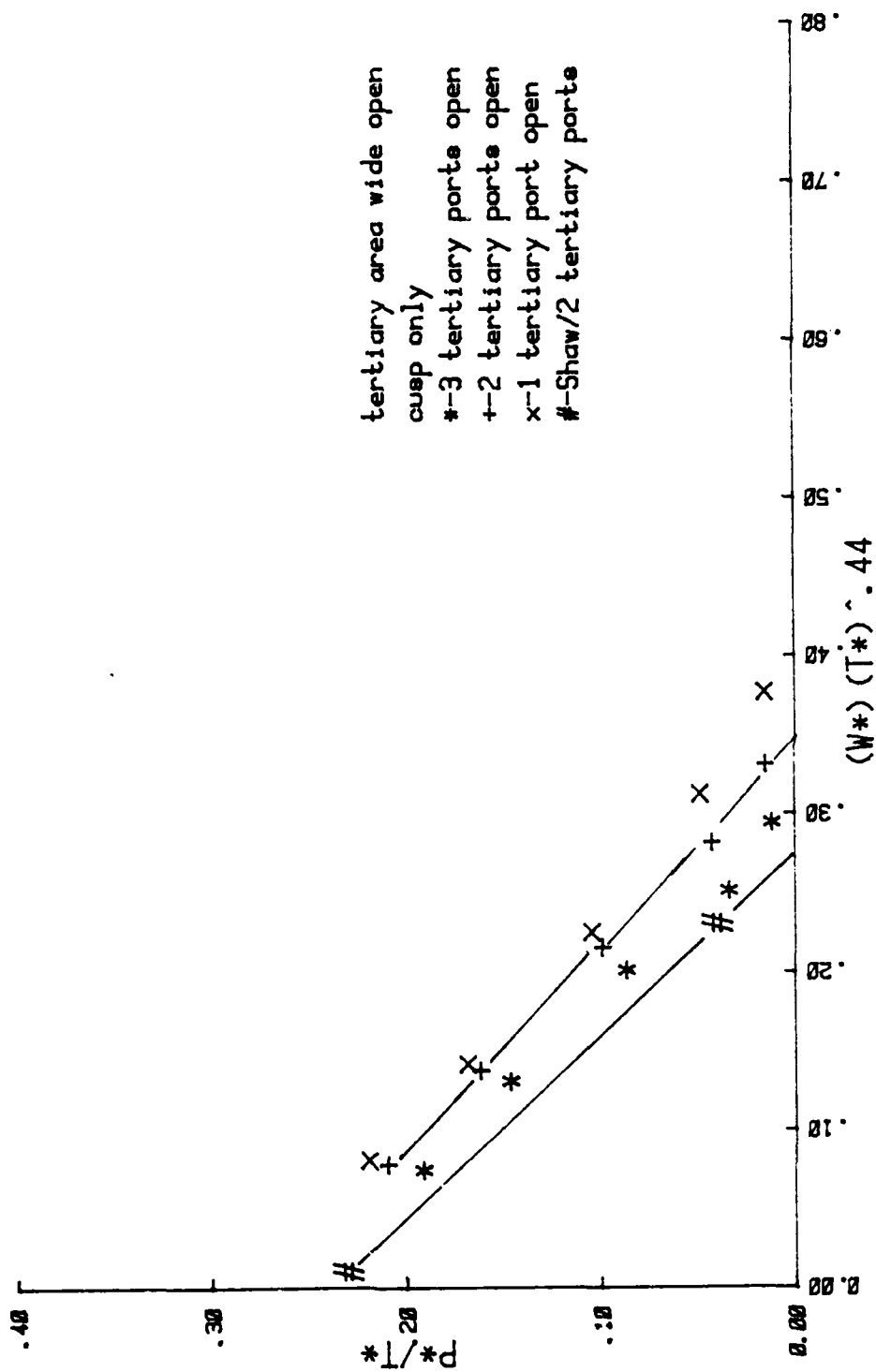


FIGURE 24a

EXPERIMENTAL PUMPING COEFFICIENT COMPARISON

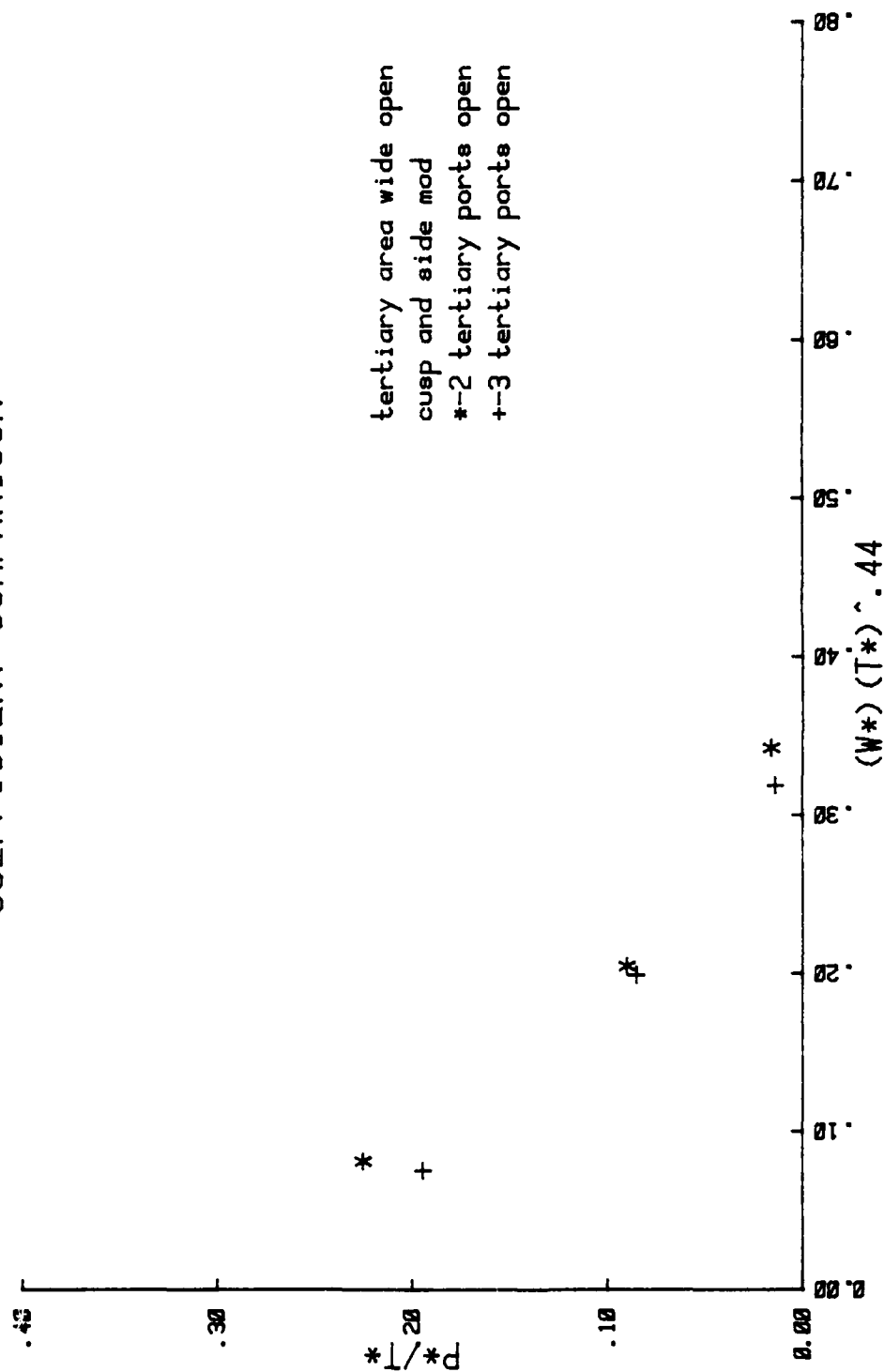


FIGURE 24b

EXPERIMENTAL PUMPING COEFFICIENT COMPARISON

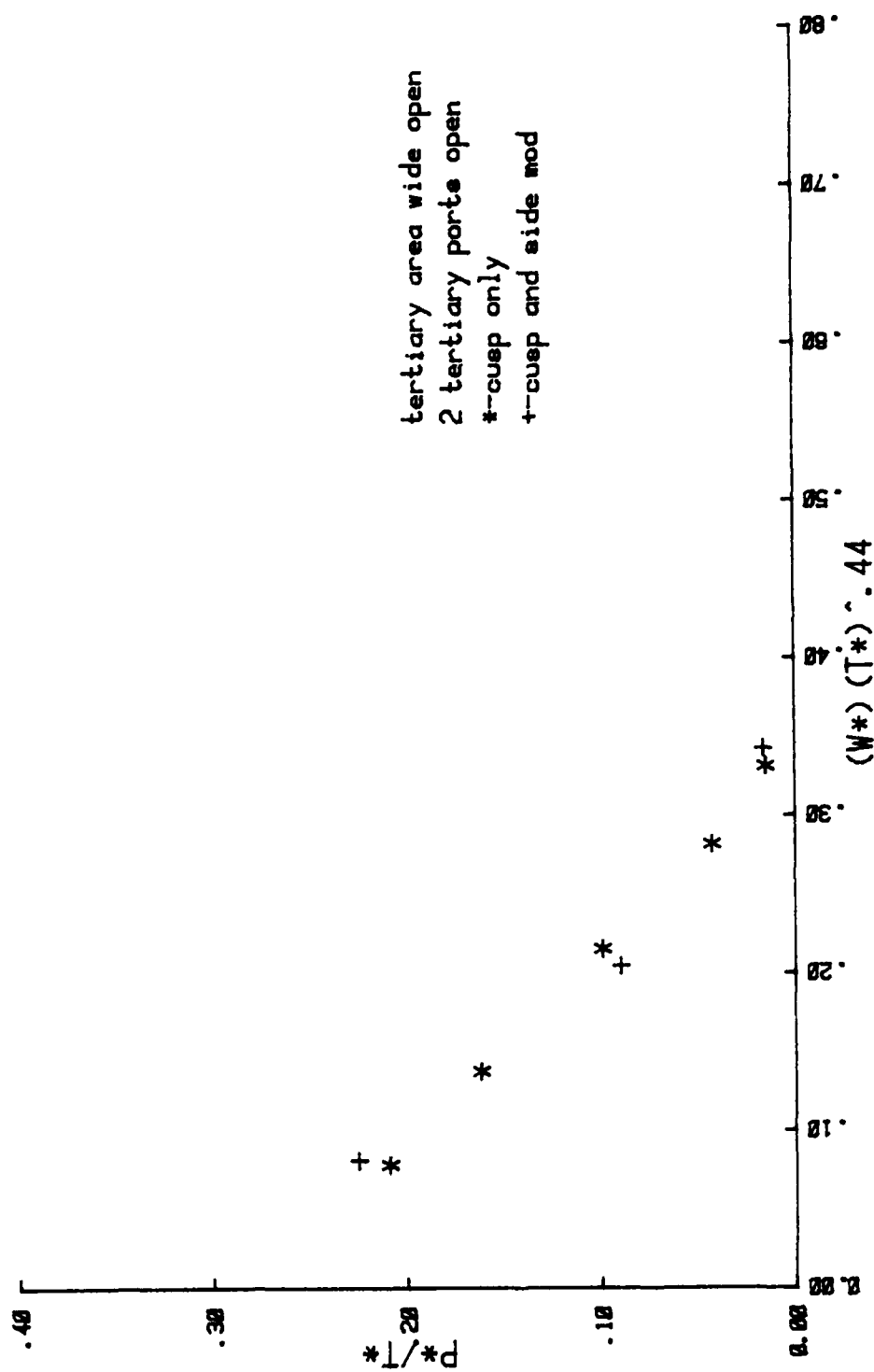
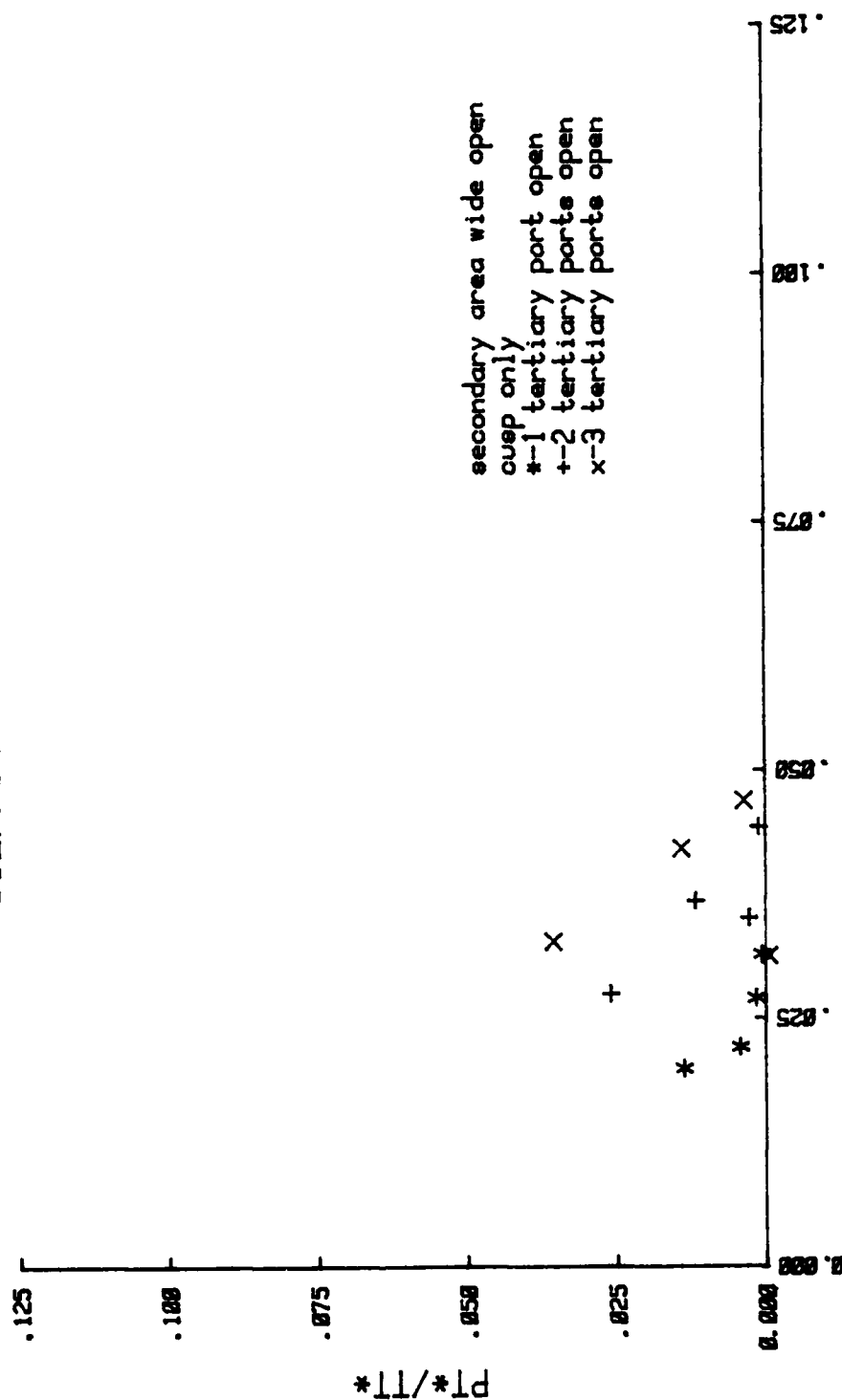


FIGURE 24c

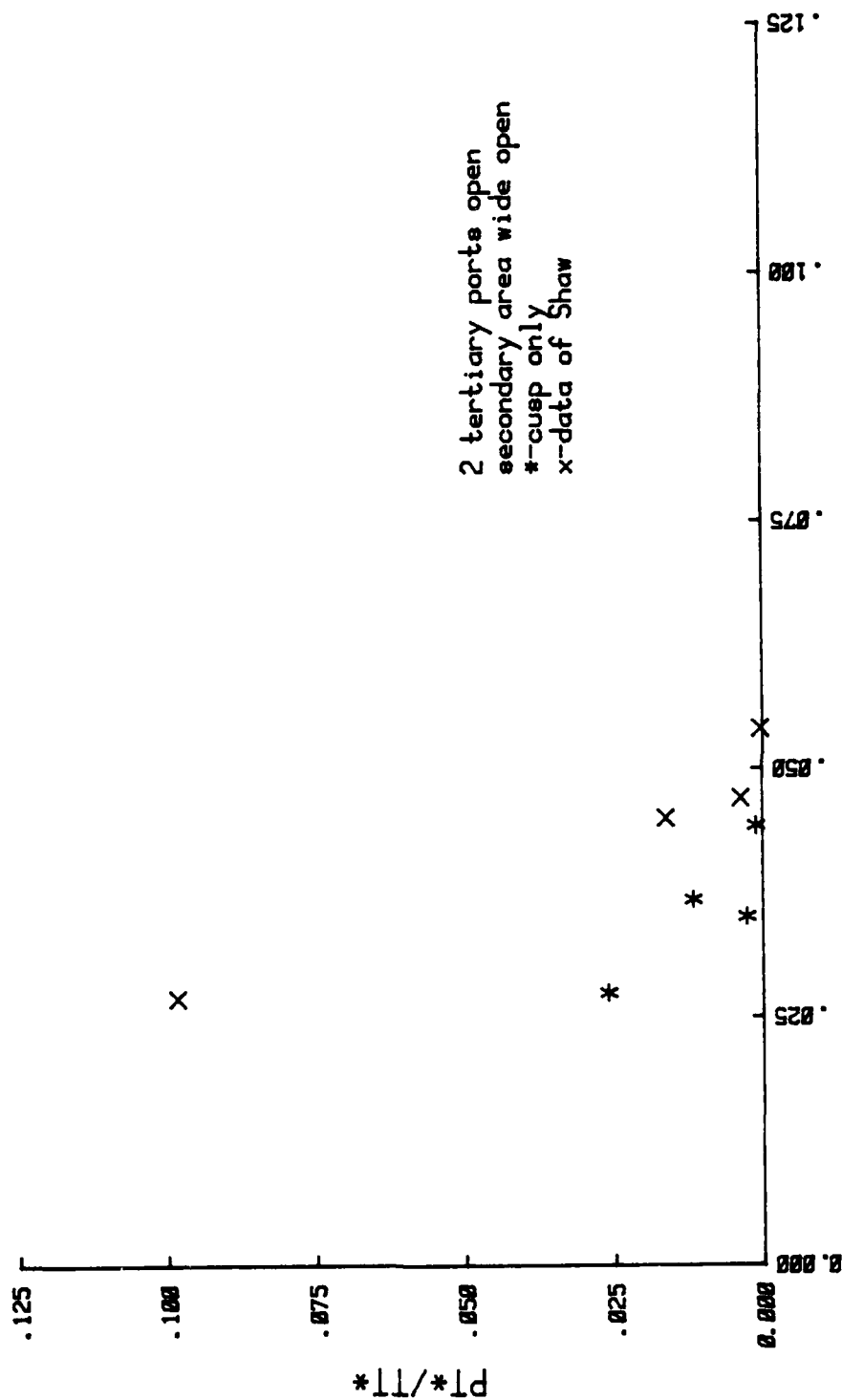
EXPERIMENTAL FILM PUMPING COEFFICIENT COMPARISON



$(WT^*)(TT^*)^{-.44}$

FIGURE 25a

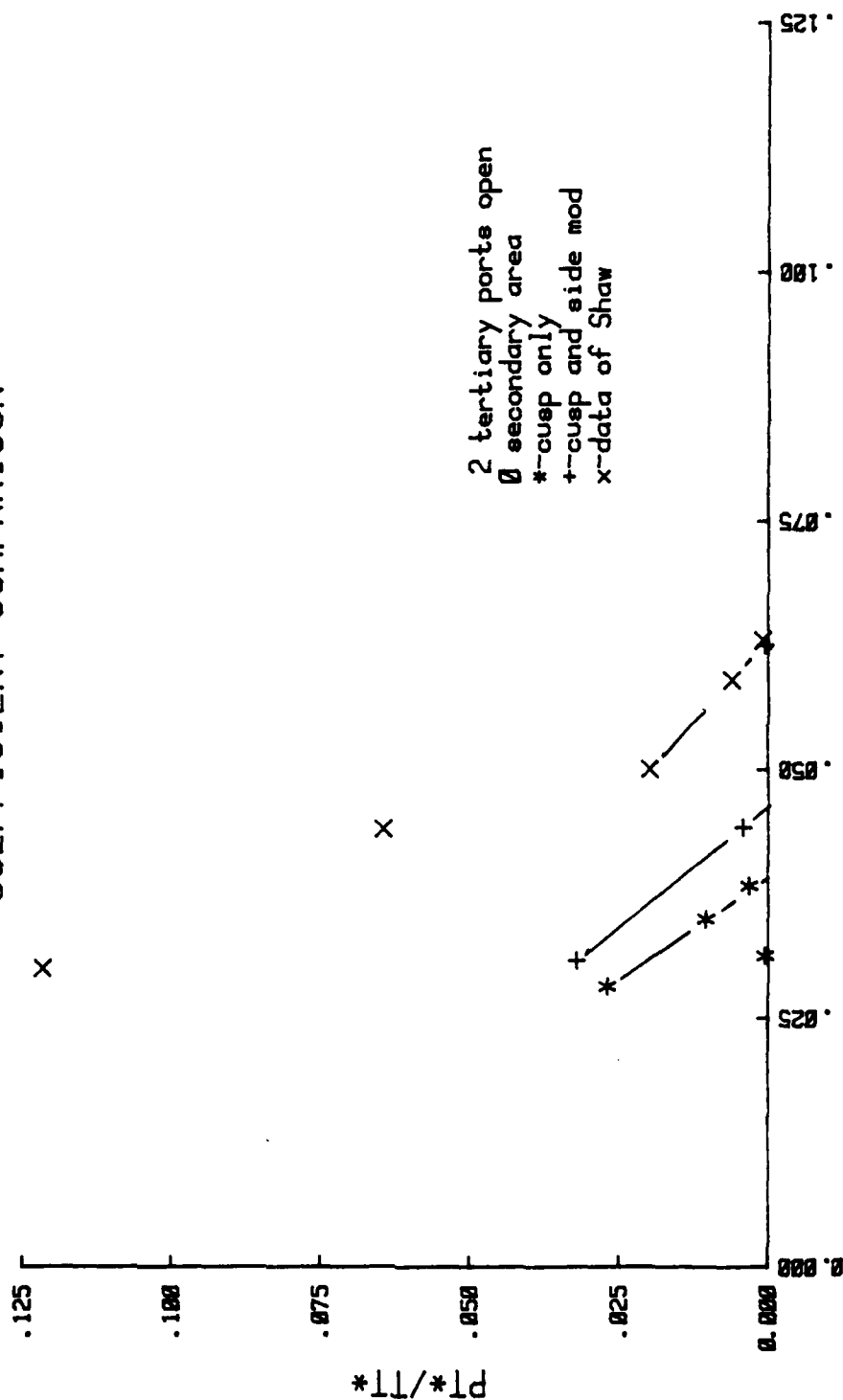
EXPERIMENTAL FILM PUMPING COEFFICIENT COMPARISON



$(WT^*) (TT^*)^{.44}$

FIGURE 25b

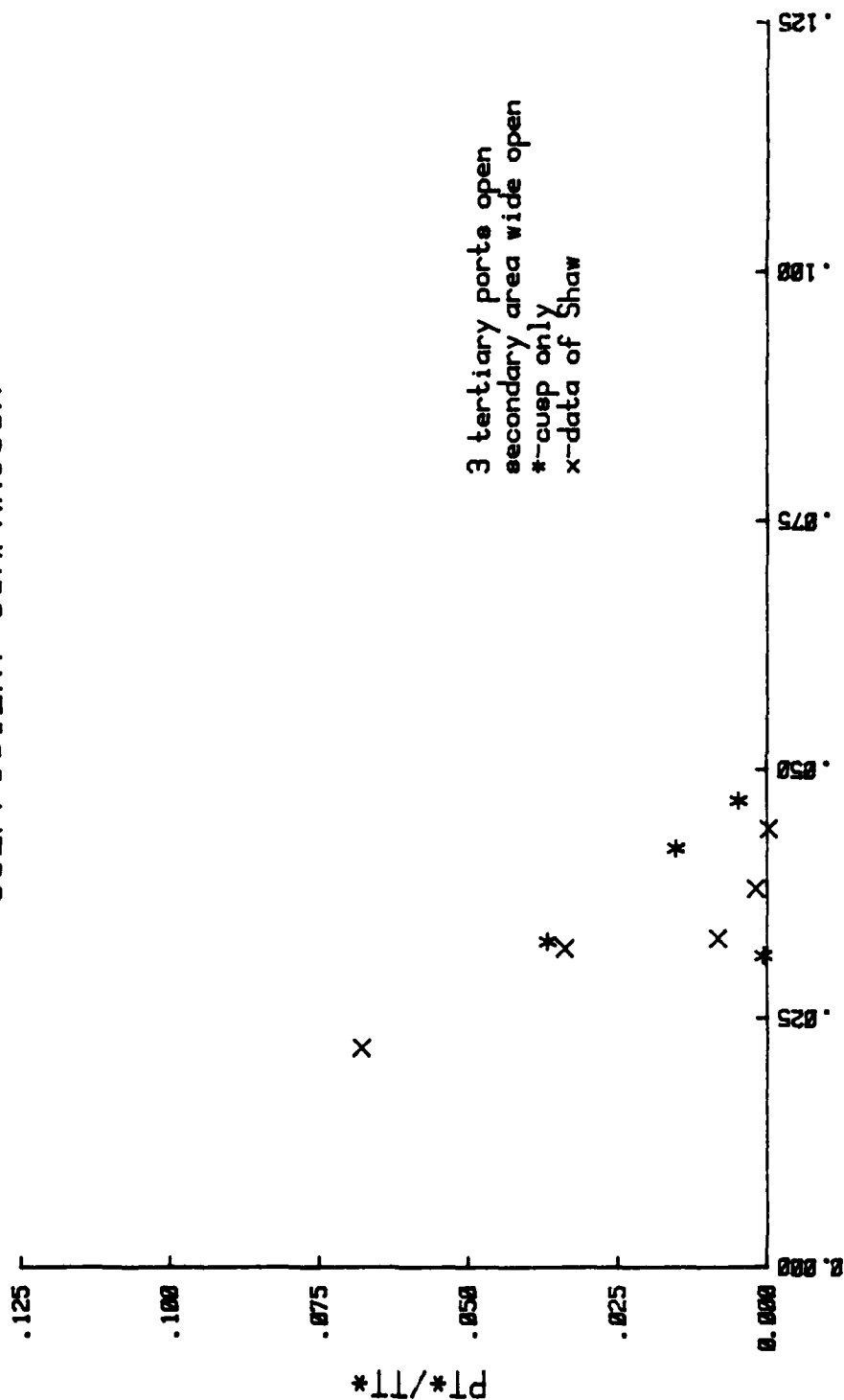
EXPERIMENTAL FILM PUMPING COEFFICIENT COMPARISON



(WT*) (TT*) .44

FIGURE 25o

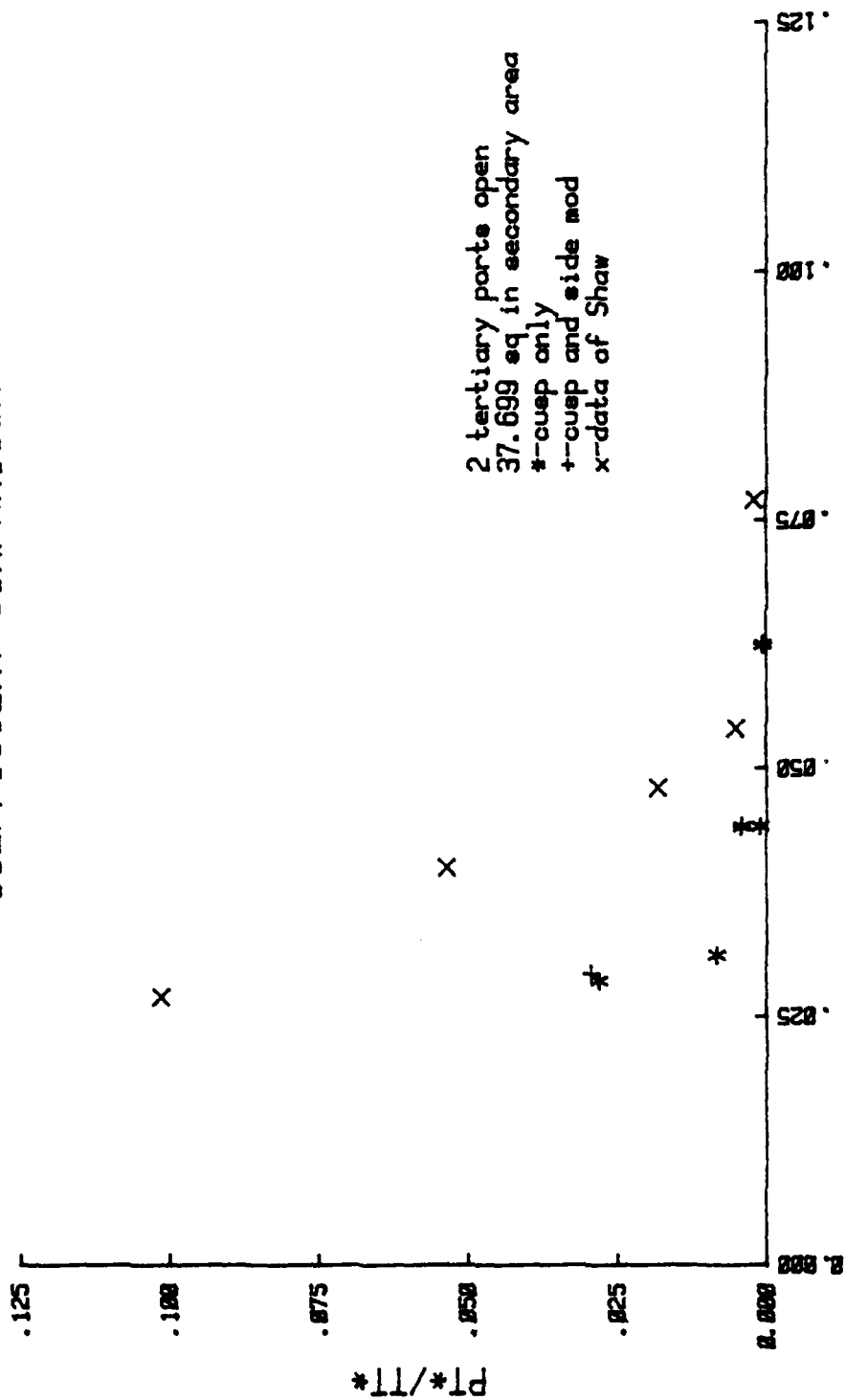
EXPERIMENTAL FILM PUMPING COEFFICIENT COMPARISON



(WT*) (TT*) ^ .44

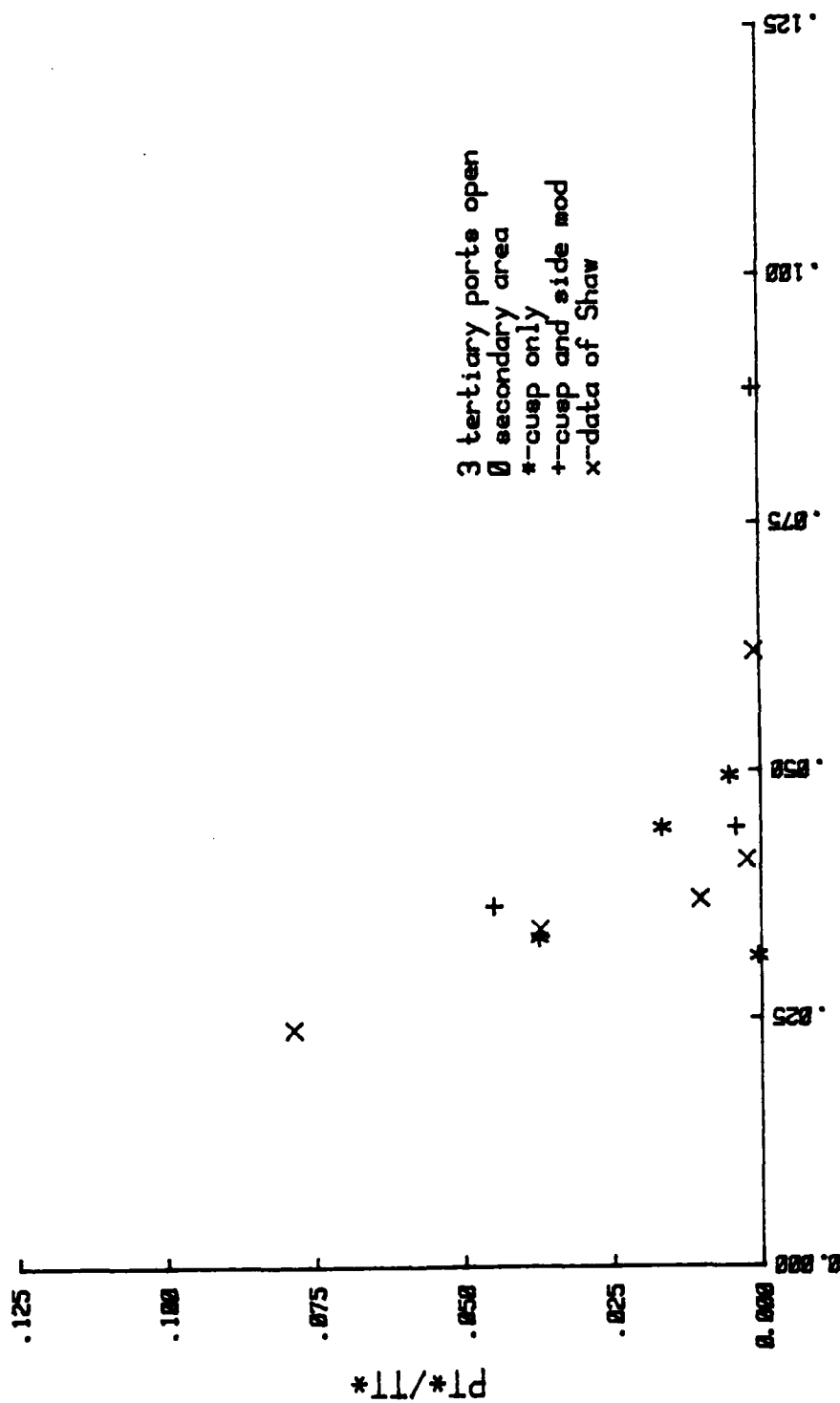
FIGURE 25d

EXPERIMENTAL FILM PUMPING COEFFICIENT COMPARISON



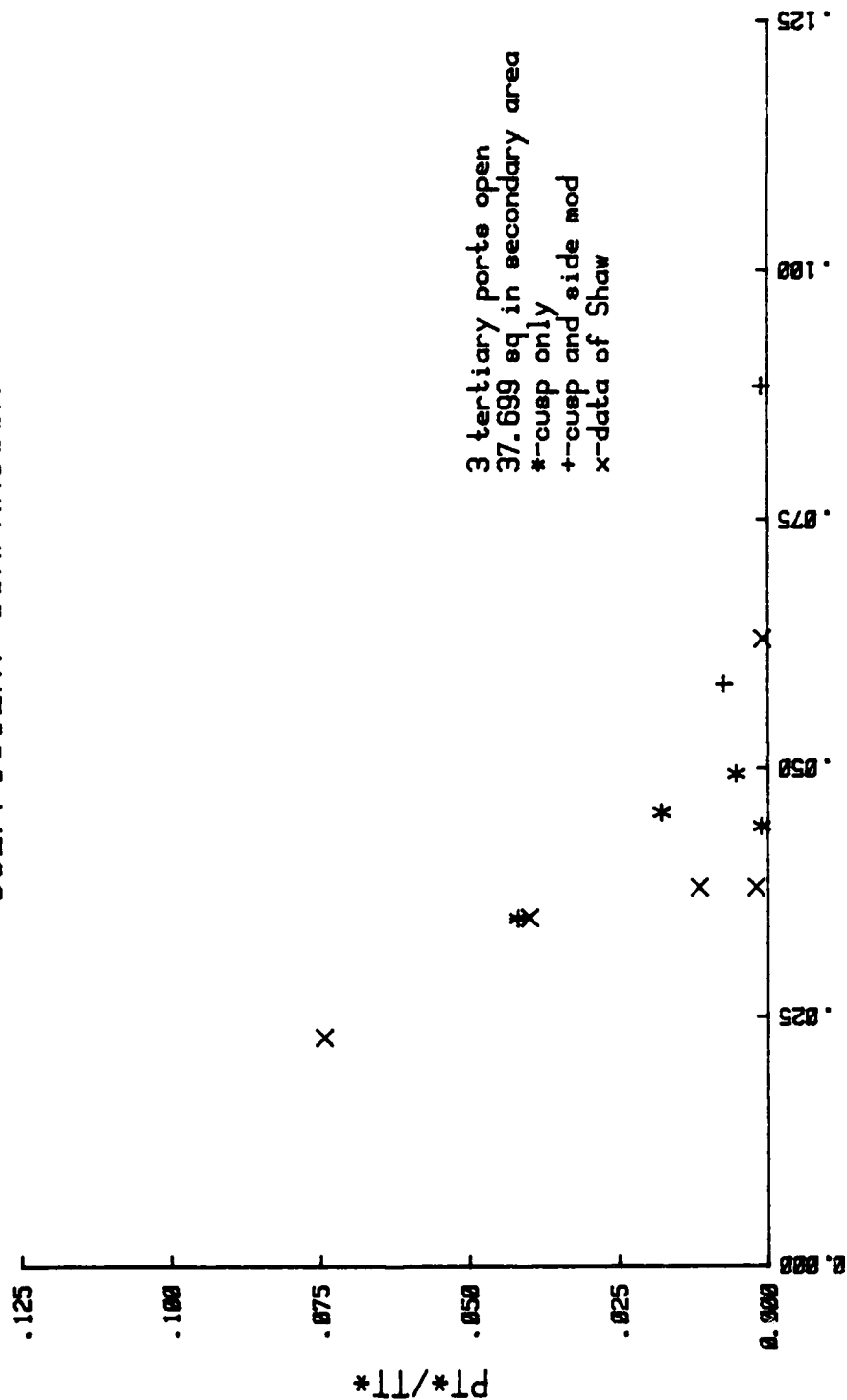
(WT*) (TT*) ^ .44
FIGURE 25a

EXPERIMENTAL FILM PUMPING COEFFICIENT COMPARISON



(WT*)(11*)^{0.44}
FIGURE 25f

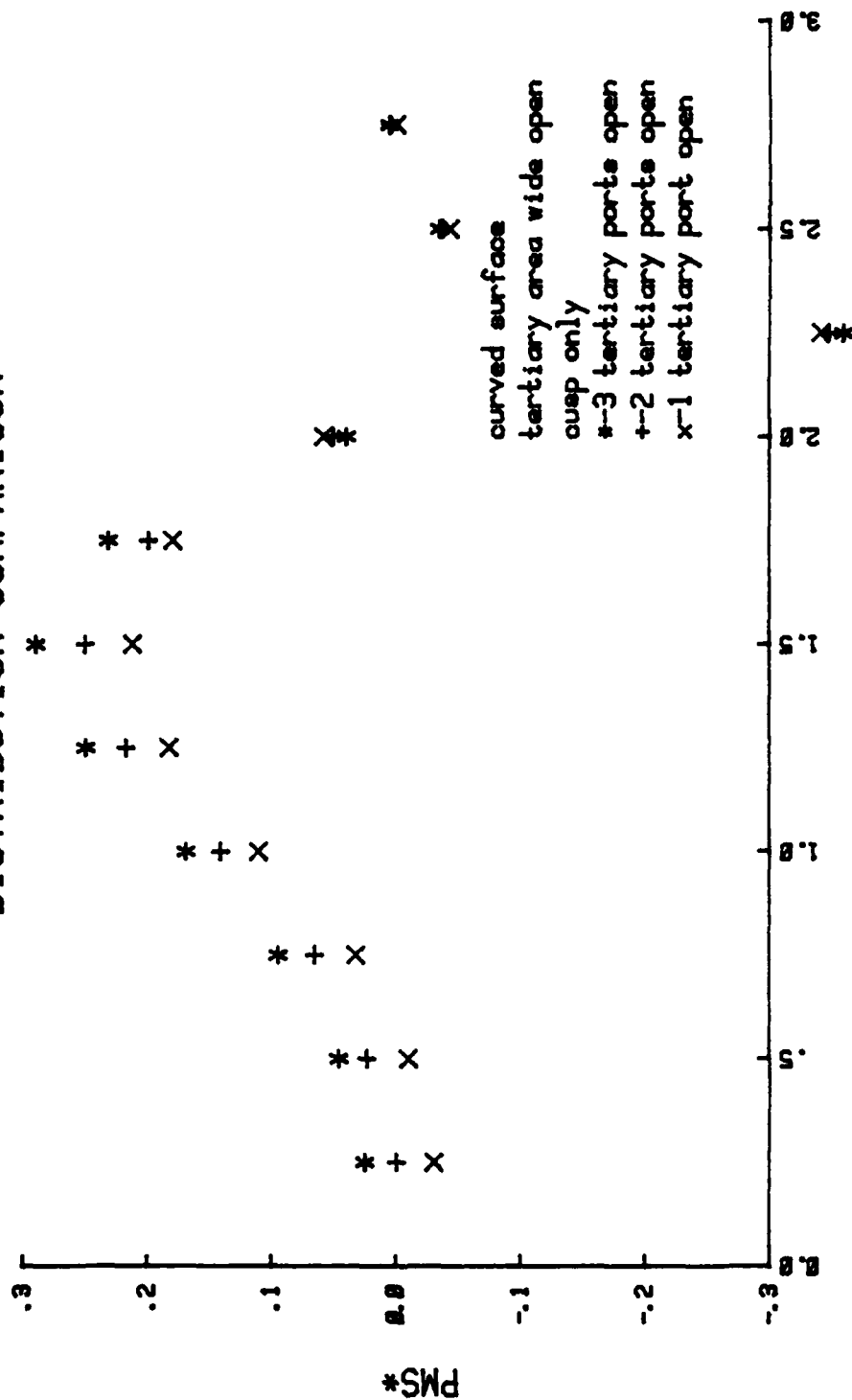
EXPERIMENTAL FILM PUMPING COEFFICIENT COMPARISON



(WT*) (11*) ^ .44

FIGURE 25g

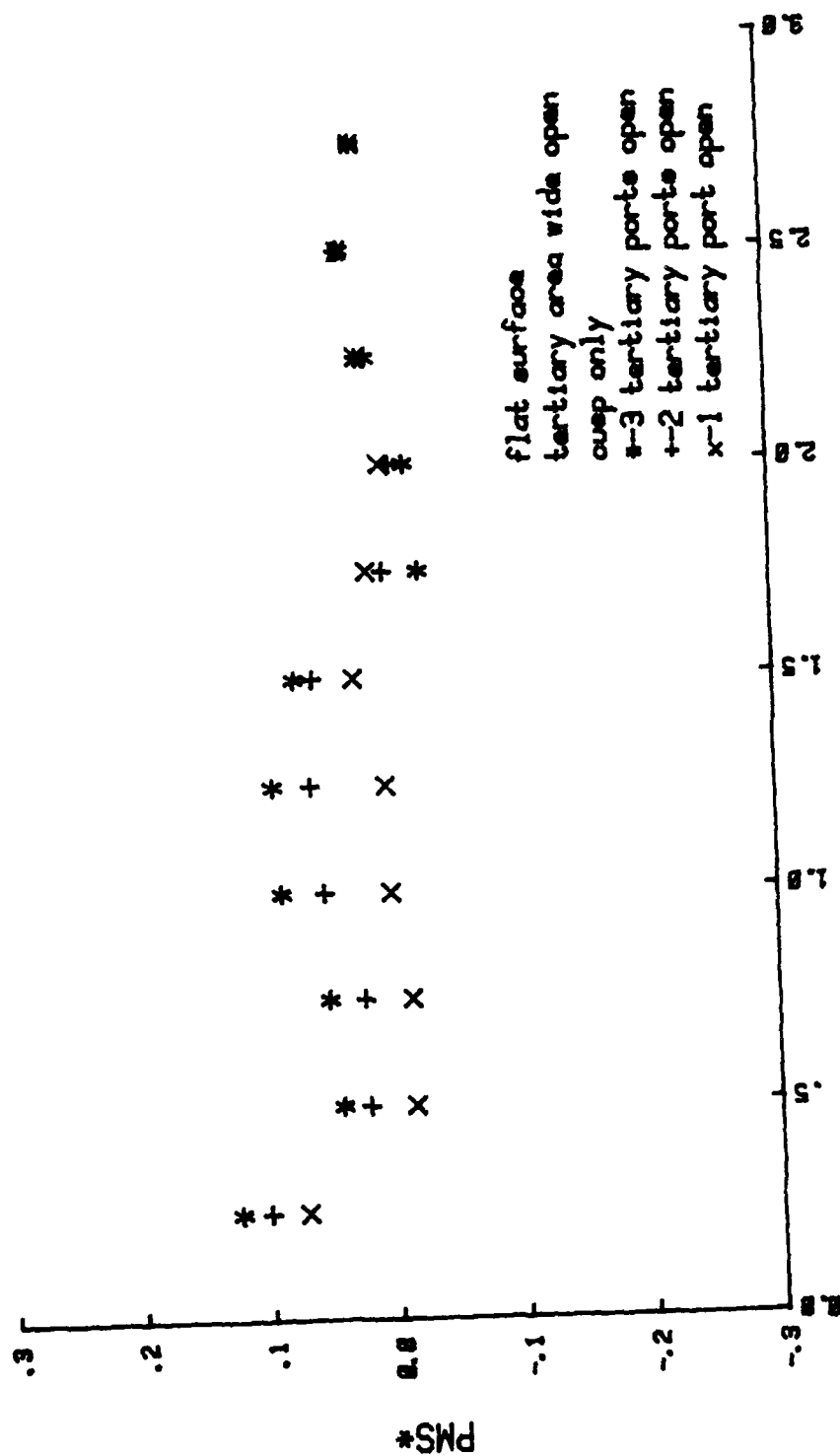
AXIAL PRESSURE DISTRIBUTION COMPARISON



AXIAL DISTANCE (X/S)

FIGURE 26a

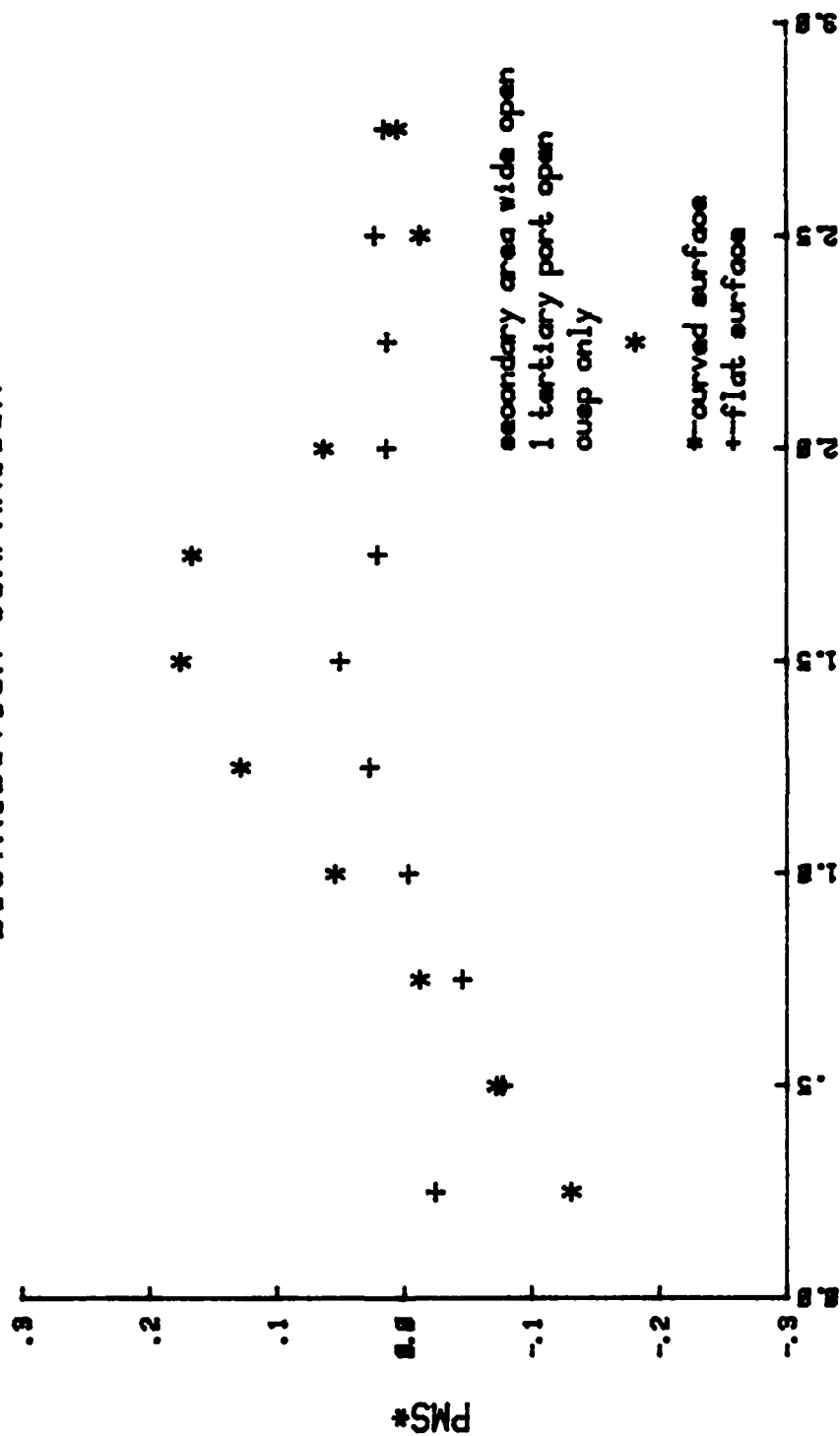
AXIAL PRESSURE DISTRIBUTION COMPARISON



AXIAL DISTANCE (X/S)

FIGURE 26b

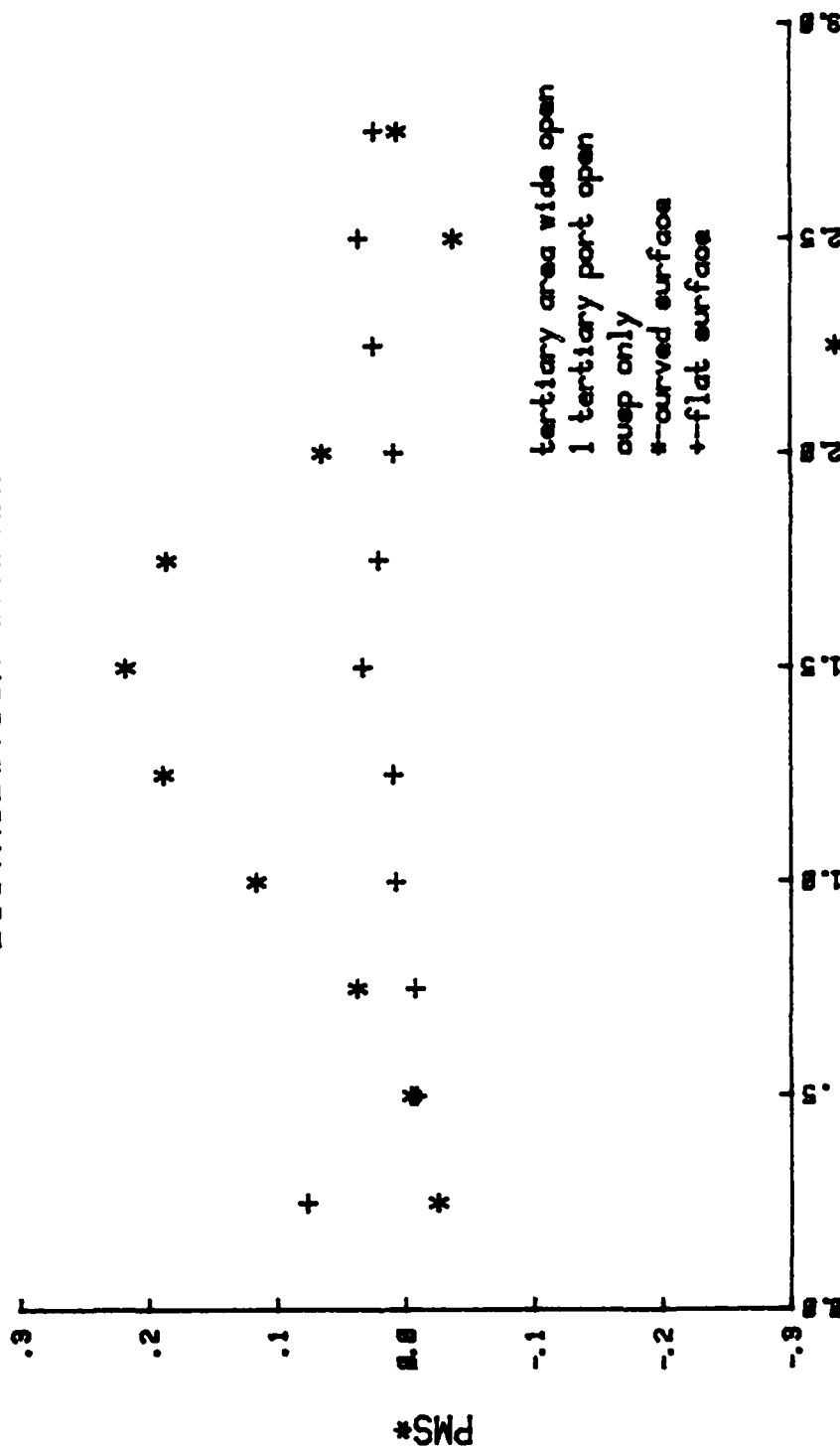
AXIAL PRESSURE DISTRIBUTION COMPARISON



AXIAL DISTANCE (X/S)

FIGURE 26c

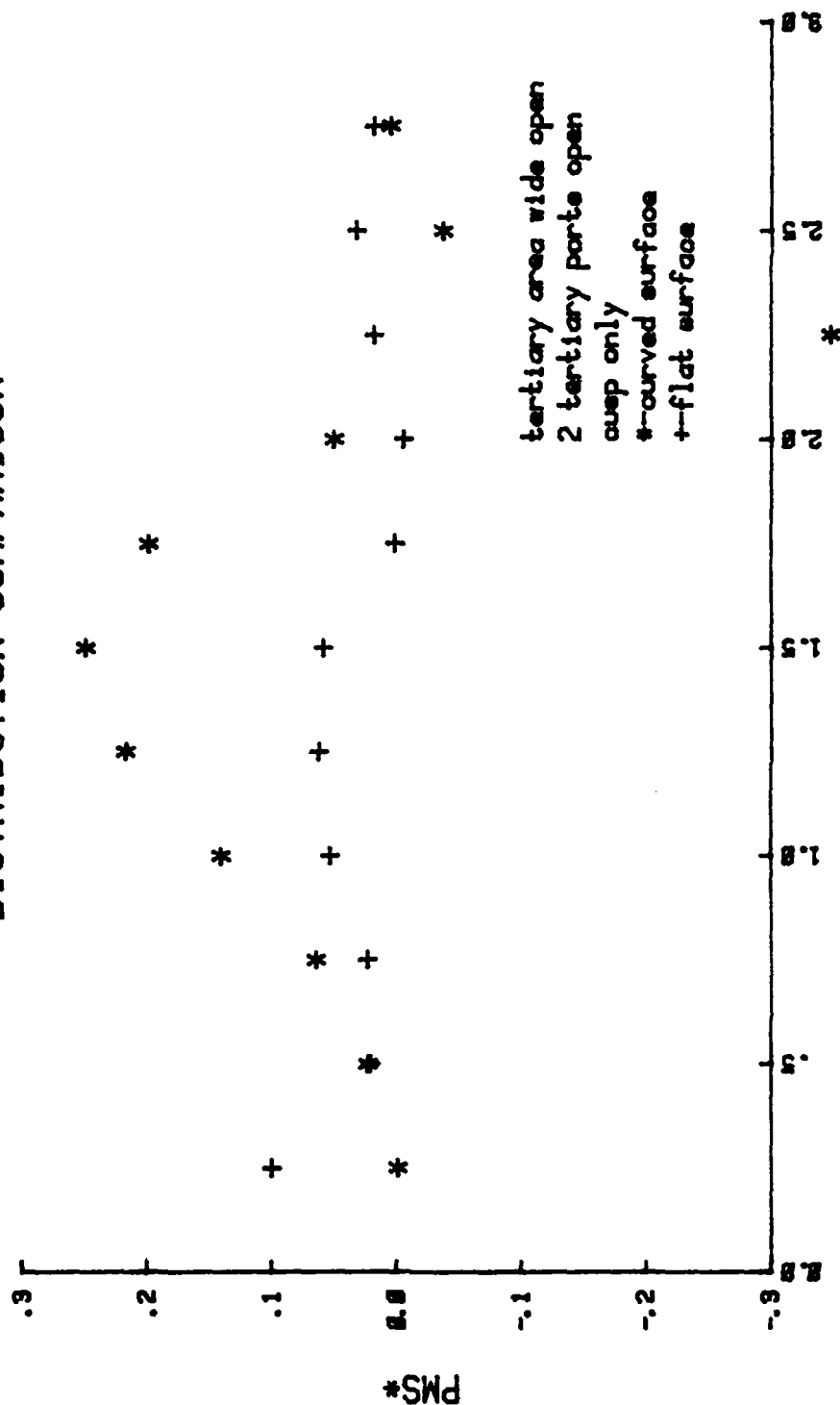
AXIAL PRESSURE DISTRIBUTION COMPARISON



AXIAL DISTANCE (X/S)

FIGURE 26d

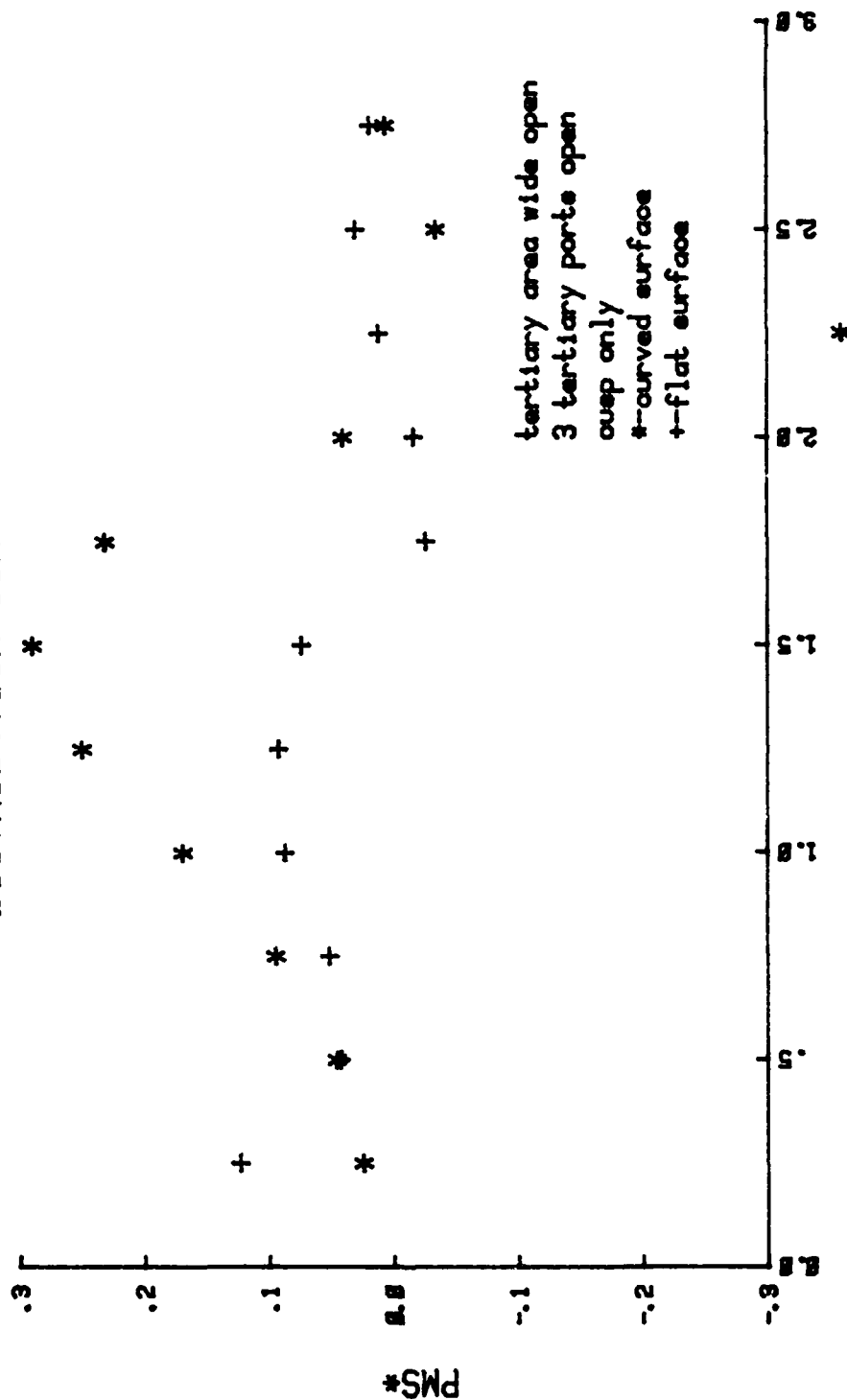
AXIAL PRESSURE DISTRIBUTION COMPARISON



AXIAL DISTANCE (X/S)

FIGURE 26e

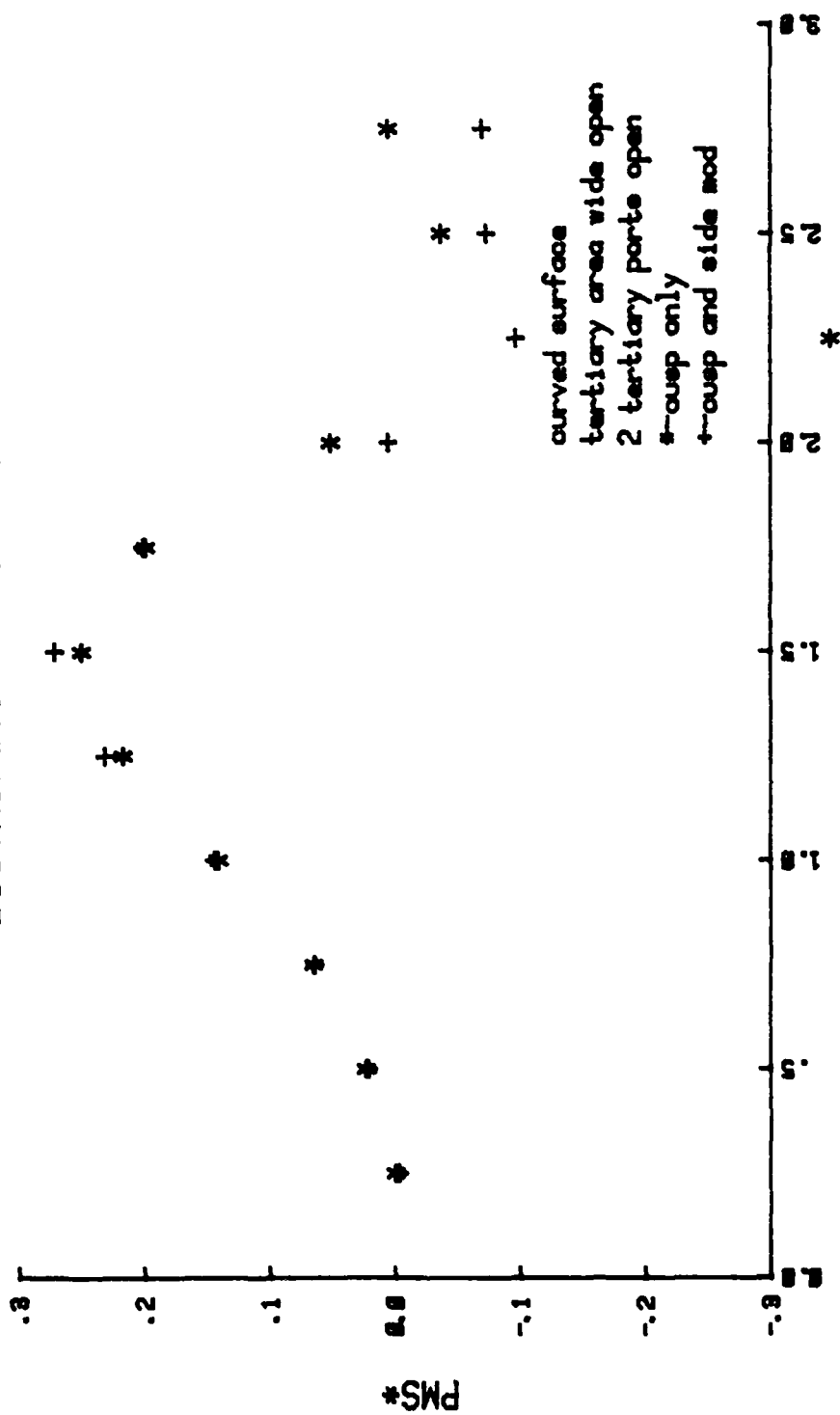
AXIAL PRESSURE DISTRIBUTION COMPARISON



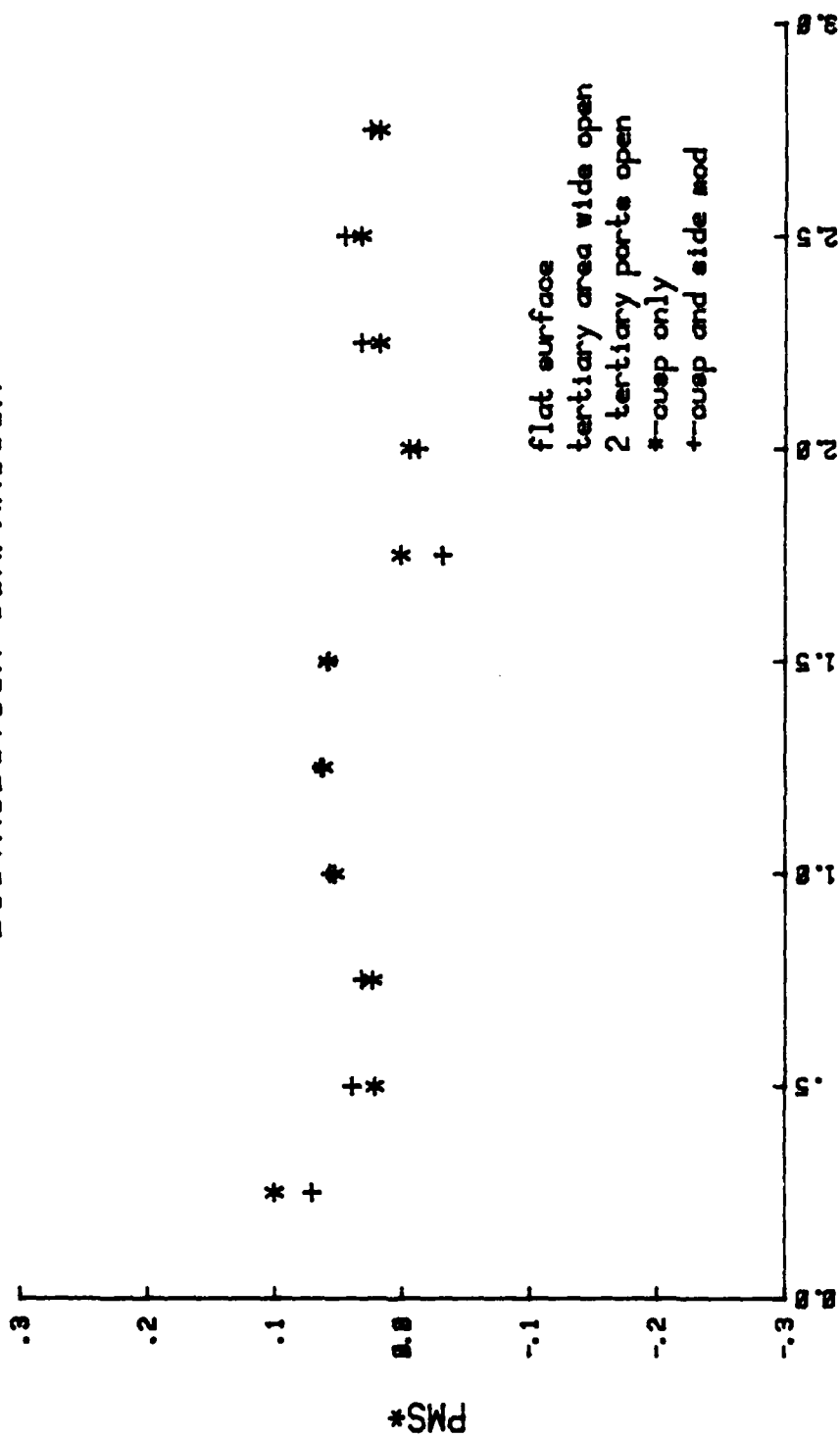
AXIAL DISTANCE (X/S)

FIGURE 26f

AXIAL PRESSURE DISTRIBUTION COMPARISON



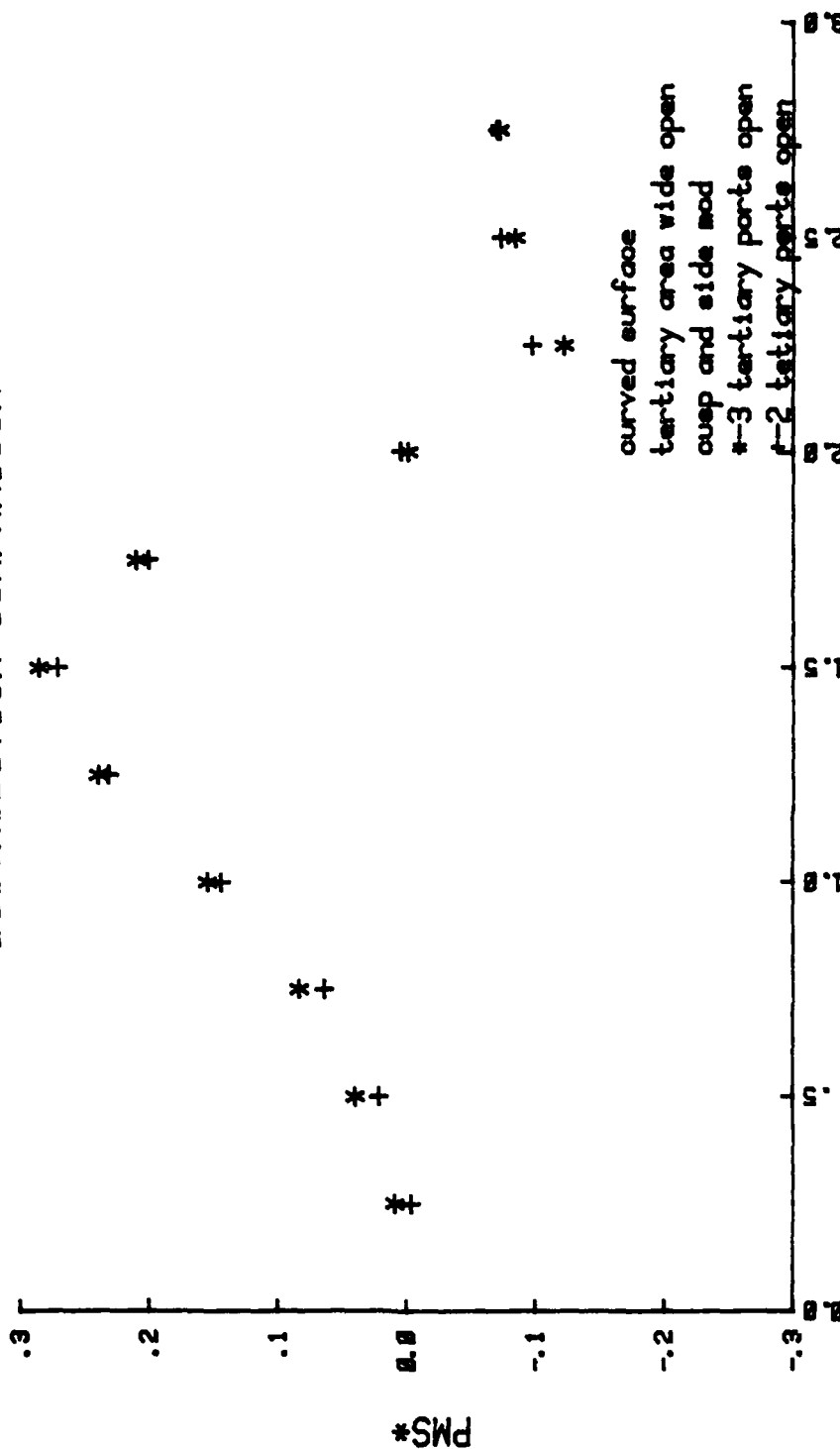
AXIAL PRESSURE DISTRIBUTION COMPARISON



AXIAL DISTANCE (X/S)

FIGURE 26h

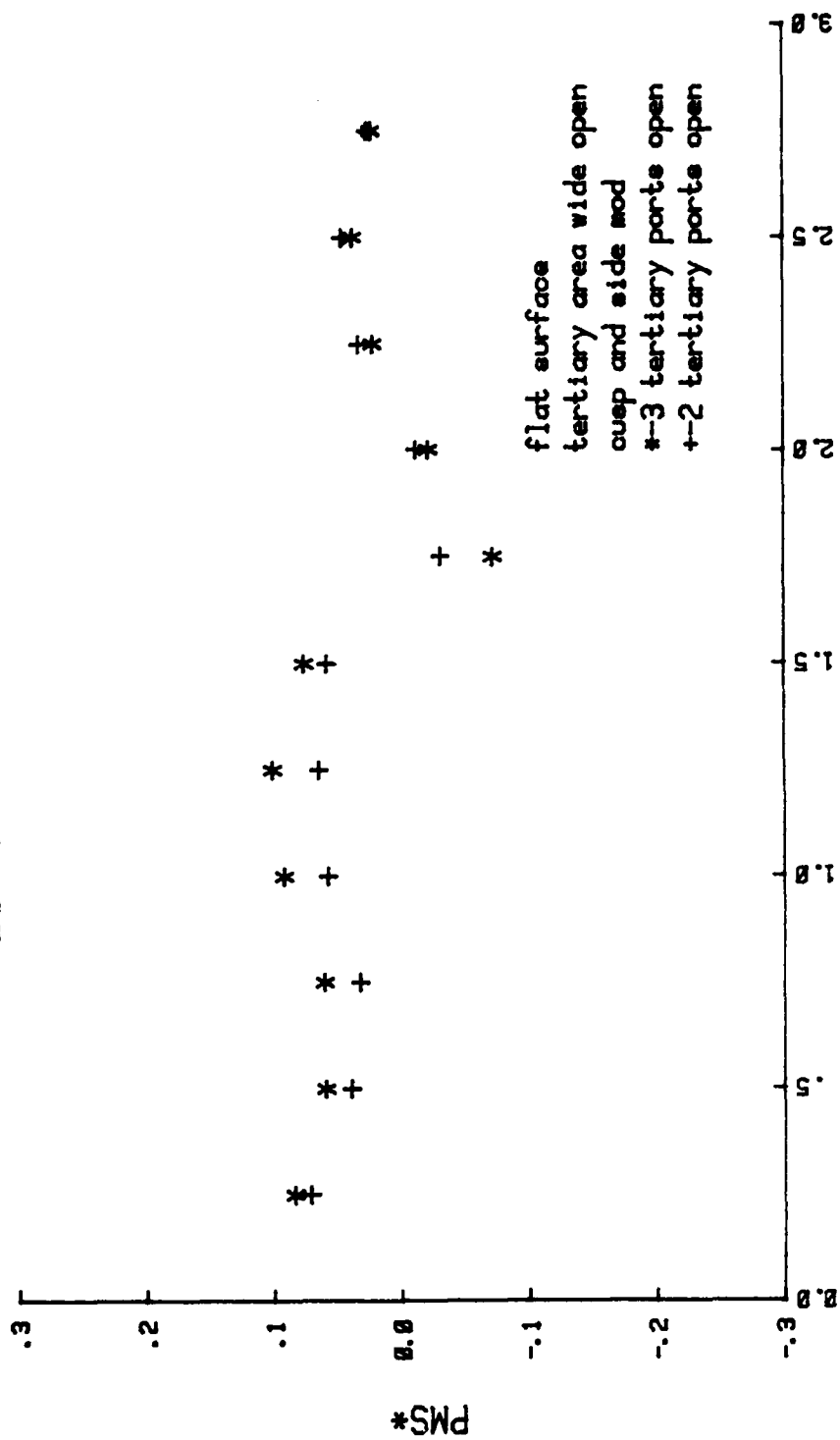
AXIAL PRESSURE DISTRIBUTION COMPARISON



AXIAL DISTANCE (X/S)

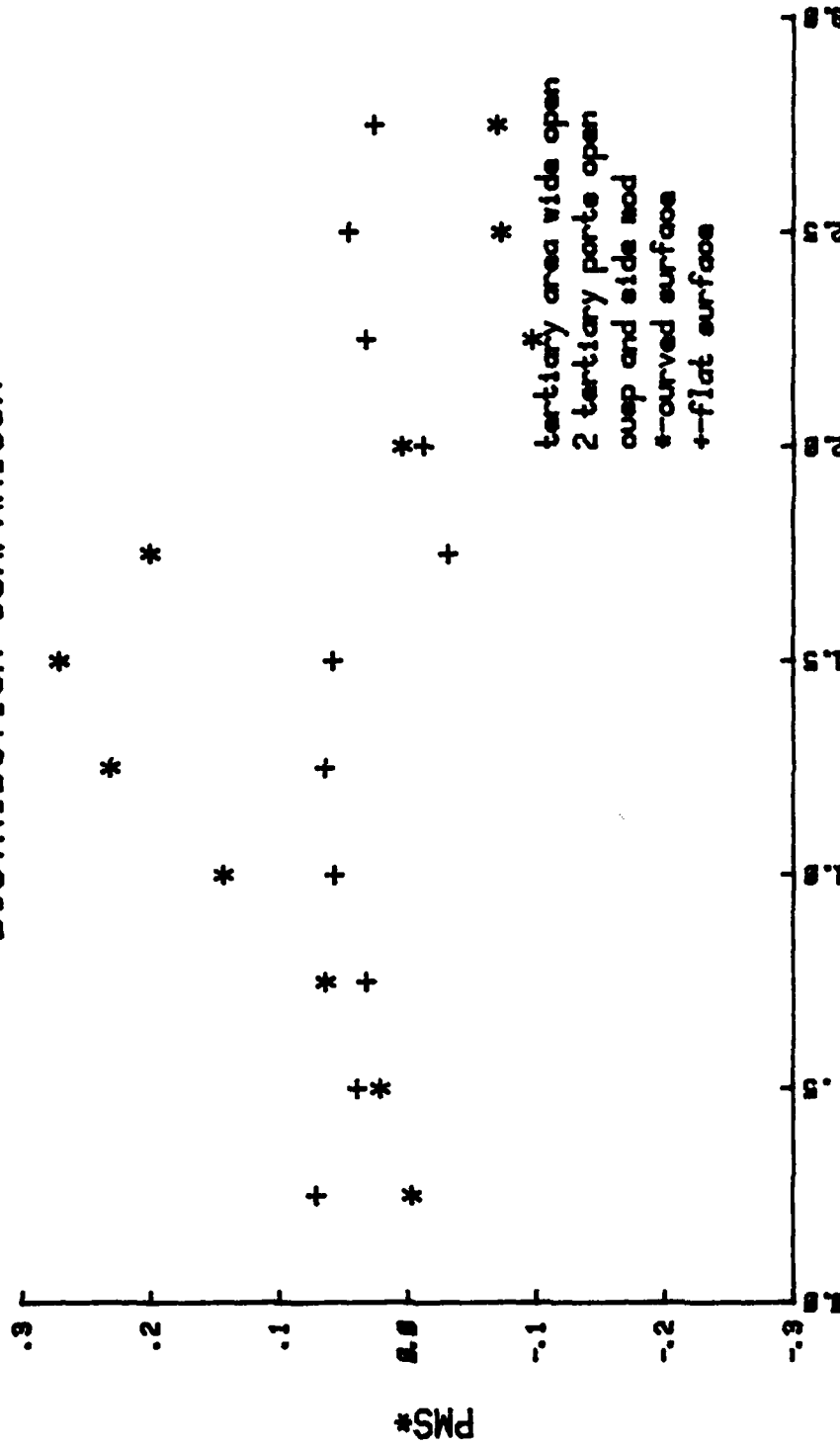
FIGURE 26i

AXIAL PRESSURE DISTRIBUTION COMPARISON



AXIAL DISTANCE (X/S)
FIGURE 26j

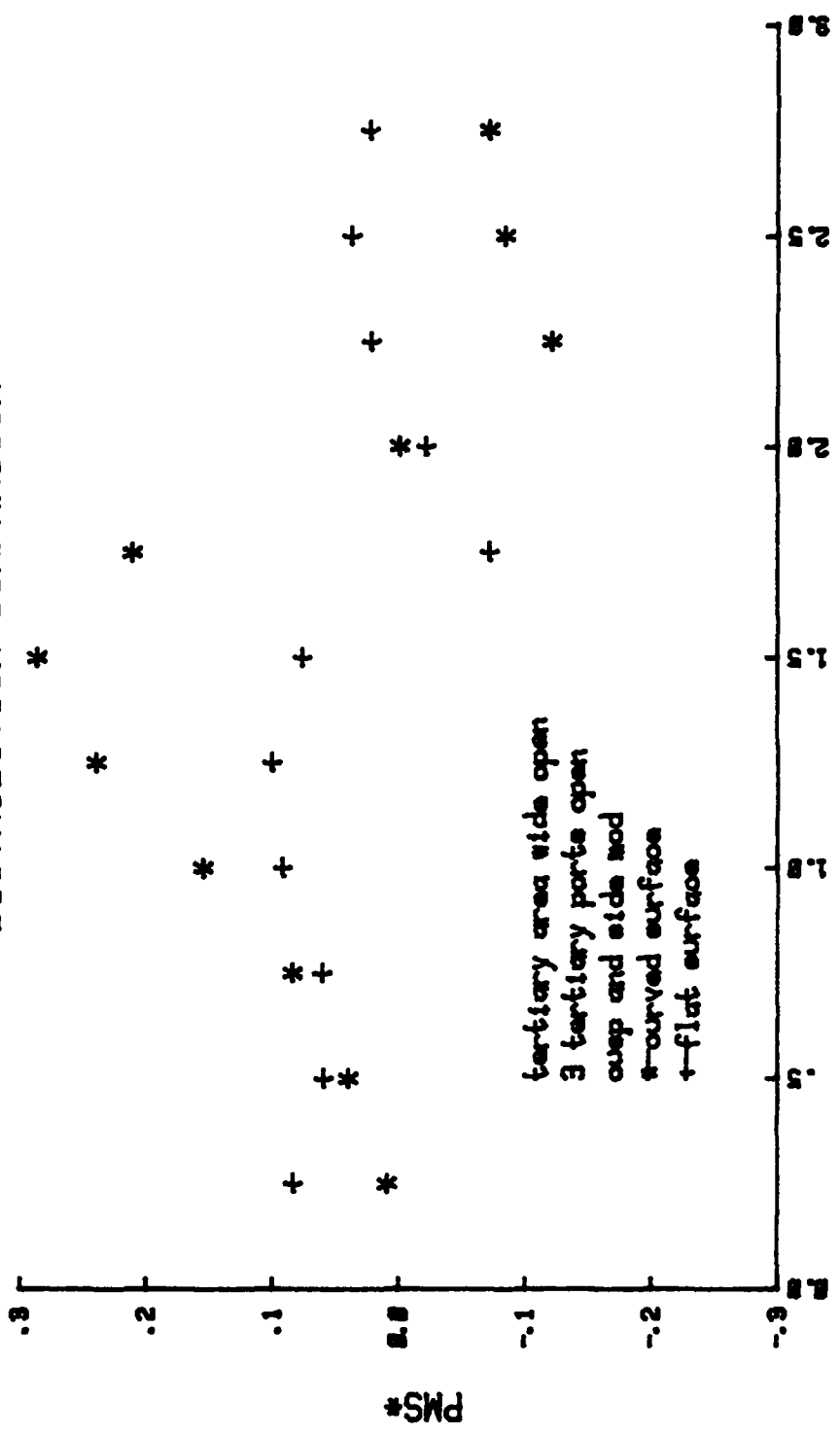
AXIAL PRESSURE DISTRIBUTION COMPARISON



AXIAL DISTANCE (X/S)

FIGURE 26k

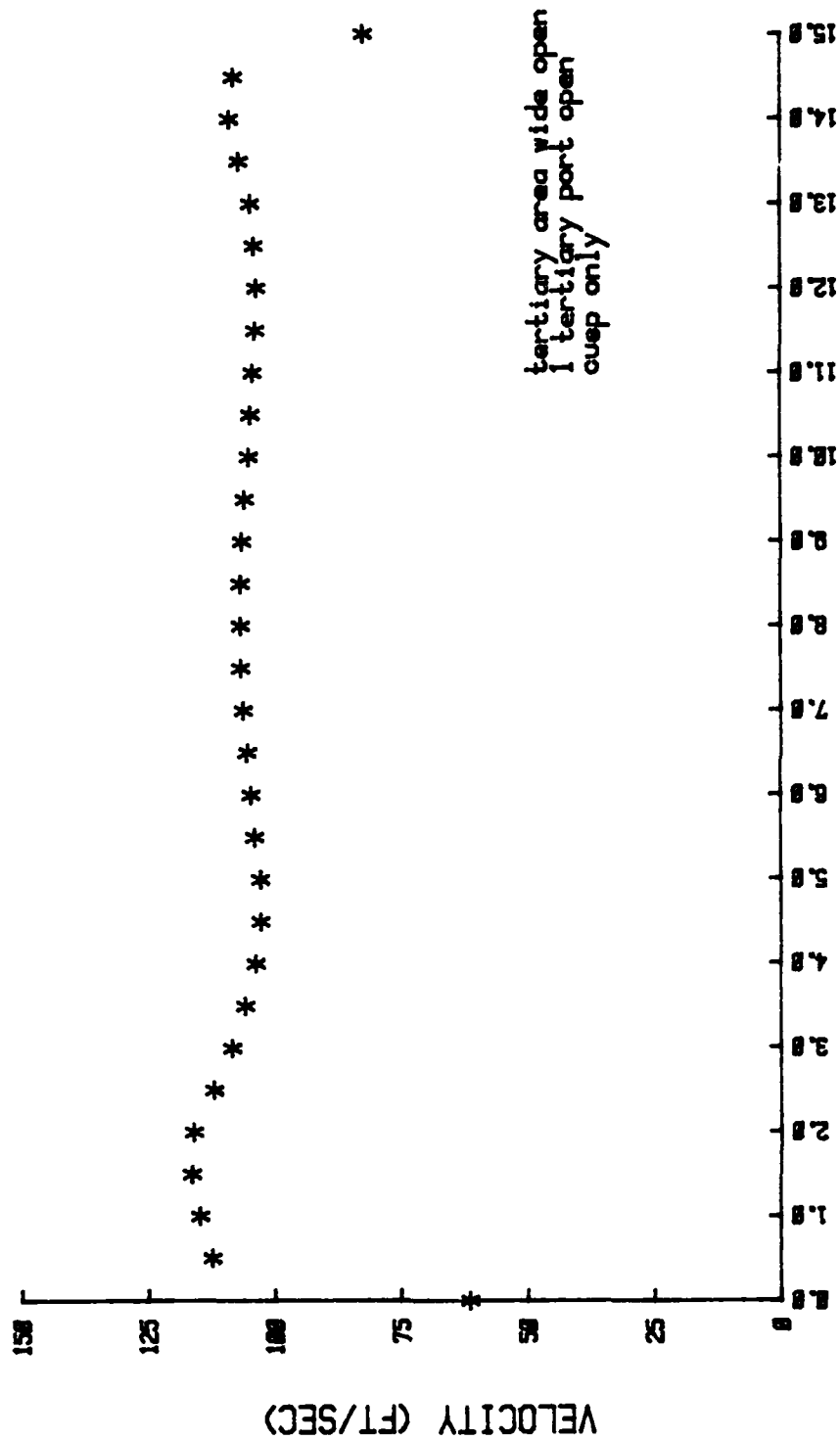
AXIAL PRESSURE DISTRIBUTION COMPARISON



AXIAL DISTANCE (X/S)

FIGURE 261

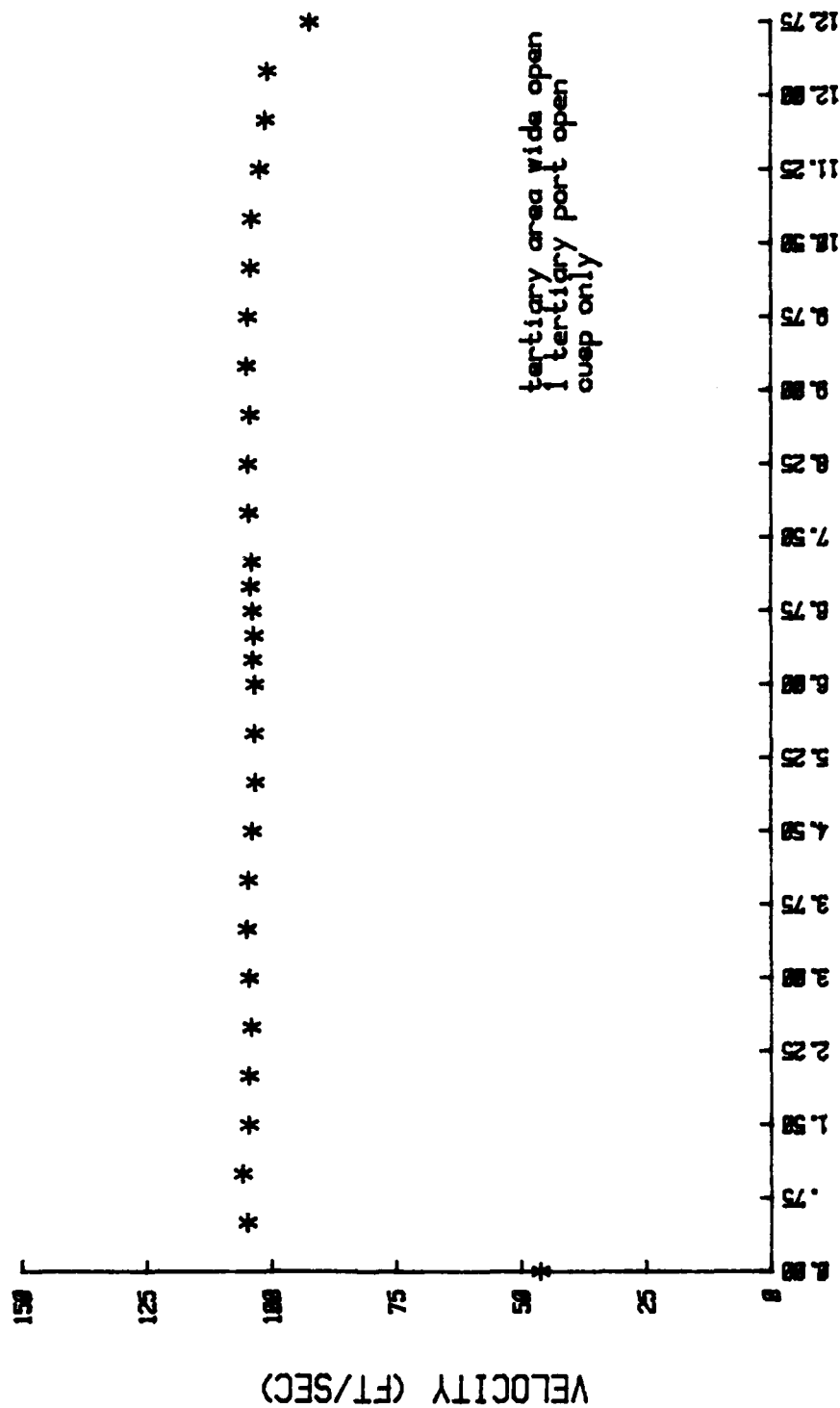
DIAGONAL VELOCITY TRAVERSE



DIAGONAL VELOCITY TRAVERSE

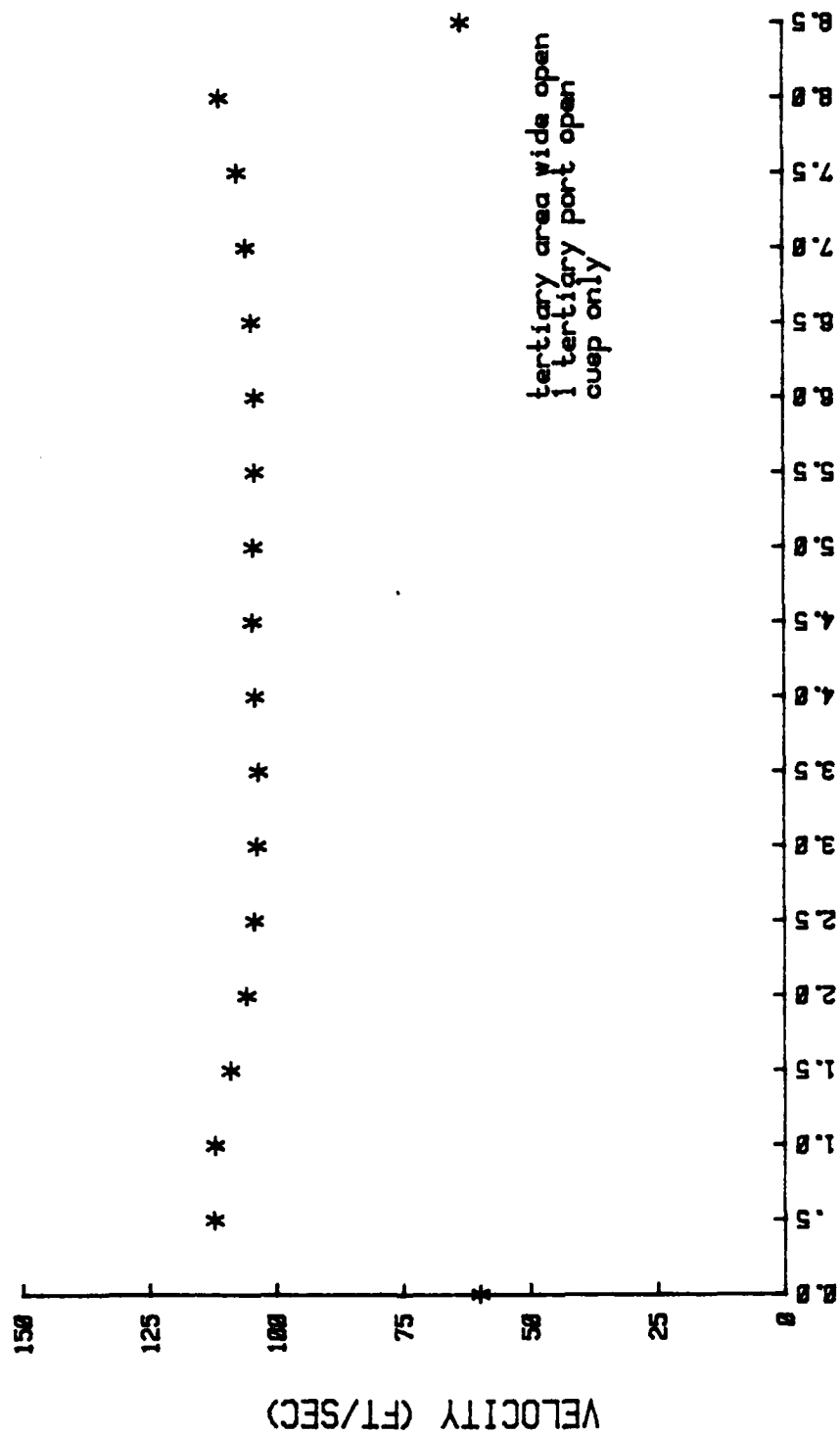
FIGURE 27a

HORIZONTAL VELOCITY TRAVERSE



HORIZONTAL DISTANCE (IN)
FIGURE 27b

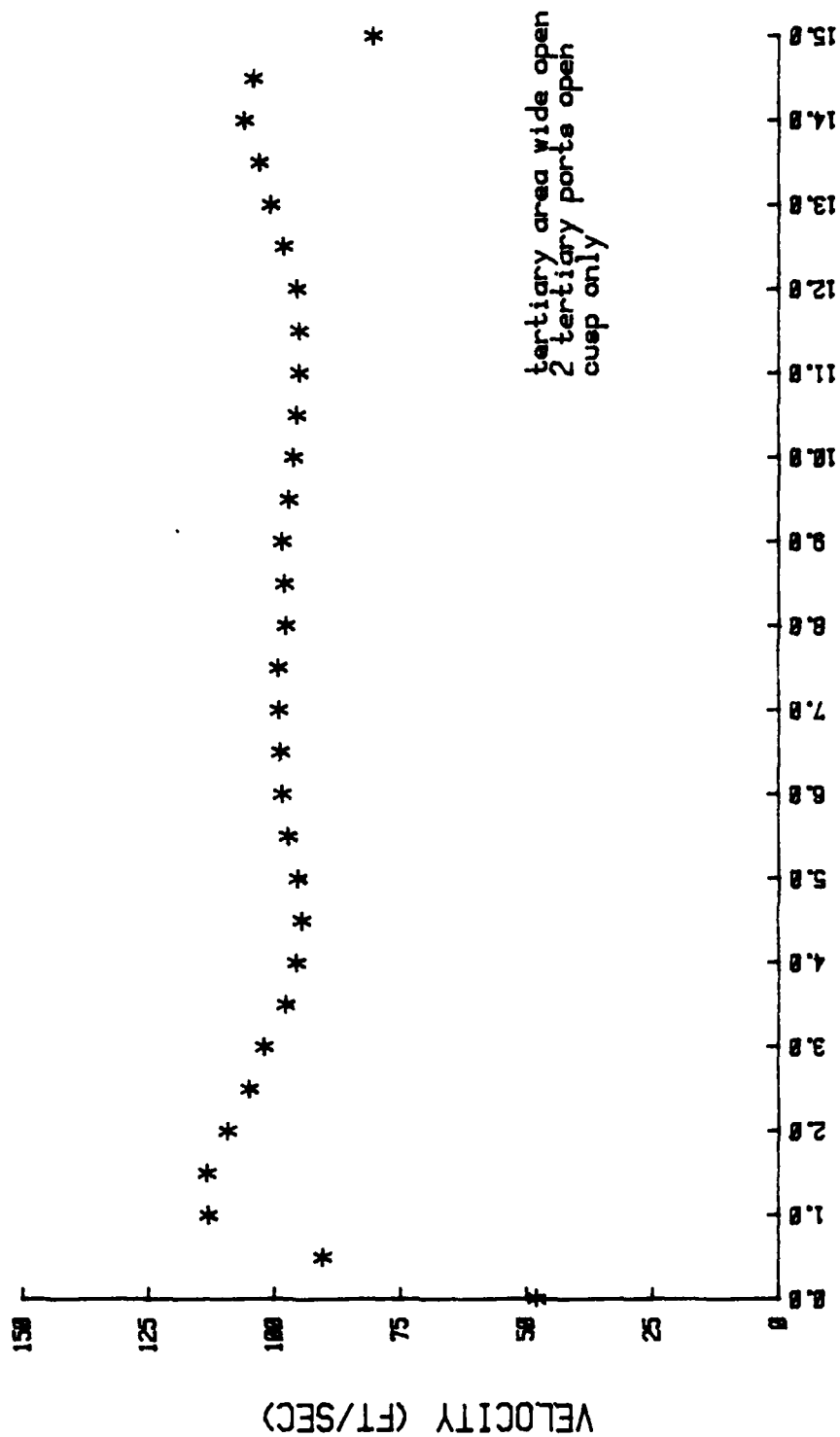
VERTICAL VELOCITY TRAVERSE



VERTICAL DISTANCE (IN)

FIGURE 27o

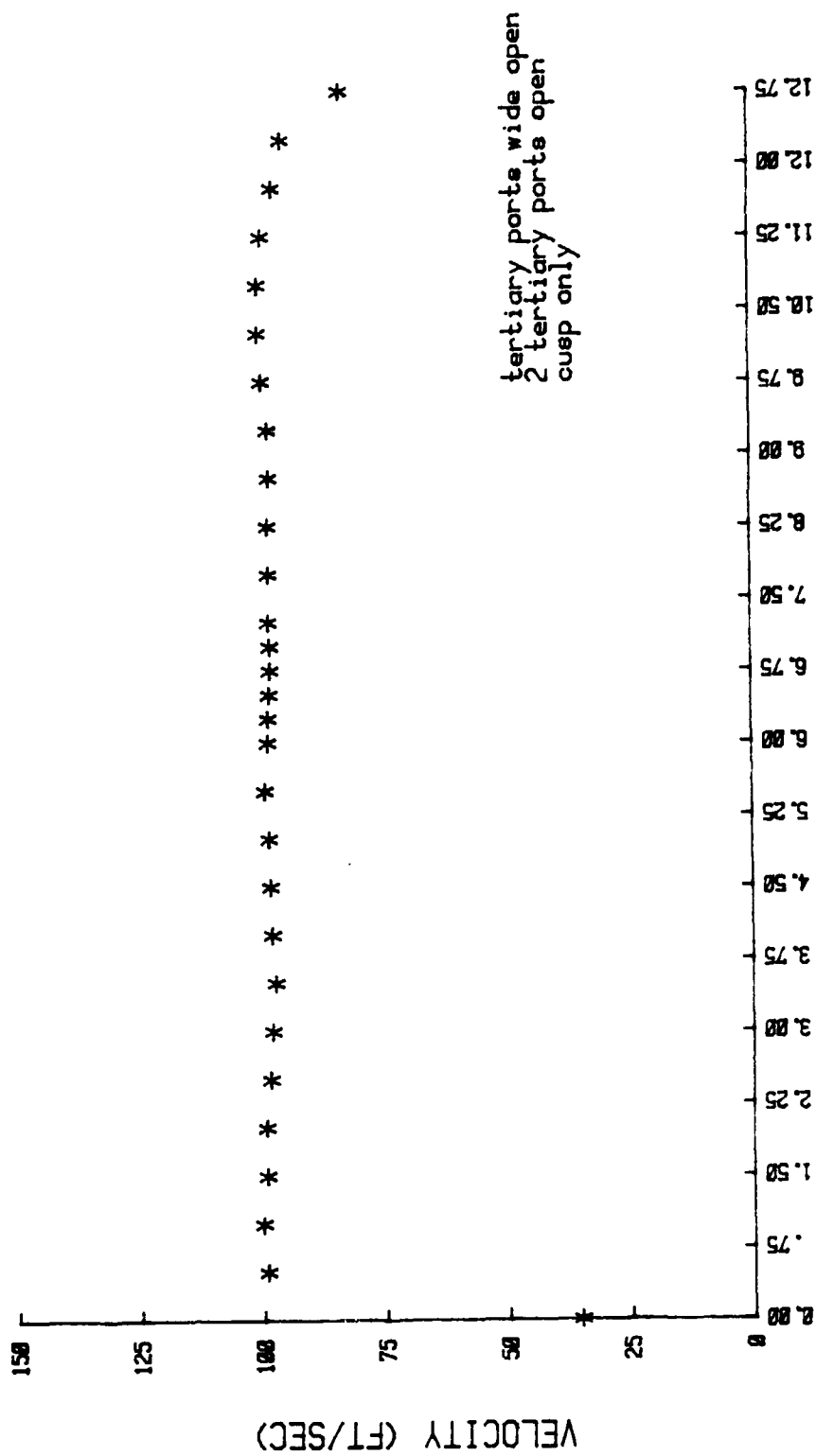
DIAGONAL VELOCITY TRAVERSE



DIAGONAL DISTANCE (IN)

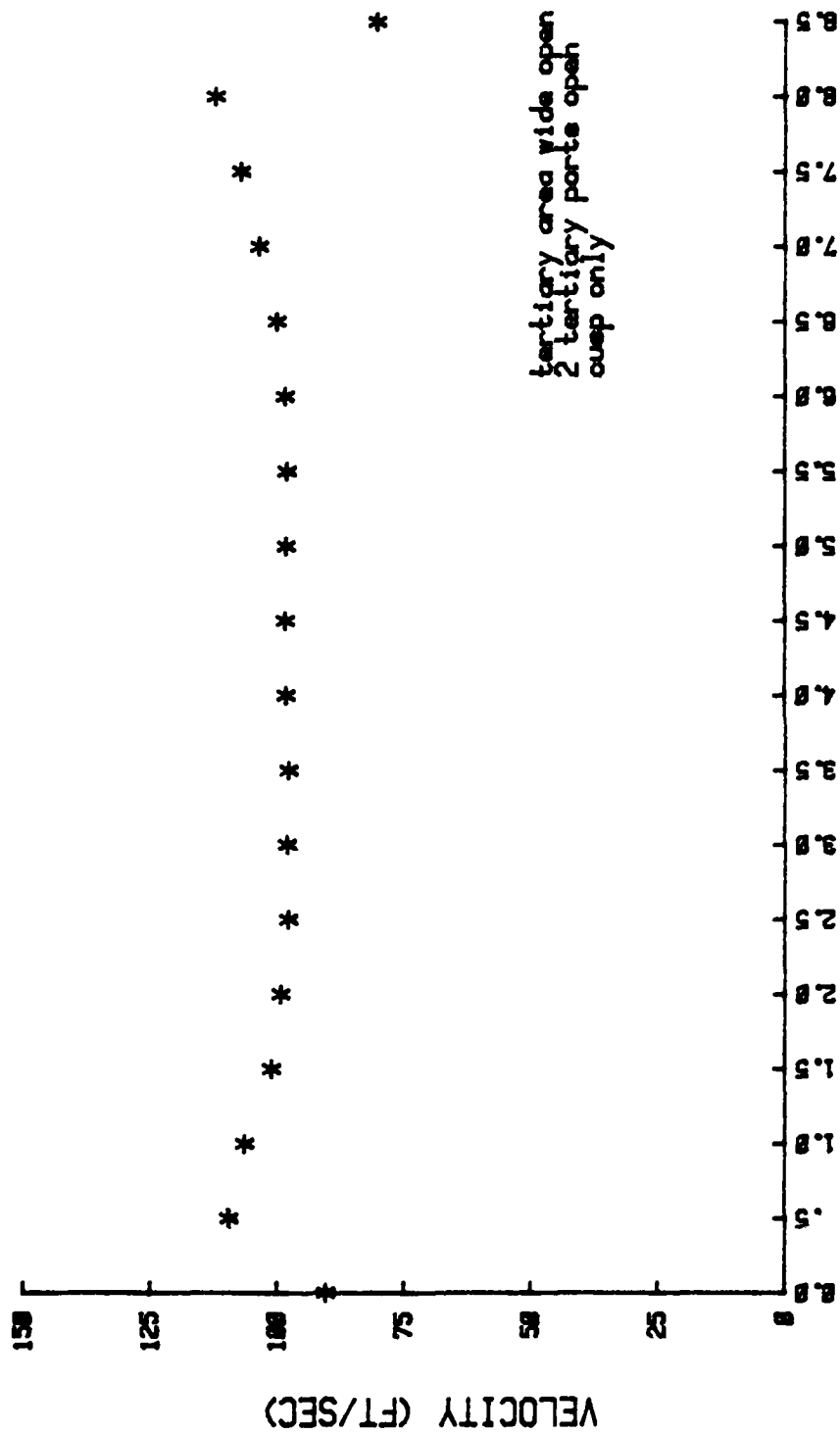
FIGURE 27d

VELOCITY (FT/SEC)



HORIZONTAL DISTANCE (IN)
FIGURE 27a

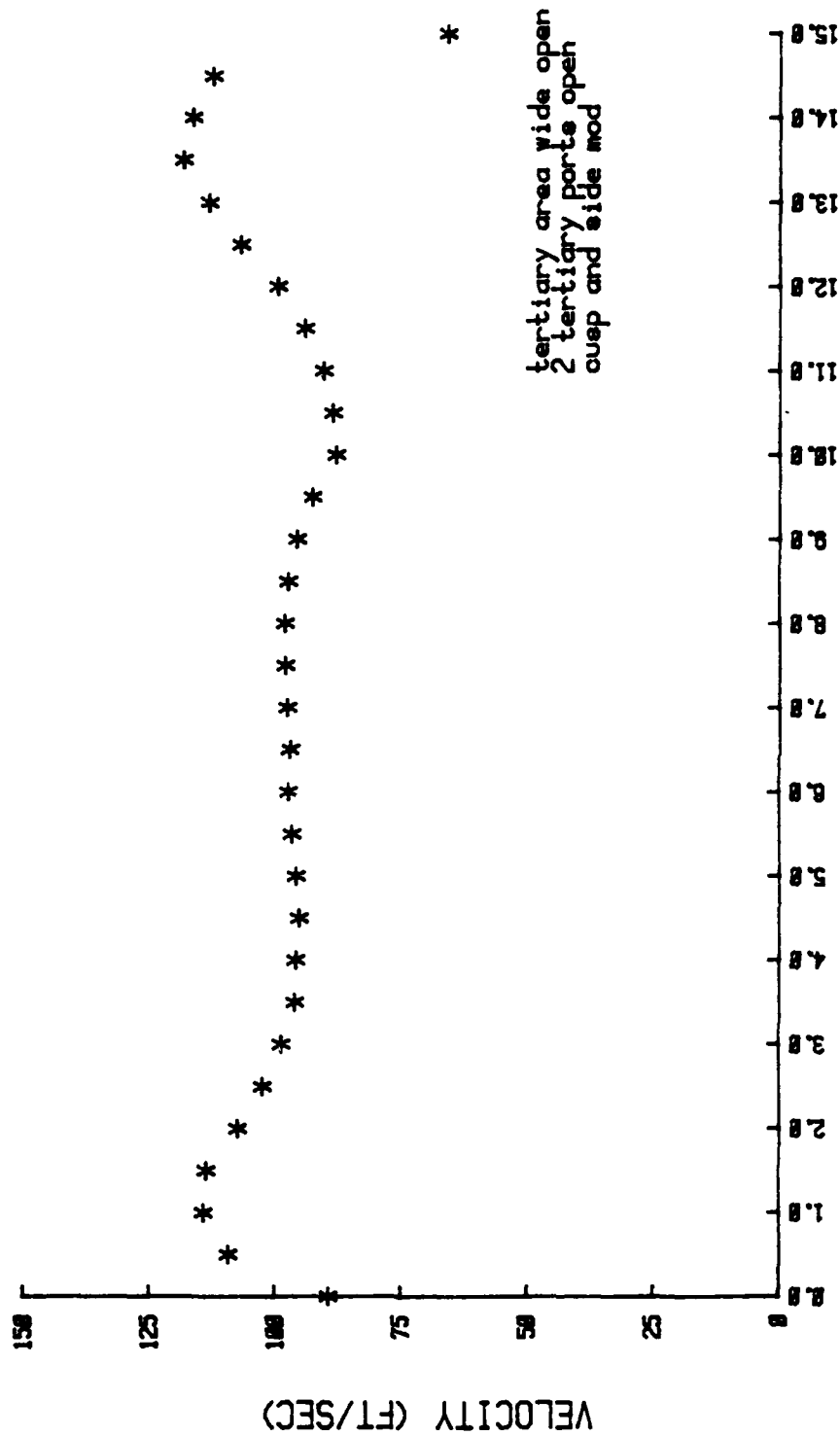
VERTICAL VELOCITY TRAVERSE



VERTICAL DISTANCE (IN)

FIGURE 27f

DIAGONAL VELOCITY TRAVERSE



DIAGONAL DISTANCE (IN)
FIGURE 27q

AD-A104 072

NAVAL POSTGRADUATE SCHOOL MONTEREY CA
FLOW CHARACTERISTICS OF A MULTIPLE NOZZLE EXHAUST GAS EDUCTOR S--ETC(U)
MAR 81 D L RYAN

F/S 21/2

UNCLASSIFIED

2 of 2
A 104 072

MI

END

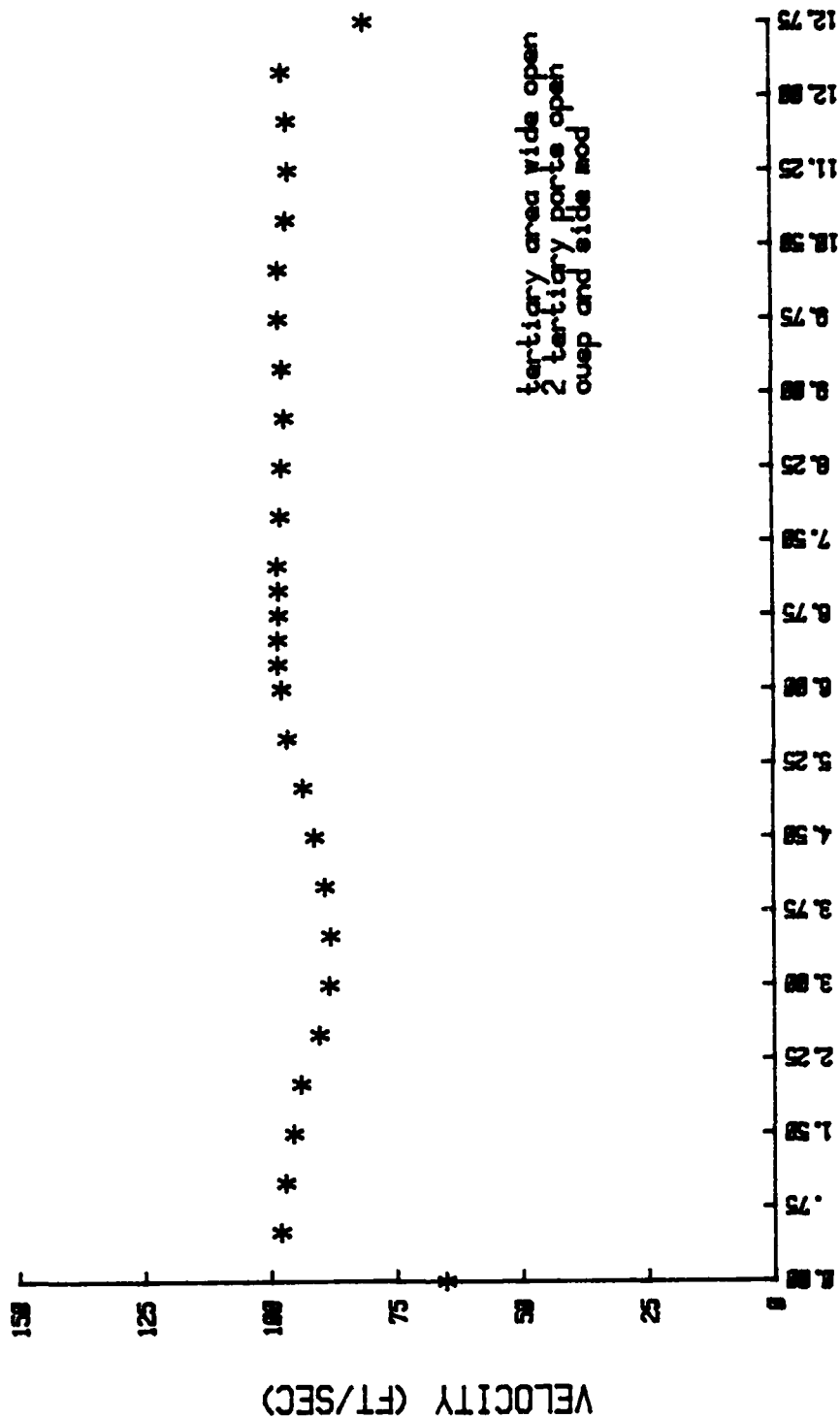
DATE

FILED

40-811

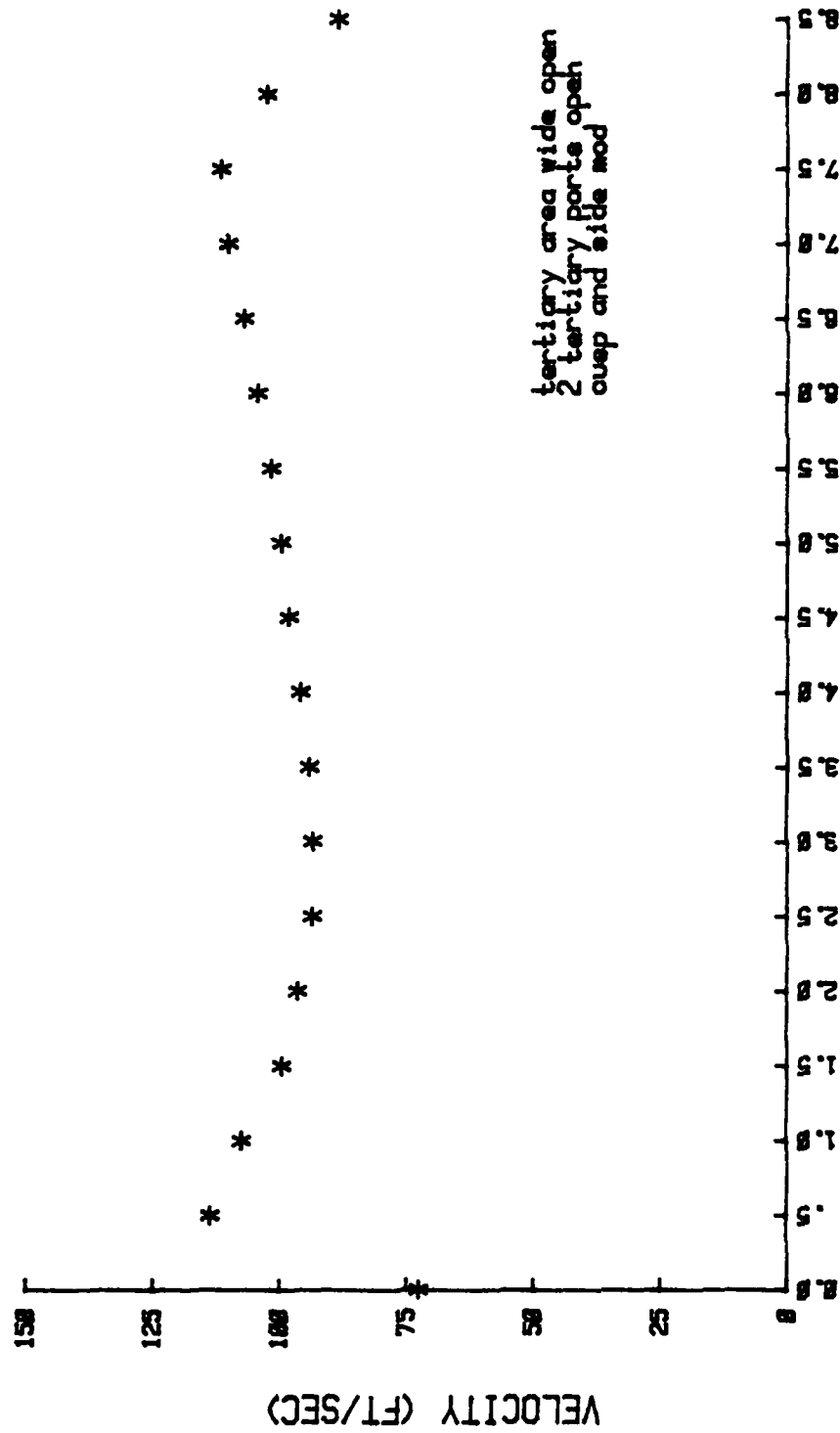
DTIC

HORIZONTAL VELOCITY TRAVERSE



HORIZONTAL DISTANCE (IN)
FIGURE 27h

VERTICAL VELOCITY TRAVERSE



VERTICAL DISTANCE (IN)
FIGURE 271

DATA TAKEN ON 27 JANUARY 1961
DATA TAKEN BY D.L. RYAN
3 TERTIARY PORTS OPEN/CUSP IN

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA: 107.51 SQ IN
PRIMARY NOZZLE AREA: 9.06 SQ IN AREA RATIO (AM/AP): 2.99
MIXING STACK LENGTH: 23.50 IN ORIFICE DIAMETER: 6.908 IN
MIXING STACK DIMENSION: 0.5 IN ORIFICE BETA: 0.497 IN
MIXING STACK L/S: 3.00 AMBIENT PRESSURE: 29.73 IN HG

N	FOR	DPOR	TOR	TUPT	TAMB	PU-PA	PA-PS	PA-PT	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O			DEGREES F		IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.7	22.1	51.3	102.9	55.0	7.70	2.41	0.00	0.000	*****
2	0.7	21.8	50.0	103.3	55.0	8.20	1.82	0.00	6.263	*****
3	0.8	22.2	48.9	103.2	55.0	9.00	1.42	0.00	12.566	*****
4	0.7	21.8	49.9	104.0	55.0	9.05	0.82	0.01	25.133	*****
5	0.7	21.8	49.8	104.3	55.0	9.50	0.32	0.01	50.265	*****
6	0.7	21.9	50.8	104.6	55.0	9.70	0.11	0.01	100.531	*****
7	0.7	21.9	50.4	104.6	55.0	9.90	0.00	0.01	*****	*****

SECONDARY BOX

N	WE	P+	T+	P+T+ W+T+ .44	HP	HS	UP	UM	UOPT	UPT	HACH
RUN					LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC		
1	0.0000	0.2280	0.9149	0.2492	0.0000	3.7697	0.0000	214.93	71.91	72.49	0.062
2	0.0779	0.1744	0.9142	0.1907	0.0749	3.7486	0.2921	213.57	76.52	72.03	0.062
3	0.1363	0.1336	0.9144	0.1461	0.1310	3.7868	0.5160	215.49	81.05	72.68	0.062
4	0.2092	0.0787	0.9131	0.0862	0.2010	3.7491	0.7842	213.33	84.98	71.95	0.062
5	0.2613	0.0308	0.9126	0.0337	0.2510	3.7495	0.9798	213.21	88.33	71.91	0.062
6	0.3060	0.0105	0.9121	0.0116	0.2939	3.7545	1.1489	213.49	91.36	72.00	0.062
7	*****	0.0000	0.9121	0.0000	*****	3.7550	0.0000	213.51	*****	72.01	0.062

TABLE Ia

TERTIARY BOX

N	WTS	PTS	ITS	PTS/ITS	WTS/ITS	WM	WT	UE
RUN						LBM/SEC	LBM/SEC	FT/SEC
1	33333	0.0000	0.9149	0.0000		3.770	33333	33333
2	33333	0.0000	0.9142	0.0000		4.041	33333	33333
3	33333	0.0000	0.9144	0.0000		4.303	33333	33333
4	33333	0.0005	0.9131	0.0005		4.533	33333	33333
5	33333	0.0005	0.9126	0.0005		4.729	33333	33333
6	33333	0.0005	0.9121	0.0005		4.903	33333	33333
7	33333	0.0005	0.9121	0.0005		33333	33333	33333

MIXING STACK PRESSURE DATA RUN

X/S	0.25	0.50	0.75
PHS(INH20)	0.250	0.470	0.980
PHS	0.024	0.045	0.094
X/S	2.00	2.25	2.50
PHS(INH20)	0.410	-3.750	-0.370
PHS	0.039	-0.359	-0.035

MIXING STACK PRESSURE DATA RUN

X/S	0.25	0.50	0.75
PHS(INH20)	1.280	0.440	0.530
PHS	0.123	0.042	0.051
X/S	2.00	2.25	2.50
PHS(INH20)	-0.100	0.110	0.300
PHS	-0.017	0.011	0.029

7 CURVED SIDE DISTRIBUTION

X/S	1.00	1.25	1.50
PHS	1.750	2.590	3.010
PHS	0.160	0.240	0.209

7 FLAT SIDE DISTRIBUTION

X/S	1.00	1.25	1.50
PHS	0.900	0.950	0.760
PHS	0.086	0.091	0.073

TABLE 1b

DATA TAKEN ON 28 JANUARY 1981
DATA TAKEN BY D.L. RYAN
2 TERTIARY PORTS OPEN/CUSP IN

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA: 187.51 SQ IN

PRIMARY NOZZLE AREA: 9.06 SQ IN AREA RATIO (AM/AP): 2.99

MIXING STACK LENGTH: 25.50 IN ORIFICE DIAMETER: 6.908 IN

MIXING STACK DIMENSION: 8.5 IN ORIFICE BETA: 0.497 IN

MIXING STACK L/S: 3.00 AMBIENT PRESSURE: 29.92 IN HG

N	POR	DPOR	TOR	TUPT	TAMB	PU-PA	PA-PS	PA-PT	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O	IN OF H2O	DEGREES F	IN OF H2O	IN OF H2O	IN OF H2O	IN OF H2O	IN OF H2O	SQARE INCHES	SQARE INCHES
1	0.7	21.8	50.3	101.6	56.0	7.25	2.57	0.00	0.000	111111
2	0.7	21.7	50.8	102.5	56.0	7.75	1.98	0.00	6.283	111111
3	0.7	21.8	50.6	103.7	56.0	8.35	1.54	0.00	12.566	111111
4	0.7	21.8	50.7	104.1	56.0	8.90	0.94	0.00	25.133	111111
5	0.7	21.7	50.7	104.3	56.0	9.30	0.40	0.00	50.265	111111
6	0.7	22.0	50.9	104.5	56.0	9.80	0.14	0.00	100.531	111111
7	0.7	21.9	51.0	104.8	56.0	9.90	0.03	0.00	111111	111111

SECONDARY BOX

N	WZ	PZ	TZ	PT/TZ	WT/TZ	WP	WS	UP	UN	UPT	UPT NACH
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.0000	0.2474	0.9188	0.2693	0.0000	3.7596	0.0000	212.58	71.12	71.69	0.062
2	0.0214	0.1316	0.9173	0.2839	0.0784	3.7431	0.3053	212.02	76.21	71.51	0.062
3	0.1433	0.1480	0.9153	0.1617	0.1378	3.7587	0.5385	212.79	80.49	71.76	0.062
4	0.2239	0.0505	0.9147	0.0389	0.2153	3.7532	0.8415	212.53	85.66	71.70	0.062
5	0.2528	0.0388	0.9144	0.0424	0.2815	3.7497	1.0979	211.90	89.86	71.47	0.061
6	0.3441	0.0134	0.9140	0.0147	0.3308	3.7746	1.2990	213.25	93.78	71.92	0.062
7	111111	0.0029	0.9135	0.0032	111111	3.7657	9.3958	212.00	111111	71.77	0.062

TABLE IIa

TERTIARY BOX

N	WT	PTS	ITS	PTS/ITS	WT/ITS	MM	WT	UE
LBM/SEC LBM/SEC FT/SEC								
1	3.760	0.0000	0.9180	0.0000	3.760	0.0000	3.760	0.0000
2	4.054	0.0000	0.9173	0.0000	4.054	0.0000	4.054	0.0000
3	4.297	0.0000	0.9153	0.0000	4.297	0.0000	4.297	0.0000
4	4.600	0.0000	0.9147	0.0000	4.600	0.0000	4.600	0.0000
5	4.848	0.0000	0.9144	0.0000	4.848	0.0000	4.848	0.0000
6	5.074	0.0000	0.9140	0.0000	5.074	0.0000	5.074	0.0000
7	5.074	0.0000	0.9135	0.0000	5.074	0.0000	5.074	0.0000

MIXING STACK PRESSURE DATA: RUN 7 CURVED SIDE DISTRIBUTION

X/S: 0.25 0.50 0.75 1.00 1.25 1.50 1.75

PHS<INH20>: -0.010 0.235 0.670 1.460 2.250 2.590 2.060

PHS<: -0.001 0.023 0.064 0.140 0.216 0.249 0.198

X/S: 2.00 2.25 2.50 2.75

PHS<INH20>: 0.520 -3.620 -0.390 0.040

PHS<: 0.050 -0.348 -0.037 0.004

MIXING STACK PRESSURE DATA: RUN 7 FLAT SIDE DISTRIBUTION

X/S: 0.25 0.50 0.75 1.00 1.25 1.50 1.75

PHS<INH20>: 1.040 0.220 0.240 0.550 0.640 0.610 0.010

PHS<: 0.100 0.021 0.023 0.053 0.061 0.059 0.001

X/S: 2.00 2.25 2.50 2.75

PHS<INH20>: -0.060 0.180 0.330 0.180

PHS<: -0.006 0.017 0.032 0.017

TABLE IIb

VERTICAL VELOCITY TRAVERSE							
POSIT<IN>	0.00	0.50	1.00	1.50	2.00	2.50	3.00
P<IN H2O>	1.84	2.78	2.55	2.30	2.22	2.15	2.16
V<FT/SEC>	89.47	108.38	105.33	100.83	98.28	96.71	96.94
POSIT<IN>	3.50	4.00	4.50	5.00	5.50	6.00	6.50
P<IN H2O>	2.15	2.17	2.18	2.17	2.16	2.18	2.25
V<FT/SEC>	96.71	97.16	97.39	97.16	96.94	97.39	98.94
POSIT<IN>	7.00	7.50	8.00	8.50			
P<IN H2O>	2.41	2.58	2.82	1.45			
V<FT/SEC>	102.40	105.95	110.76	79.43			

HORIZONTAL VELOCITY TRAVERSE							
POSIT<IN>	0.00	0.50	1.00	1.50	2.00	2.50	3.00
P<IN H2O>	0.28	2.22	2.26	2.22	2.22	2.18	2.16
V<FT/SEC>	34.90	98.28	99.16	98.28	98.28	97.39	96.94
POSIT<IN>	3.50	4.00	4.50	5.00	5.50	6.00	6.25
P<IN H2O>	2.13	2.16	2.17	2.18	2.22	2.19	2.18
V<FT/SEC>	96.26	96.94	97.16	97.39	98.28	97.61	97.39
POSIT<IN>	6.50	6.75	7.00	7.25	7.75	8.25	8.75
P<IN H2O>	2.17	2.16	2.16	2.17	2.17	2.17	2.16
V<FT/SEC>	97.16	96.94	96.94	97.16	97.16	97.16	96.94
POSIT<IN>	9.25	9.75	10.25	10.75	11.25	11.75	12.25
P<IN H2O>	2.17	2.22	2.25	2.25	2.21	2.11	2.03
V<FT/SEC>	97.16	98.28	98.94	98.94	98.06	95.81	93.98
POSIT<IN>	12.75						
P<IN H2O>	1.55						
V<FT/SEC>	82.12						

DIAGONAL VELOCITY TRAVERSE							
POSIT<IN>	0.00	0.50	1.00	1.50	2.00	2.50	3.00
P<IN H2O>	0.52	1.84	2.88	2.89	2.69	2.48	2.34
V<FT/SEC>	47.56	89.47	111.94	112.13	108.18	103.87	100.90
POSIT<IN>	3.50	4.00	4.50	5.00	5.50	6.00	6.50
P<IN H2O>	2.15	2.06	2.01	2.05	2.13	2.18	2.20
V<FT/SEC>	96.71	94.67	93.51	94.44	96.26	97.39	97.83
POSIT<IN>	7.00	7.50	8.00	8.50	9.00	9.50	10.00
P<IN H2O>	2.21	2.21	2.15	2.16	2.18	2.12	2.08
V<FT/SEC>	98.06	98.06	96.71	96.94	97.39	96.04	95.13
POSIT<IN>	10.50	11.00	11.50	12.00	12.50	13.00	13.50
P<IN H2O>	2.05	2.03	2.03	2.05	2.16	2.28	2.38
V<FT/SEC>	94.44	93.98	93.98	94.44	96.94	99.60	101.76
POSIT<IN>	14.00	14.50	15.00				
P<IN H2O>	2.52	2.43	1.45				
V<FT/SEC>	104.71	102.82	79.43				

TABLE IIo

DATA TAKEN ON 20 JANUARY 1981
DATA TAKEN BY D.L.RYAN
1 TERTIARY FORT OPEN/CUSP IN

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA: 107.51 SQ IN
PRIMARY NOZZLE AREA: 9.06 SQ IN AREA RATIO (AM/AP): 2.99
MIXING STACK LENGTH: 25.50 IN ORIFICE DIAMETER: 6.908 IN
MIXING STACK DIMENSION: 0.5 IN ORIFICE BETA: 0.497 IN
MIXING STACK L/S: 3.00 AMBIENT PRESSURE: 29.94 IN HG

N	POR	DPOR	TOR	TUPT	TAMB	PU-PA	PA-PS	PA-PT	SECONDARY AREA SQUARE INCHES	TERTIARY AREA SQUARE INCHES
RUN	IN OF H2O	IN OF H2O	DEGREES F			IN OF H2O				
1	0.7	21.8	50.7	105.0	65.0	7.10	2.73	0.00	0.000	xxxxxx
2	0.7	21.8	50.2	104.9	65.0	7.70	2.13	0.00	6.283	xxxxxx
3	0.7	21.9	50.1	104.9	65.0	8.15	1.65	0.00	12.566	xxxxxx
4	0.7	21.8	50.3	104.9	65.0	8.75	1.03	0.00	25.133	xxxxxx
5	0.7	22.0	50.1	104.7	65.0	9.45	0.50	0.00	50.265	xxxxxx
6	0.7	21.8	50.4	104.7	65.0	9.75	0.18	0.00	100.531	xxxxxx
7	0.9	21.8	49.8	104.7	65.0	9.85	0.03	0.00	xxxxxx	xxxxxx

SECONDARY BOX

N	WT	P#	T#	P#TX	WT#	MP	WS	UP	UN	UUPT	UPT	MACH
RUN							LBW/SEC	LBW/SEC	FT/SEC	FT/SEC		
1	0.0000	0.2642	0.9292	0.2843	0.0000	3.7594	0.0000	213.80	71.53	72.10	0.062	
2	0.0835	0.2065	0.9293	0.2223	0.0808	3.7612	0.3141	213.55	76.96	72.02	0.062	
3	0.1466	0.1597	0.9293	0.1718	0.1420	3.7782	0.5528	213.80	81.24	72.11	0.062	
4	0.2323	0.1005	0.9293	0.1081	0.2219	3.7688	0.8736	212.95	86.59	71.82	0.062	
5	0.3321	0.0485	0.9297	0.0521	0.3120	3.7787	1.2173	213.61	92.84	72.84	0.062	
6	0.3885	0.0176	0.9297	0.0190	0.3752	3.7685	1.4608	212.41	96.72	71.64	0.062	
7	xxxxxx	0.0029	0.9297	0.0032	xxxxxx	3.7620	9.3180	212.41	xxxxxx	71.64	0.062	

TABLE IIIa

RUN	N	WT	PT	TT	PT/TT	WT/TT	LBM/SEC	LBM/SEC	WT	UE
1	33333	0.0000	0.9292	0.0000	3.759	3.759	3.759	3.759	3.759	3.759
2	33333	0.0000	0.9293	0.0000	4.075	4.075	4.075	4.075	4.075	4.075
3	33333	0.0000	0.9293	0.0000	4.323	4.323	4.323	4.323	4.323	4.323
4	33333	0.0000	0.9293	0.0000	4.634	4.634	4.634	4.634	4.634	4.634
5	33333	0.0000	0.9297	0.0000	4.996	4.996	4.996	4.996	4.996	4.996
6	33333	0.0000	0.9297	0.0000	5.221	5.221	5.221	5.221	5.221	5.221
7	33333	0.0000	0.9297	0.0000	5.221	5.221	5.221	5.221	5.221	5.221

MIXING STACK PRESSURE DATA				7 CURVED SIDE DISTRIBUTION			
X/S	0.25	0.50	0.75	1.00	1.25	1.50	1.75
PMS<INNH20>	0.260	0.050	0.380	0.180	1.910	2.210	1.680
PMS<1	-0.025	-0.005	0.037	0.116	0.187	0.217	0.180
X/S	2.00	2.25	2.50	2.75			
PMS<INNH20>	0.650	3.420	0.390	0.050			
PMS<1	0.064	-0.335	-0.038	0.005			

MIXING STACK PRESSURE DATA				7 FLAT SIDE DISTRIBUTION			
X/S	0.25	0.50	0.75	1.00	1.25	1.50	1.75
PMS<INNH20>	0.780	-0.090	-0.080	0.070	0.090	0.330	0.200
PMS<1	0.076	-0.009	-0.008	0.007	0.009	0.032	0.020
X/S	2.00	2.25	2.50	2.75			
PMS<INNH20>	0.080	0.240	0.360	0.350			
PMS<1	0.008	0.024	0.035	0.023			

TABLE IIIb

VERTICAL VELOCITY TRAVERSE

POSIT(IN):	0.00	0.50	1.00	1.50	2.00	2.50	3.00
P(IN H20):	0.81	2.84	2.83	2.68	2.52	2.45	2.42
V(FT/SEC):	59.86	112.08	111.89	108.88	105.58	104.10	103.46
POSIT(IN):	3.50	4.00	4.50	5.00	5.50	6.00	6.50
P(IN H20):	2.41	2.44	2.46	2.45	2.44	2.43	2.46
V(FT/SEC):	103.25	103.89	104.32	104.10	103.89	103.68	104.32
POSIT(IN):	7.00	7.50	8.00	8.50			
P(IN H20):	2.51	2.59	2.76	0.90			
V(FT/SEC):	105.37	107.04	110.49	63.10			

HORIZONTAL VELOCITY TRAVERSE

POSIT(IN):	0.00	0.50	1.00	1.50	2.00	2.50	3.00
P(IN H20):	0.48	2.48	2.52	2.46	2.46	2.44	2.46
V(FT/SEC):	46.08	104.74	105.58	104.32	104.32	103.89	104.32
POSIT(IN):	3.50	4.00	4.50	5.00	5.50	6.00	6.25
P(IN H20):	2.48	2.47	2.43	2.40	2.41	2.41	2.43
V(FT/SEC):	104.74	104.53	103.68	103.04	103.25	103.23	103.68
POSIT(IN):	6.50	6.75	7.00	7.25	7.75	8.25	8.75
P(IN H20):	2.42	2.43	2.45	2.44	2.46	2.47	2.45
V(FT/SEC):	103.46	103.68	104.10	103.89	104.32	104.53	104.10
POSIT(IN):	9.25	9.75	10.25	10.75	11.25	11.75	12.25
P(IN H20):	2.48	2.47	2.44	2.43	2.35	2.30	2.28
V(FT/SEC):	104.74	104.53	103.89	103.68	101.96	100.87	100.43
POSIT(IN):	12.75						
P(IN H20):	1.91						
V(FT/SEC):	91.92						

DIAGONAL VELOCITY TRAVERSE

POSIT(IN):	0.00	0.50	1.00	1.50	2.00	2.50	3.00
P(IN H20):	0.85	2.85	2.97	3.05	3.04	2.83	2.65
V(FT/SEC):	61.32	112.28	114.62	116.15	115.96	111.89	108.27
POSIT(IN):	3.50	4.00	4.50	5.00	5.50	6.00	6.50
P(IN H20):	2.52	2.42	2.38	2.38	2.43	2.46	2.50
V(FT/SEC):	105.58	103.46	102.61	102.61	103.68	104.32	105.16
POSIT(IN):	7.00	7.50	8.00	8.50	9.00	9.50	10.00
P(IN H20):	2.54	2.56	2.56	2.56	2.55	2.52	2.48
V(FT/SEC):	106.00	106.42	106.42	106.42	106.21	105.53	104.74
POSIT(IN):	10.50	11.00	11.50	12.00	12.50	13.00	13.50
P(IN H20):	2.46	2.44	2.42	2.41	2.43	2.46	2.57
V(FT/SEC):	104.32	103.89	103.46	103.25	103.68	104.32	106.62
POSIT(IN):	14.00	14.50	15.00				
P(IN H20):	2.66	2.62	1.52				
V(FT/SEC):	100.47	107.66	82.00				

TABLE IIIo

DATA TAKEN ON 1 FEBRUARY 1981
DATA TAKEN BY O.L. RYAN
1 TERTIARY PORT OPEN/CUSP IN

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA: 107.51 SQ IN

PRIMARY NOZZLE AREA: 9.06 SQ IN AREA RATIO (AN/AP): 2.99

MIXING STACK LENGTH: 25.50 IN ORIFICE DIAMETER: 6.908 IN

MIXING STACK DIMENSION: 0.5 IN ORIFICE BETA: 0.497 IN

MIXING STACK L/S: 3.00 AMBIENT PRESSURE: 30.34 IN HG

N	POR	DPOR	TOR	TUPT	TAMB	PU-PA	PR-PS	PR-PT	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O	IN OF H2O	DEGREES F	IN OF H2O	IN OF H2O	IN OF H2O	IN OF H2O	IN OF H2O	SQUARE INCHES	SQUARE INCHES
1	0.7	21.9	43.5	93.9	54.0	6.90	2.76	0.50	0.000	0.000
2	0.7	21.9	43.4	95.3	54.0	7.20	2.76	0.11	0.000	6.283
3	0.7	21.9	43.2	96.0	54.0	7.20	2.77	0.03	0.000	12.566
4	0.7	21.9	43.4	96.8	54.0	7.20	2.77	0.01	0.000	25.133
5	0.7	21.9	42.9	97.0	54.0	7.20	2.77	0.01	0.000	37.699
6	0.7	21.9	43.3	97.0	54.0	7.20	2.80	0.01	0.000	100.531
7	0.7	21.9	43.4	96.8	54.0	7.20	2.78	0.00	0.000	*****

SECONDARY BOX

N	WS	PA	Tz	Pz/Tz	WzTz	NP	WS	UP	UH	UUPT	UPT MACH
RUN	LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC
1	0.0000	0.2670	0.9273	0.2878	0.0000	3.8203	0.0000	210.18	70.32	70.88	0.061
2	0.0000	0.2655	0.9256	0.2870	0.0000	3.8207	0.0000	210.73	70.50	71.07	0.062
3	0.0000	0.2658	0.9244	0.2875	0.0000	3.8214	0.0000	211.04	70.61	71.18	0.062
4	0.0000	0.2651	0.9231	0.2872	0.0000	3.8207	0.0000	211.31	70.70	71.26	0.062
5	0.0000	0.2647	0.9228	0.2868	0.0000	3.8226	0.0000	211.49	70.76	71.33	0.062
6	0.0000	0.2677	0.9228	0.2901	0.0000	3.8211	0.0000	211.42	70.73	71.30	0.062
7	0.0000	0.2661	0.9231	0.2882	0.0000	3.8207	0.0000	211.31	70.70	71.27	0.062

TABLE IVa

TERTIARY BOX

N	WT	PT	TT	PT/TT	WTATT	WM	WT	UE
1	0.0000	0.0484	0.9279	0.0521	0.0000	3.820	0.000	70.32
2	0.0190	0.0106	0.9256	0.0114	0.0184	3.821	0.073	71.84
3	0.0198	0.0029	0.9244	0.0031	0.0192	3.821	0.076	72.01
4	0.0229	0.0010	0.9231	0.0010	0.0221	3.821	0.088	72.32
5	0.0344	0.0010	0.9220	0.0010	0.0332	3.823	0.131	73.19
6	0.0648	0.0005	0.9220	0.0005	0.0626	3.821	0.248	75.32
7	*****	0.0000	0.9231	0.0000	*****	3.821	*****	*****

MIXING STACK PPESSURE DATA: RUN 7 CURVED SIDE DISTRIBUTION

X/S:	0.25	0.50	0.75	1.00	1.25	1.50	1.75
PMS(IHH20):	-1.370	-0.760	-0.120	0.560	1.330	1.820	1.730
PHS:	-0.131	-0.073	-0.012	0.054	0.127	0.174	0.166
X/S:	2.00	2.25	2.50	2.75			
PMS(IHH20):	0.650	-1.900	-0.140	0.040			
PHS:	0.062	-0.102	-0.013	0.004			

MIXING STACK PPESSURE DATA: RUN 7 FLAT SIDE DISTRIBUTION

X/S:	0.25	0.50	0.75	1.00	1.25	1.50	1.75
PMS(IHH20):	-0.260	-0.610	-0.480	-0.040	0.280	0.520	0.210
PHS:	-0.025	-0.078	-0.046	-0.004	0.027	0.050	0.020
X/S:	2.00	2.25	2.50	2.75			
PMS(IHH20):	0.140	0.130	0.230	0.150			
PHS:	0.013	0.012	0.022	0.014			

TABLE IVb

VERTICAL VELOCITY TRAVERSE							
POSIT(IN)	0.00	0.50	1.00	1.50	2.00	2.50	3.00
P(IN H20)	0.61	1.49	1.46	1.33	1.32	1.32	1.32
V(FT/SEC)	58.84	79.80	78.99	77.07	75.11	75.11	75.11
POSIT(IN)	3.50	4.00	4.50	5.00	5.50	6.00	6.50
P(IN H20)	1.35	1.36	1.36	1.35	1.33	1.31	1.31
V(FT/SEC)	75.96	76.24	76.24	75.96	75.39	74.82	74.82
POSIT(IN)	7.00	7.50	8.00	8.50			
P(IN H20)	1.38	1.35	1.48	0.49			
V(FT/SEC)	74.54	75.96	79.53	45.76			

HORIZONTAL VELOCITY TRAVERSE							
POSIT(IN)	0.00	0.50	1.00	1.50	2.00	2.50	3.00
P(IN H20)	0.61	1.32	1.26	1.23	1.22	1.25	1.27
V(FT/SEC)	51.06	75.11	73.38	72.50	72.21	73.09	73.67
POSIT(IN)	3.50	4.00	4.50	5.00	5.50	6.00	6.25
P(IN H20)	1.30	1.32	1.34	1.34	1.35	1.34	1.34
V(FT/SEC)	74.54	75.11	75.68	75.68	75.96	75.68	75.68
POSIT(IN)	6.50	6.75	7.00	7.25	7.75	8.25	8.75
P(IN H20)	1.35	1.34	1.36	1.36	1.38	1.39	1.43
V(FT/SEC)	75.96	75.68	76.24	76.24	76.80	77.07	78.18
POSIT(IN)	9.25	9.75	10.25	10.75	11.25	11.75	12.25
P(IN H20)	1.42	1.43	1.41	1.38	1.35	1.34	1.38
V(FT/SEC)	77.90	78.18	77.63	76.80	75.96	75.68	76.80
POSIT(IN)	12.75						
P(IN H20)	1.10						
V(FT/SEC)	68.56						

DIAGONAL VELOCITY TRAVERSE							
POSIT(IN)	0.00	0.50	1.00	1.50	2.00	2.50	3.00
P(IN H20)	0.33	1.83	1.83	1.72	1.62	1.50	1.43
V(FT/SEC)	37.55	88.44	88.44	85.74	83.21	80.07	78.18
POSIT(IN)	3.50	4.00	4.50	5.00	5.50	6.00	6.50
P(IN H20)	1.33	1.30	1.33	1.35	1.35	1.35	1.36
V(FT/SEC)	75.39	74.54	75.39	75.96	75.96	75.96	76.24
POSIT(IN)	7.00	7.50	8.00	8.50	9.00	9.50	10.00
P(IN H20)	1.37	1.36	1.35	1.35	1.36	1.34	1.34
V(FT/SEC)	76.52	76.24	75.96	75.96	76.24	75.68	75.68
POSIT(IN)	10.50	11.00	11.50	12.00	12.50	13.00	13.50
P(IN H20)	1.33	1.30	1.29	1.25	1.22	1.23	1.27
V(FT/SEC)	75.39	74.54	74.25	73.09	72.21	72.50	73.67
POSIT(IN)	14.00	14.50	15.00				
P(IN H20)	1.33	1.44	0.90				
V(FT/SEC)	75.96	78.45	62.02				

TABLE IVc

DATA TAKEN ON 1 FEBRUARY 1981
DATA TAKEN BY D.L. RYAN
1 TERTIARY PORT OPEN/CUSP IN

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA: 107.51 SQ IN
PRIMARY NOZZLE AREA: 9.06 SQ IN AREA RATIO (AM/AP): 2.99
MIXING STACK LENGTH: 25.50 IN ORIFICE DIAMETER: 6.908 IN
MIXING STACK DIMENSION: 0.5 IN ORIFICE BETA: 0.497 IN
MIXING STACK L/S: 3.00 AMBIENT PRESSURE: 30.35 IN HG

N	FOR	OPOR	TOR	TUPT	TAMB	PU-PA	PA-PS	PA-PT	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O	DEGREES F	IN OF H2O	SQ INCHES	SQ INCHES	SQ INCHES	SQ INCHES	SQ INCHES	SQ INCHES	SQ INCHES
1	0.7	21.9	42.9	97.4	58.0	9.25	0.57	0.58	37.699	0.000
2	0.7	21.9	43.4	97.3	58.0	9.25	0.53	0.14	37.699	6.283
3	0.7	21.9	43.7	97.4	58.0	9.30	0.51	0.05	37.699	12.566
4	0.7	21.9	43.3	97.6	58.0	9.30	0.51	0.02	37.699	25.133
5	0.7	21.9	42.8	97.4	58.0	9.35	0.48	0.01	37.699	37.699
6	0.7	21.9	43.2	97.5	58.0	9.30	0.48	0.00	37.699	100.531
7	0.7	21.9	42.0	97.4	58.0	9.30	0.47	0.00	37.699	#####

SECONDARY BOX

N	M*	P*	T*	P*/T*	W* T*	HP	NS	UP	UN	UUPT	UPT HACH
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.2584	0.0554	0.9293	0.0596	0.2502	3.8232	0.9381	210.47	87.31	70.98	0.061
2	0.2493	0.0516	0.9294	0.0555	0.2414	3.8213	0.9528	210.31	86.65	70.93	0.061
3	0.2446	0.0497	0.9293	0.0534	0.2369	3.8202	0.9346	210.28	86.33	70.92	0.061
4	0.2446	0.0496	0.9289	0.0534	0.2367	3.8217	0.9346	210.44	86.38	70.97	0.061
5	0.2371	0.0467	0.9293	0.0502	0.2296	3.8236	0.9067	210.45	85.91	70.98	0.061
6	0.2372	0.0467	0.9291	0.0502	0.2297	3.8221	0.9067	210.40	85.89	70.96	0.061
7	0.2345	0.0456	0.9293	0.0491	0.2270	3.8267	0.8972	210.61	85.80	71.03	0.061

TABLE Va

TERTIARY BOX

N	WT	PT	TT	PT/TT	WT*TT*.44	WM	WT	UE
LBM/SEC LBM/SEC FT/SEC								
RUN								
1	0.0000	0.0564	0.9293	0.0607	0.0000	4.811	0.000	87.31
2	0.0214	0.0136	0.9294	0.0147	0.0207	4.774	0.082	88.13
3	0.0255	0.0849	0.9293	0.0052	0.0247	4.755	0.098	88.10
4	0.0323	0.0019	0.9289	0.0021	0.0313	4.756	0.123	88.62
5	0.0342	0.0010	0.9293	0.0010	0.0331	4.730	0.131	88.28
6	0.0000	0.0000	0.9291	0.0000	0.0000	4.729	0.000	85.89
7	*****	0.0000	0.9293	0.0000	*****	4.724	*****	*****

MIXING STACK PRESSURE DATA: RUN 7 CURVED SIDE DISTRIBUTION

X/S:	0.25	0.50	0.75	1.00	1.25	1.50	1.75
PHS(INH20):	-0.520	-0.230	0.200	0.930	1.760	2.090	1.920
PMS:	-0.050	-0.022	0.019	0.090	0.171	0.203	0.186
X/S:	2.00	2.25	2.50	2.75			
PHS(INH20):	0.840	-3.050	-0.260	0.060			
PMS:	0.082	-0.296	-0.025	0.006			

MIXING STACK PRESSURE DATA: RUN 7 FLAT SIDE DISTRIBUTION

X/S:	0.25	0.50	0.75	1.00	1.25	1.50	1.75
PHS(INH20):	0.780	-0.220	-0.240	0.030	0.230	0.400	0.110
PMS:	0.076	-0.021	-0.023	0.003	0.022	0.039	0.011
X/S:	2.00	2.25	2.50	2.75			
PHS(INH20):	0.150	0.300	0.450	0.270			
PMS:	0.015	0.029	0.044	0.026			

TABLE VB

DATA TAKEN ON 2 FEBRUARY 1981
DATA TAKEN BY D.L. RYAN
1 TERTIARY PORT OPEN/CUSP IN

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA: 107.51 SQ IN
PRIMARY NOZZLE AREA: 9.06 SQ IN AREA RATIO (AN/AP): 2.99
MIXING STACK LENGTH: 25.50 IN ORIFICE DIAMETER: 6.908 IN
MIXING STACK DIMENSION: 0.5 IN ORIFICE BETA: 0.497 IN
MIXING STACK L/S: 3.00 AMBIENT PRESSURE: 30.27 IN HG

N	FOR	OPOR	TOR	TUPT	TAMB	PU-PA	PA-PS	PA-PT	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O	DEGREES F				IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.7	21.9	50.3	104.2	66.0	9.85	0.01	0.62	111111	0.000
2	0.7	22.0	52.0	104.5	66.0	9.65	0.01	0.13	111111	6.283
3	0.7	22.1	51.5	104.6	66.0	9.90	0.01	0.04	111111	12.566
4	0.7	22.1	50.8	104.8	66.0	9.90	0.01	0.02	111111	25.133
5	0.7	21.8	52.5	105.2	66.0	9.80	0.01	0.01	111111	50.265
6	0.7	21.8	50.2	105.0	66.0	9.80	0.01	0.00	111111	100.531
7	0.7	21.8	51.7	105.1	66.0	9.80	0.00	0.00	111111	111111

SECONDARY BOX

N	HE	PS	TS	PT/TS	WT^4.44	HP	WS	UP	UM	UUPT	UPT
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	MACH
1	111111	0.0005	0.9323	0.0005	111111	3.7903	3.8213	211.48	111111	71.32	0.061
2	111111	0.0005	0.9318	0.0005	111111	3.7927	3.8213	211.72	111111	71.41	0.061
3	111111	0.0005	0.9316	0.0005	111111	3.8031	3.8213	212.35	111111	71.62	0.062
4	111111	0.0005	0.9313	0.0005	111111	3.8057	3.8213	212.57	111111	71.69	0.062
5	111111	0.0005	0.9306	0.0005	111111	3.7736	3.8213	210.92	111111	71.13	0.061
6	111111	0.0005	0.9309	0.0005	111111	3.7821	3.8213	211.32	111111	71.27	0.061
7	111111	0.0000	0.9308	0.0000	111111	3.7765	0.0000	211.04	111111	71.18	0.061

TABLE VIa

TERTIARY BOX

N	WT	PT	TT	PT/TT	MTT	HM	W	UE
RUN						LBH/SEC	LBH/SEC	FT/SEC
1	0.0000	0.0608	0.9323	0.0652	0.0000	*****	0.000	*****
2	0.0205	0.0127	0.9318	0.0136	0.0199	*****	0.078	*****
3	0.0227	0.0039	0.9316	0.0042	0.0220	*****	0.086	*****
4	0.0270	0.0015	0.9313	0.0016	0.0270	*****	0.106	*****
5	0.0324	0.0005	0.9306	0.0005	0.0314	*****	0.122	*****
6	0.0000	0.0000	0.9309	0.0000	0.0000	*****	0.000	*****
7	*****	0.0000	0.9308	0.0000	*****	*****	*****	*****

MIXING STACK PRESSURE DATA' RUN 7 CURVED SIDE DISTRIBUTION

X/S:	0.25	0.50	0.75	1.00	1.25	1.50	1.75
PMS(IHH20):	-0.240	-0.030	0.400	1.080	1.950	2.230	1.790
PHS1:	-0.024	-0.003	0.039	0.106	0.192	0.219	0.176
X/S:	2.00	2.25	2.50	2.75			
PMS(IHH20):	0.570	-3.540	-0.390	0.050			
PHS1:	0.056	-0.348	-0.038	0.005			

MIXING STACK PRESSURE DATA' RUN 7 FLAT SIDE DISTRIBUTION

X/S:	0.25	0.50	0.75	1.00	1.25	1.50	1.75
PMS(IHH20):	1.090	0.040	0.060	0.110	0.200	-0.540	0.160
PHS1:	0.107	0.004	0.006	0.011	0.020	-0.053	0.016
X/S:	2.00	2.25	2.50	2.75			
PMS(IHH20):	0.210	0.260	0.350	0.260			
PHS1:	0.021	0.026	0.034	0.026			

TABLE VIb

DATA TAKEN ON 2 FEBRUARY 1981
DATA TAKEN BY D. L. RYAN
2 TERTIARY PORTS OPEN/CUSP IN

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA: 107.51 SQ IN
PRIMARY NOZZLE AREA: 9.06 SQ IN AREA RATIO (AM/AP): 2.99
MIXING STACK LENGTH: 25.50 IN ORIFICE DIAMETER: 6.900 IN
MIXING STACK DIMENSION: 0.5 IN ORIFICE BETA: 0.497 IN
MIXING STACK L/S: 3.00 AMBIENT PRESSURE: 30.25 IN HG

N	POR	DPOR	TOR	TUPT	TAMB	PU-PA	PA-PS	PA-PT	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O		DEGREES F			IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.7	21.9	43.5	97.3	58.0	7.20	2.78	1.00	0.000	0.000
2	0.7	21.9	42.6	96.9	58.0	7.35	2.63	0.26	0.000	6.283
3	0.7	21.9	42.5	96.6	58.0	7.40	2.60	0.10	0.000	12.566
4	0.7	21.9	43.1	96.7	58.0	7.40	2.57	0.03	0.000	25.133
5	0.7	21.9	42.6	96.9	58.0	7.40	2.57	0.01	0.000	50.265
6	0.7	21.9	42.9	96.9	58.0	7.40	2.56	0.00	0.000	100.531
7	0.7	21.9	42.9	96.8	58.0	7.40	2.56	0.00	0.000	###

SECONDARY BOX

N	W1	P%	T%	P%/T%	W1/T%	W1	WS	UP	UK	UUP	UPT	NACH
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.0000	0.2677	0.9294	0.2080	0.0000	3.8152	0.0000	211.76	70.85	71.42	0.062	
2	0.0000	0.2534	0.9301	0.2724	0.0000	3.8187	0.0000	211.72	70.84	71.41	0.062	
3	0.0000	0.2507	0.9306	0.2694	0.0000	3.8191	0.0000	211.62	70.80	71.37	0.062	
4	0.0000	0.2481	0.9304	0.2666	0.0000	3.8169	0.0000	211.51	70.76	71.33	0.062	
5	0.0000	0.2477	0.9301	0.2663	0.0000	3.8187	0.0000	211.69	70.83	71.39	0.062	
6	0.0000	0.2468	0.9301	0.2654	0.0000	3.8175	0.0000	211.62	70.80	71.37	0.062	
7	0.0000	0.2469	0.9303	0.2654	0.0000	3.8175	0.0000	211.59	70.79	71.36	0.062	

TABLE VIIa

Run	N	WT3	PT3	TT3	PT3/TT3	WT3TT3.44	WM	WT	UE
							LBM/SEC	LBM/SEC	FT/SEC
1	0.0000	0.0353	0.9234	0.1036	0.0000		3.815	0.000	70.85
2	0.0291	0.0350	0.9301	0.0269	0.0282		3.819	0.111	72.90
3	0.0351	0.0056	0.9306	0.0104	0.0349		3.819	0.138	73.35
4	0.0355	0.0052	0.9304	0.0031	0.0383		3.817	0.151	73.56
5	0.0323	0.0005	0.9301	0.0005	0.0313		3.819	0.123	73.11
6	0.0000	0.0000	0.9301	0.0000	0.0000		3.818	0.000	70.00
7	0.0000	0.0000	0.9303	0.0000	0.0000		3.818	0.000	70.00

TABLE VIIb

DATA TAKEN ON 2 FEBRUARY 1981
DATA TAKEN BY D.L. RYAN
2 TERTIARY PORTS OPEN/CUSP IN

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA: 107.51 SQ IN
PRIMARY NOZZLE AREA: 9.06 SQ IN AREA RATIO (AM/AP): 2.99
MIXING STACK LENGTH: 25.50 IN ORIFICE DIAMETER: 6.900 IN
MIXING STACK DIMENSION: 0.5 IN ORIFICE BETA: 0.497 IN
MIXING STACK L/S: 3.00 AMBIENT PRESSURE: 30.24 IN HG

N	POR	DPOR	TOR	TUPT	TAMB	PU-PA	PA-PS	PA-PT	SECONDARY AREA SQUARE INCHES	TERTIARY AREA SQUARE INCHES
RUN	IN OF H2O	IN OF H2O	DEGREES F	IN OF H2O	IN OF H2O	IN OF H2O	IN OF H2O	IN OF H2O	IN OF H2O	IN OF H2O
1	0.7	22.1	43.0	96.9	57.0	9.00	1.04	1.00	37.699	0.400
2	0.7	22.1	43.4	97.5	57.0	9.10	0.90	0.27	37.699	6.283
3	0.7	22.1	43.7	97.2	57.0	9.10	0.90	0.08	37.699	12.566
4	0.7	22.0	42.8	96.9	57.0	9.10	0.89	0.04	37.699	25.133
5	0.7	22.0	43.1	96.8	57.0	9.10	0.89	0.01	37.699	50.263
6	0.7	22.0	43.5	97.0	57.0	9.10	0.89	0.01	37.699	100.531
7	0.7	22.0	43.6	97.3	57.0	9.10	0.89	0.00	37.699	***

SECONDARY BOX

N	HS	Pz	Tt	Pz/Tt	WtT^4.44	HP	HS	UP	UN	UUP	UPT	MACH
RUN	LBM/SEC	LBM/SEC	LBM/SEC	LBM/SEC	LBM/SEC	LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC
1	0.3479	0.0999	0.9283	0.1077	0.3367	3.8333	1.3335	211.85	93.71	71.45	0.062	0.062
2	0.3237	0.0864	0.9273	0.0932	0.3132	3.8318	1.2405	211.92	92.14	71.47	0.062	0.062
3	0.3238	0.0966	0.9278	0.0933	0.3133	3.8306	1.2405	211.75	92.08	71.41	0.062	0.062
4	0.3225	0.0859	0.9283	0.0926	0.3121	3.8254	1.2336	211.34	91.83	71.27	0.062	0.062
5	0.3226	0.0960	0.9285	0.0927	0.3122	3.8242	1.2336	211.23	91.79	71.24	0.062	0.062
6	0.3227	0.0860	0.9281	0.0927	0.3123	3.8227	1.2336	211.23	91.79	71.24	0.062	0.062
7	0.3227	0.0860	0.9276	0.0927	0.3122	3.8223	1.2336	211.32	91.82	71.27	0.062	0.062

TABLE VIIIa

N	WT8	PT8	TT8	PT8/TT8	WT8TT8.44	LBM/SEC	LBM/SEC	WT	UE
1	0.0000	0.0061	0.9293	0.1033	0.0000	5.167	0.000	93.71	
2	0.0296	0.0359	0.9273	0.0280	0.0286	5.072	0.113	94.20	
3	0.0322	0.0077	0.9278	0.0083	0.0311	5.071	0.123	94.32	
4	0.0456	0.0079	0.9293	0.0042	0.0441	5.059	0.174	94.99	
5	0.0456	0.0010	0.9285	0.0010	0.0441	5.058	0.174	94.96	
6	0.0645	0.0005	0.9281	0.0005	0.0624	5.056	0.247	96.27	
7	0.0000	0.0000	0.9276	0.0000	0.0000	5.056	0.000	93.71	

DATA TAKEN ON 2 FEBRUARY 1961
DATA TAKEN BY D.L. RYAN
2 TERTIARY PORTS OPEN/CUSP IN

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA: 107.51 SQ IN
PRIMARY NOZZLE AREA: 9.06 SQ IN AREA RATIO (AM/AP): 2.99
MIXING STACK LENGTH: 25.50 IN ORIFICE DIAMETER: 6.900 IN
MIXING STACK DIMENSION: 0.5 IN ORIFICE BETA: 0.497 IN
MIXING STACK L/S: 3.00 AMBIENT PRESSURE: 30.24 IN HG

N	POR	DPOR	TOR	TUPT	TABD	PU-PA	PA-PS	PA-PT	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O	IN OF H2O	DEGREES F	IN OF H2O	IN OF H2O	IN OF H2O	IN OF H2O	IN OF H2O	SQUARE INCHES	SQUARE INCHES
1	0.7	21.8	43.5	94.7	55.0	9.85	0.01	1.20	*****	0.000
2	0.7	21.8	43.6	96.2	55.0	9.80	0.01	0.25	*****	6.283
3	0.7	21.8	43.9	96.0	55.0	9.85	0.01	0.11	*****	12.566
4	0.7	21.8	43.3	96.6	55.0	9.85	0.01	0.03	*****	25.133
5	0.7	21.9	43.5	96.9	55.0	9.85	0.01	0.01	*****	50.265
6	0.7	21.8	43.8	97.0	55.0	9.85	0.01	0.00	*****	100.531
7	0.7	21.9	43.7	97.2	55.0	9.85	0.00	0.00	*****	*****

SECONDARY BOX

N	HS	Pz	Tt	Pz-Tz	WAT	HP	HS	UP	UM	UUPT	UFT	MACH
PUN							LBM/SEC	LBM/SEC	FT/SEC	FT/SEC		
1	0.3372	0.0942	0.9298	0.1013	0.3265	3.8165	1.2868	210.89	92.62	71.13	0.061	
2	0.3060	0.0777	0.9298	0.0836	0.2964	3.8184	1.1686	210.91	90.60	71.13	0.062	
3	0.3003	0.0748	0.9299	0.0805	0.2909	3.8181	1.1465	210.84	90.20	71.11	0.061	
4	0.2964	0.0730	0.9303	0.0785	0.2872	3.8169	1.1315	210.69	89.89	71.06	0.061	
5	0.2961	0.0728	0.9303	0.0783	0.2868	3.8216	1.1315	210.96	89.98	71.15	0.062	
6	0.2958	0.0727	0.9303	0.0781	0.2865	3.8252	1.1315	211.15	90.05	71.21	0.062	
7	0.2938	0.0717	0.9304	0.0771	0.2846	3.8256	1.1239	211.13	89.91	71.20	0.062	

TABLE IXa

TERTIARY BOX

N	WT	PT	TT	PTA/TT	WT/TT	WM	WT	UE
LBM/SEC LBM/SEC FT/SEC								
RUN								
1	0.0000	0.1309	0.9298	0.1494	0.0000	5.103	0.000	92.62
2	0.0361	0.0388	0.9298	0.0410	0.0349	4.987	0.130	93.11
3	0.0470	0.0165	0.9299	0.0170	0.0456	4.965	0.180	93.46
4	0.0510	0.0049	0.9303	0.0052	0.0494	4.948	0.195	93.43
5	0.0456	0.0010	0.9303	0.0010	0.0442	4.953	0.174	93.15
6	0.0000	0.0000	0.9303	0.0000	0.0000	4.957	0.000	90.05
7	0.0000	0.0000	0.9304	0.0000	0.0000	4.950	0.000	90.05

TABLE IXb

DATA TAKEN ON 2 FEBRUARY 1981
DATA TAKEN BY D.L. RYAN
3 TERTIARY PORTS OPEN/CUSP IN

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA: 107.51 SQ IN

PRIMARY NOZZLE AREA: 9.06 SQ IN AREA RATIO (AM/AP): 2.99

MIXING STACK LENGTH: 25.50 IN ORIFICE DIAMETER: 6.900 IN

MIXING STACK DIMENSION: 0.5 IN ORIFICE BETA: 0.497 IN

MIXING STACK L/S: 3.00 AMBIENT PRESSURE: 30.24 IN HG

N	POR	OPOR	TOR	TUPT	TAMB	PU-PA	PA-PS	PA-PT	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O	IN OF H2O	DEGREES F			IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.7	21.9	42.3	96.7	58.0	7.25	2.77	1.34	0.000	0.000
2	0.7	21.9	41.9	96.5	58.0	7.45	2.50	0.36	0.000	6.283
3	0.7	21.9	42.8	96.6	58.0	7.50	2.44	0.16	0.000	12.566
4	0.7	21.9	43.0	96.7	58.0	7.50	2.40	0.05	0.000	25.133
5	0.7	21.9	43.2	96.8	58.0	7.55	2.40	0.01	0.000	50.265
6	0.7	21.9	42.6	96.7	58.0	7.50	2.40	0.00	0.000	100.531
7	0.7	21.9	42.9	96.8	58.0	7.50	2.38	0.00	0.000	xxxxxx

SECONDARY BOX

N	W#	P#	T#	P#T#	W#T#	44	MP	HS	UP	UM	UOPT	UPT	MACH
RUN							LB#M/SEC	LB#M/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.0000	0.2667	0.9304	0.2866	0.0000	0.0000	3.8186	0.0000	211.85	70.88	71.45	0.062	
2	0.0000	0.2410	0.9308	0.2589	0.0000	0.0000	3.8201	0.0000	211.72	70.84	71.41	0.062	
3	0.0000	0.2356	0.9306	0.2532	0.0000	0.0000	3.8167	0.0000	211.54	70.77	71.34	0.062	
4	0.0000	0.2318	0.9304	0.2491	0.0000	0.0000	3.8159	0.0000	211.52	70.77	71.34	0.062	
5	0.0000	0.2318	0.9303	0.2492	0.0000	0.0000	3.8151	0.0000	211.51	70.76	71.33	0.062	
6	0.0000	0.2316	0.9304	0.2489	0.0000	0.0000	3.8174	0.0000	211.60	70.79	71.36	0.062	
7	0.0000	0.2290	0.9303	0.2470	0.0000	0.0000	3.8163	0.0000	211.56	70.70	71.35	0.062	

TABLE Xa

TERTIARY BOX

N	WT*	PI*	TI*	PI*/TI*	WT*TI*.44	WM	WT	UE
RUN						LBM/SEC	LBM/SEC	FT/SEC
1	0.0000	0.1290	0.9304	0.1387	0.0000	3.819	0.000	70.88
2	0.0342	0.0347	0.9308	0.0373	0.0331	3.820	0.131	73.26
3	0.0456	0.0155	0.9306	0.0166	0.0442	3.817	0.174	74.00
4	0.0510	0.0048	0.9304	0.0052	0.0494	3.816	0.195	74.38
5	0.0323	0.0005	0.9303	0.0005	0.0313	3.815	0.123	73.05
6	0.0000	0.0000	0.9304	0.0000	0.0000	3.817	0.000	70.79
7	*****	0.0000	0.9303	0.0000	*****	3.816	*****	*****

TABLE Xb

DATA TAKEN ON 2 FEBRUARY 1981
DATA TAKEN BY D.L. RYAN
3 TERTIARY PORTS OPEN/CUSP IN

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA: 107.51 SQ IN

PRIMARY NOZZLE AREA: 9.06 SQ IN AREA RATIO (AM/AP): 2.99

MIXING STACK LENGTH: 25.50 IN ORIFACE DIAMETER: 6.908 IN

MIXING STACK DIMENSION: 0.5 IN ORIFICE BETA: 0.497 IN

MIXING STACK L/S: 3.00 AMBIENT PRESSURE: 30.25 IN HG

N	POR	OPOR	TOR	TUPT	TAMB	PU-PA	PA-PS	PA-PT	SECONDARY AREA SQUARE INCHES	TERTIARY AREA SQUARE INCHES
RUN	IN OF H2O	IN OF H2O	DEGREES F			IN OF H2O				
1	0.7	21.9	43.0	97.1	58.0	9.00	0.97	1.43	37.699	0.000
2	0.7	21.9	42.5	97.1	58.0	9.15	0.80	0.40	37.699	6.283
3	0.7	21.9	42.6	97.0	58.0	9.15	0.77	0.17	37.699	12.566
4	0.7	21.9	42.9	96.8	58.0	9.20	0.75	0.05	37.699	25.133
5	0.7	22.0	43.9	96.8	58.0	9.20	0.75	0.01	37.699	50.265
6	0.7	22.0	43.0	96.8	58.0	9.15	0.75	0.00	37.699	100.531
7	0.7	22.0	42.9	96.7	58.0	9.20	0.74	0.00	37.699	188.111

SECONDARY BOX

SECONDARY DATA													
N	MS	Px	Tx	Px/Tx	WXT-44	HP	WS	UP	UM	UUP	UPT	MACH	
RUN													
						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC			
1	0.3372	0.0942	0.9298	0.1013	0.3265	3.8165	1.2868	210.89	92.62	71.13	0.061		
2	0.3060	0.0777	0.9298	0.0836	0.2564	3.8184	1.1686	210.91	90.60	71.13	0.062		
3	0.3093	0.0748	0.9299	0.0805	0.2308	3.8181	1.1465	210.84	90.20	71.11	0.061		
4	0.2964	0.0730	0.9303	0.0785	0.2872	3.8169	1.1315	210.69	89.89	71.06	0.061		
5	0.2961	0.0728	0.9303	0.0783	0.2868	3.8218	1.1315	210.96	89.98	71.15	0.062		
6	0.2958	0.0727	0.9303	0.0781	0.2865	3.8252	1.1315	211.15	90.05	71.21	0.062		
7	0.2938	0.0717	0.9304	0.0771	0.2846	3.8256	1.1239	211.13	89.91	71.20	0.062		

TABLE XIa

TERTIARY BOX

N	WT*	PT*	TT*	PT*/TT*	WT*TT*.44	WM	WT	UE
LBN/SEC LBN/SEC FT/SEC								
RUN								
1	0.0000	0.1389	0.9298	0.1494	0.0000	5.103	0.000	92.62
2	0.0361	0.0388	0.9298	0.0418	0.0349	4.987	0.138	93.11
3	0.0470	0.0165	0.9299	0.0178	0.0456	4.965	0.180	93.46
4	0.0510	0.0049	0.9303	0.0052	0.0494	4.948	0.195	93.43
5	0.0456	0.0010	0.9303	0.0010	0.0442	4.953	0.174	93.15
6	0.0000	0.0000	0.9303	0.0000	0.0000	4.957	0.000	90.05
7	*****	0.0000	0.9304	0.0000	*****	4.950	*****	*****

TABLE XIb

DATA TAKEN ON 2 FEBRUARY 1981
DATA TAKEN BY D.L. RYAN
3 TERTIARY PORTS OPEN/CUSP IN

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA: 107.51 SQ IN
PRIMARY NOZZLE AREA: 9.06 SQ IN AREA RATIO (AM/AP): 2.99
MIXING STACK LENGTH: 25.50 IN ORIFICE DIAMETER: 6.908 IN
MIXING STACK DIMENSION: 0.5 IN ORIFICE BETA: 0.497 IN
MIXING STACK L/S: 3.00 AMBIENT PRESSURE: 30.25 IN HG

N	POR	DPOR	TOR	TUPT	TAMB	PU-PA	PA-PS	PA-PT	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O	IN OF H2O	DEGREES F	IN OF H2O	IN OF H2O	IN OF H2O	IN OF H2O	IN OF H2O	SQUARE INCHES	SQUARE INCHES
1	0.7	21.9	42.7	97.0	58.0	9.80	0.00	1.59	111111	0.000
2	0.7	21.9	42.4	96.7	58.0	9.85	0.00	0.35	111111	6.283
3	0.7	21.9	42.8	96.9	58.0	9.85	0.00	0.15	111111	12.566
4	0.7	21.9	42.6	96.8	58.0	9.90	0.00	0.05	111111	25.133
5	0.7	21.9	42.7	96.5	58.0	9.90	0.00	0.01	111111	50.265
6	0.7	21.9	42.2	96.5	58.0	9.90	0.00	0.00	111111	100.531
7	0.7	21.9	42.0	96.5	58.0	9.90	0.00	0.00	111111	111111

SECONDARY BOX

N	WS	PT	TX	PT/TX	WTX^44	WP	WS	UP	UN	UPT	UPT MACH
RUN	LBH/SEC	LBH/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC
1	111111	0.0000	0.9299	0.0000	111111	3.8177	0.0000	210.42	111111	70.97	0.061
2	111111	0.0000	0.9304	0.0000	111111	3.8188	0.0000	210.37	111111	70.95	0.061
3	111111	0.0000	0.9301	0.0000	111111	3.8173	0.0000	210.36	111111	70.95	0.061
4	111111	0.0000	0.9303	0.0000	111111	3.8181	0.0000	210.37	111111	70.95	0.061
5	111111	0.0000	0.9308	0.0000	111111	3.8177	0.0000	210.23	111111	70.90	0.061
6	111111	0.0000	0.9308	0.0000	111111	3.8196	0.0000	210.34	111111	70.94	0.061
7	111111	0.0000	0.9300	0.0000	111111	3.8203	0.0000	210.30	111111	70.95	0.061

TABLE XIIa

TERTIARY BOX

N	WT	PT	TT	PT/TT	WT/TT	WM	WT	UE
RUN								
1	0.0000	0.1551	0.9299	0.1668	0.0000	xxxxx	0.000	xxxxx
2	0.0337	0.0342	0.9304	0.0367	0.0327	xxxxx	0.129	xxxxx
3	0.0434	0.0142	0.9301	0.0152	0.0421	xxxxx	0.166	xxxxx
4	0.0484	0.0044	0.9303	0.0047	0.0469	xxxxx	0.185	xxxxx
5	0.0323	0.0005	0.9308	0.0005	0.0313	xxxxx	0.123	xxxxx
6	0.0000	0.0000	0.9308	0.0000	0.0000	xxxxx	0.000	xxxxx
7	xxxxx	0.0000	0.9308	0.0000	xxxxx	xxxxx	xxxxx	xxxxx

TABLE XIIb

DATA TAKEN ON 9 MARCH 1981
 DATA TAKEN BY D.L. RYAN
 2 TERTIARY PORTS OPEN/SIDE MOD

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA: 107.51 SQ IN
 PRIMARY NOZZLE AREA: 9.86 SQ IN AREA RATIO (AM/AP): 2.99
 MIXING STACK LENGTH: 25.50 IN ORIFICE DIAMETER: 6.908 IN
 MIXING STACK DIMENSION: 0.5 IN ORIFICE BETA: 0.497 IN
 MIXING STACK L/S: 3.00 AMBIENT PRESSURE: 30.23 IN HG

N	POR	OPOR	TOR	TUPT	TAMB	PU-PA	PA-PS	PA-PT	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O	IN OF H2O	DEGREES F	IN OF H2O	IN OF H2O	IN OF H2O	IN OF H2O	IN OF H2O	SQUARE INCHES	SQUARE INCHES
1	0.7	22.0	58.0	113.2	83.0	7.00	2.17	0.00	6.203	111.111
2	0.7	22.0	57.6	112.6	83.0	9.10	0.86	0.00	25.133	111.111
3	0.7	22.0	59.6	113.0	83.0	9.70	0.15	0.00	100.531	111.111

SECONDARY BOX

N	WS	PS	TS	PS/TS	WAT	44	WP	WS	UP	UM	UUP	UPT	MACH
PUN													
1	0.0832	0.2130	0.9473	0.2249	0.0812	3.7652	0.3132	214.64	77.51	72.46	0.062		
2	0.2092	0.0850	0.9483	0.0896	0.2044	3.7695	0.7887	214.10	85.85	72.23	0.062		
3	0.3502	0.0149	0.9476	0.0157	0.3420	3.7623	1.3175	213.55	95.15	72.02	0.061		

TABLE XIIIa

TERTIARY BOX

N	WT	PT	TT	PT/TT	WT/TT	MM	MT	UE
LBM/SEC LBM/SEC FT/SEC								
1	0.0000	0.0000	0.9473	0.0000	0.0000	4.078	0.0000	0.0000
2	0.0000	0.0000	0.9483	0.0000	0.0000	4.558	0.0000	0.0000
3	0.0000	0.0000	0.9476	0.0000	0.0000	5.000	0.0000	0.0000

MIXING STACK PRESSURE DATA: RUN 3 CURVED SIDE DISTRIBUTION

X/S:	0.25	0.50	0.75	1.00	1.25	1.50	1.75
PMS(INH20):	-0.040	0.210	0.640	1.440	2.320	2.720	2.010
PMS:	-0.004	0.021	0.064	0.143	0.231	0.270	0.200
X/S:	2.00	2.25	2.50	2.75			
PMS(INH20):	0.040	-0.900	-0.740	-0.710			
PMS:	0.004	-0.097	-0.074	-0.071			

MIXING STACK PRESSURE DATA: RUN 3 FLAT SIDE DISTRIBUTION

X/S:	0.25	0.50	0.75	1.00	1.25	1.50	1.75
PMS(INH20):	0.710	0.330	0.320	0.570	0.640	0.580	-0.320
PMS:	0.071	0.039	0.032	0.057	0.064	0.058	-0.032
X/S:	2.00	2.25	2.50	2.75			
PMS(INH20):	-0.130	0.320	0.450	0.250			
PMS:	-0.013	0.032	0.045	0.025			

TABLE XIIIb

VERTICAL VELOCITY TRAVERSE

POSIT(IN):	0.00	0.50	1.00	1.50	2.00	2.50	3.00
P(IN H20):	1.16	2.85	2.54	2.19	2.05	1.93	1.92
V(FT/SEC):	72.50	113.64	107.28	99.62	96.38	93.52	93.20
POSIT(IN):	3.50	4.00	4.50	5.00	5.50	6.00	6.50
P(IN H20):	1.96	2.03	2.12	2.19	2.28	2.40	2.52
V(FT/SEC):	94.24	95.91	98.01	99.62	101.64	104.29	106.86
POSIT(IN):	7.00	7.50	8.00	8.50			
P(IN H20):	2.67	2.74	2.81	1.72			
V(FT/SEC):	110.00	111.43	102.31	88.28			

HORIZONTAL VELOCITY TRAVERSE

POSIT(IN):	0.00	0.50	1.00	1.50	2.00	2.50	3.00
P(IN H20):	0.94	2.12	2.08	2.01	1.95	1.80	1.72
V(FT/SEC):	65.27	98.01	97.08	95.44	94.00	90.31	88.28
POSIT(IN):	3.50	4.00	4.50	5.00	5.50	6.00	6.25
P(IN H20):	1.71	1.75	1.83	1.92	2.05	2.10	2.13
V(FT/SEC):	88.03	89.05	91.06	93.28	96.38	97.55	98.24
POSIT(IN):	6.50	6.75	7.00	7.25	7.75	8.25	8.75
P(IN H20):	2.13	2.12	2.12	2.13	2.10	2.09	2.06
V(FT/SEC):	98.24	98.01	98.01	98.24	97.55	97.32	96.62
POSIT(IN):	9.25	9.75	10.25	10.75	11.25	11.75	12.25
P(IN H20):	2.08	2.11	2.11	2.04	2.02	2.03	2.07
V(FT/SEC):	97.08	97.78	97.78	96.15	95.67	95.91	96.85
POSIT(IN):	12.75						
P(IN H20):	1.43						
V(FT/SEC):	80.50						

DIAGONAL VELOCITY TRAVERSE

POSIT(IN):	0.00	0.50	1.00	1.50	2.00	2.50	3.00
P(IN H20):	1.76	2.64	2.83	2.85	2.55	2.32	2.15
V(FT/SEC):	89.30	109.33	114.24	113.64	107.49	102.53	98.70
POSIT(IN):	3.50	4.00	4.50	5.00	5.50	6.00	6.50
P(IN H20):	2.04	2.03	2.00	2.03	2.06	2.09	2.08
V(FT/SEC):	96.15	95.91	95.20	95.91	96.62	97.32	97.08
POSIT(IN):	7.00	7.50	8.00	8.50	9.00	9.50	10.00
P(IN H20):	2.10	2.12	2.12	2.03	2.02	1.89	1.70
V(FT/SEC):	97.55	93.01	98.01	97.32	95.67	92.54	87.77
POSIT(IN):	10.50	11.00	11.50	12.00	12.50	13.00	13.50
P(IN H20):	1.73	1.80	1.95	2.18	2.51	2.82	3.08
V(FT/SEC):	88.54	90.31	94.00	99.39	106.65	113.04	118.14
POSIT(IN):	14.00	14.50	15.00				
P(IN H20):	2.90	2.70	0.95				
V(FT/SEC):	116.21	112.24	65.61				

TABLE XIIIo

DATA TAKEN ON 9 MARCH 1981
DATA TAKEN BY D.L. RYAN
2 TERTIARY PORTS OPEN/SIDE MOD

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA: 107.51 SQ IN
PRIMARY NOZZLE AREA: 9.06 SQ IN AREA RATIO (AM/AP): 2.99
MIXING STACK LENGTH: 25.50 IN ORIFICE DIAMETER: 6.908 IN
MIXING STACK DIMENSION: 0.5 IN ORIFICE BETA: 0.497 IN
MIXING STACK L/S: 3.00 AMBIENT PRESSURE: 30.29 IN HG

N	POR	OPOR	TOR	TUPT	TAMB	PU-PA	PA-PS	PA-PT	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O			DEGREES F		IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.7	22.0	47.0	100.2	57.0	7.40	2.59	0.31	0.000	6.283
2	0.7	22.0	48.0	101.2	57.0	7.45	2.56	0.04	0.000	25.133
3	0.7	22.0	47.0	101.4	57.0	7.45	2.54	0.01	0.000	100.531

SECONDARY BOX

N	W3	P3	T3	P3/T3	W3/T3	MP	WS	UP	UM	UUPT	UPT	HACH
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC		
1	0.0000	0.2476	0.9220	0.2683	0.0000	3.6096	0.0000	212.24	71.01	71.58	0.062	
2	0.0000	0.2440	0.9212	0.2648	0.0000	3.6088	0.0000	212.56	71.12	71.69	0.062	
3	0.0000	0.2410	0.9209	0.2626	0.0000	3.6096	0.0000	212.67	71.15	71.72	0.062	

TABLE XIVa

TERTIARY BOX

N	WTs	PTs	TTs	PTs/TTs	WTsTTs	WM	WT	UE
RUN						LBM/SEC	LBM/SEC	FT/SEC
1	0.0319	0.0296	0.9228	0.0321	0.0308	3.810	0.121	73.27
2	0.0458	0.0038	0.9212	0.0041	0.0442	3.809	0.174	74.37
3	0.0648	0.0005	0.9209	0.0005	0.0625	3.818	0.247	75.76

TABLE XIVb

DATA TAKEN ON 9 MARCH 1981
 DATA TAKEN BY D.L. RYAN
 2 TERTIARY PORTS OPEN/SIDE MOD

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA: 107.51 SQ IN
 PRIMARY NOZZLE AREA: 9.06 SQ IN AREA RATIO (AM/AP): 2.99
 MIXING STACK LENGTH: 25.50 IN ORIFICE DIAMETER: 6.900 IN
 MIXING STACK DIMENSION: 0.5 IN ORIFICE BETA: 0.497 IN
 MIXING STACK L/S: 3.00 AMBIENT PRESSURE: 30.30 IN HG

N	POR	OPOR	TOR	TUPT	TAMB	PU-PA	PA-PS	PA-PT	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O			DEGREES F		IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.7	22.0	48.4	102.2	58.0	9.48	0.57	0.28	37.699	6.283
2	0.7	22.0	48.0	102.2	58.0	9.48	0.57	0.04	37.699	25.133
3	0.7	22.0	49.0	102.2	58.0	9.48	0.57	0.01	37.699	100.531

SECONDARY BOX

N	WE	PS	TS	PS/TS	WST	HP	WS	UP	UM	UUPT	UPT	MACH
RUN							LBM/SEC	LBM/SEC	FT/SEC	FT/SEC		
1	0.2593	0.0548	0.9213	0.0595	0.2501	3.8080	0.9872	211.79	87.76	71.43	0.061	
2	0.2594	0.0548	0.9213	0.0595	0.2502	3.8065	0.9872	211.71	87.73	71.40	0.061	
3	0.2594	0.0549	0.9213	0.0596	0.2502	3.8057	0.9872	211.67	87.72	71.39	0.061	

TABLE XVa

RUN	N	WT%	PT%	TT%	PT%/TT%	WT%TT%	MM	WT	UE
							LBM/SEC	LBM/SEC	FT/SEC
1	0.0303	0.0269	0.9213	0.0292	0.0292	4.795	0.115	89.87	
2	0.0458	0.0338	0.9213	0.0042	0.0442	4.794	0.174	90.92	
3	0.0648	0.0005	0.9213	0.0005	0.0635	4.793	0.247	92.23	

DATA TAKEN ON 9 MARCH 1981
 DATA TAKEN BY D.L. RYAN
 3 TERTIARY PORTS OPEN/SIDE MOD

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA: 107.51 SQ IN
 PRIMARY NOZZLE AREA: 9.06 SQ IN AREA RATIO (AM/AP): 2.99
 MIXING STACK LENGTH: 25.30 IN ORIFICE DIAMETER: 6.908 IN
 MIXING STACK DIMENSION: 0.5 IN ORIFICE BETA: 0.497 IN
 MIXING STACK L/S: 3.00 AMBIENT PRESSURE: 30.32 IN HG

N	POR	OPOR	TOR	TUPT	TAMB	PU-PA	PA-PS	PA-PT	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O			DEGREES F		IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.7	21.9	53.4	107.0	68.0	8.10	1.86	0.00	6.283	*****
2	0.7	22.0	53.2	107.2	68.0	9.20	0.81	0.00	25.133	*****
3	0.7	22.0	52.6	106.6	68.0	9.80	0.13	0.00	100.531	*****
4	0.7	21.9	53.4	107.0	68.0	9.85	0.03	0.00	*****	*****

SECONDARY BOX

N	W*	P*	T*	P*/T*	W*/T*	HP	WS	UP	UN	UUP	UPT
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC
1	0.0779	0.1807	0.9312	0.1540	0.0755	3.7820	0.2945	212.67	76.29	71.72	0.061
2	0.2050	0.0786	0.3308	0.0845	0.1987	3.7913	0.7774	212.73	84.73	71.74	0.061
3	0.3284	0.0127	0.9318	0.0136	0.3183	3.7936	1.2457	212.20	92.74	71.59	0.061
4	*****	0.0029	0.9312	0.0032	*****	3.7820	9.3502	211.73	*****	71.41	0.061

TABLE XVIa

TERTIARY BOX

N	WT	PT	YT	PT/TT	WT	UE
LBM/SEC LBM/SEC FT/SEC						
1	0.0000	0.9312	0.0000	0.076	0.0000	0.0000
2	0.0000	0.9300	0.0000	0.076	0.0000	0.0000
3	0.0000	0.9318	0.0000	0.076	0.0000	0.0000
4	0.0000	0.9312	0.0000	0.076	0.0000	0.0000

MIXING STACK PRESSURE DATA: RUN 4 CURVED SIDE DISTRIBUTION

X/S:	0.25	0.50	0.75	1.00	1.25	1.50	1.75
PHS(LNH20):	0.030	0.400	0.850	1.570	2.440	2.910	2.140
PHS:	0.003	0.039	0.083	0.154	0.239	0.285	0.210
X/S:	2.00	2.25	2.50	2.75			
PHS(LNH20):	-0.020	-1.250	-0.870	-0.740			
PHS:	-0.002	-0.122	-0.085	-0.073			

MIXING STACK PRESSURE DATA: RUN 4 FLAT SIDE DISTRIBUTION

X/S:	0.25	0.50	0.75	1.00	1.25	1.50	1.75
PHS(LNH20):	0.850	0.600	0.610	0.930	1.020	0.770	-0.740
PHS:	0.003	0.059	0.060	0.091	0.100	0.075	-0.073
X/S:	2.00	2.25	2.50	2.75			
PHS(LNH20):	-0.230	0.210	0.370	0.220			
PHS:	-0.023	0.021	0.036	0.022			

TABLE XVIb

VERTICAL VELOCITY TRAVERSE				
POSIT(IN):	0.00	0.50	1.00	
P(IN H20):	1.57	2.77	2.35	
V(FT/SEC):	83.05	110.31	101.61	
POSIT(IN):	3.50	4.00	4.50	
P(IN H20):	1.88	1.92	2.03	
V(FT/SEC):	90.88	91.84	94.44	
POSIT(IN):	7.00	7.50	8.00	
P(IN H20):	2.86	2.93	2.69	
V(FT/SEC):	112.09	113.45	108.71	
	1.50	2.00	2.50	3.00
	2.07	1.92	1.84	1.85
	95.36	91.84	89.91	90.15
	5.00	5.50	6.00	6.50
	2.16	2.31	2.36	2.63
	97.41	100.74	101.82	107.49
	8.50			
	0.95			
	64.60			

HORIZONTAL VELOCITY TRAVERSE				
POSIT(IN):	0.00	0.50	1.00	
P(IN H20):	1.05	1.85	1.80	
V(FT/SEC):	67.92	90.15	88.92	
POSIT(IN):	3.50	4.00	4.50	
P(IN H20):	1.82	1.86	1.91	
V(FT/SEC):	89.42	90.39	91.60	
POSIT(IN):	6.50	6.75	7.00	
P(IN H20):	2.01	1.98	2.00	
V(FT/SEC):	93.97	93.26	93.73	
POSIT(IN):	9.25	9.75	10.25	
P(IN H20):	2.01	2.03	2.07	
V(FT/SEC):	93.97	94.44	95.36	
POSIT(IN):	12.75			
P(IN H20):	1.04			
V(FT/SEC):	67.59			
	1.50	2.00	2.50	3.00
	1.86	1.85	1.83	1.81
	90.39	90.15	89.66	89.17
	5.00	5.50	6.00	6.25
	1.97	2.00	2.03	1.99
	93.03	93.73	94.44	93.50
	7.25	7.75	8.25	8.75
	1.99	1.98	1.98	1.97
	93.50	93.26	93.26	93.03
	10.75	11.25	11.75	12.25
	2.04	2.01	1.96	1.84
	94.67	93.97	92.79	89.91

DIAGONAL VELOCITY TRAVERSE				
POSIT(IN):	0.00	0.50	1.00	
P(IN H20):	1.30	2.43	2.74	
V(FT/SEC):	75.57	103.32	109.71	
POSIT(IN):	3.50	4.00	4.50	
P(IN H20):	2.16	2.12	2.11	
V(FT/SEC):	97.41	96.51	96.28	
POSIT(IN):	7.00	7.50	8.00	
P(IN H20):	1.93	1.94	1.94	
V(FT/SEC):	92.88	92.32	92.32	
POSIT(IN):	10.50	11.00	11.50	
P(IN H20):	1.87	1.97	1.95	
V(FT/SEC):	90.64	90.64	92.56	
POSIT(IN):	14.00	14.50	15.00	
P(IN H20):	2.47	2.30	1.98	
V(FT/SEC):	104.17	100.52	93.26	
	1.50	2.00	2.50	3.00
	2.78	2.63	2.41	2.26
	110.51	107.49	102.89	93.64
	5.00	5.50	6.00	6.50
	2.10	2.09	2.03	1.97
	96.05	95.82	94.44	93.03
	8.50	9.00	9.50	10.00
	1.99	2.00	1.98	1.95
	93.50	93.73	93.26	92.56
	12.00	12.50	13.00	13.50
	2.10	2.28	2.59	2.71
	96.05	100.00	106.67	109.11

TABLE XVII

DATA TAKEN ON 9 MARCH 1981
 DATA TAKEN BY D.L. RYAN
 3 TERTIARY PORTS OPEN/SIDE MOD

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA: 107.51 SQ IN
 PRIMARY NOZZLE AREA: 9.06 SQ IN AREA RATIO (AM/AP): 2.99
 MIXING STACK LENGTH: 25.50 IN ORIFICE DIAMETER: 6.908 IN
 MIXING STACK DIMENSION: 8.5 IN ORIFICE BETA: 0.497 IN
 MIXING STACK L/S: 3.00 AMBIENT PRESSURE: 30.28 IN HG

N	POR	DPOR	TOR	TUPT	TAMB	PU-PA	PA-PS	PA-PT	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O			DEGREES F		IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.7	22.0	49.6	99.0	56.0	7.50	2.46	0.43	0.000	6.283
2	0.7	22.0	49.4	100.8	56.0	7.60	2.35	0.04	0.000	25.133
3	0.7	22.0	49.2	101.4	56.0	7.65	2.35	0.01	0.000	100.531

SECONDARY BOX

N	WS	Pt	Tz	Ps/Tz	Wt/Tz	WP	WS	UP	UM	UUPT	UPT MACH
RUN						LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.0000	0.2367	0.9230	0.2564	0.0000	3.8022	0.0000	211.38	70.72	71.29	0.062
2	0.0000	0.2247	0.9201	0.2442	0.0000	3.8030	0.0000	212.04	70.94	71.51	0.062
3	0.0000	0.2241	0.9191	0.2438	0.0000	3.8037	0.0000	212.31	71.03	71.60	0.062

TABLE XVIIa

N	WT§	PT§	TT§	PT§/TT§	WT/TT-44	WM	WT	UE
						LBM/SEC	LBM/SEC	FT/SEC
1	0.0376	0.0414	0.9230	0.0440	0.0353	3.002	0.143	73.38
2	0.0459	0.0378	0.9201	0.0042	0.0443	3.003	0.175	74.20
3	0.0918	0.0010	0.9191	0.0010	0.0095	3.004	0.349	77.55

DATA TAKEN ON 9 MARCH 1981
DATA TAKEN BY O.L. RYAN
3 TERTIARY PORTS OPEN/SIDE MOD

NUMBER OF PRIMARY NOZZLES: 4 UPTAKE AREA: 107.51 SQ IN
PRIMARY NOZZLE AREA: 9.86 SQ IN AREA RATIO (AM/AP): 2.99
MIXING STACK LENGTH: 25.50 IN ORIFICE DIAMETER: 6.908 IN
MIXING STACK DIMENSION: 0.5 IN ORIFICE BETA: 0.497 IN
MIXING STACK L/S: 3.00 AMBIENT PRESSURE: 30.28 IN HG

N	POR	DPOR	TOR	TUPT	TAMB	PU-PA	PA-PS	PA-PT	SECONDARY AREA	TERTIARY AREA
RUN	IN OF H2O			DEGREES F		IN OF H2O			SQUARE INCHES	SQUARE INCHES
1	0.7	22.0	48.6	102.0	58.0	9.50	0.53	0.40	37.699	6.283
2	0.7	22.0	48.4	101.6	58.0	9.50	0.48	0.07	37.699	25.133
3	0.7	22.0	48.4	101.0	58.0	9.50	0.46	0.01	37.699	100.531

SECONDARY BOX

N	W3	P3	T3	P3/T3	W3/T3	44	HP	WS	UP	UH	UUP	UPT	MACH
RUN							LBM/SEC	LBM/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC	
1	0.2500	0.0510	0.9217	0.0554	0.2412	3.8060	0.9517	211.72	87.14	71.41	0.061		
2	0.2379	0.0463	0.9223	0.0502	0.2296	3.8067	0.9057	211.59	86.31	71.36	0.061		
3	0.2329	0.0443	0.9220	0.0481	0.2247	3.8067	0.8866	211.65	86.00	71.38	0.061		

TABLE XVIIIa

TERTIARY BOX

N	WT	PI	TI	PI/TI	WT/PI	WT	UE
RUN					LBM/SEC	LBM/SEC	FT/SEC
1	0.0362	0.0385	0.9217	0.0418	0.0349	4.750	0.138 89.66
2	0.0606	0.0667	0.9223	0.0873	0.0585	4.712	0.231 90.53
3	0.0916	0.0910	0.9220	0.0810	0.0884	4.693	0.349 92.39

TABLE XVIIIb

APPENDIX: A

ONE-DIMENSIONAL ANALYSIS OF A SIMPLE EDUCTOR

This investigation, being an extension of the work of Shaw [Ref. 8], and others Ref. 1, 2 and 7] uses the same one-dimensional analysis of a simple eductor system. Similarity between the basic geometry tested by previous researchers was maintained in order to correlate data. The dimensionless parameters controlling the flow phenomena used previously were also used in this investigation along with the basic means of data analysis and presentation. Dynamic similarity was maintained by using Mach number similarity to establish the model's primary flow rate.

Although the analysis presented here is for an eductor model with only primary and secondary air flows, it should be kept in mind that many of the results presented are for systems with primary, secondary, and tertiary air flows. Systems with tertiary and film or wall cooling air flows have been non-dimensionalized with the same base parameters as the secondary air flow and have been calculated using the same one-dimensional analysis. This allows for easy comparison of the results. Parameters pertaining to the secondary systems are subscripted with an "s", those relating to the tertiary box are subscripted with a "t".

A. MODELING TECHNIQUE

Dynamic similarity between the models tested and the actual prototype was maintained by using the same primary air flow Mach number. For the primary air flow Mach number used (0.064), and based on the average flow properties within the mixing stack and the hydraulic diameter of the mixing stack, the air flow through the eductor system is turbulent ($Re > 10^5$). As a consequence of this, momentum exchange is predominant over shear interaction, and the kinetic and internal energy terms are more influential on the flow than are viscous forces. It can also be shown that the Mach number represents the ratio of kinetic energy of a flow to its internal energy and is, therefore, a more significant parameter than the Reynolds number in describing the primary flow through the uptakes.

B. ONE-DIMENSIONAL ANALYSIS OF A SIMPLE EDUCTOR

The theoretical analysis of an eductor may be approached in two ways. One method attempts to analyze the details of the mixing process of the primary and secondary air streams as it takes place inside the mixing stack. This requires an interpretation of the mixing phenomenon which, when applied to a multiple nozzle system, becomes extremely complex. The other method, which was chosen here, analyzes the overall performance of the eductor system and is not concerned with the actual mixing process. The one-dimensional analysis

based on a single primary nozzle exhausting into a mixing stack, as shown in Figure A-1. To avoid repetition with previous reports, only the main parameters and assumption will be represented here. A complete derivation of analysis used can be found in References [1] and [4]. The one-dimensional flow analysis of the simple eductor system described depends on the simultaneous solution of the continuity, momentum and energy equations coupled with the equation of state, all compatible with specific boundary conditions.

The idealizations made for simplifying the analysis are as follows:

1. The flow is steady state and incompressible.
2. Adiabatic flow exists throughout the eductor with isentropic flow of the secondary stream from the plenum (at section 0) to the throat or entrance of the mixing stack (at section 1) and irreversible adiabatic mixing of the primary and secondary streams occurs in the mixing stack (between sections 1 and 2).
3. The static pressure across the flow at the entrance and exit planes of the mixing-tube (at sections 1 and 2) is uniform.
4. At the mixing-stack entrance (section 1) the primary flow velocity U_p and temperature T_p are uniform across the primary stream, and the secondary flow velocity U_s and temperature T_s are uniform across

the secondary stream, but U_p does not equal U_s , and T_p does not equal T_s .

5. Incomplete mixing of the primary and secondary streams in the mixing stack is accounted for by the use of a non-dimensional momentum correction factor K_m which relates the actual momentum rate to the pseudo-rate based on the bulk-average velocity and density and by the use of a non-dimensional kinetic energy correction factor K_e which relates the actual kinetic energy rate to the pseudo-rate based on the bulk-average velocity and density.
6. Both gas flows behave as perfect gases.
7. Flow potential energy position changes are negligible.
8. Pressure changes P_{s0} to P_{s1} and P_1 to P_a are small relative to the static pressure so that the gas density is essentially dependent upon temperature (and atmospheric pressure).
9. Wall friction in the mixing stack is accounted for with the convectional pipe friction factor term based on the bulk-average flow velocity U_m and the mixing stack wall area A_w .

The following parameter, defined here for clarity, will be used in the following development.

$$\frac{A_p}{A_m}$$

area ratio of primary flow area to mixing stack cross sectional area

$\frac{A_w}{A_m}$	area ratio of wall friction area to mixing stack cross sectional area
k_p	momentum correction factor for primary mixing
K_m	momentum correction factor for mixed flow
f	wall friction factor

Base on the continuity equation, the conservation of mass principle for steady flow yields

$$W_m = W_p + W_s + W_t \quad (1)$$

where

$$\begin{aligned} W_p &= \rho_p U_p A_p \\ W_s &= \rho_s U_s A_s \\ W_t &= \rho_t U_t A_t \\ W_m &= \rho_m U_m A_m \end{aligned} \quad (1a)$$

All of the above velocity and density terms, with the exception of ρ_m and U_m , are defined without ambiguity by the virtue of idealizations (3) and (4) above. Combining equations (1) and (1a) above, the bulk average velocity at the exit plane of the mixing stack becomes

$$U_m = \frac{W_s + W_t + W_p}{\rho_m A_m} \quad (1b)$$

where A_m is fixed by the geometric configuration and

$$\rho_m = \frac{p_a}{RT_m} \quad (2)$$

where T_m is calculated as the bulk average temperature from the energy equation (9) below. The momentum equation stems

from Newton's second and third laws of motion and is the conventional force and momentum-rate balance in fluid mechanics.

$$K_p \left(\frac{W_p U_p}{g_c} \right) + \left(\frac{W_s U_s}{g_c} \right) + \left(\frac{W_t U_t}{g_c} \right) + P_1 A_1 = K_m \left(\frac{W_m U_m}{g_c} \right) + P_2 A_2 + F_{fr} \quad (3)$$

Note the introduction of idealizations (3) and (5). To account for a possible non-uniform velocity profiles across the primary nozzle exit, the momentum correction factor K_p is introduced here. It is defined in a manner similar to that of K_m and by idealization (4), supported by work conducted by Moss, it is set equal to unity. K_p is carried through this analysis only to illustrate its effect on the final result. The momentum correction factor for the mixing stack exit is defined by the relation

$$K_m = \frac{1}{W_m U_m} \int_0^{A_m} U_m^2 \rho_2 dA \quad (4)$$

where U_m is evaluated as the bulk-average velocity from equation (1b). The wall skin friction force F_{fr} can be related to the flow stream velocity by

$$F_{fr} = f A_w \left(\frac{U_m^2 \rho_m}{2 g_c} \right) \quad (5)$$

using idealization (9). As a reasonably good approximation for turbulent flow, the friction factor may be calculated from the Reynolds number

$$f = 0.046(\text{Re}_m)^{-0.2}. \quad (6)$$

Applying the conservation of energy principle to the steady flow system in the mixing stack between the entrance and exit planes,

$$\begin{aligned} W_p \left(h_p + \frac{U_p^2}{2g_c} \right) + W_s \left(h_s + \frac{U_s^2}{2g_c} \right) + W_t \left(h_t + \frac{U_t^2}{2g_c} \right) \\ = W_m \left(h_m + K_e \frac{U_m^2}{2g_c} \right) \end{aligned} \quad (7)$$

neglecting potential energy of position changes (idealization 7). Note the introduction of the kinetic energy correction factor K_e , which is defined by the relation

$$K_e = \frac{1}{W_m U_m^2} \int_0^{A_m} U_z^3 \rho_z dA \quad (8)$$

It may be demonstrated that for the purpose of evaluating the mixed mean flow temperature T_m , the kinetic energy terms may be neglected to yield

$$h_m = \frac{W_p}{W_m} h_p + \frac{W_s}{W_m} h_s + \frac{W_t}{W_m} h_t \quad (9)$$

where $T_m = \phi(h_m)$ only, with the idealization (6).

The energy equation for the isentropic flow of the secondary air from the plenum to the entrance of the mixing stack may be shown to reduce to

$$\frac{P_o - P_s}{\rho_s} = \frac{U_s^2}{2g_s} \quad (10)$$

similarly, the energy equation for the tertiary air flow reduces to

$$\frac{P_o - P_t}{\rho_t} = \frac{U_t^2}{2g_c}$$

The forgoing equations may be combined to yield the vacuum produced by the eductor action in either the secondary or tertiary air plenums. For the secondary air plenum, the vacuum produced is

$$P_a - P_{os} = \frac{1}{g_c A_m} \left(K_p \frac{W_p^2}{A_p \rho_p} + \frac{W_s^2}{A_s \rho_s} \left(1 - \frac{1}{2} \frac{A_m}{A_s} \right) - \frac{W_m^2}{A_m \rho_m} \left(K_m + \frac{f}{2} \frac{A_w}{A_m} \right) \right) \quad (11)$$

where it is understood that A_p and ρ_s apply to the secondary flow at this same section, and A_m and ρ_m apply to the mixed flow at the exit of the mixing stack system. P_a is atmospheric pressure, and is equal to the pressure at the exit of the mixing stack. A_w is the area of the inside wall of the mixing stack.

For the tertiary air plenum, the vacuum produced is

$$\begin{aligned} P_a - P_{ot} &= \frac{1}{g_c A_m} \left(K_p \frac{(W_p + W_s)^2}{(A_p \rho_p + A_s \rho_s)} + \frac{W_t^2}{A_t \rho_t} \left(1 - \frac{1}{2} \frac{A_m}{A_t} \right) \right. \\ &\quad \left. - \frac{W_m^2}{A_m \rho_m} \left(K_m + \frac{f}{2} \frac{A_w}{A_m} \right) \right) \end{aligned} \quad (11a)$$

where the primary flow now consists of both the primary and secondary air flows.

C. NON-DIMENSIONAL FORM OF THE SIMPLE EDUCTOR EQUATION

In order to provide the criteria of similarity of flows with geometric similarity, the non-dimensional parameters which govern the flow must be determined. The means chosen for determining these parameters is to normalize equations (11) and (11a) with the following dimensionless groupings.

$$\Delta P^* = \frac{P_a - P_{os}}{\frac{\rho_s}{U_p^2} \frac{U_p^2}{2g_c}}$$

a pressure coefficient which compares the pumped head $P_a - P_{os}$ for the secondary flow to the driving head $\frac{U_p^2}{2g_c}$ of the primary flow

$$\Delta PT^* = \frac{P_a - P_{ot}}{\frac{\rho_t}{U_p^2} \frac{U_p^2}{2g_c}}$$

a pressure coefficient which compares the pumped head $P_a - P_{os}$ for the tertiary flow to the driving head $\frac{U_p^2}{2g_c}$ of the primary flow

$$W^* = \frac{W_s}{W_p}$$

a flow rate ratio, secondary to primary mass flow rate

$$WT^* = \frac{W_t}{W_p}$$

a flow rate ratio, tertiary to primary mass flow rate

$$T^* = \frac{T_s}{T_p}$$

an absolute temperature ratio, secondary to primary

$$TT^* = \frac{T_t}{T_p}$$

an absolute temperature ratio, tertiary to primary

$$\rho_s^* = \frac{\rho_s}{\rho_p}$$

a flow density ratio of the secondary to primary flows. (note that since the fluids are considered perfect gases,

$$\rho_s^* = \frac{T_p}{T_s} = \frac{1}{T_s^*})$$

$$\rho_t^* = \frac{\rho_t}{\rho_p}$$

a flow density ratio of the tertiary or film cooling flow to primary flows. (Note that since the fluids are considered perfect gases,

$$\rho_t^* = \frac{T_p}{T_t} = \frac{1}{T_t^*})$$

$$A_s^* = \frac{A_s}{A_p}$$

an area ratio of secondary flow area to primary flow area

$$A_t^* = \frac{A_t}{A_p}$$

an area ratio of tertiary flow area to primary flow area

With these non-dimensional groupings, equations (11) and (11a) can be rewritten in dimensionless form. Since both equations follow the same format, only the results for the secondary air plenum will be presented here.

$$\begin{aligned} \frac{\Delta P^*}{T^*} = 2 \frac{A_p}{A_m} & \left((K_p - \frac{A_p}{A_m} \beta) - W^*(K_p + T^*) \frac{A_p}{A_m} \beta \right. \\ & \left. + W^{*2} T^* \left(\frac{1}{A^*} (K_p - \frac{A_m}{2A^* A_p}) - \frac{A_p}{A_m} \beta \right) \right) \end{aligned} \quad (12)$$

where

$$\beta = K_m + \frac{f}{2} \frac{A_w}{A_m}.$$

This may be rewritten as

$$\frac{P^*}{T^*} = C_1 + C_2 W^*(T + 1) + C_3 W^{*2} T^* \quad (13)$$

where

$$C_1 = 2 \frac{A_p}{A_m} (K_p - \frac{A_p}{A_m} \beta),$$

$$C_2 = - 2 \left(\frac{A_p}{A_n} \right)^2 \beta, \text{ and}$$

$$C_3 = 2 \frac{A_p}{A_m} \left(\frac{1}{A^*} - \frac{A_m}{2A^*A_p} \beta - \frac{A_p}{A_m} \beta \right).$$

As can be seen from equation (13),

$$\Delta P^* = F(W^*, T^*).$$

The additional dimensionless quantities listed below were used to correlate the static pressure distribution down the length of the mixing stack.

$$PMS^* = \frac{\frac{PMS}{\rho_s}}{\frac{U_p^2}{2g_c}}$$

a pressure coefficient which compares the pumping head $\frac{PMS}{\rho_s}$ for the secondary flow to the driving head $\frac{U_p^2}{2g_c}$ of the primary flow, where PMS = static pressure along the mixing stack length

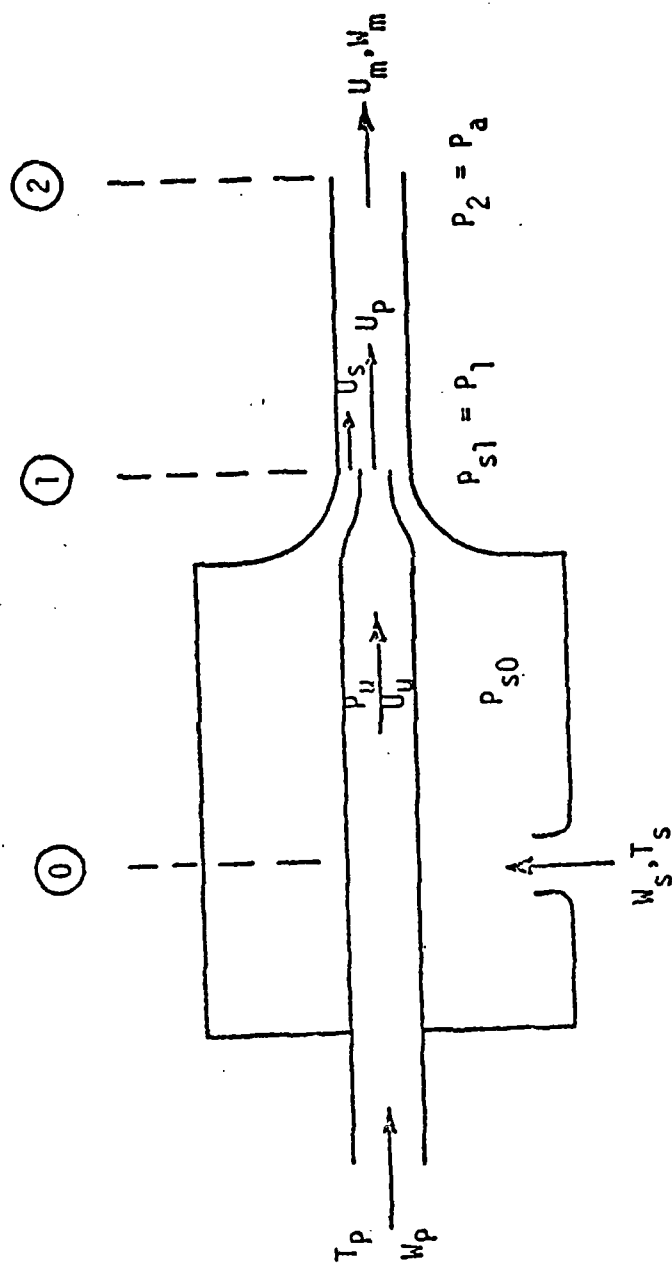


FIGURE A-I. SIMPLE SINGLE NOZZLE EDUCTOR SYSTEM

APPENDIX: B

FORMULA

Presented here are the fomulas used to obain the primary and secondary mass flow rates. According to the ASME Power Test Code (5), the general equation for mass flow rate appearing in equation (a)

$$W(\text{lbm/sec}) = (0.12705) K A Y F_a (\rho \Delta P)^{0.5} \quad (a)$$

may be used with flow nozzles and square edge orifices provided the flow is subsonic. In the above equation, K (dimensionless) represents the flow coefficient for the metering device and is defined as $K = C(1 - \beta^4)^{-0.5}$ where C is the coefficient of discharge and β is the ratio of throat to inlet diameters; $A(\text{in}^2)$ is the total cross sectional area of the metering device; Y (dimensionless) is the expansion factor for the flow; F_a (dimensionless) is the area thermal expansion factor; ρ (lbm/ft^3) is the flow mass density; and ΔP (inches H_2O) is the differential pressure across the metering device. Each of these quantittites are evaluated, according to the guidelines set forth in Reference [5], for the specific type of flow measuring device used.

Using a square edge orifice for measurement of the primary mass flow rate, the quantities in equation (a) are defined as follows:

1. The flow coefficient K is 0.62 based on a β of 0.502 and a constant coefficient of discharge over the range of flows considered of 0.60.
2. The orifice area is 37.4145 in².
3. Corresponding to the range of pressure ratios encountered across the orifice, the expansion factor Y is 0.98.
4. Since the temperature of the metered air is nearly ambient temperature, thermal expansion factor is essentially 1.0.
5. The primary air mass density ρ_{or} is calculated using the perfect gas relationship with pressure and temperature evaluated upstream of the orifice.

Substituting these values into equation (a) yields

$$W_p \text{ (lbm/sec)} = (2.8882) (\rho_{or} \Delta P_{or})^{0.5} \quad (b)$$

The secondary mass flow rate is measured using long radius flow nozzles for which case the quantities in equation (a) becomes:

1. For a flow nozzle installed in a plenum, β is approximately zero in which case the flow coefficient is approximately equal to the coefficient of discharge. For the range of secondary flows encountered, the flow coefficient becomes 0.98.
2. A is the sum of the throat areas of the flow nozzles in use.

3. Since the pressure ratios across the flow nozzles are very close to unity, the expansion coefficient Y is 1.0.
4. Since the temperature of the metered air is nearly ambient temperature, the thermal expansion factor is essentially 1.0.
5. The secondary air mass density ρ_s is evaluated using the perfect gas relationship at ambient conditions.

Substituting these values into equation (a) yields the equation for the secondary mass flow rate measured using long radius flow nozzles.

$$W_s \text{ (lbm/sec)} = (0.13451) A (\rho_s \Delta P_s)^{0.5} \quad (c)$$

APPENDIX: C

DATA ACQUISITION AUTOMATION

The method used in taking data with this and previous theses has been completely manual. Although the procedure has been adequate, it has been combersome. An ancillary objective of this thesis has been to assemble a system to automatically collect, reduce ans store the data required.

The system developed utilizes the following equipment:

- 1) Hewlett Packard Model 85 Computer
- 2) Hewlett Packard Model 82901M Flexible Disc Drive
- 3) Hewlett Packard Model 7225-A Plotter
- 4) Hewlett Packard Model 3497A Data Acquisition/Control Unit.

These equipments were connected via a Hewlett Packard Model 82937A Interface Bus. Additionally, the HP-85 had installed the Mass Storages, Plotter/Printer, and Matrix ROMS (Read Only Memories). Figures C-I and C-II show a system schematic and the actual equipment used.

Pressure reading were taken with poly-flo tubing from the scanivalve via a manifold arrangement to Validyne Model DP 103 pressure transducers. Two transducers are utilized, one with a pressure range of 0 to 5.5 inches of H₂O (0-0.2 psi), the other with a pressure range of 0 to 35 inches of

H₂O (0-1.2 psi). The DC electrical signal from the transducer is amplified through a Validyne CD10 Carrier Demodulator. The carrier demodulator also provides controls for setting the zero point of the transducer and varying the span of the voltage output from the unit. The DC output from the demodulator is measured by the voltmeter within the HP-3497A data acquisition unit. The 3497A transmits the voltage value to the HP-85 where a subroutine of the acquisition program converts the voltage to a pressure value.

Temperature readings are taken in a similar manner. The thermocouple voltages are read directly by the 3497A data acquisition unit. A different subroutine within the data acquisition program converts the voltage reading to temperature values.

The conversion formula for temperature was derived from reference tables for type T copper-constantan thermocouples. Voltages from the reference table at ten degree increments from 0 to 120 degrees Fahrenheit were input into a program from the HP-85 Math Pac. This program provided the coefficients for a degree Chebyshev polynomial. The following formula results:

$$T = .0608773(V)^3 - 1.289098(V)^2 + 46.58608(V) + 32.00443$$

where T is degrees Fahrenheit and V is millivolts.

Unlike the thermocouple, calibration of the transducers must be accomplished everytime the equipment is energized. This is because the location of the zero point is not always

constant. Calibration of the transducers required use of the building air supply. The compressor in the building is a Worthington Air Compressor set at a nominal operating pressure of 100 psig. Sufficient air pressure was obtained by regulating the supply valve from the building air system and installing a throttling valve prior to a manifold. Both the pressure transducers and a 20 inch water manometer are connected to the manifold. In addition an exhaust valve that can be throttled is also attached to the manifold. With the building air supply completely disconnected and all manifold valves open, the zero point is set. The air supply is then connected to the manifold and the pressure is raised to 5.0 or 20 inches of water depending on the transducer to be calibrated. A vacuum can be obtained by inserting a tee fitting into the poly-flo tubing ahead of the inlet throttling valve. This forms an eductor that takes a suction on the manifold. By varying the building air supply valve and the throttle valves connected to the manifold the desired vacuum can be reached. When calibrating the 0 to 35 inch transducer it is vital that the valve isolating the lower range transducer be secured. An additional safety precaution is to have a vent valve installed between the manifold and the transducer. This safety valve is to be open whenever the 5.5 inch transducer is not in use. After raising the pressure to the high end calibration point the pressure is trapped in the manifold by closing all valves. A transducer reading is

then taken and recorded with the pressure reading from the manometer. The process is then repeated with several values at the low end of the pressure range. These voltages and corresponding pressure values are then inputted into the Chebyshev polynomial program and the coefficients for a 1st degree equation are obtained. These coefficients are then inserted into the data acquisition program.

It is important to note that the transducer can be set for reading either positive or negative differential pressure. Once a transducer has been calibrated for the desired positive or negative range measuring a pressure of the opposite sign will cause the zero point of the transducer to shift. Recalibration will then be required. Because both positive and negative differential pressures were measured it was found that one transducer had to be calibrated for pressures less than atmospheric and one for pressures greater than atmospheric. A Sample calibration program is included in Table C-I.

Once the calibration process is complete the data acquisition program is run. This program will record the required pressures and temperatures and upon completion store the values under the desired filename on the flexible disc. The data reduction program is then loaded from the disc storage and executed. Upon completion of the data reduction program, plot programs are called which will provide output on the 7225-A Plotter.

The data acquisition system as presently configured is semi-automatic. Temperatures can be automatically taken in sequence but the program must stop and allow the operator to manually step the scanivalve and arrange the valving for the correct transducer. The use of a digital stepping device would further automate the process. Additionally, a transducer dedicated to only determining positive or negative differential pressure and electrically operated manifold valves would complete the process.

Even though the system is not yet completely automatic, the ability to reduce data on site provides more flexibility and ease of conducting the thesis research.

```

10 ! The name of this program          430 MAT PRINT X
    is CAL35XD.                        440 END
20 OPTION BASE 0
30 DISP "This program is design
    ed to"
40 DISP "calibrate the 0-35 in
    trans-"
50 DISP "ducer. It will give you
    values"
60 DISP "to input into the CHEB
    Y pro-"
70 DISP "gram to get coefficient
    is for a"
80 DISP "calibration function. M
    ake sure"
90 DISP "that the 5.5 in transd
    ucer is"
100 DISP "DISCONNECTED from the
    manifold."
110 DIM X(4,1)
120 DISP "With the 35 in transdu
    cer dis-"
130 DISP "connected at the manif
    old, set"
140 DISP "the zero point on the
    carrier"
150 DISP "demodulator."
160 OUTPUT 709 ; "VR5ARAC3SA"
170 DISP "Press CONT when ready."
180 PAUSE
190 DISP "Reconnect transducer t
    o the"
200 DISP "manifold. When air Pres
    sure is"
210 DISP "set at 20 in H2O Press
    CONT."
220 PAUSE
230 I=20
240 FOR J=4 TO 0 STEP -1
250 X(J,0)=I
260 OUTPUT 709 ; "VR5A13SA"
270 ENTER 709 ; X(J,1)
280 OUTPUT 709 ; "ARAC3"
290 DISA X(J,0),X(J,1)
300 I=I-5
310 DISP "Decrement IN H2O by 5
    IN to ";I
320 IF J=0 THEN 340
330 PAUSE
340 NEXT J
350 DISP "  P      V"
360 DISP "inH2O voltage"
370 MAT DISP X;
380 DISP "HARD COPY(1=yes 2=no)"
390 INPUT N
400 IF N#1 THEN 440
410 PRINT "  P      V"
420 PRINT "inH2O voltage"

```

TABLE C-I. SAMPLE CALIBRATION PROGRAM

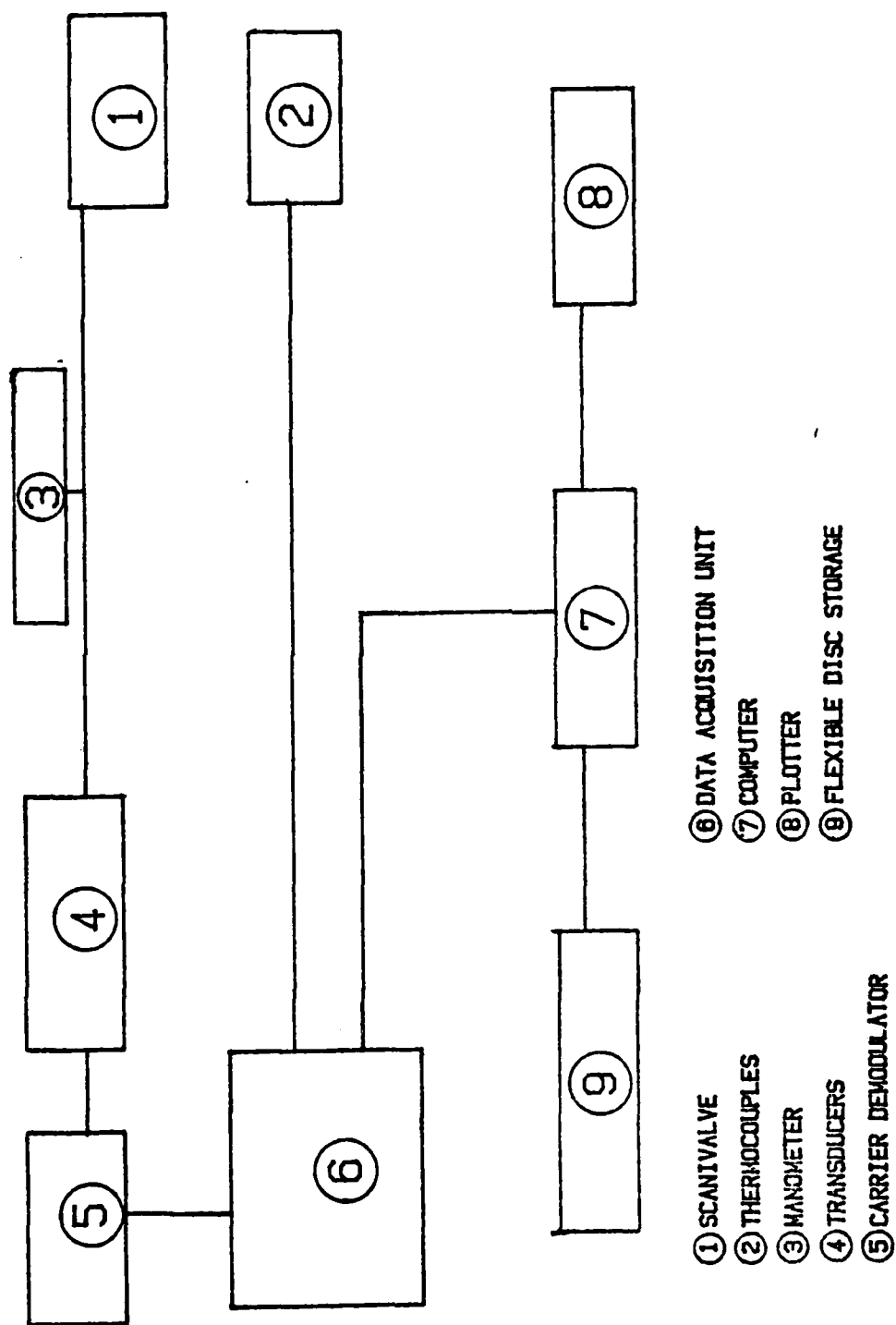


FIGURE C-1. SCHEMATIC OF DATA ACQUISITION SYSTEM

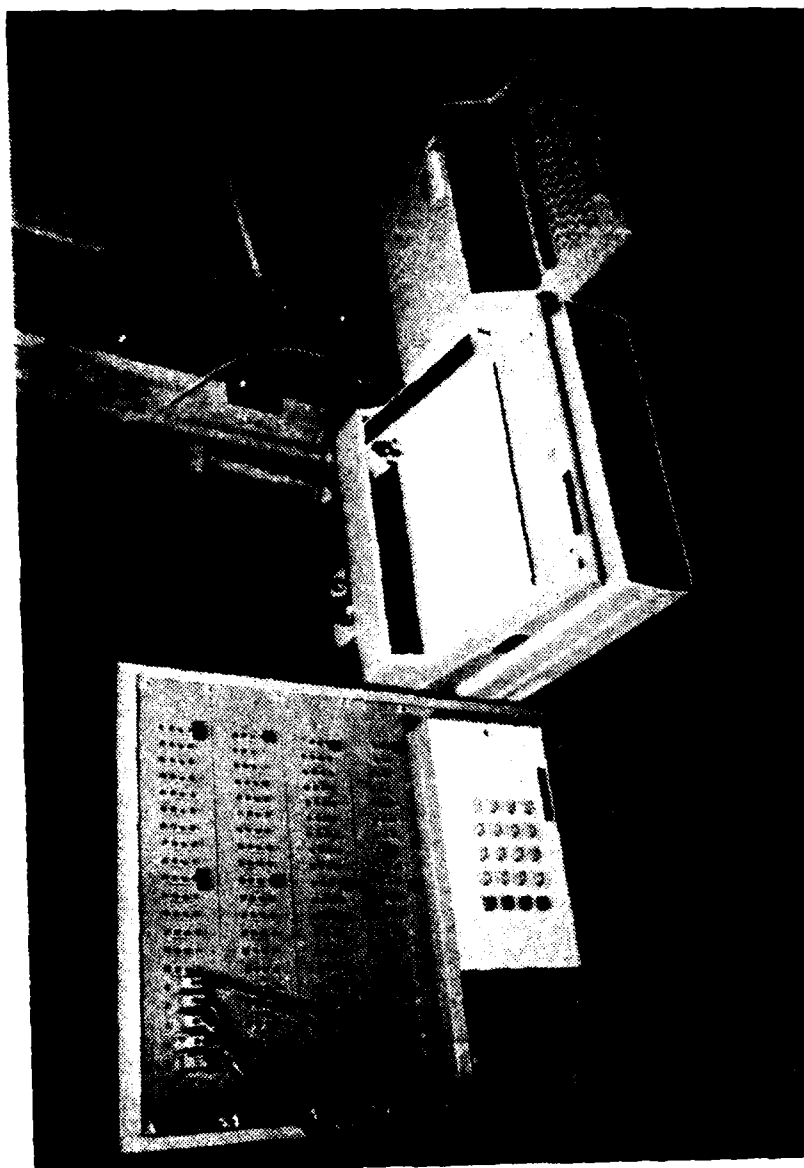


FIGURE C-IIa. ILLUSTRATION OF DATA ACQUISITION SYSTEM



FIGURE C-IIb. ILLUSTRATION OF DATA ACQUISITION SYSTEM

APPENDIX: D

UNCERTAINTY ANALYSIS

The determination of the uncertainties in the experimentally determined pressure coefficients, pumping coefficients, and velocity profiles was made using the method described by Kline and McClintock [6]. The uncertainties obtained by Ellin [1] using the second order equation suggested by Kline and McClintock [6] are all applicable to the experimental work reported herein and are summarized in the following table.

TABLE XIV

UNCERTAINTY IN MEASURED VALUES

T_s	$\pm 1 \text{ R}$
T_p	$\pm 1 \text{ R}$
P_a	$\pm 0.01 \text{ psia}$
ΔP	$\pm 0.01 \text{ in. H}_2\text{O}$
P_v	$\pm 0.01 \text{ in. H}_2\text{O}$
P_u	$\pm 0.05 \text{ in. H}_2\text{O}$
$\Delta P_s (+)$	$\pm 0.01 \text{ in. H}_2\text{O}$
$\Delta P_t (**)$	$\pm 0.01 \text{ in. H}_2\text{O}$
P_{or}	$\pm 0.01 \text{ in. H}_2\text{O}$
ΔP_{or}	$\pm 0.20 \text{ in. H}_2\text{O}$

T_{or}	$\pm 1 R$
T_a	$\pm 1 R$
PT (+++)	$\pm 0.1 \text{ in. H}_2\text{O}$

UNCERTAINTY IN CALCULATED VALUES

$\frac{AP^*}{T^*}$	1.9%
$W^*T^{*0.44}$	1.4%
V/V_{avg}	2.5%

- (+) The pressure differential across the secondary flow nozzles, P_s , is the major source of uncertainty in the pumping coefficient.
- (++) The pressure differential across the tertiary flow nozzles, P_t , is the major source of uncertainty in the pumping coefficient.
- (+++)
- The measurement of the total pressure for the velocity profile is the major source of uncertainty in the velocity calculation.

INITIAL DISTRIBUTION LIST

	No. Copies
1. Defense Technical Information Center Cameron Station Alexandria, Virginia 22314	2
2. Library, Code 0142 Naval Postgraduate School Monterey, California 93940	2
3. Department Chairman, Code 69 Department of Mechanical Engineering Naval Postgraduate School Monterey, California 93940	2
4. Professor Paul F. Pucci, Code 69Pc Department of Mechanical Engineering Naval Postgraduate School Monterey, California 93940	5
5. LT Charles R. Ellin 13512 Westwind Drive Silver Spring, Maryland 20904	1
6. Mr. Charles Miller NAVSEA Code 0331 Naval Ship Systems Command Washington, D.C. 20362	1
7. Mr. Olin M. Pearcy NSRDC Code 2833 Naval Ship Research and Development Center Annapolis, Maryland 21402	1
8. Mr. Mark Goldberg NSRDC Code 2833 Naval Ship Research and Development Center Annapolis, Maryland 21402	1
9. Mr. Eugene P. Wienert Head, Combined Power and Gas Turbine Branch Naval Ship Engineering Center Philadelphia, Pennsylvania 19112	1

- | | | |
|-----|---|---|
| 10. | Mr. Donald N. McCallum
NAVSEC Code 6136
Naval Ship Engineering Center
Washington, D.C. 21362 | 1 |
| 11. | LT J.P. Harrell, Jr., USN
2004 Cloverleaf Place
Ardmore, Oklahoma 73401 | 1 |
| 12. | LT J.A. Hill
Route 2, Box 61
Wood River, Nebraska 68883 | 1 |
| 13. | LT C.M. Moss
625 Midway Road
Powder Springs, Georgia 30073 | 1 |
| 14. | LT R.J. Lemke
2902 No. Cheyenne
Tacoma, Washington 98407 | 1 |
| 15. | LCDR D.L. Ryan III
6393 Caminito Luisito
San Diego, California 92111 | 2 |
| 16. | LT. R.S. Shaw
147 Wampee Curve
Summerville, South Carolina 29483 | 1 |
| 17. | LT. C.P. Staehli
Route 2, Box 64B
Burton, Washington 98013 | 1 |
| 18. | LT. D. Welch
1036 Brestwick Commons
Virginia Beach, Virginia | 1 |
| 19. | Dean of Research, Code 012
Naval Postgraduate School
Monterey, California 93940 | 1 |

END

DATE
FILMED

10-81

DTIC