AEROJET
GENERAL TIRE
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REPORT NO. RN-S-0099
TO
AEC-NASA SPACE NUCLEAR PROPULSION OFFICE

PERFORMANCE CHARACTERISTICS OF ETS-1 NUCLEAR EXHAUST SYSTEM

ROCKET ENGINE OPERATIONS — NUCLEAR

NERVA PROGRAM JUNE 1964 CONTRACT SNP-1

AEROJET-GENERAL CORPORATION
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

ABSTRACT

This report presents the test results of the ejector scale model test program of Contract Year 1963 and 1964 as they apply to the full scale Engine Test Stand-1 (ETS-1). The purpose of this evaluation was to determine the performance envelope for the selected subsonic turn ejector system in the Nuclear Exhaust System (NES) for the ETS-1. The experimental tests were conducted on 1/8 scale models. The analytical and experimental results, and the evaluation of the sub-scale model tests performed during Contract Year 1963, are presented in REON Report No. 2679. The work performed during Contract Year 1964 will be presented in detail at the conclusion of the Contract Year. As a result of the data obtained through this experimental and analytical evaluation, the design implications for the NES for ETS-1 have been drawn.

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FOREWORD

This report is presented in partial fulfillment of SNP-1 Contract Task Item 3.1.3 which states in part: "Provide the engineering effort to plan, conduct and analyze data from the scale model tests to define the (NES) ETS-1 performance envelope."

CONTENTS

CONTENTS (cont.)

CONTENTS (cont.)

I. INTRODUCTION

This report is a presentation of the results of the ejector scale model test program of Contract Year 1963 and 1964, as they apply to the full scale Engine Test Stand Number 1 (ETS-1) ejector design. The purpose of the test program was to define the engine compartment conditions for test planning and operation of the ETS-1 Nuclear Exhaust System (NES). The test results and analyses pertinent to the NES were incorporated into the preliminary design and integrated within the design schedule. The ETS-1 NES operating map with the two nozzles presently being considered, AGC (ϵ = 10:1) and RN-6 (ϵ = 12:1), is presented.

This report is one of four reports which define the operation, performance and handling of the ETS-1 NES. The other reports are:

(1) Use and Operational Analysis for NES

(2) Malfunction Analysis for NES

(3) Assembly and Installation Plan of NES Duct at ETS-1, REON Report RN-S-0097

II. EJECTOR CONFIGURATION

Figure 1 shows the ejector configuration tested. The ejector system consists of an entrance cone (to station 52.3), a second throat (to station 364.3), a subsonic diffuser (to station 468.1), a 90° elbow, a contraction section, and a secondary safety purge system. The purpose of the secondary safety purge system is to act as an aerodynamic check valve in case of an engine malfunction. Certain types of malfunctions would cause an instantaneous stoppage of propellant to the engine which would result in a large pressure differential between the atmosphere and the engine compartment. The pressure differential would cause a flow of air into the ejector, resulting in engine-compartment seal separation and an explosive hydrogen air mixture in the ejector. The steam flow from the secondary safety purge system prevents this from happening.

The nozzles tested and reported herein are the 10:1 conical Aerojet nozzle and the 12:1 contoured RN-6 Rocketdyne nozzle. The shape and location of the tested and recommended turbine exhaust nozzles are shown in Figure 2.

The dimensions and tolerances concerned with the location of the XE-1 engine with respect to the ETS-1 duct entrance are:

1. Nozzle exit plane to duct entrance plane
   9" ± 1" at minimum distance between planes (consistent with 9" plug shield clearance)

2. Nozzle centerline lateral misalignment at nozzle exit plane
   ± 1" from duct entrance centerline

3. Nozzle centerline angularity misalignment
   ± 1° at the nozzle exit plane providing tolerance No. 2 is not exceeded

The maximum misalignment of the Engine/Test Stand Thrust Structure Interface (located approximately 26' - 6" above the vault floor) with respect to the duct centerline.

4. Centerline lateral misalignment
   ± 1"

5. Centerline angularity misalignment
   ± 0° 30'

It should be noted that the maximum misalignment of the Engine/Test Stand Thrust Structure interface would lead to a misalignment at the nozzle exit plane greater than the $\pm$ 1" from the duct centerline as specified in No. 2 above. This can be corrected by gimballing the engine prior to testing such that the nozzle exit centerline does not misalign with the duct entrance centerline by more than 1".

III. EXPECTED FULL SCALE PERFORMANCE

A. AERODYNAMIC

1. Engine Compartment Pressure

The expected engine compartment pressure when testing the 10:1 area ratio, conical NERVA nozzle in the Nuclear Exhaust System at ETS-1 is shown in Figure 3. Figure 4 shows the expected engine compartment pressure when testing the 12:1 area ratio, contoured Rocketdyne (RN-6) nozzle.

2. Wall Pressures and Mach Numbers

The internal wall pressure profiles are illustrated in the graphs in Figure 5 through 8. The internal Mach numbers, based on the pressure profiles and one dimensional flow, are given in Figures 9 through 12. The location of these pressures is shown in Figure 13.

3. Off-Design Turbine Exhaust and Seal Leakage Flow

The effect of various turbine exhaust and seal leakage flow rates on the nozzle exit and the engine compartment pressures are shown in Figures 14 through 21. The seal leakage and turbine exhaust flow rates needed to cause flow separation in the nozzle are well above the expected 1.5 lbs/sec of N_2 seal leakage and the previously reported values of turbine flow rate. It should be emphasized that flow rates greater than those expected increase the engine compartment pressure and should be avoided.

B. HEAT TRANSFER

The full-scale coolant passage configuration was determined after evaluation of the sub-scale test results, fabrication techniques and stress considerations. The coolant passage configuration and the coolant flow conditions are shown in Figure 22.

The gas-side heat transfer coefficient, heat flux, gas-side wall temperature, wall temperature change, liquid-side heat transfer coefficient and coolant bulk temperature vs duct station are shown in Figure 23 through 28, respectively. The test data obtained from the impingement side of the ejector were assumed to apply completely around the ejector and were used to obtain the information presented.

The design heat transfer condition for the hot side of the duct was based on the NERVA engine operating conditions. In addition, an engine malfunction condition producing higher heat flux was considered. This condition was caused by the reactor core break-up with resulting high thermally radiating materials traversing the duct. The heat was transferred to the duct by radiation in addition to the convective heat transfer from the gases. The heat transferred by radiation during this malfunction condition was assumed to be the maximum obtainable, i.e., blackbody radiation emissivity factor, and all radiant energy emitted falling on the inside surface of the duct.

C. SAFETY PURGE

The ejector system must, at all times, exhaust the hydrogen gas so that it may be safely disposed of by burning. Air must not be allowed to mix with the hydrogen inside the duct. While the engine is running, the primary ejector accomplishes this, and prior to start-up the air is replaced by nitrogen from the pre-fire ejector purge system located in the environmental cell. During engine cooldown with hydrogen, the steam flow is maintained to preclude the air.

A major malfunction such as main propellant line rupture or a turbine seizure could cause an instantaneous cessation of flow to the engine, and in turn collapse the established shock structure in the duct. Upon collapse of the shock structure, a large pressure differential exists between the engine compartment ($P_v \leq 3$ psia) and the atmosphere (P_a = 12.8 psia at NTO). This pressure gradient would force in air, mix it with the residual hydrogen in the duct, and create an explosive mixture. This surge of gas would also cause overpressurization of the engine compartment and separate the side shields. A secondary purge system is provided whereby an annular nozzle is mounted at the end of the contraction cone aft of the elbow to introduce the safety purge field. This inert fluid will fill the engine compartment and prevent air from entering the ejector in the event of a malfunction as described.

The required secondary safety purge fluid for the ejector system is primarily steam with the following properties:

Ratio of specific heats	1.25
Molecular weight	20.2
Nozzle stagnation pressure	100 psia
Nozzle stagnation temperature	$1650^{\circ}R$
Flow Rate	120 lb/sec
Nozzle throat area	119 $in.^2$

The secondary safety purge flow rate is equal to the sum of the choked flow rate (97 lb/sec) required to fill the engine compartment without allowing air to enter the ejector in the event of an instantaneous termination of the reactor working fluid, and the flow rate (23 lb/sec) required to prevent penetration of 35 mph air into the ejector (see Section IV,C).

It should be emphasized that the safety purge chamber pressures, or flow rates greater than, or temperatures lower than those required increase the starting pressure of the ejector system as illustrated in Figure 29.

The effect of off-design safety purge on the starting pressures of the ejector is shown in Figure 29.

D. PRE-FIRE PURGE

The engine compartment and the ejector must be purged with an inert gas prior to operation. The purge gas should be introduced through many orifices located at the top of the engine compartment and at points where air could possibly be trapped. It is recommended that the purging process take place over at least a 100 second period to allow thorough mixing to take place. A checkout run at NTS to determine the O_2 content in different locations (corners, thrust structure, etc.) in the engine compartment as a function of pre-fire purge flow duration, is required for safety considerations. The safe O_2 content is 4% or less by volume.

E. EXHAUST PLUME

The predicted exhaust plume size and shape, based on test data as well as analysis, is illustrated in Figure 30 and the predicted thermal radiation from this exhaust plume is illustrated in Figure 31.

Temperature rise-time data were calculated for the concrete floor below the exhaust plume, Figure 32, and the aluminum radiation shield on the vault door, Figures 33 and 34. Temperature rise-time information can be obtained for various locations by using the data present in Figures 32, 33 and 34. The validity of the mathematical model used for these predictions is currently being checked with Kiwi test data.

IV. METHOD AND CONFIDENCE OF PREDICTIONS

A. AERODYNAMIC

The aerodynamic performance, pressure profile, and local Mach numbers, of the full scale duct will be essentially the same as those obtained from the sub-scale model because of the independence of scale size (boundary layer is small with respect to physical dimensions of scale model), working fluid (the ratio of specific heats are the same) and total temperature on the pressure and Mach number.

An analytical model to predict nozzle separation as a function of turbine exhaust flow rate and seal leakage flow rate was not verified by the test data. Therefore, to increase the low level of confidence in scaling the phenomena, all full scale parameters (such as temperatures, molecular weights, chamber pressures, and ratio of flow rates), were duplicated where possible. If it was not possible to duplicate a specific flow parameter, it was assumed to be a conservative value.

B. HEAT TRANSFER

Conversion of the scale model heat transfer coefficient data to the full-scale condition required that a correlation be developed to interpret the test data. Since the local Mach number and mass flow rate vary considerably along the ejector wall, it was not possible to obtain a direct correlation of the test data. Instead, the test data were converted to a form where a comparison could be made between the test data, and a turbulent pipe flow correlation, based on the assumption that the shock structure in the ejector remained fixed.

Thus, it was assumed that the local mass-flow rates throughout the ejector would vary as chamber pressure to the 0.8 power and a plot of $h_r/P_c^{0.8}$ should form a single curve. Figure 35 provides the normalized heat transfer data for the impingement side as a function of L/D of the primary ejector. The normalized test data spread (3σ) was found to be $\pm$ 25% for the tests run with heated nitrogen and indicated good agreement with turbulent pipe flow correlation theory.

When using hydrogen gas as the test fluid the test data show reasonably good agreement with the nitrogen data as shown in Figure 35.

The conversion of the scale model heat transfer coefficients to full scale values is the same as previously reported.[1]

The heat transfer tests were run with an ejector system having a primary ejector exit diameter 92% of that shown in Figure 1. Enlarging the primary ejector exit diameter 8% will not appreciably affect the shock system upstream of the expansion section and does not affect the pressure and mass distribution in the elbow at steady state chamber conditions; therefore, the heating rates will not change significantly.

C. SAFETY PURGE

Many safety purge tests were conducted, varying the different parameters, to check out the analysis. The safety purge fluid molecular weights tested were 2, 28, and 121 lb/mol and the fluid temperatures varied between 60 and 650°F. Other variables in the analysis were varied over similar ranges and the experimental data verified the analysis. The maximum deviation from the predicted values for 75% of the data was ± 10% and in no case did the deviation exceed ± 22%. The maximum deviation for the selected system is +11% and -22%. The majority of the data scatter is believed to be instrumentation and reading errors.

The scaled full-scale safety purge flow rate was increased by the amount calculated to prevent penetration into the ejector of a 35 mph gust of air occurring simultaneously with instantaneous termination of the reactor working fluid.

D. PRE-FIRE PURGE

The scale model experimental test results indicate that a safe oxygen content, less than 4% by volume, is obtained by purging with approximately 1.5 ejector system (including engine compartment) volumes of nitrogen. This amounts to approximately 1000 lb of nitrogen if the ejector system volume pressure is at one atmosphere. Because of the strong dependence of purge nozzle locations and orientations on reducing the oxygen content in semi-isolated areas, it is recommended that serious consideration be given to the location and orientation of these nozzles. A checkout run at NTS to determine the oxygen content in various locations in the engine compartment (corners, thrust structure, and other semi-isolated areas), as a function

[1] AGC Report No. 2403 - Evaluation Report, 90° Turn Ejectors for Engine Test Stand-1, November 1962.

of pre-fire purge flow duration, is required for safety considerations. Since safe operation of the ejector system must be assured, a safety factor of at least 2 is recommended in the amount of nitrogen used for purging.

E. EXHAUST PLUME

1. Exhaust Plume Shape

One part of the analyses to determine the thermal radiation from the hydrogen exhaust flame is to establish a model to predict the flame shape. Hawthorne, Weddell, and Hottel have developed a model in which flame length is derived by applying the laws of conservation of mass and momentum and an equation of state along with the assumption that the flame shape is an inverted right circular cone (i.e., the angle spread of the flame is a constant). The model is described and the equations are given in REON Report 2678.

An estimate of flame length was made from motion pictures and still photos taken of the hydrogen flame from the scale model system, indicating a flame length of 85 and 75 duct exit diameters respectively. Equation (4) of REON Report 2678 predicts a flame length of 93.7 duct exit diameters for the conditions under which the test was conducted. The estimate of the flame length from the movies is subject to a higher degree of error and should not be viewed as experimental substantiation of the model but at the same time, the degree of agreement between calculated and measured flame length is encouraging. Since the flame length is predicted in terms of duct exit diameters, the value of flame length predicted by the above cited Equation (4) applied to the full scale system.

2. Exhaust Plume Thermal Radiation

As a high temperature gas mixture, the exhaust plume is a source of thermal radiation. It is important to determine the magnitude of this thermal radiation in order to ascertain the thermal environment of the exhaust duct and that of any hardware and structure associated with its operation.

Two groups of tests were conducted. One group was conducted without secondary safety-purge. The emittance of the flame at a length of 47 secondary duct exit diameters was 12.4 Btu/ft^2 sec and the flame temperature was approximately 2700°R. Water* was introduced into the nitrogen safety-purge fluid for the second group of tests. The water turned to steam, which resulted in a higher emissivity of the flame. The emittance of the flame for these tests was 13.3 Btu/ft^2 sec measured at a length of 47 secondary duct exit diameters and 5.3 Btu/ft^2 sec measured at a length of 9.4 secondary duct exit diameters and the flame temperature was approximately 2700°R.

The flame emittance was measured at two locations during sub-scale testing; this analysis assumed the emittance to vary linearly along the plume centerline in accordance with these two measurements. The measured subscale and calculated full-scale flame temperatures were 2700°R and 3900°R respectively. Since thermal radiation is proportional to the fourth power of the absolute temperature of the radiation source, a correction multiplication factor $C_f = \left(\frac{3900}{2700}\right)^4 = 4.34$ was used to convert scale model flame emittance to full scale.

A more detailed description of the scaling method used is described in REON Report No. 2679.

It is recommended that during the first short duration tests, measurements of thermal radiation and metal wall temperature rise at points of interest be obtained. If the results indicate that cooling (or additional cooling) is required for full thrust-full duration firings, it would be known prior to possible damage of surrounding structures or surfaces.

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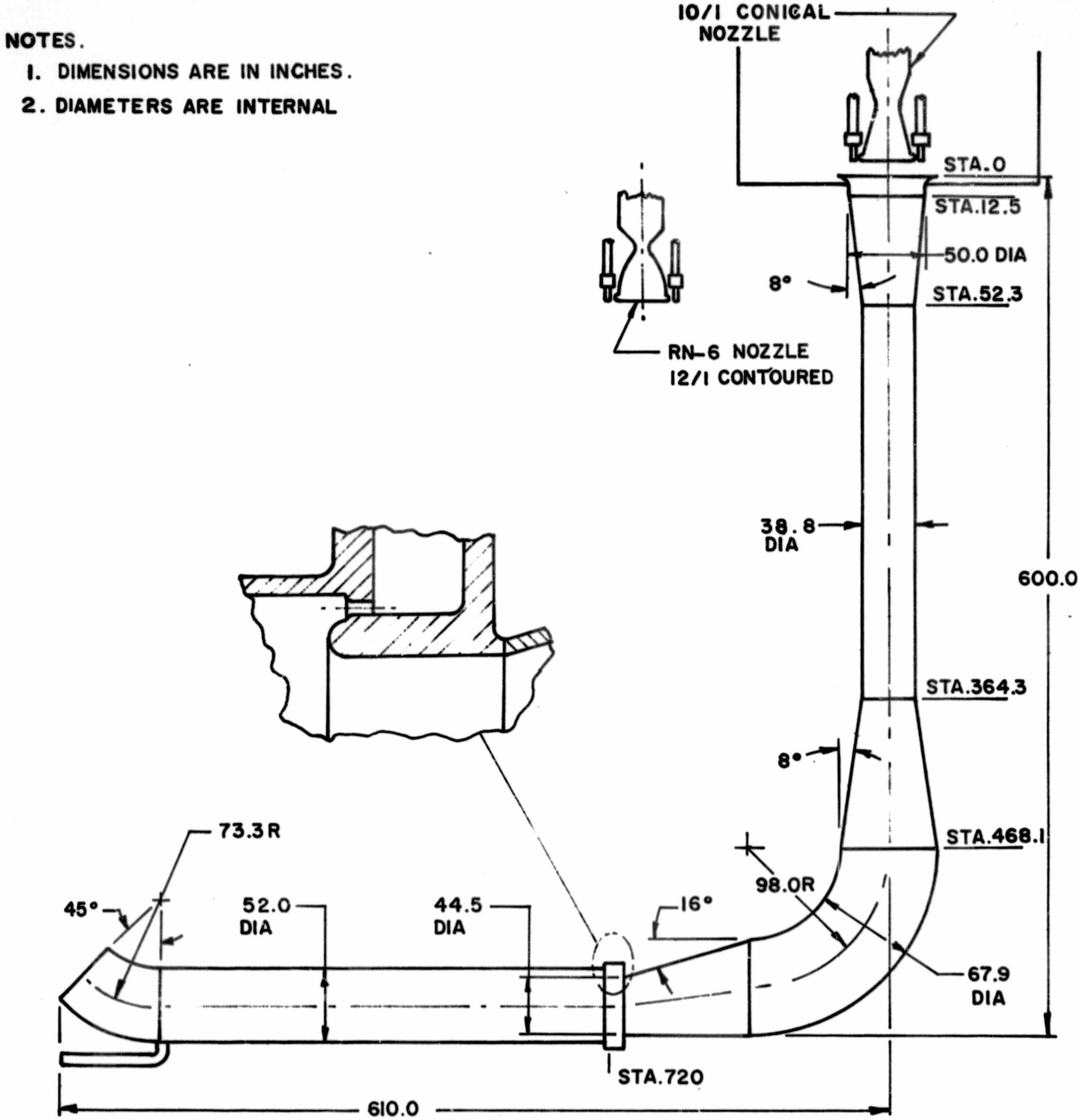
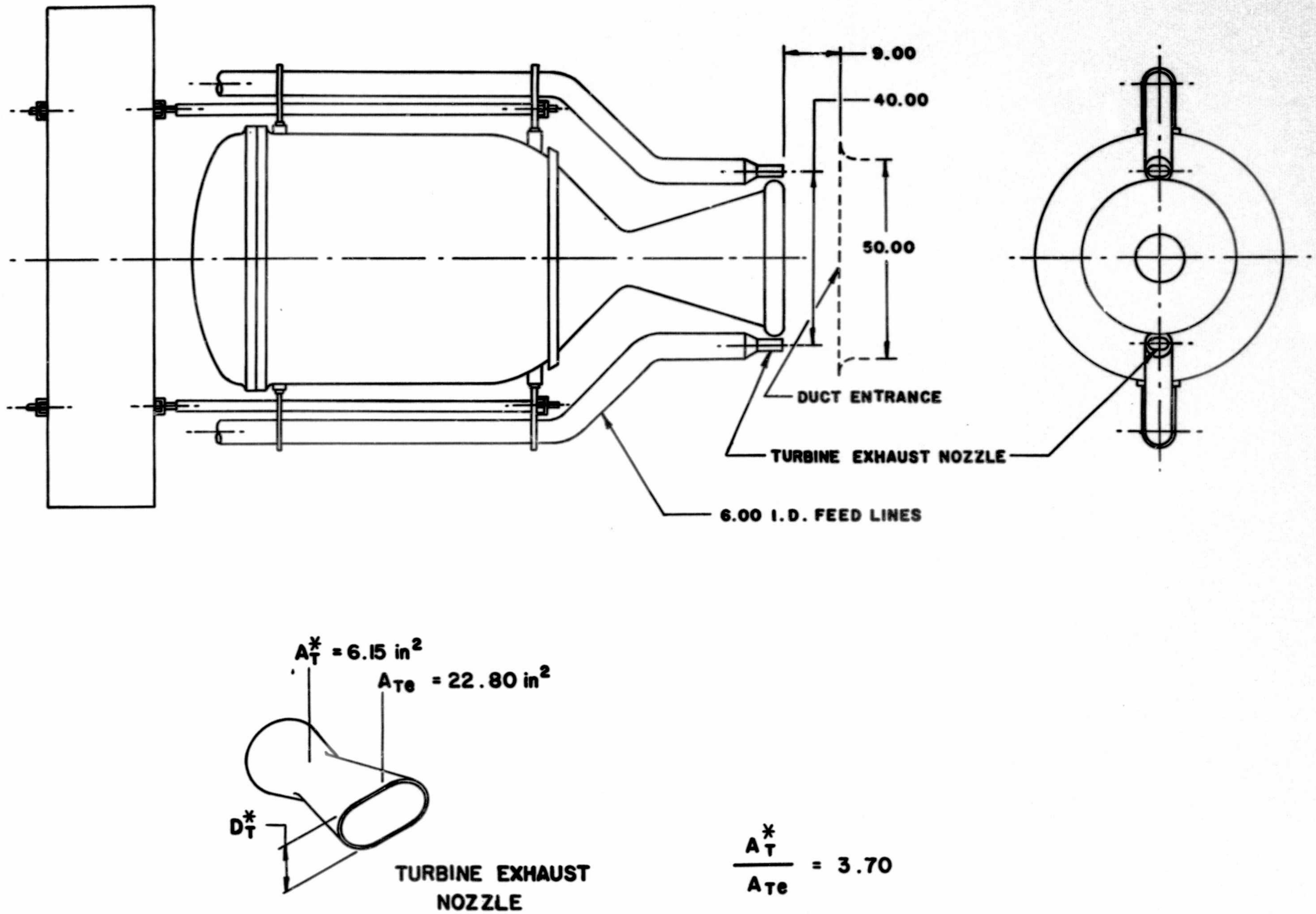
*The full scale safety purge will contain some carbon dioxide; analysis shows that the effect of this carbon dioxide upon thermal radiation is negligible.



NES Subsonic Turn Ejector System
For Use at ETS-1

Figure 1

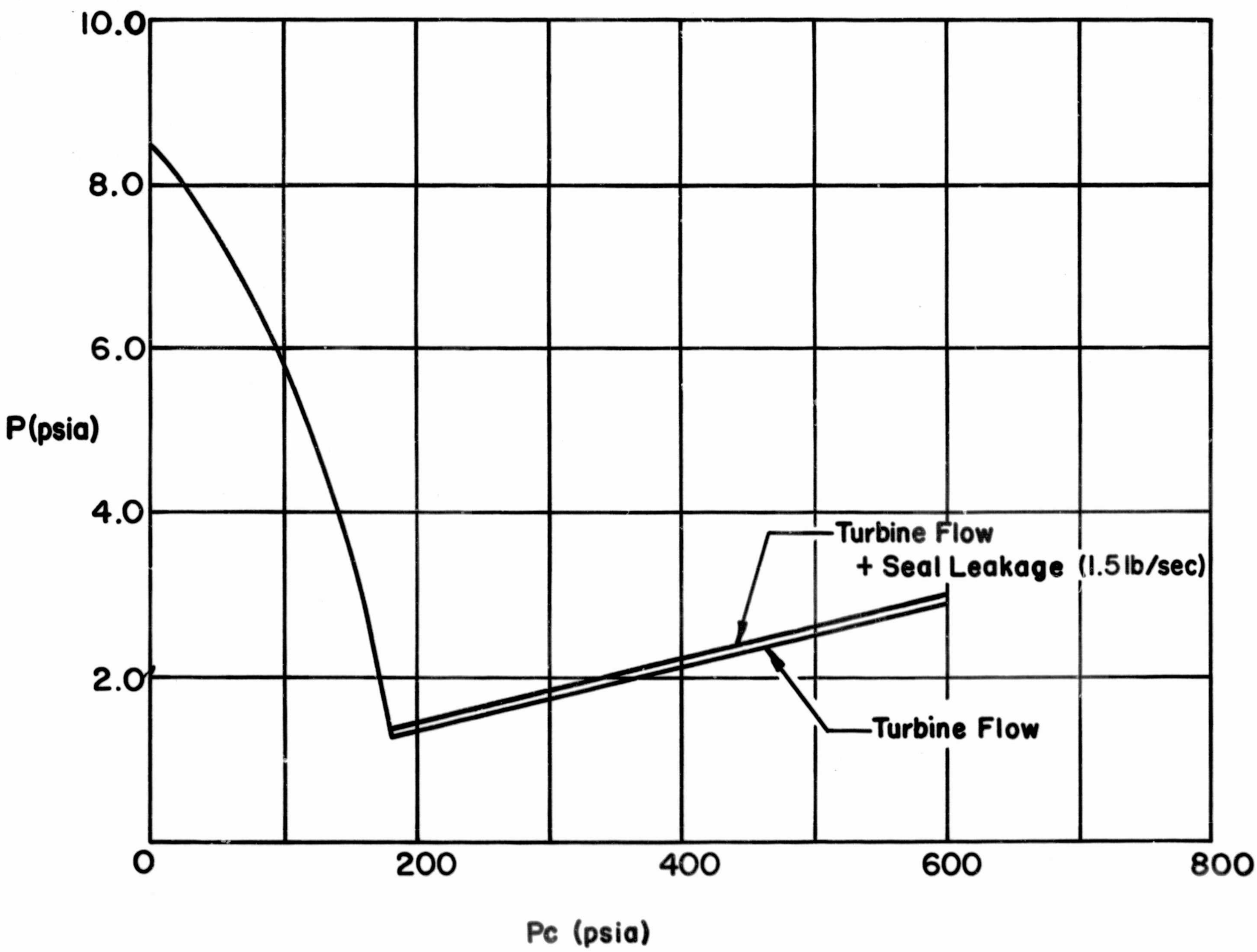


NOTE. Throat Dimensions Subject To Change.

PROPOSED TURBINE EXHAUST NOZZLES AND LOCATION

Figure 2.

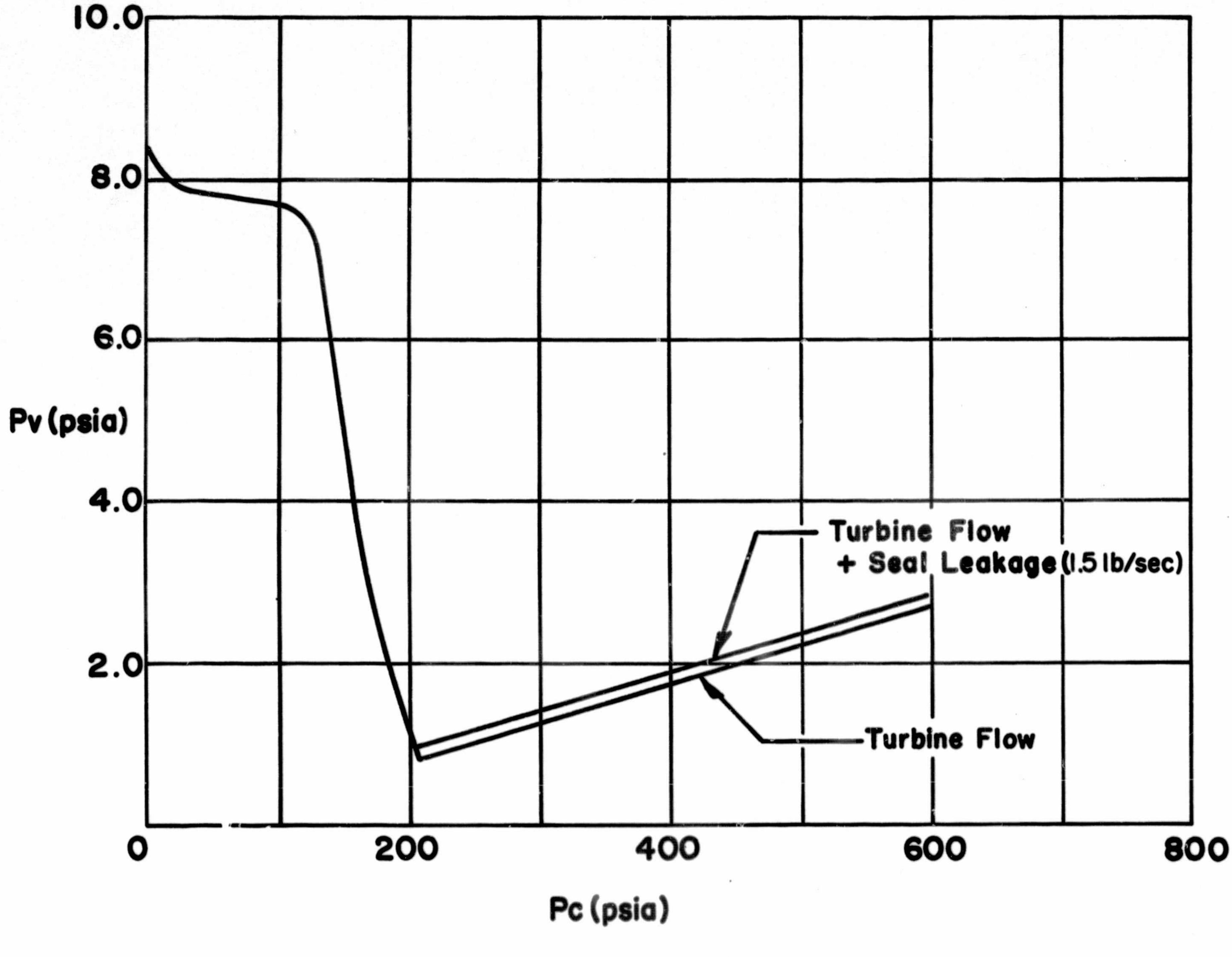
NOTES.
1. TURBINE EXHAUST FLOW AT ENGINE DESIGN VALUE
2. SAFETY PURGE – P_{sc} = 100 psia; T_{sc} = 1650° R ; $\dot{W}_s$ = 120 lb/sec
3. SEAL LEAKAGE FLOW – 1.5 lb/sec . amb. N_2.
4. P_a = 12.8 psia



ENGINE COMPARTMENT PRESSURE Pv, Vs 10/1 CONICAL NERVA NOZZLE CHAMBER Pc.

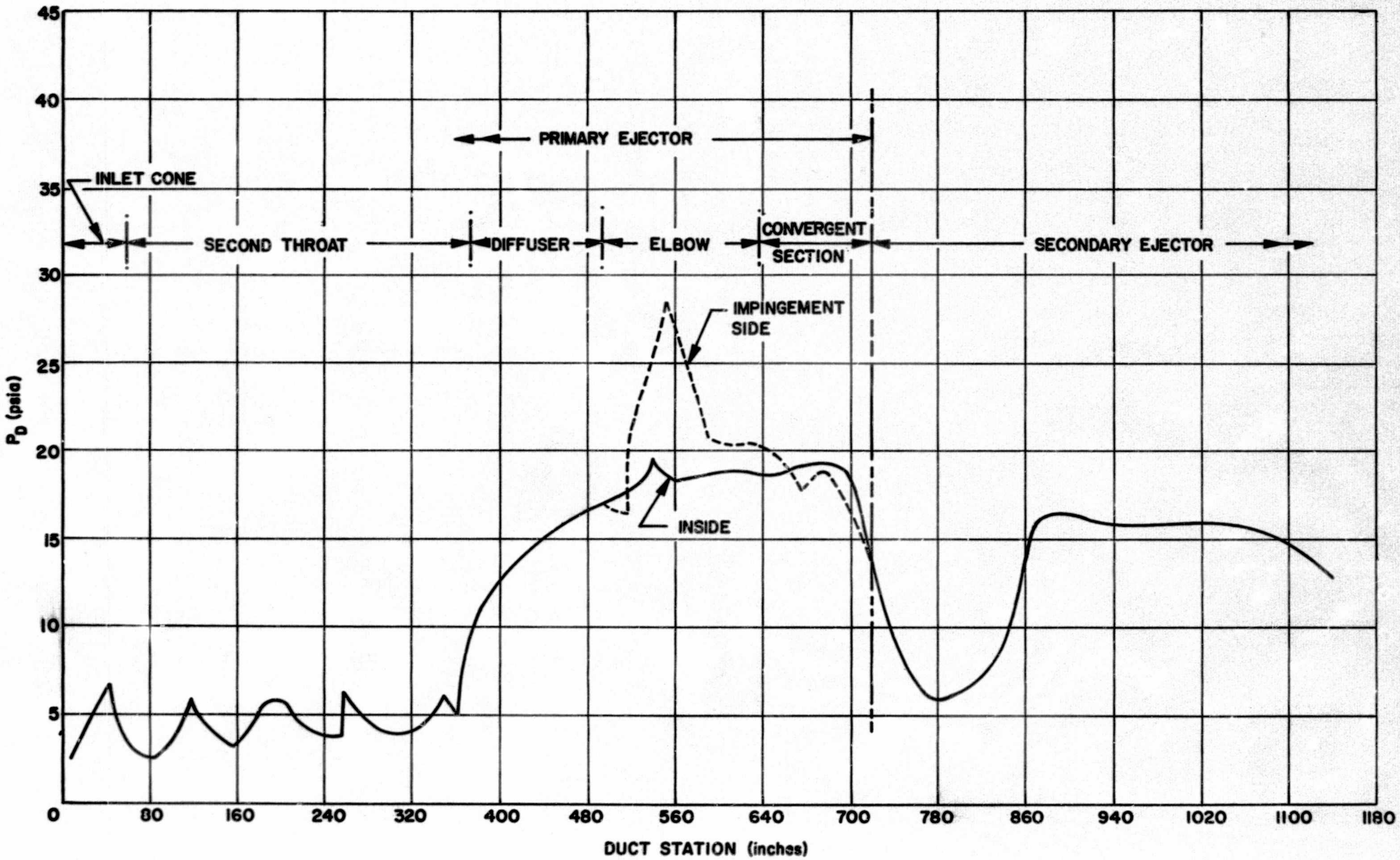
FIGURE 3

NOTES.
1. TURBINE EXHAUST FLOW AT ENGINE DESIGN VALUE
2. SAFETY PURGE – Psc = 100 psia; Tsc = 1650 °R.; $\dot{W}s$ = 120 lb/sec.
3. SEAL LEAKAGE FLOW – 1.5 lb/sec. amb. N_2.
4. Pa = 12.8 psia



ENGINE COMPARTMENT PRESSURE Pv, Vs 12/1 CONTOURED NOZZLE CHAMBER Pc.

FIGURE 4.



EJECTOR WALL PRESSURES WHEN TESTING THE 10/1 NOZZLE

100 % Pc

Figure 5.

EJECTOR WALL PRESSURES WHEN TESTING THE 10/1 NOZZLE
(40% Pc)

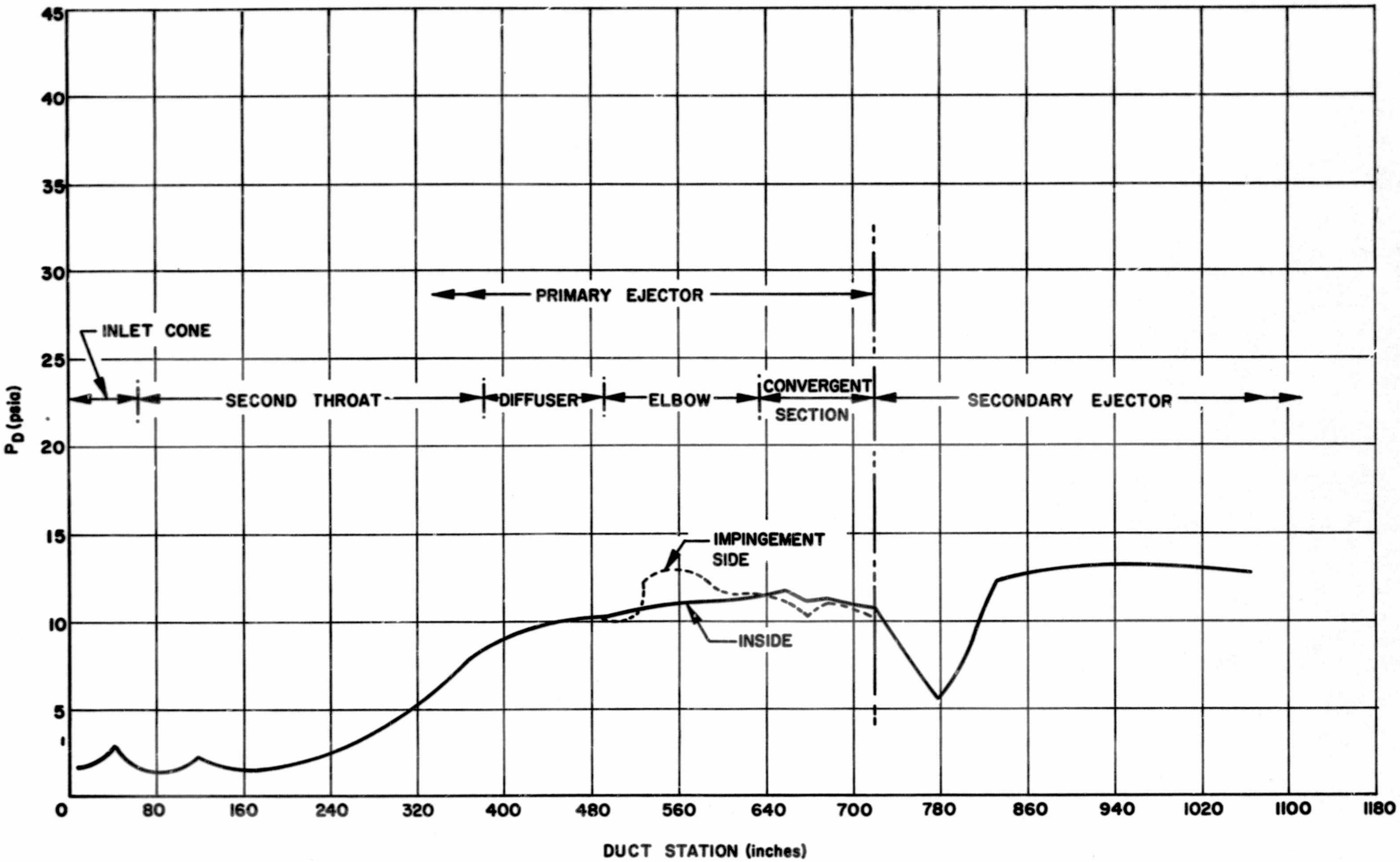


Figure 6.

EJECTOR WALL PRESSURES WHEN TESTING THE 12/1 NOZZLE

(100% Pc)

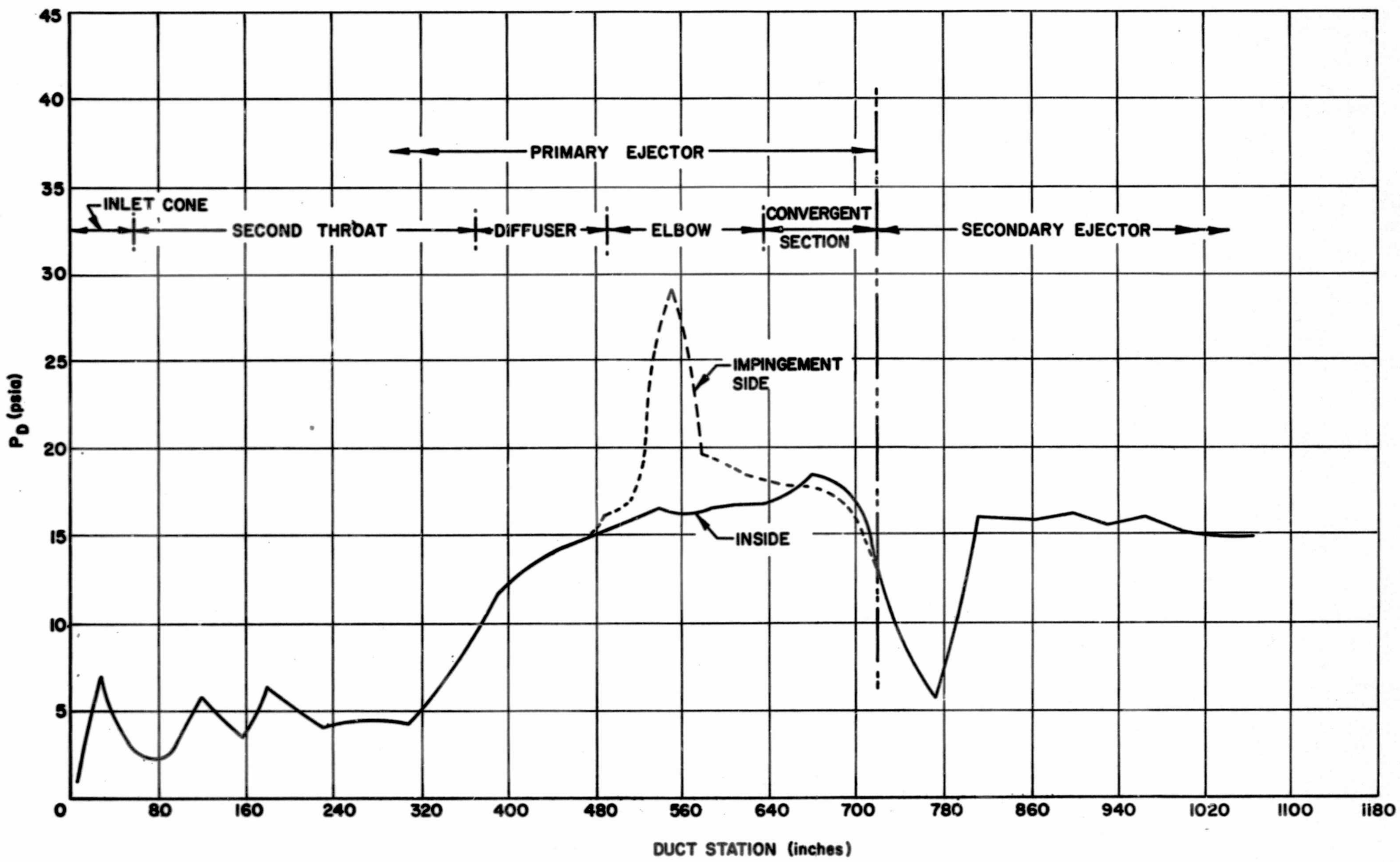
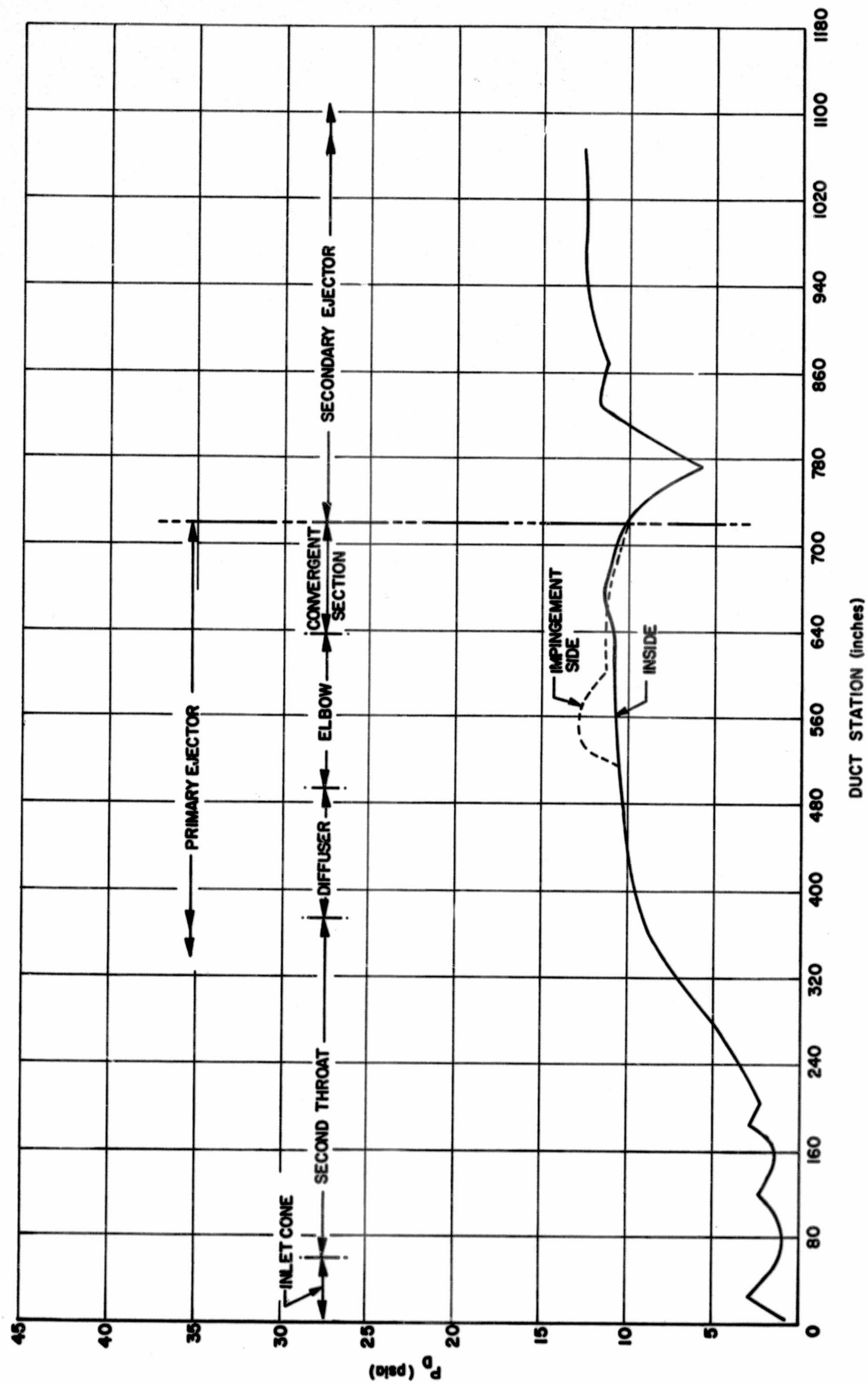
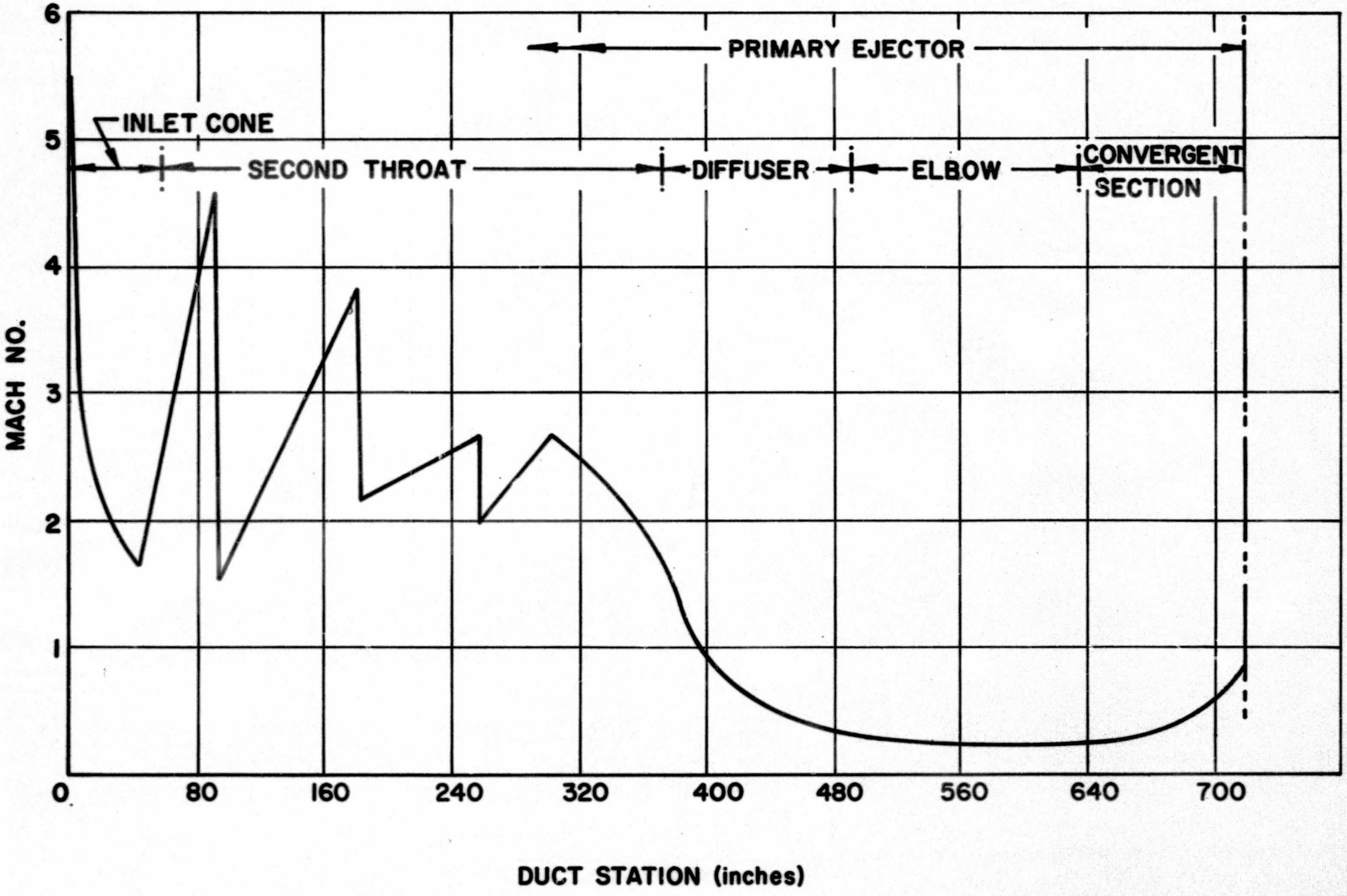


Figure 7.



EJECTOR WALL PRESSURES WHEN TESTING THE 12/1 NOZZLE (40% Pc)

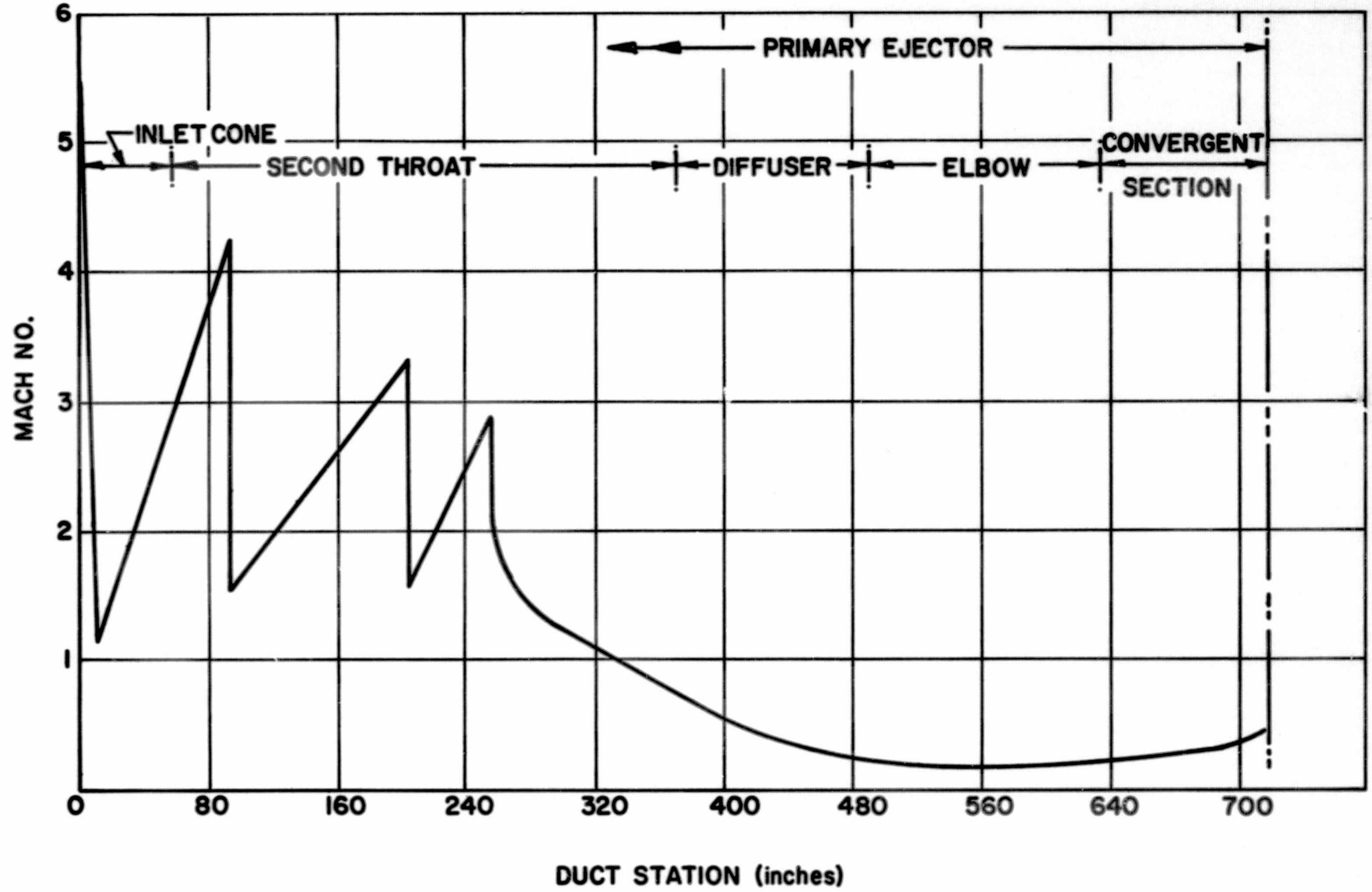
Figure 8.



MACH NUMBERS WHEN TESTING THE 10/1 NOZZLE

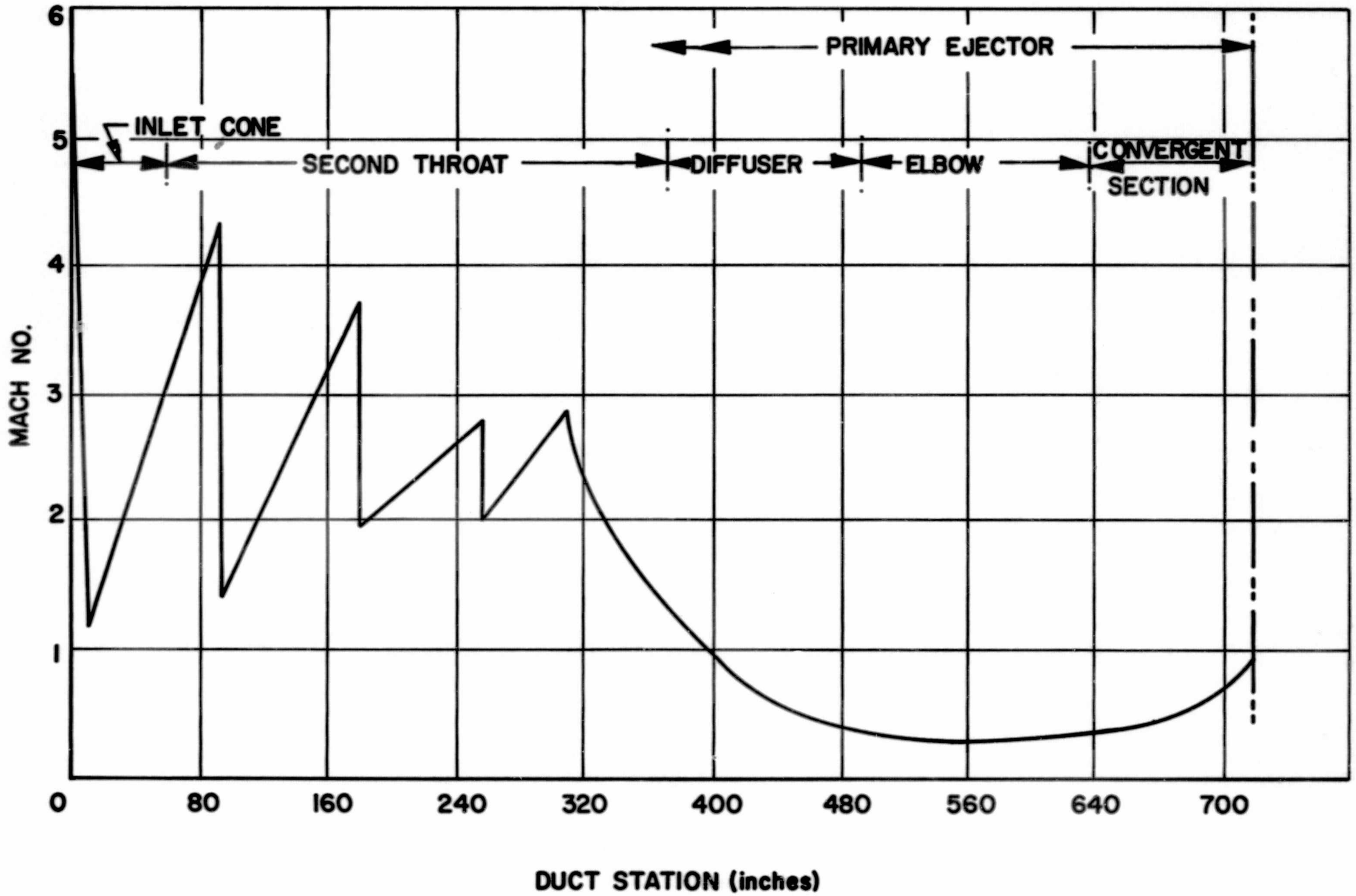
(100 % Pc)

Figure 9.



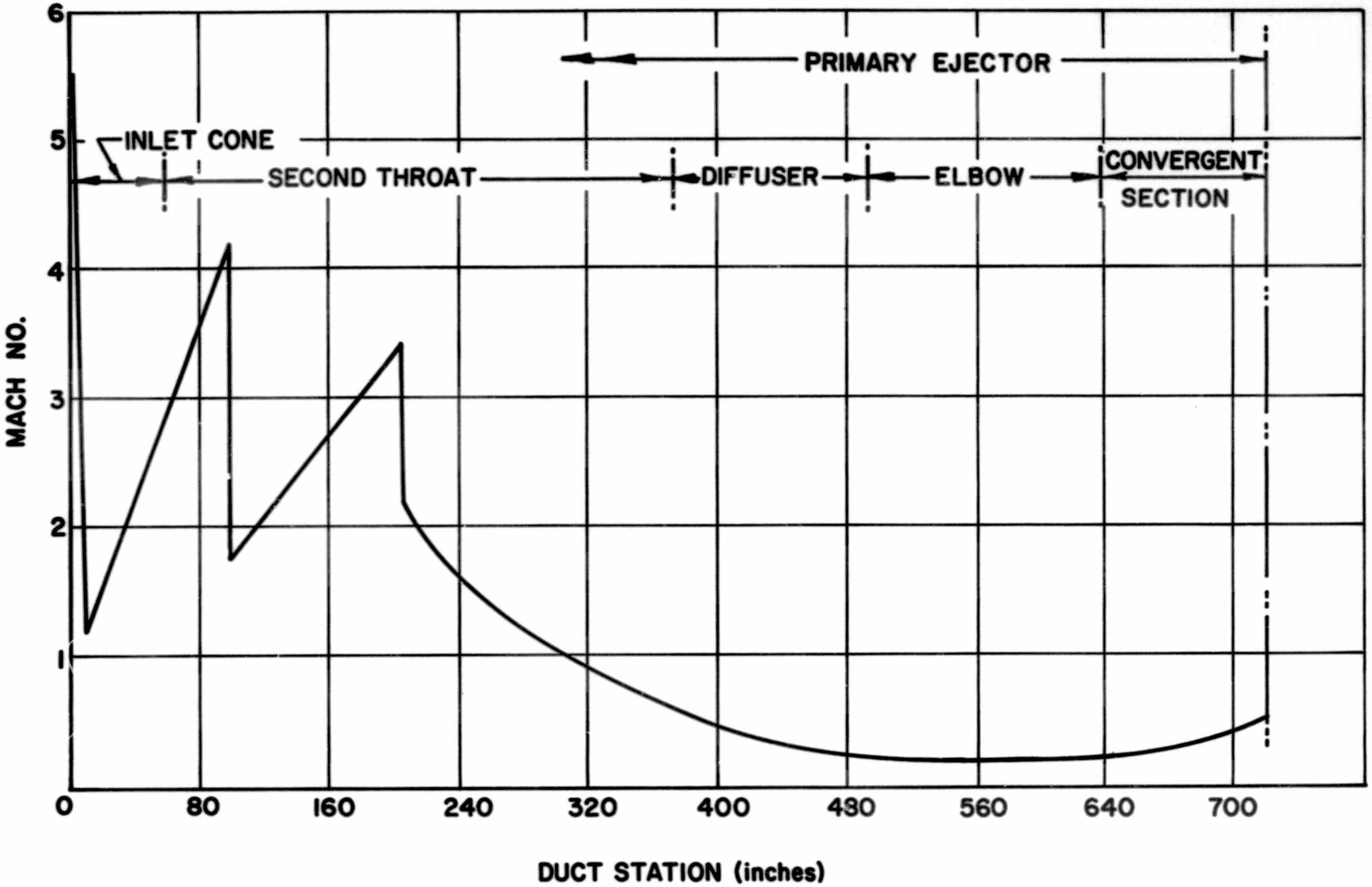
MACH NUMBERS WHEN TESTING THE 10/1 NOZZLE
(40% Pc)

Figure 10.



MACH NUMBERS WHEN TESTING THE 12/1 NOZZLE
(100% Pc)

Figure 11.



MACH NUMBERS WHEN TESTING THE 12/1 NOZZLE
(40% Pc)

Figure 12.

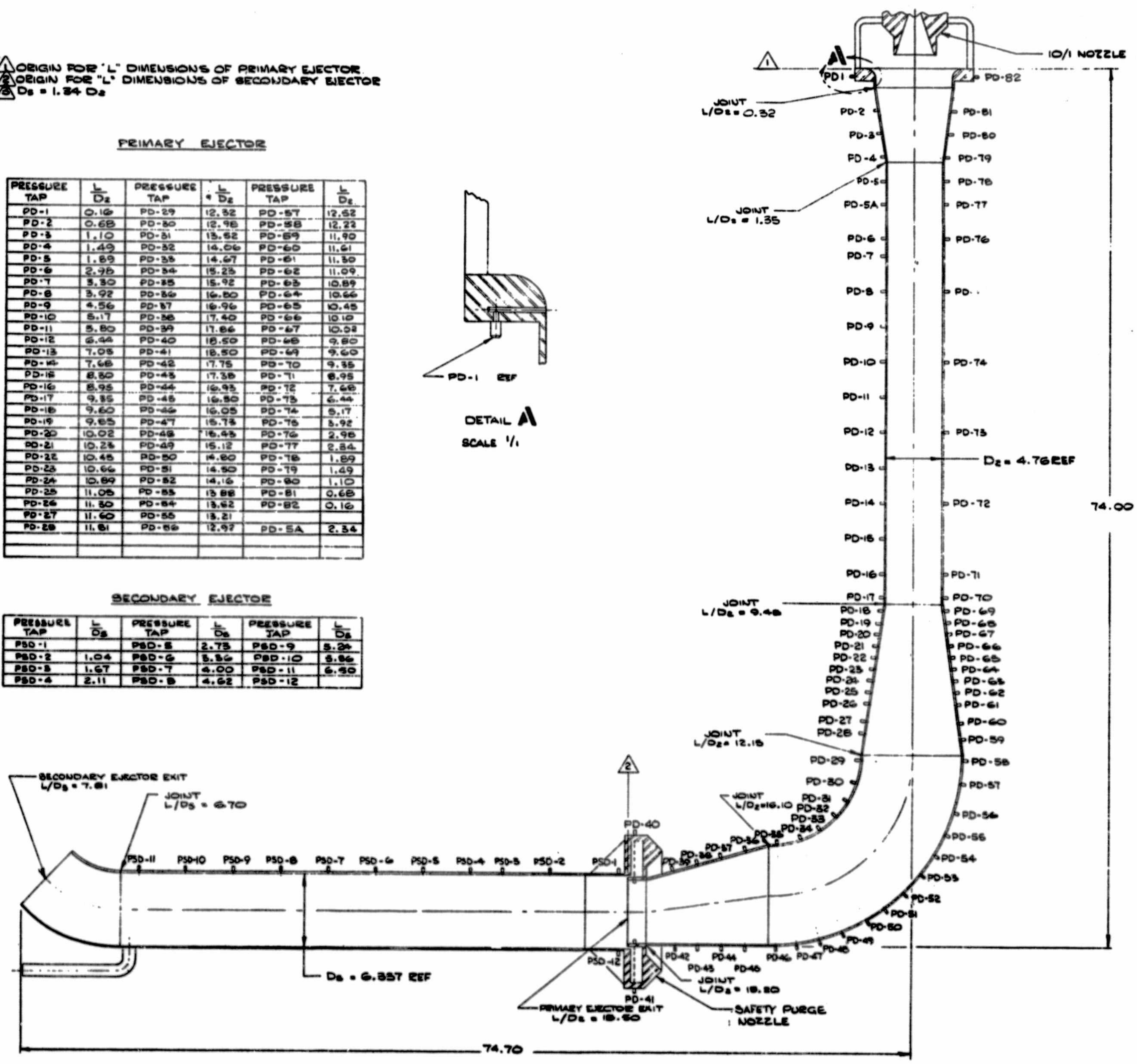
NOTES
1. ORIGIN FOR "L" DIMENSIONS OF PRIMARY EJECTOR.
2. ORIGIN FOR "L" DIMENSIONS OF SECONDARY EJECTOR
3. $D_3 = 1.34\ D_2$

PRIMARY EJECTOR

PRESSURE TAP	L/D_2	PRESSURE TAP	L/D_2	PRESSURE TAP	L/D_2
PD-1	0.16	PD-29	12.32	PD-57	12.52
PD-2	0.68	PD-30	12.96	PD-58	12.22
PD-3	1.10	PD-31	13.52	PD-59	11.90
PD-4	1.49	PD-32	14.06	PD-60	11.61
PD-5	1.89	PD-33	14.67	PD-61	11.30
PD-6	2.98	PD-34	15.23	PD-62	11.09
PD-7	3.30	PD-35	15.92	PD-63	10.89
PD-8	3.92	PD-36	16.80	PD-64	10.66
PD-9	4.56	PD-37	16.96	PD-65	10.45
PD-10	5.17	PD-38	17.40	PD-66	10.10
PD-11	5.80	PD-39	17.86	PD-67	10.02
PD-12	6.44	PD-40	18.50	PD-68	9.80
PD-13	7.08	PD-41	18.50	PD-69	9.60
PD-14	7.68	PD-42	17.75	PD-70	9.35
PD-15	8.80	PD-43	17.38	PD-71	8.95
PD-16	8.95	PD-44	16.93	PD-72	7.68
PD-17	9.35	PD-45	16.50	PD-73	6.44
PD-18	9.60	PD-46	16.05	PD-74	5.17
PD-19	9.85	PD-47	15.73	PD-75	3.92
PD-20	10.02	PD-48	15.43	PD-76	2.98
PD-21	10.23	PD-49	15.12	PD-77	2.34
PD-22	10.45	PD-50	14.80	PD-78	1.89
PD-23	10.66	PD-51	14.50	PD-79	1.49
PD-24	10.89	PD-52	14.16	PD-80	1.10
PD-25	11.08	PD-53	13.88	PD-81	0.68
PD-26	11.30	PD-54	13.62	PD-82	0.16
PD-27	11.60	PD-55	13.21		
PD-28	11.81	PD-56	12.97	PD-5A	2.34

SECONDARY EJECTOR

PRESSURE TAP	L/D_3	PRESSURE TAP	L/D_3	PRESSURE TAP	L/D_3
PSD-1		PSD-5	2.73	PSD-9	5.24
PSD-2	1.04	PSD-6	3.36	PSD-10	5.86
PSD-3	1.67	PSD-7	4.00	PSD-11	6.50
PSD-4	2.11	PSD-8	4.62	PSD-12	



PRESSURE TAP LOCATIONS

Figure 13.

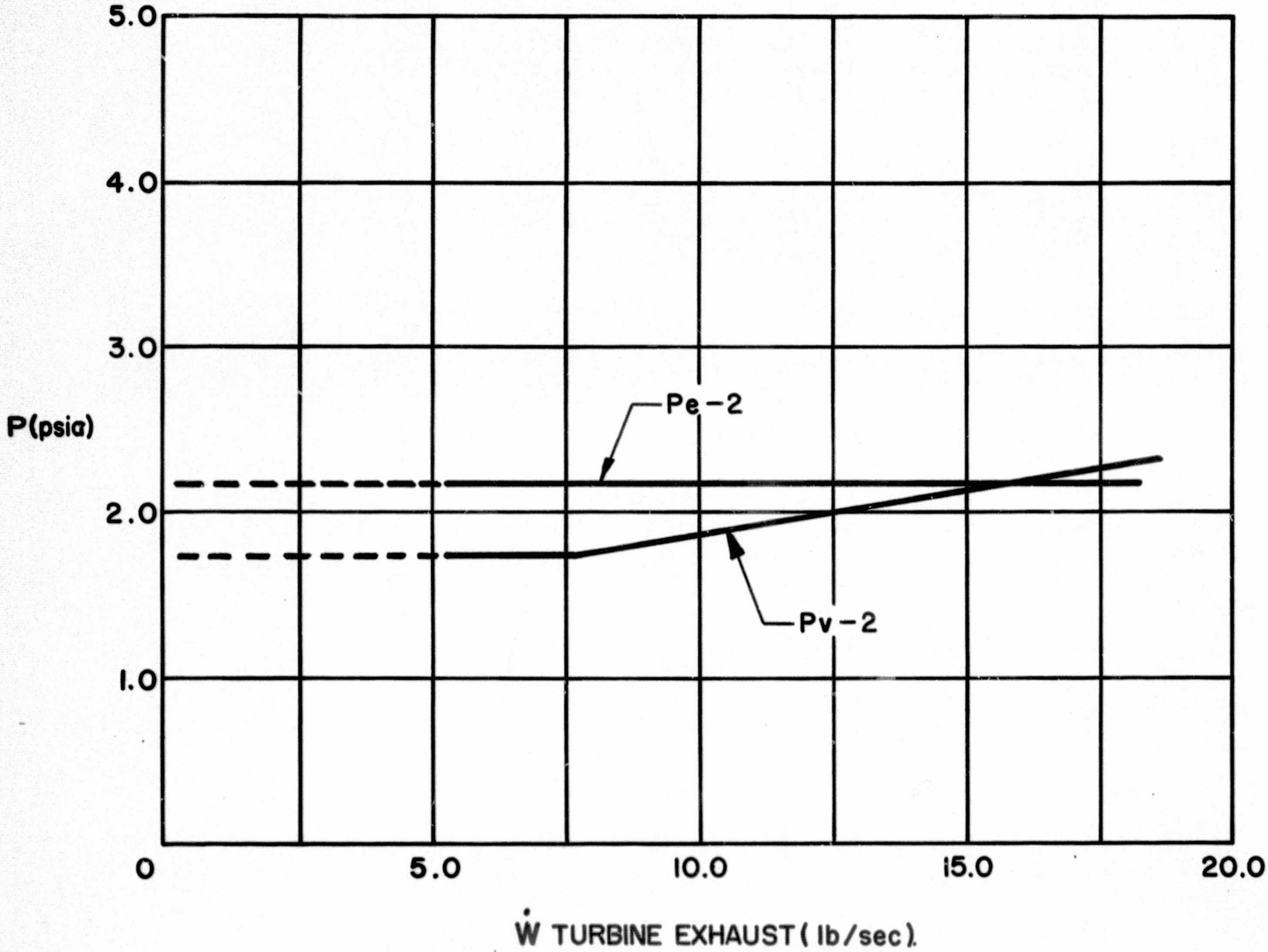
NOTES. 1. RUN NO. 276-LQ-107

2. Pe−2 = NOZZLE EXIT PRESSURE; Pv−2 = ENGINE COMPARTMENT PRESSURE.

3. N_2 SEAL LEAKAGE = 2.06 / 1.52 lb/sec.

4. SAFETY PURGE AT DESIGN VALUE

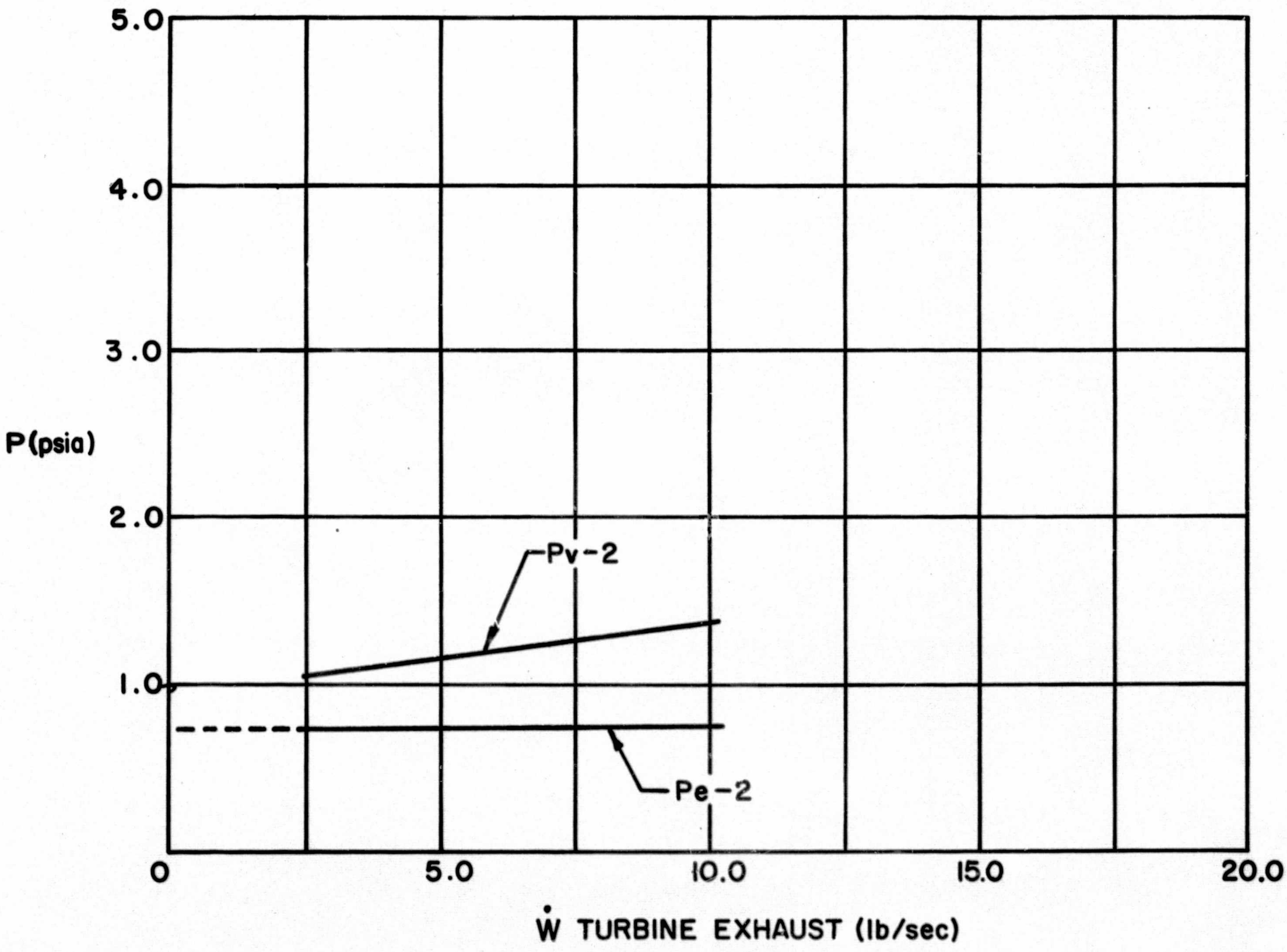
5. Pa = 12.8 psia.



NOZZLE EXIT AND ENGINE COMPARTMENT PRESSURES
VS. TURBINE EXHAUST FLOW RATE
WHEN TESTING THE 10:1 NOZZLE, 100% Pc

Figure 14

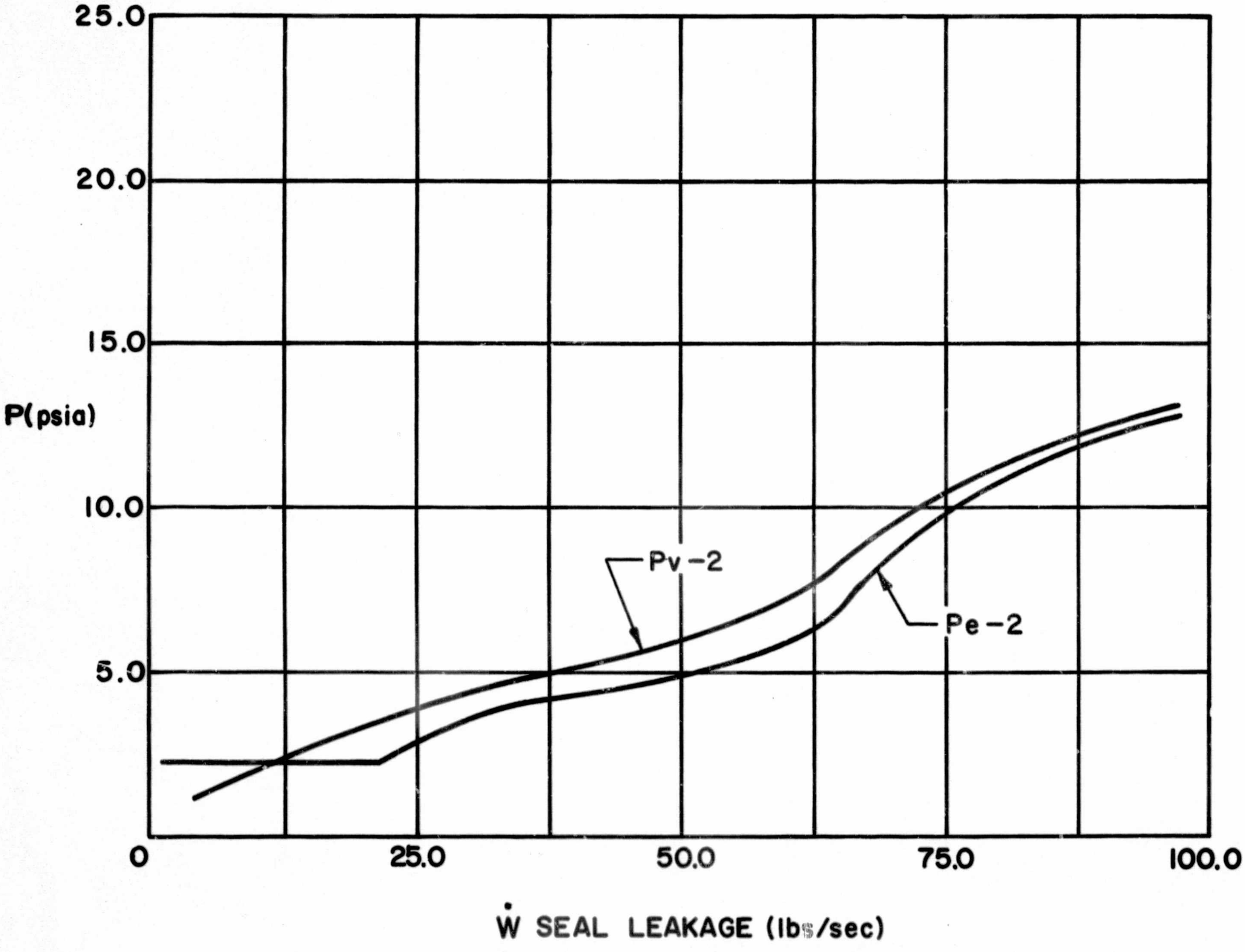
NOTES.
1. RUN NO. 276-LQ-110.
2. Pe-2 = NOZZLE EXIT PRESSURE, Pv-2 = ENGINE COMPARTMENT PRESSURE
3. N_2 SEAL LEAKAGE = 2.21/1.24 lb/sec.
4. SAFETY PURGE AT DESIGN VALUE.
5. Pa = 12.8 psia.



NOZZLE EXIT AND ENGINE COMPARTMENT PRESSURES
VS. TURBINE EXHAUST FLOW RATE
WHEN TESTING THE 10:1 NOZZLE, 50,% Pc

Figure 15

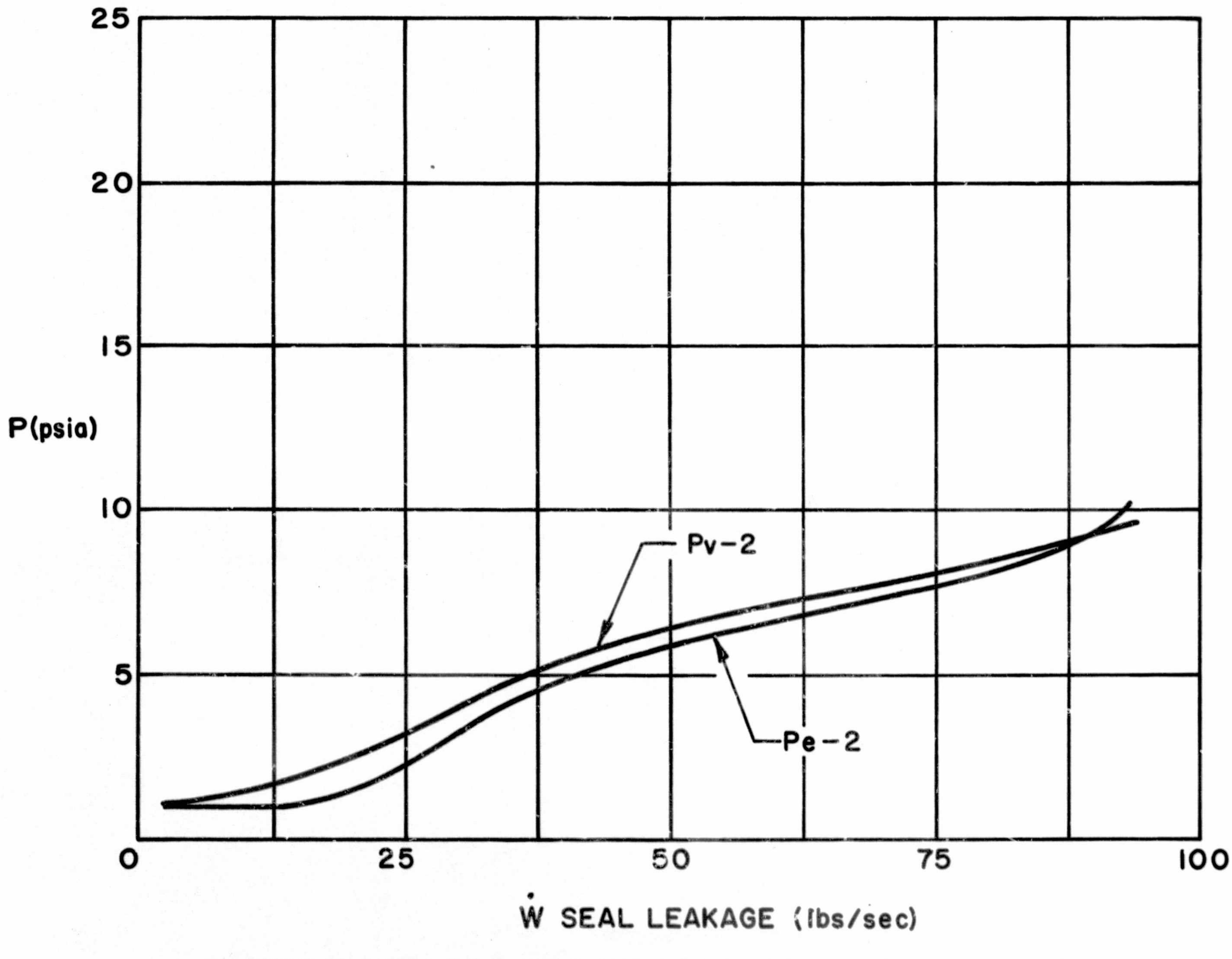
NOTES. 1. RUN NO. 276-LQ-108.
2. Pe-2 = NOZZLE EXIT PRESSURE, Pv-2 = ENGINE COMPARTMENT PRESSURE
3. TURBINE EXHAUST FLOW = 5.37 lb/sec.
4. SAFETY PURGE AT DESIGN VALUE.
5. Pa = 12.8 psia.



NOZZLE EXIT AND ENGINE COMPARTMENT PRESSURES
VS. SEAL LEAKAGE FLOW RATE
WHEN TESTING THE 10:1 NOZZLE, 100 % Pc

Figure 16

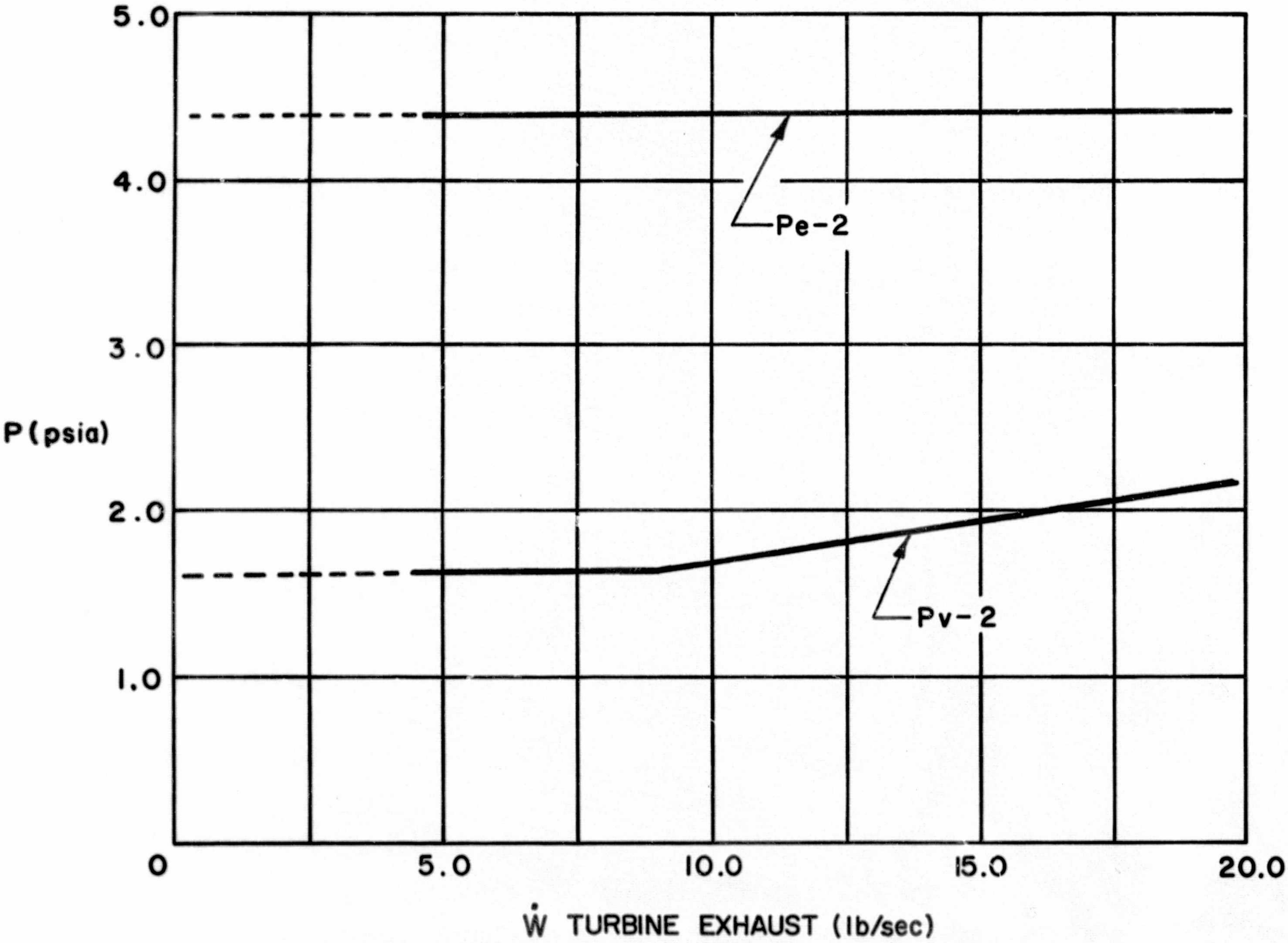
NOTES. 1. RUN NO. 276 - LQ - 109.
2. Pe-2 = NOZZLE EXIT PRESSURE, Pv-2 = ENGINE COMPARTMENT PRESSURE.
3. TURBINE EXHAUST FLOW = 2.14 lb/sec.
4. SAFETY PURGE AT DESIGN VALUE
5. Pa = 12.8 psia.



NOZZLE EXIT AND ENGINE COMPARTMENT PRESSURES
VS. SEAL LEAKAGE FLOW RATE
WHEN TESTING THE 10:1 NOZZLE, 50 % Pc

Figure 17

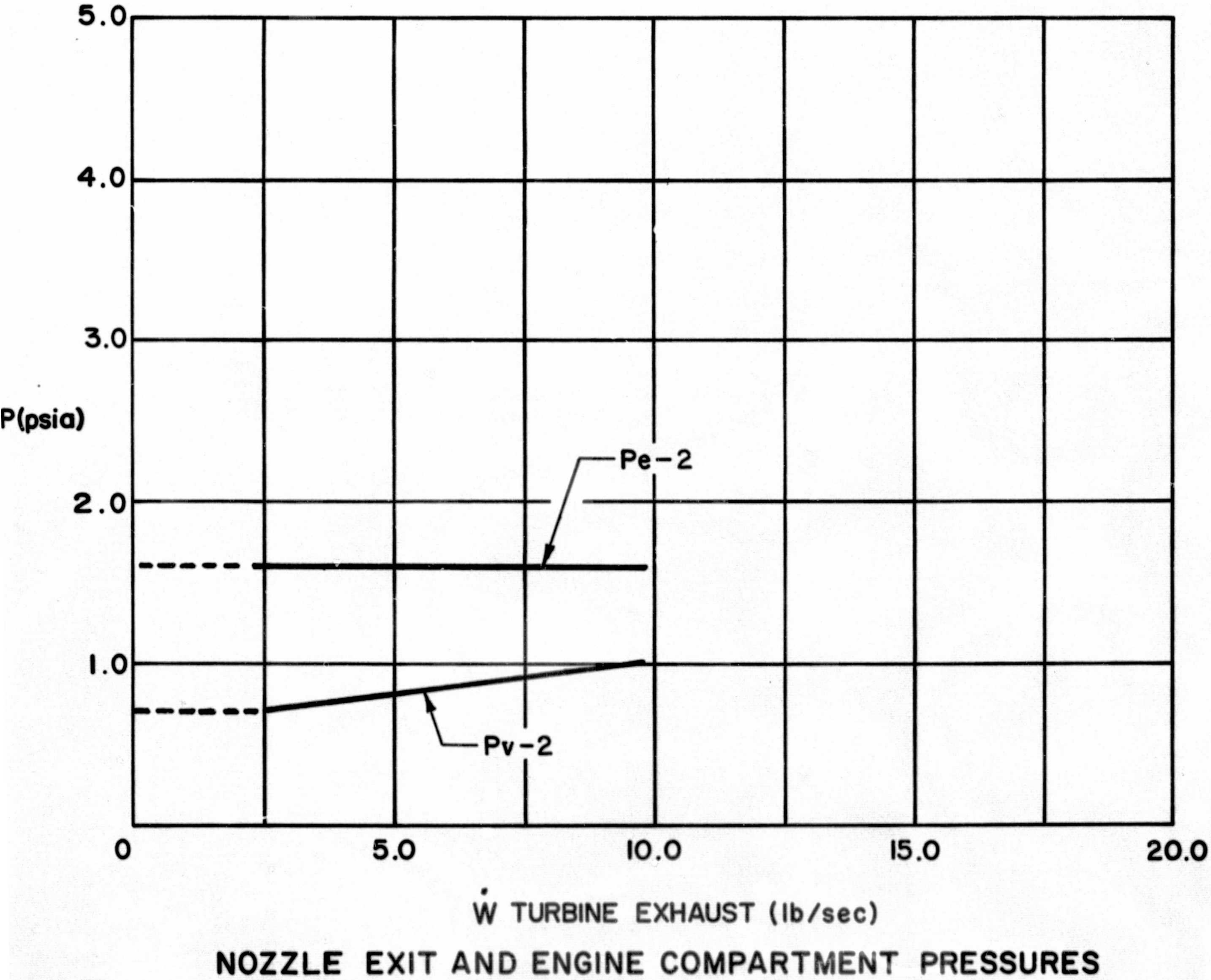
NOTES. 1. RUN NO. 276-LQ-97
2. Pe-2 = NOZZLE EXIT PRESSURE, Pv-2 = ENGINE COMPARTMENT PRESSURE
3. N_2 SEAL LEAKAGE = 1.26 lb/sec.
4. SAFETY PURGE AT DESIGN VALUE.
5. Pd = 12.8 psia.



NOZZLE EXIT AND ENGINE COMPARTMENT PRESSURES
VS. TURBINE EXHAUST FLOW RATE
WHEN TESTING THE 12:1 NOZZLE, 100 % Pc

Figure 18

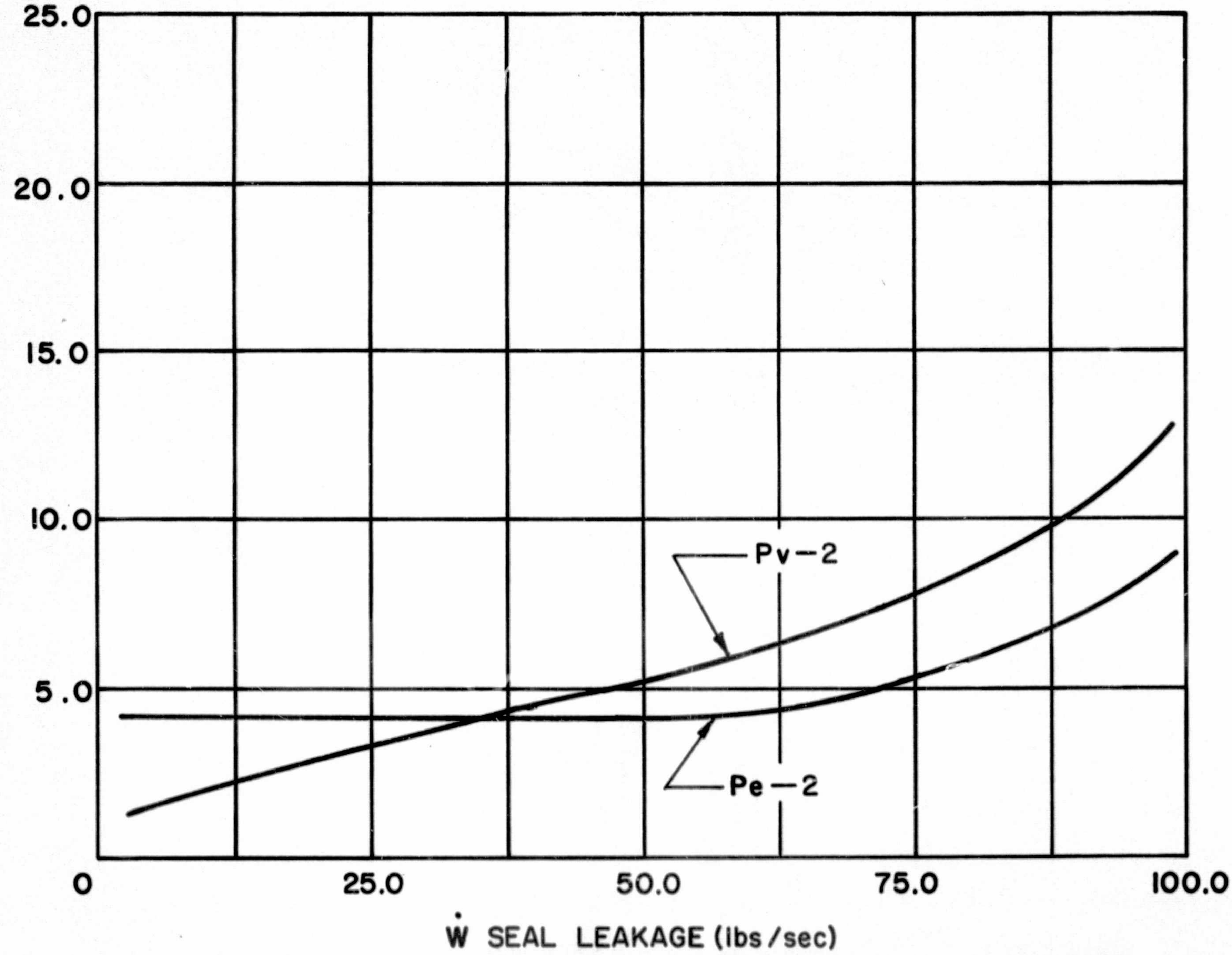
NOTES. 1. RUN NO. 276 - LQ - 100
2. Pe-2 = NOZZLE EXIT PRESSURE, Pv-2 = ENGINE COMPARTMENT PRESSURE.
3. N_2 SEAL LEAKAGE = 1.56 lb/sec.
4. SAFETY PURGE AT DESIGN VALUE.
5. Pa = 12.8 psia.



NOZZLE EXIT AND ENGINE COMPARTMENT PRESSURES
VS. TURBINE EXHAUST FLOW RATE
WHEN TESTING THE 12:1 NOZZLE, 50% Pc

Figure 19

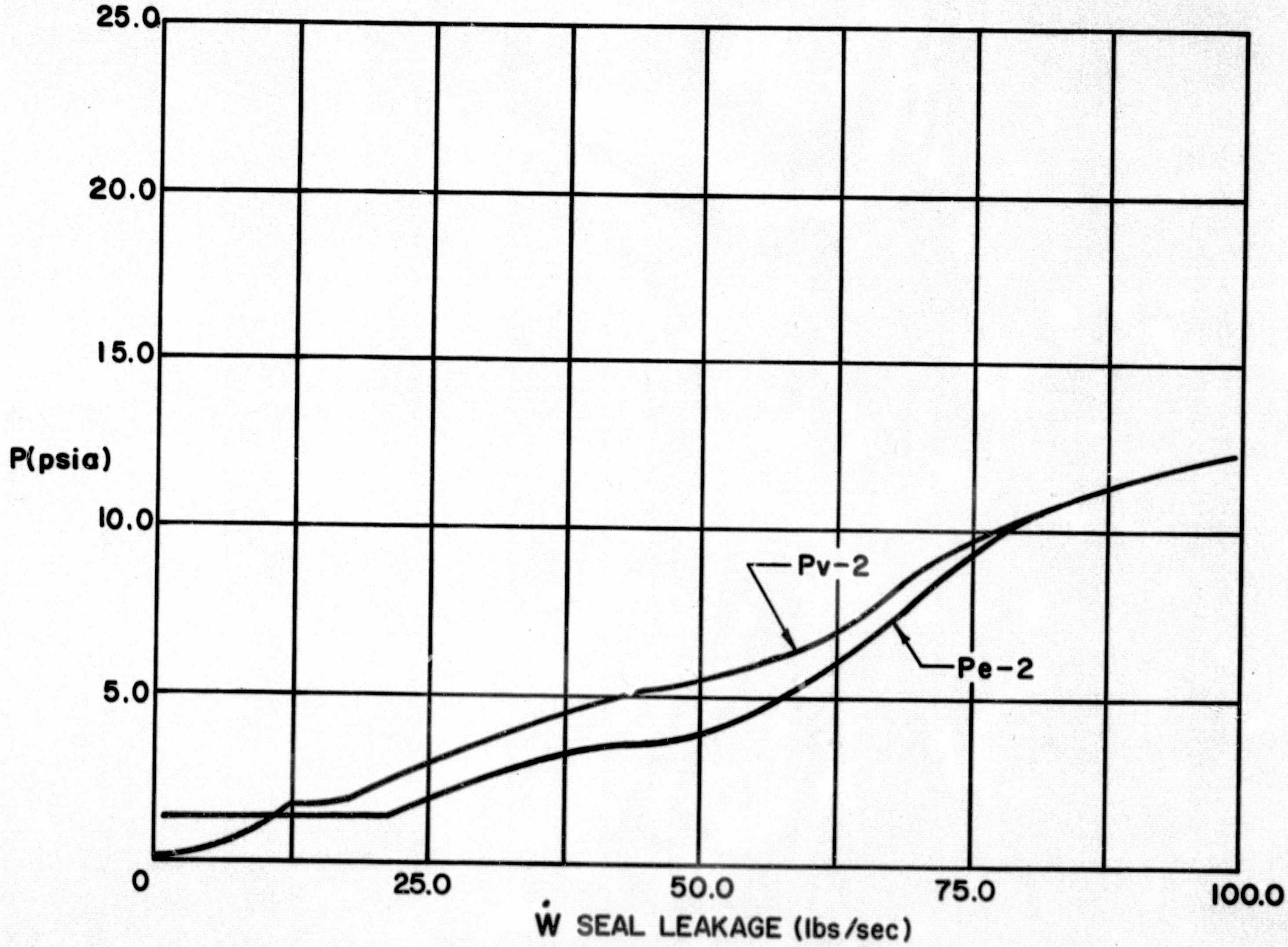
NOTES.
1. RUN NO. 276 - LQ - 98.
2. Pe −2 = NOZZLE EXIT PRESSURE ; Pv−2 = ENGINE COMPARTMENT PRESSURE.
3. TURBINE EXHAUST FLOW = 5.25 lb/sec .
4. SAFETY PURGE AT DESIGN VALUE.
5. Pa = 12.8 psia.



NOZZLE EXIT AND ENGINE COMPARTMENT PRESSURES
VS. SEAL LEAKAGE FLOW RATE
WHEN TESTING THE 12:1 NOZZLE, 100% Pc

Figure 20

NOTES. 1. RUN NO. 276 - LQ - 99
2. Pe-2 = NOZZLE EXIT PRESSURE; Pv-2 = ENGINE COMPARTMENT PRESSURE.
3. TURBINE EXHAUST FLOW = 2.15 lb/sec.
4. SAFETY PURGE AT DESIGN VALUE.
5. Pa = 12.8 psia.



NOZZLE EXIT AND ENGINE COMPARTMENT PRESSURES
VS. SEAL LEAKAGE FLOW RATE
WHEN TESTING THE 12:1 NOZZLE, 50% Pc

Figure 21

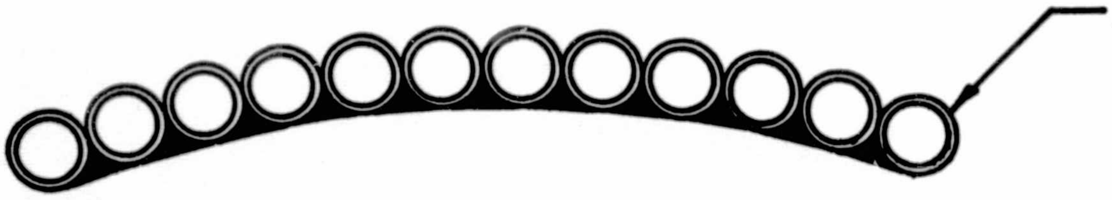
FLOW CONDITIONS

The following are the flow requirements for each section of the duct:

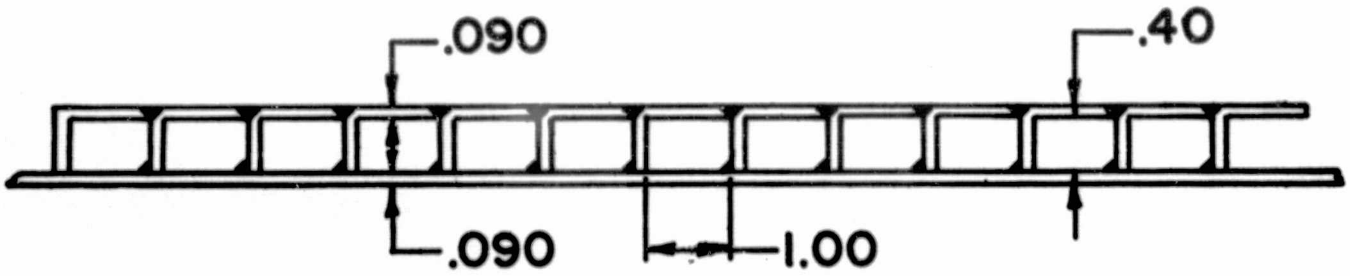
	GPM	Calculated Min. Press at Duct Inlet psig	Nom. Temp. at Duct Inlet °F	Overload Bulk °F	Operation Bulk Temp. °F	Max. ΔP Manif. to Manif. psi
Section I	8,650	193	85	180	140	62
Section II	11,600	190	85	180	140	139
Section III	10,500	192	85	180	140	68

TOTAL FLOW = 30,750 GPM

The above requirements are based on a minimum water head in the storage tank of 3.5 feet of water, with a total flow of 44,000 gpm in the 42 in. supply line and 30,750 gpm in the duct system.



TYPICAL ELBOW (Section II)



TYPICAL STRAIGHT SECTION
(Sections I & III)

COOLANT PASSAGE CONFIGURATION & FLOW CONDITIONS

FIGURE 22.

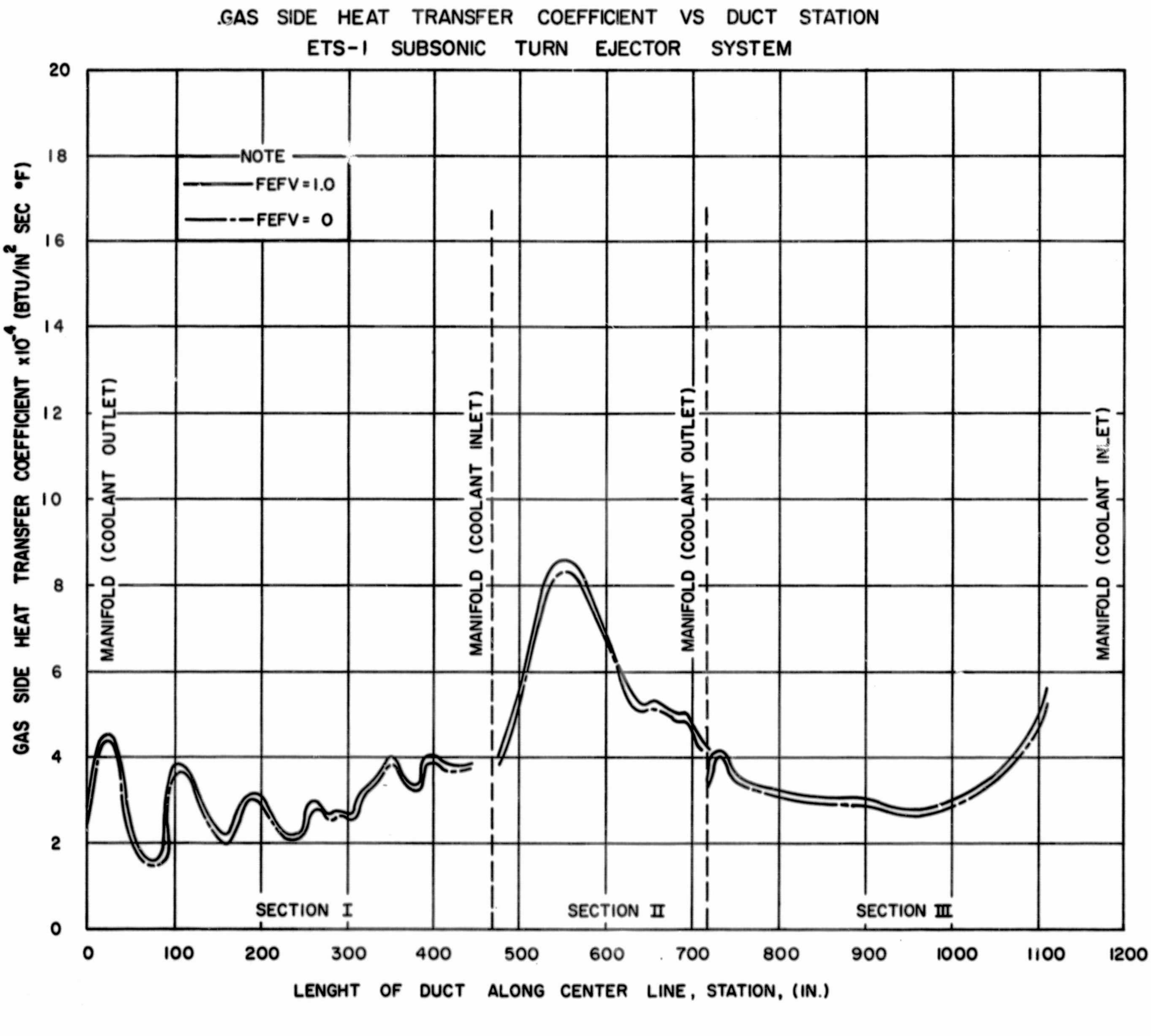


Figure 23

Gas-Side Heat Transfer Coefficient vs Duct Station

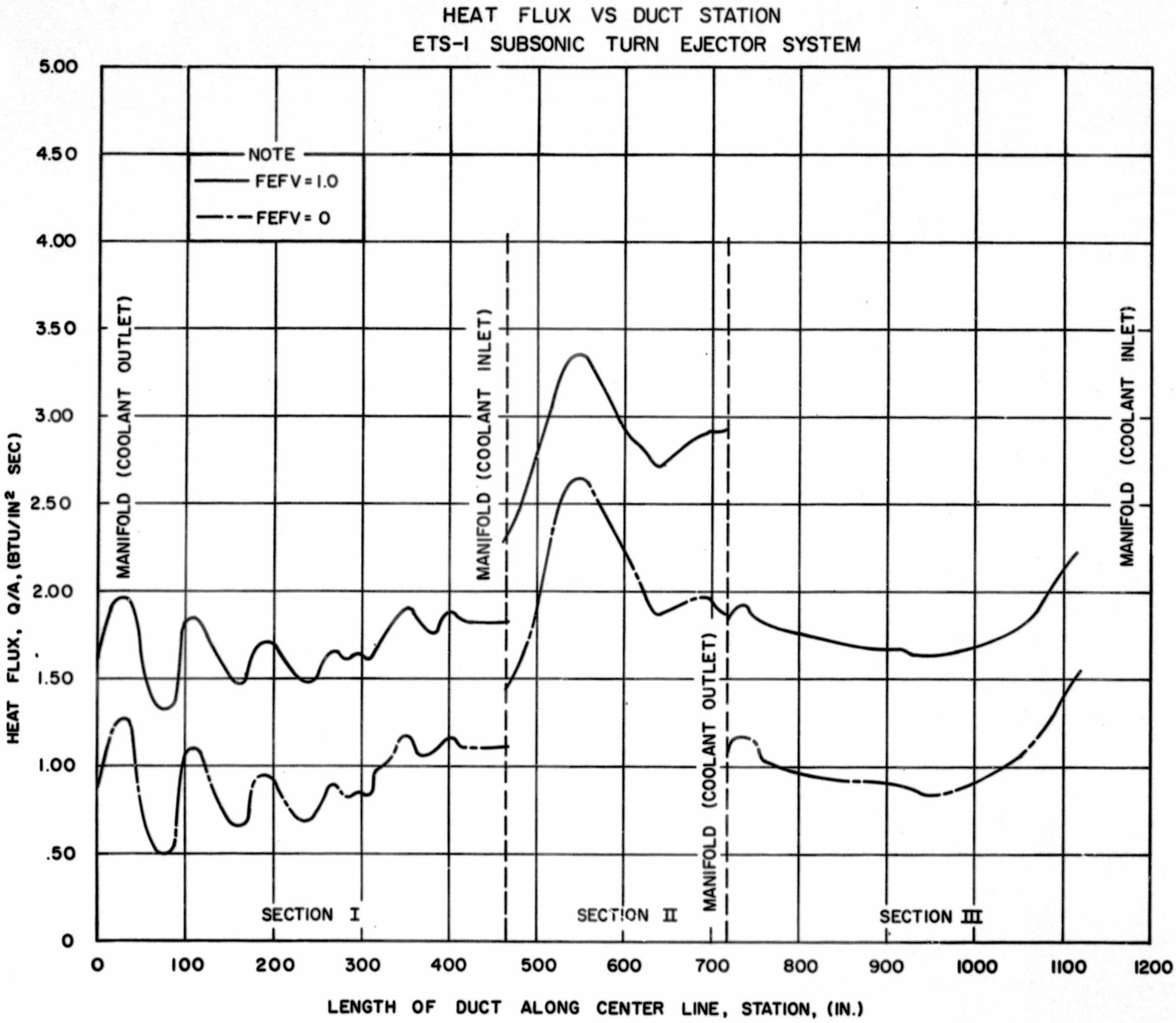


Figure 24

Heat Flux vs Duct Station

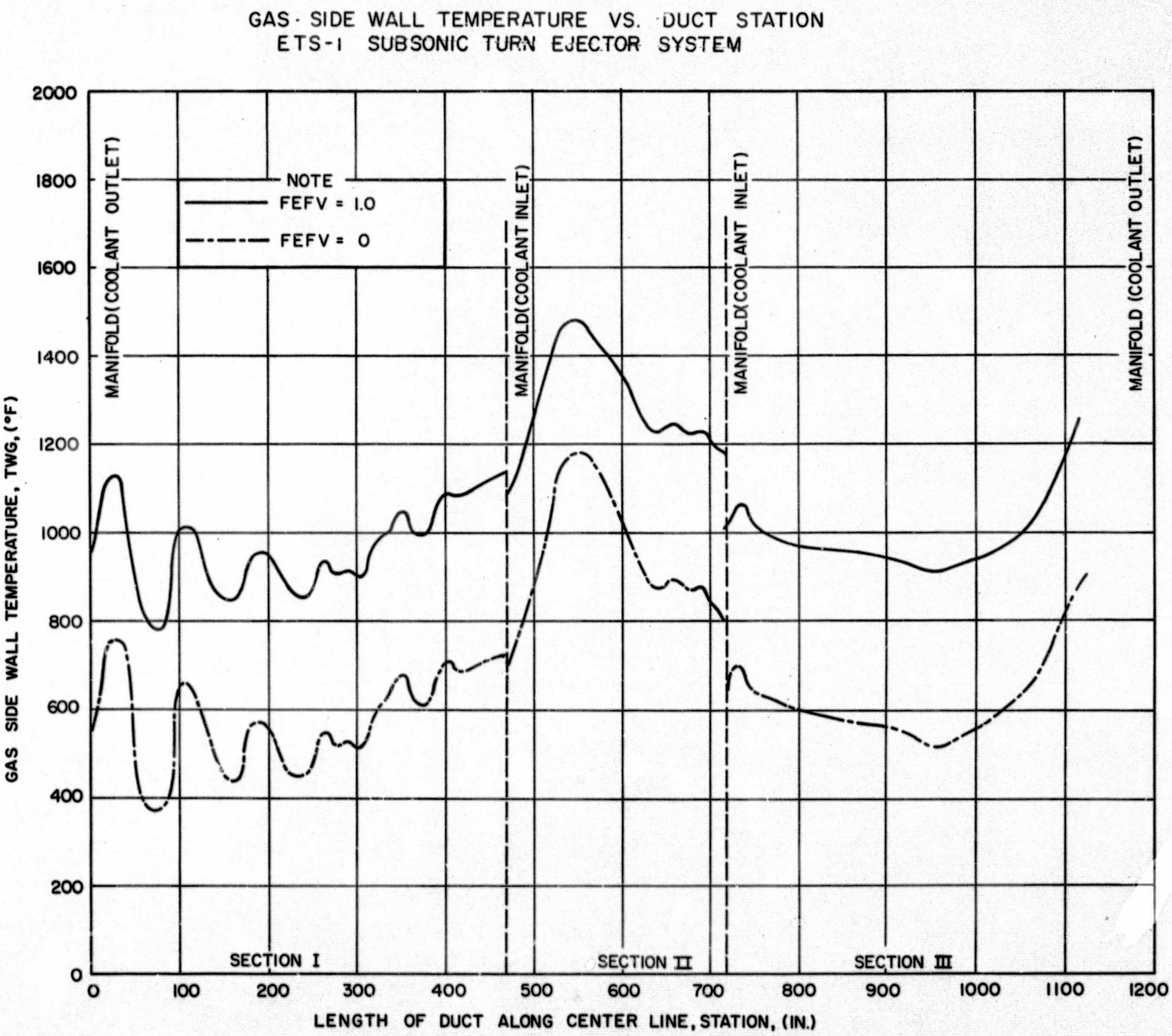


Figure 25

Gas-Side Wall Temperature vs Duct Station

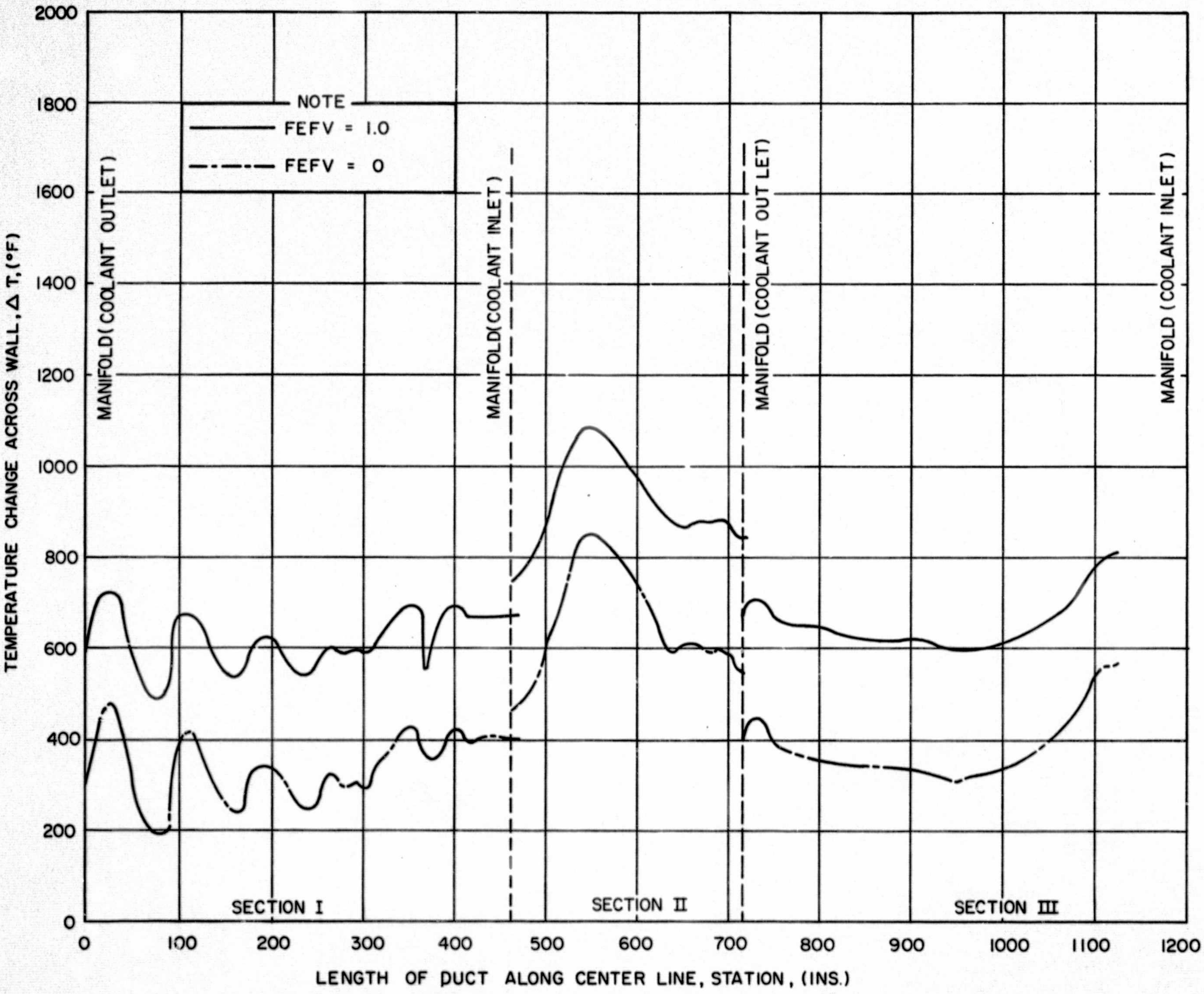


Figure 26

Wall Temperature Change vs Duct Station

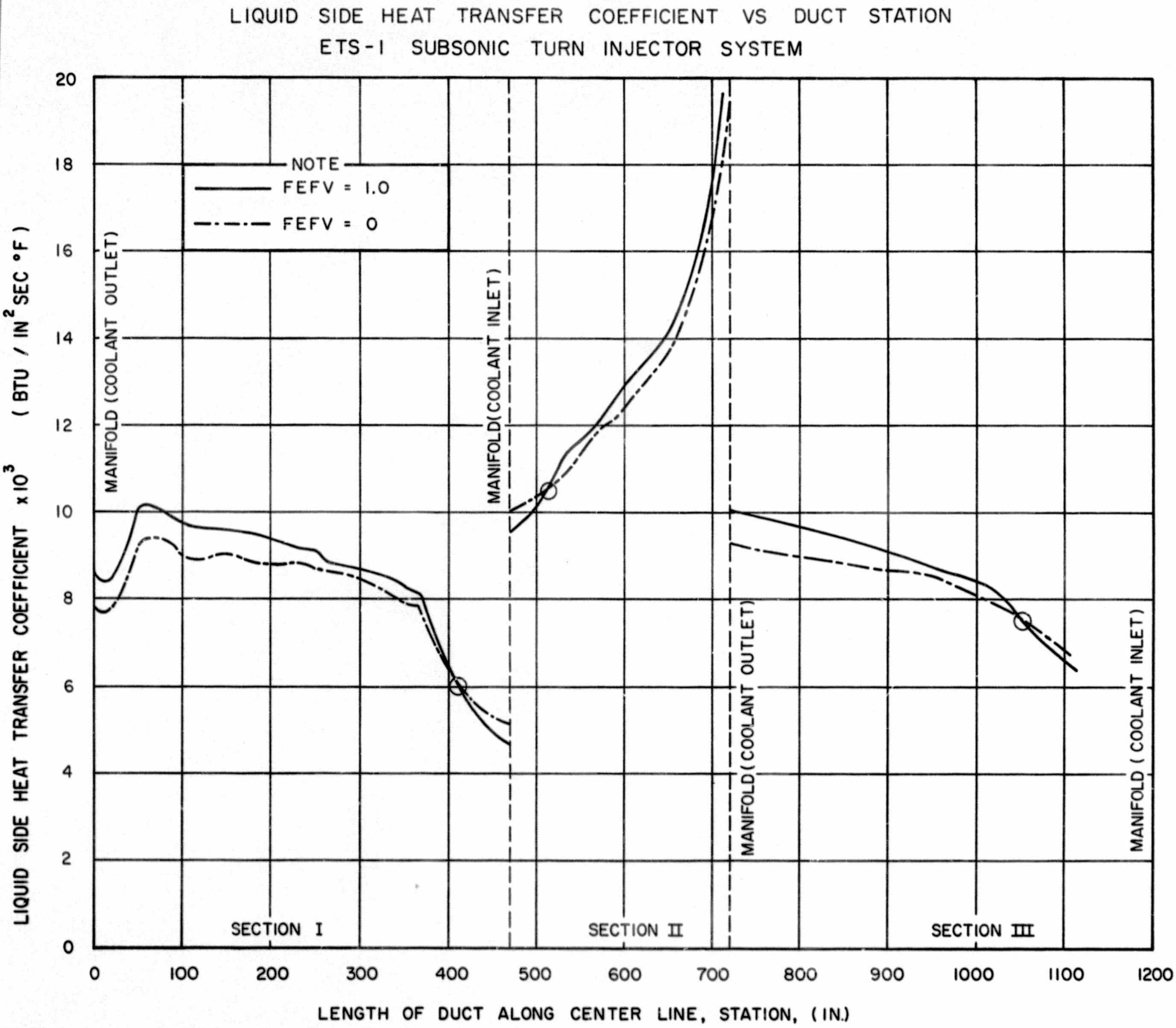


Figure 27

Liquid-Side Heat Transfer Coefficient vs Duct Station

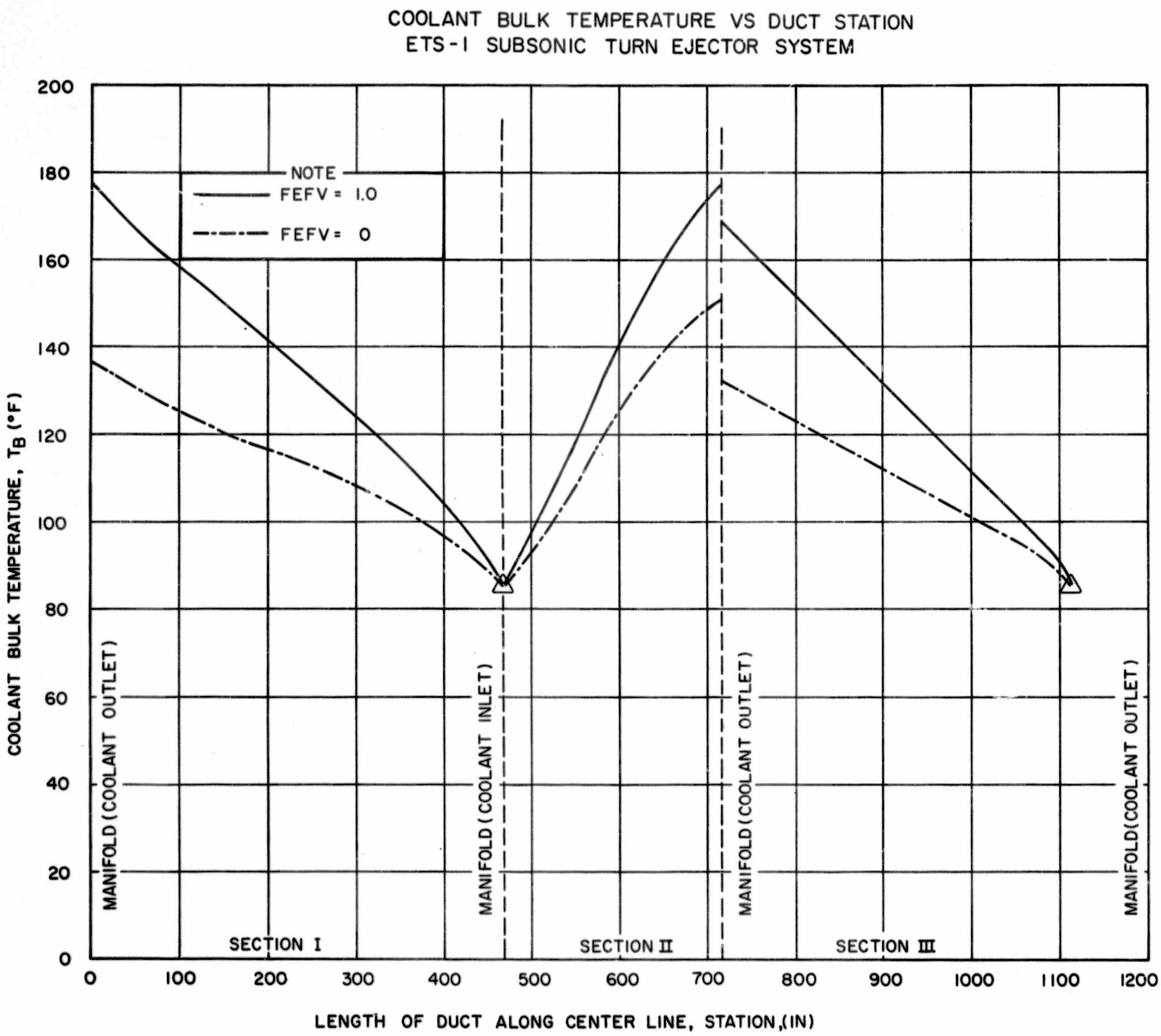
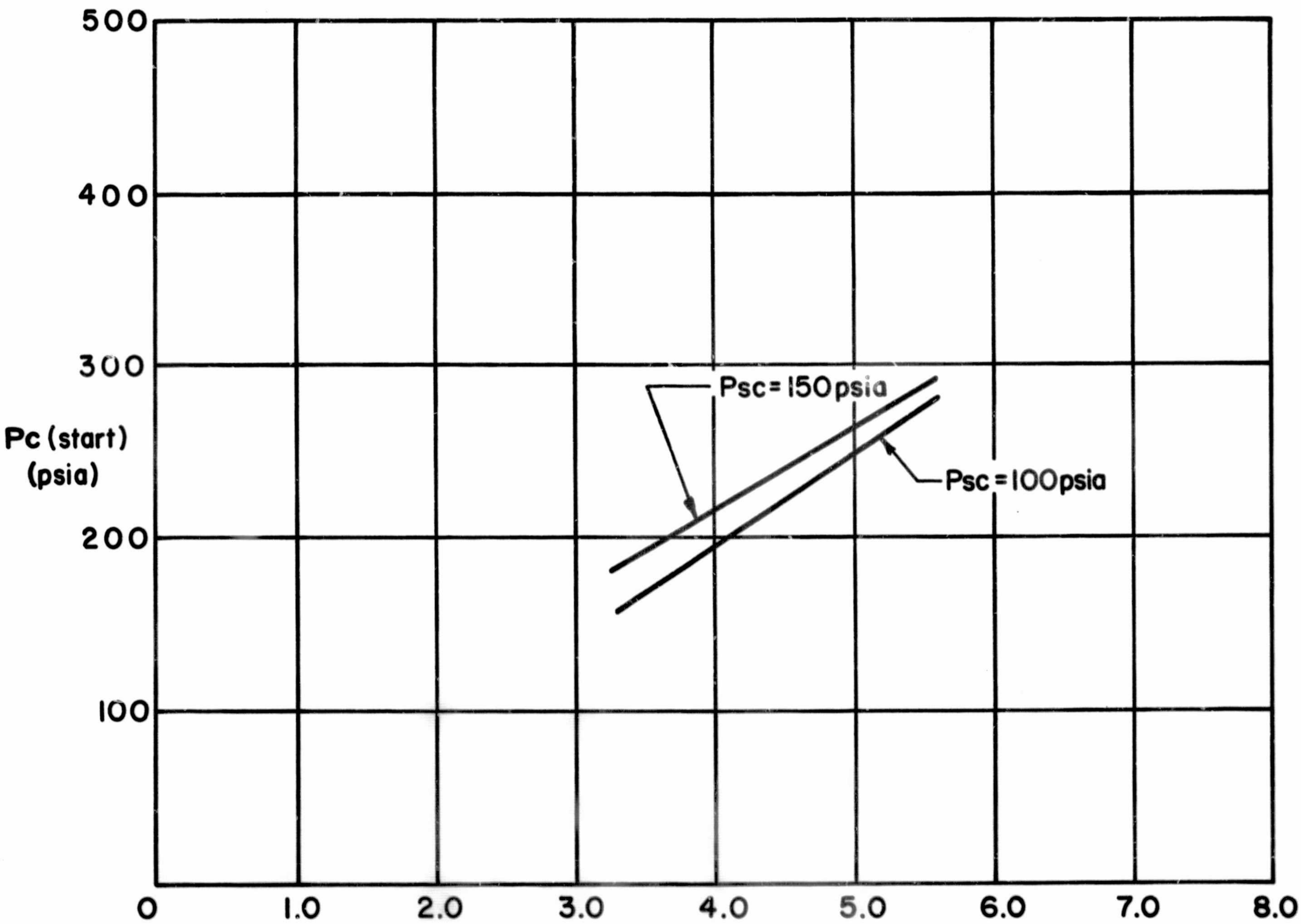


Figure 28

Coolant Bulk Temperature vs Duct Station

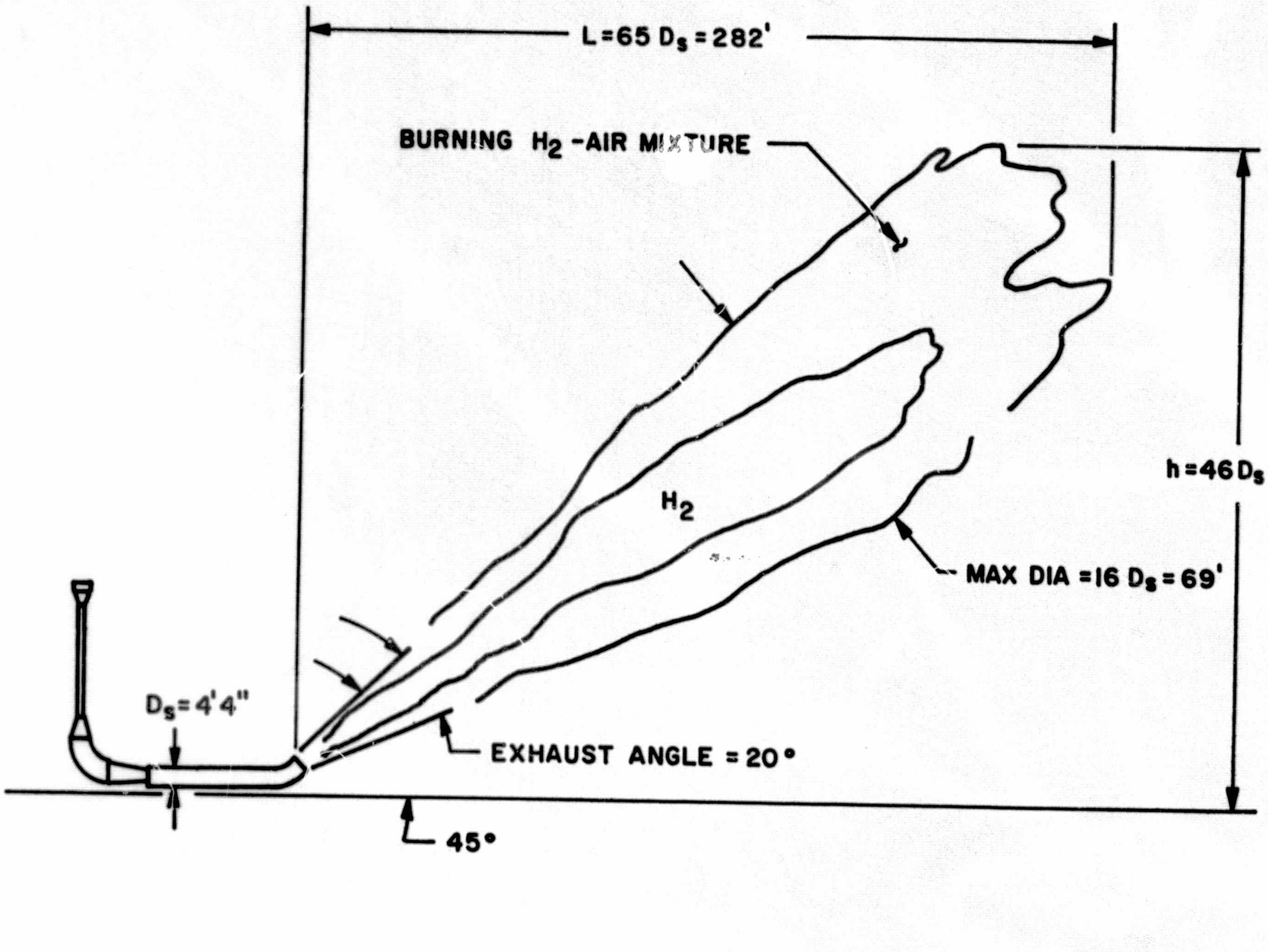
NOTES. 1. RUN NO. 276 - LQ - 117, 118, 119, 120.
2. N_2 SEAL LEAKAGE = 1.54/1.72 lb/sec.
3. Amb H_2 TURBINE EXHAUST — PROGRAMMED AT DESIGN VALUE
4. 10/1 CONICAL NOZZLE
5. Pa = 12.8 psia.



$$\Omega = \sqrt{\frac{(Tc/m)_{prm.}}{(Tc/m)_{sec}}}$$

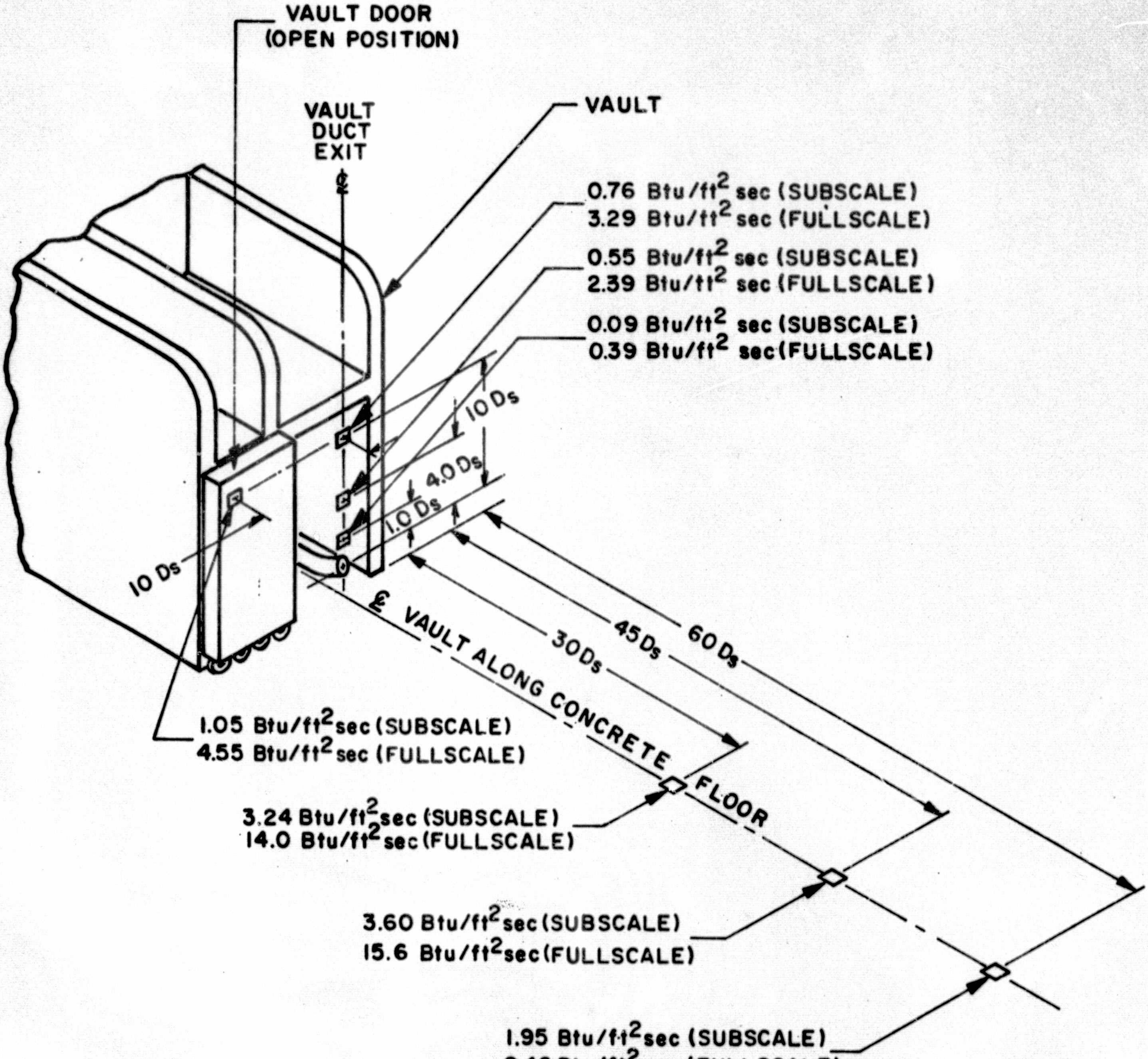
EFFECTS OF OFF-DESIGN SAFETY PURGE
ON STARTING PRESSURE

Figure 29



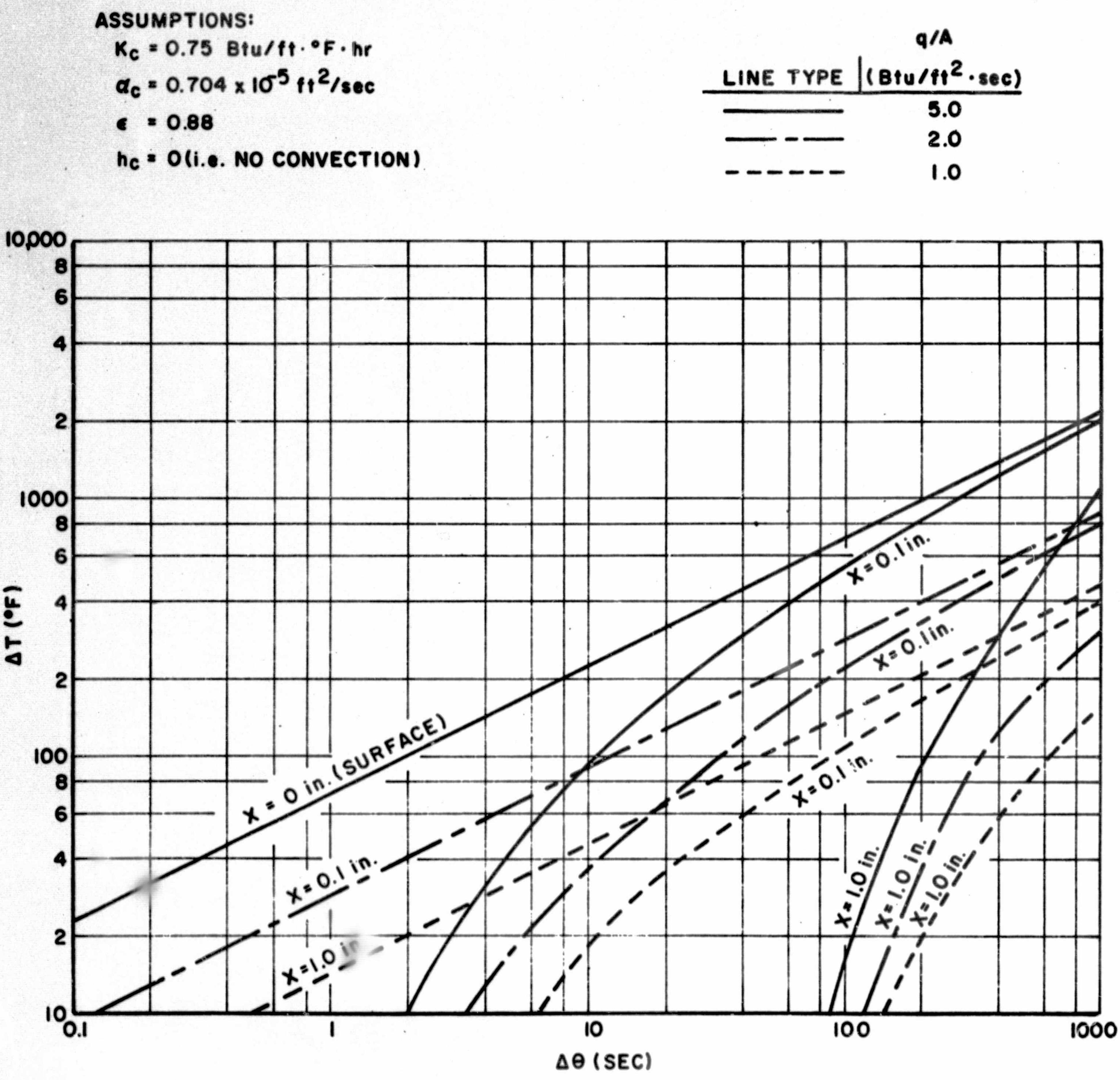
PREDICTED HYDROGEN EXHAUST PLUME
SIZE & SHAPE

Figure 30



THERMAL RADIATION FLUX FROM NERVA
EXHAUST PLUME AT SELECTED LOCATIONS

Figure 31



TEMPERTURE RISE FOR SEMI-INFINITE CONCRETE SLAB AS A FUNCTION OF DISTANCE (X) FROM SLAB SURFACE AND TIME INCREMENT (Δθ) FOR RADIATIVE HEAT FLUXES q/A = 1.0, 2.0, & 5.0 Btu/ft^2 · sec

Figure 32

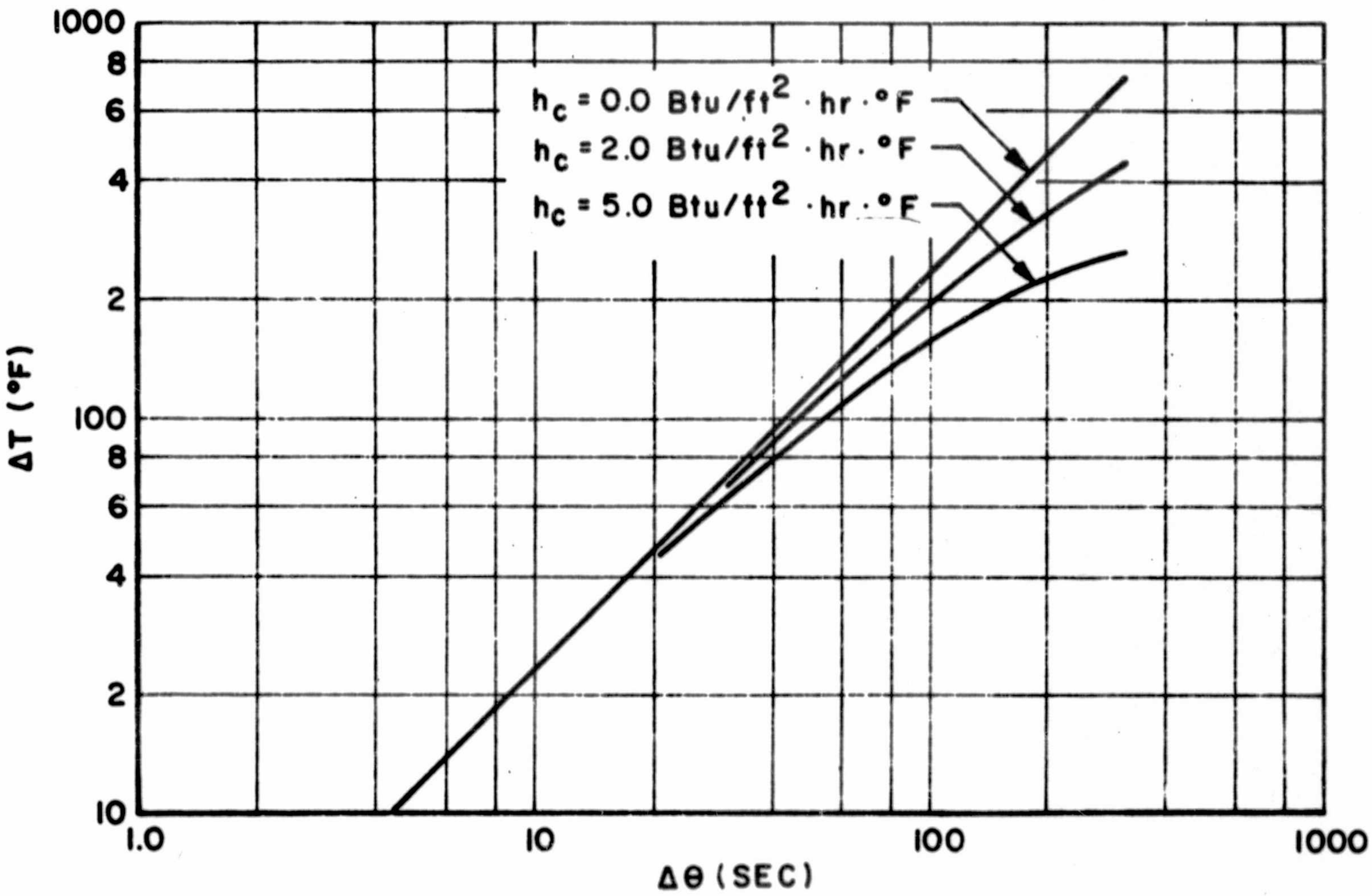
ASSUMPTIONS:

(1) SURFACE EMISSIVITY = 0.19

(2) ALUMINUM IS COOLED BY CONVECTION ON ONE SIDE ONLY-OTHER SIDE IS INSULATED

(3) NO THERMAL GRADIENT THROUGH SHEET

(4) AIR AMBIENT TEMPERATURE = 90 °F = CONSTANT



TEMPERATURE RISE (ΔT) FOR 14 GAGE (0.064 in. THICK) SHEET ALUMINUM RECEIVING A CONSTANT RADIATIVE HEAT FLUX OF 2.0 Btu/ft^2 · SEC AS A FUNCTION OF TIME (Δθ) AND ADJACENT AIR CONVECTION COEFFICIENT (h_c)

Figure 33

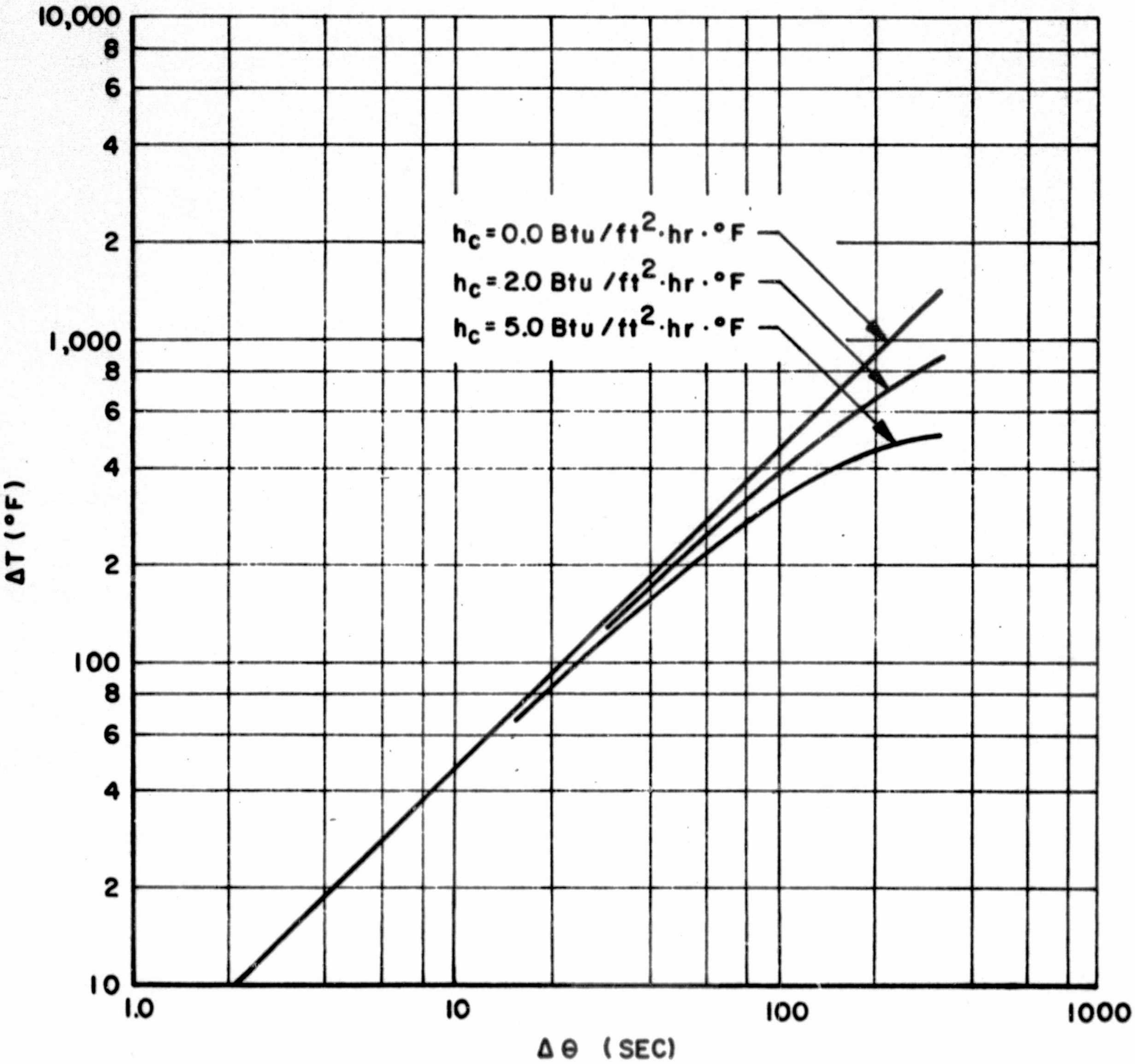
ASSUMPTIONS:

(1) SURFACE EMISSIVITY (ξ) = 0.19

(2) ALUMINUM IS COOLED BY CONVECTION OF ONE SIDE ONLY - OTHER SIDE IS INSULATED

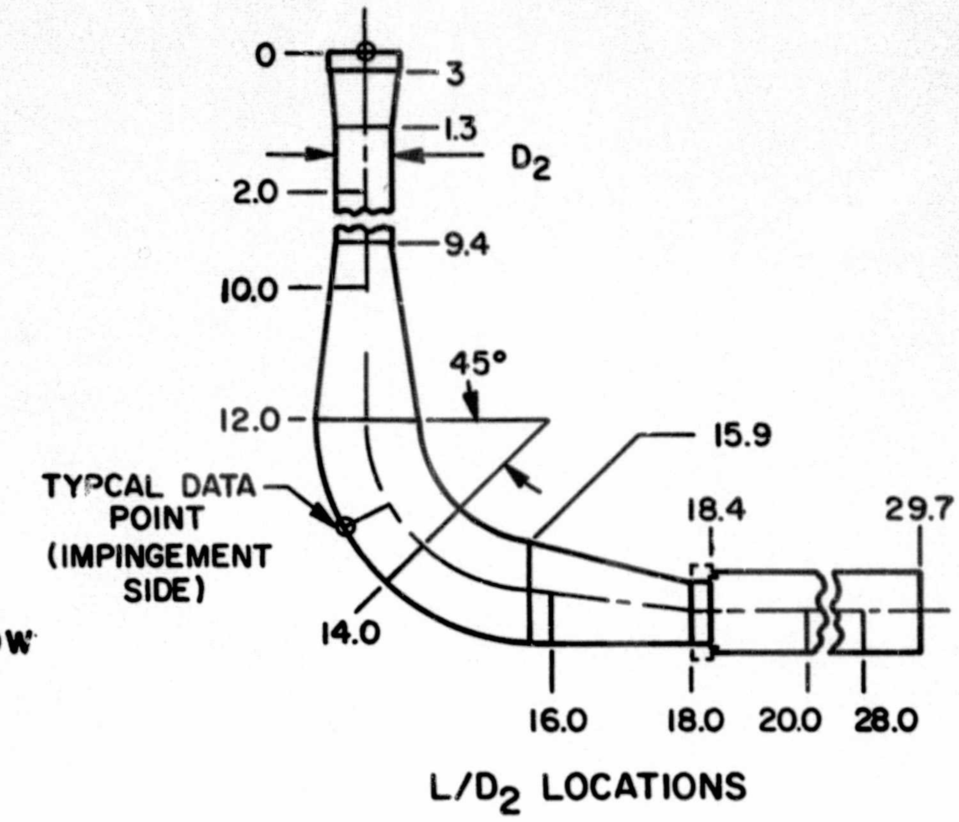
(3) NO THERMAL GRADIENT THROUGH SHEET

(4) AIR AMBIENT TEMPERATURE = 90 °F = CONSTANT



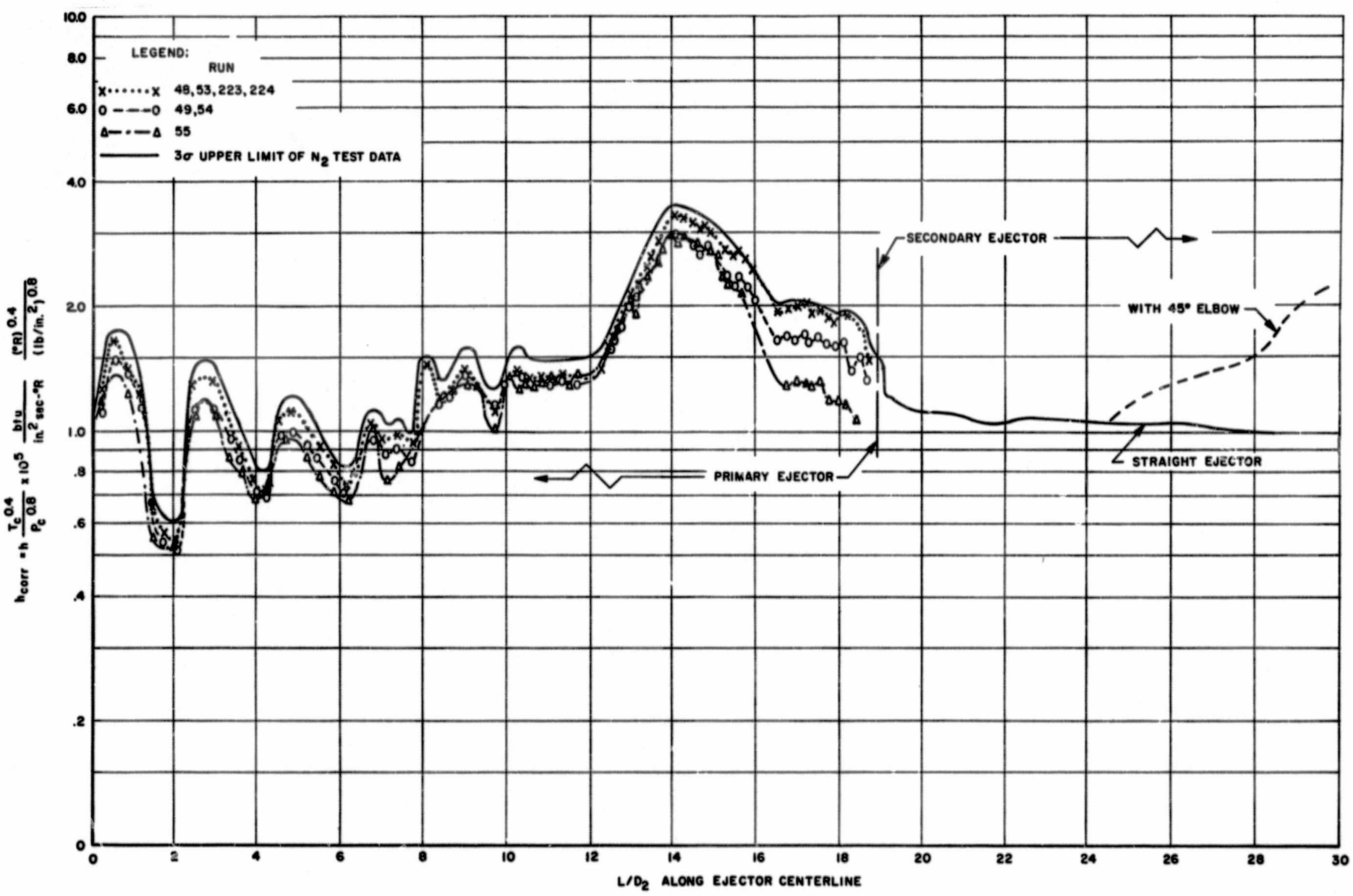
TEMPERATURE RISE (ΔT) FOR SHEET ALUMINUM (14 GAGE) RECEIVING A CONSTANT RADIATIVE HEAT FLUX OF 4.0 Btu/ft^2 SEC AS A FUNCTION OF TIME (ΔΘ) AND ADJACENT AIR CONVECTION COEFFICIENT (h_c)

Figure 34



NOTES:

1. Points Taken On Impingement Side of Elbow
2.



NORMALIZED SUBSCALE HEAT TRANSFER COEFFICIENTS

Figure 35