LMSC-HREC TR D568366

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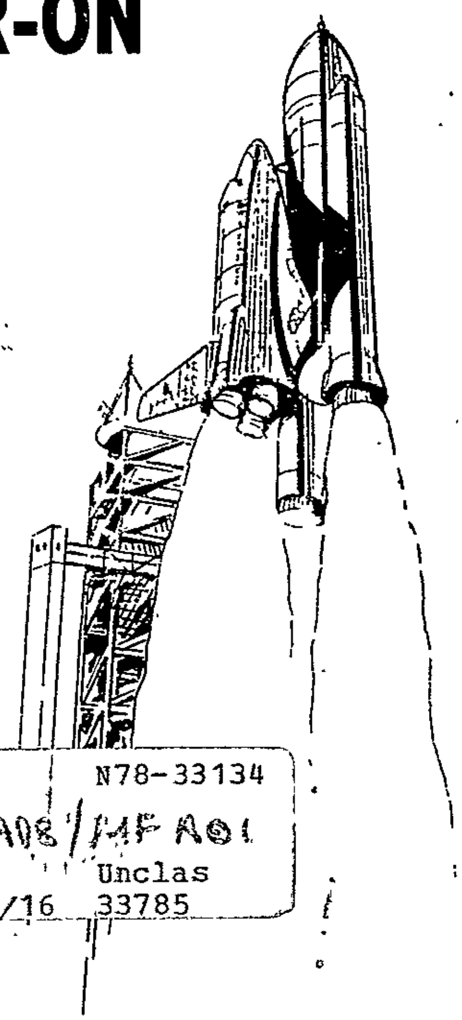
DEVELOPMENT OF BASE PRESSURE SIMILARITY PARAMETERS FOR APPLICATION TO SPACE SHUTTLE LAUNCH VEHICLE POWER-ON AERODYNAMIC TESTING

Final Report

Contract NAS8-32658

September 1978



Prepared for

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

(NASA-CR-150826) DEVELOPMENT OF BASE PRESSURE SIMILARITY PARAMETERS FOR APPLICATION TO SPACE SHUTTLE LAUNCH VEHICLE POWER-ON AERODYNAMIC TESTING Final Report (Lockheed Missiles and Space Co.) 156 p HC A08/MF A01 N78-33134 Unclas G3/16 33785

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FOREWORD

This report presents the results of a study performed by personnel in the Fluid Technology Application Section of the Lockheed-Huntsville Research & Engineering Center in fulfillment of the requirements of Contract NAS8-32658 with NASA-Marshall Space Flight Center. The NASA-MSFC contracting officer's technical representative for this study was Joseph L Sims, ED32

SUMMARY

A base pressure data correlation study was conducted to define exhaust plume similarity parameters for use in Space Shuttle power-on launch vehicle aerodynamic test programs Data correlations were performed for single bodies having, respectively, single and triple nozzle configurations and for a triple body configuration with single nozzles on each of the outside bodies Base pressure data were obtained experimentally from a series of test programs conducted by NASA-Marshall Space Flight Center and from analytical predictions for single body single nozzle configurations using the Addy program The experimental data includes both "hot" and "cold" flow test data for freestream Mach numbers of 0 9, 1 2, 1 46 and 3.48 Analytically generated base pressure data were for a Mach number of 2 0

Base pressure similarity parameters were found to differ for the single nozzle and triple nozzle configurations However, the correlation parameter for each was found to be a strong function of the nozzle exit momentum The correlation parameter for the single nozzle configuration is

$$\frac{P_b}{P_\infty} \text{ vs } \frac{\text{Momentum})_e}{\text{Momentum})_\infty} \left\{ \frac{\gamma_j M_j^2}{\gamma_\infty M_\infty^2} \right\}$$

while the correlation parameter for the triple nozzle and triple body configuration is

$$\frac{P_b}{P_\infty} \text{ vs } \frac{\text{Momentum})_e}{\text{Momentum})_\infty} \left\{ \frac{M_j \delta_j}{\gamma_j} \right\}$$

Analyses of the analytical data have suggested that these similarity parameters are not universally applicable for all conceivable test conditions Consequently,

there may be some restrictive conditions on their use which cannot be adequately defined with the currently available data base

Results of the data base evaluation are presented indicating an assessment of all data points. Analytical/experimental data comparisons were made for nozzle calibrations and correction factors derived, where indicated for use in nozzle exit plane data calculations. The complete experimental data base used in the correlation analyses is presented in tabular form Tabulated values of the data base include experimental measurements (chamber pressure, nozzle wall pressure) as well as analytical data which define nozzle operating characteristics and jet boundary parameters

Documentation of the correlation analysis is concluded with the description of a procedure to apply base pressure correlation parameters to power-on tests.

CONTENTS

SYMBOLS AND NOTATION

Symbol	Description
A/A^*	nozzle area ratio, dimensionless
AC	nozzle chamber speed of sound, ft/sec
AJ	jet boundary speed of sound, ft/sec
C_p	specific heat at constant pressure, Btu/lbm
C_v	specific heat at constant volume, Btu/lbm
DELTA(J)	initial plume expansion angle measured from the nozzle centerline, deg
GAMMA	jet boundary ratio of specific heats, dimensionless
GAMMAE	nozzle exit plane ratio of specific heats, dimensionless
H	wind tunnel total pressure, lbf/in^2
M	wind tunnel freestream Mach number, dimensionless
MJ	jet boundary Mach number, dimensionless
ME	nozzle exit plane Mach number, dimensionless
NU	Prandtl-Meyer turning angle, deg
P	wind tunnel freestream static pressure, lbf/in^2
p	nozzle static pressure, lbf/in^2
PB	vehicle base region pressure, lbf/in^2
PC	nozzle chamber pressure, lbf/in^2
PE	nozzle exit plane static pressure, lbf/in^2
P(INF)	wind tunnel freestream static pressure, lbf/in^2
PJ	jet boundary static pressure, lbf/in^2
PS	afterbody surface pressure, lbf/in^2

Symbol	Description
PW	nozzle wall static pressure, lbf/in^2
RHO	wind tunnel freestream density, slug/ft^3
RHOC	nozzle chamber density, slug/ft^3
RHOJ	nozzle chamber density, slug/ft^3
R N	Reynolds number, 1/ft
T(INF)	wind tunnel freestream static temperature, R
T(O)	wind tunnel freestream total temperature, R
TC	nozzle chamber temperature, R
TJ	jet boundary static temperature, R
THETA	nozzle wall angle, deg
UJ	jet boundary velocity, ft/sec
V	wind tunnel freestream velocity, ft/sec
Greek	
γ	ratio of specific heats, dimensionless
δ	uncertainty of an experimentally determined value
ρ	density, lbm/ft^3
Subscripts	
b	vehicle base region conditions
c	nozzle chamber conditions
e	nozzle exit plane conditions
j	jet boundary conditions
∞	wind tunnel freestream conditions

1 INTRODUCTION

During the initial phase (liftoff to solid rocket motor (SRM) staging) of a nominal flight trajectory, the Space Shuttle vehicle thrust is provided by two SRMs and three Space Shuttle main engines (SSMEs). The plumes formed by the exhaust gases of the SRM and SSME propulsion systems have been shown to interact with the freestream air flowing over the vehicle surface, thereby affecting the vehicle aerodynamic characteristics Specific items of interest include aerodynamic changes due to: (1) base pressure associated with the SSME and SRM plumes, and (2) plume-induced separation on the aft surfaces of the launch vehicle Performance of the aerodynamic control surfaces (such as elevons and control surfaces on the vertical fin) located in the separated flow region is adversely affected, resulting in a reduction in vehicle aerodynamic control effectiveness The extent of the influence of the propulsion system exhaust plumes on vehicle aerodynamics is a complex function of vehicle geometry, propulsion system geometry and operating conditions, and vehicle flight trajectory Therefore, the magnitude and significance of plume/ vehicle aerodynamics interaction must be determined for each launch vehicle system being considered As a result of the study, a set of vehicle aerodynamic characteristics unique to that vehicle will result

As is the case for all scale model tests, the appropriate similarity parameters for the physical processes must be selected and duplicated if the tests are to apply to the full-scale vehicle. When a complex flow field such as a rocket exhaust plume is to be modeled, it is usually impossible to simulate all of the gasdynamic parameters over the entire flow field when a simulant gas is used Thus, it is necessary to identify the important physical phenomena and the similarity parameters which control them. The principal phenomena to be simulated during the launch vehicle test program is the effect the exhaust plume produces on the flow over adjacent vehicle surfaces, that is, the base pressure and the plume-induced boundary layer separation These phenomena are driven by both inviscid and viscous forces A model plume will produce the correct inviscid effects if it is the correct size and shape and is in the proper location The viscous effect will be correct if the mixing of the approach flow with the exhaust gas is correctly simulated

The application of similarity parameters to Space Shuttle power-on testing has been biased by consideration of test facility capabilities and model design requirements Items which have influenced the application of simulation parameters are:

- Model nozzle exit plane diameter and location fixed by model scale
- Overall length of the model nozzles constrained by air plenum design and vehicle configuration
- SRM model nozzle throat diameter constrained by external aerodynamic configuration considerations, and
- Room temperature air used as simulant gas

The primary influence each of these items exerts is to constrain the model geometry. However, the use of unheated air as the simulant gas makes simultaneous matching of the inviscid and viscous similarity parameters impossible The inviscid similarity conditions were, consequently, assumed to be the dominant factors influencing exhaust plume simulation Model nozzles for use in simulating SRM and SSME exhaust plumes were designed, therefore, on the premise of satisfying only the inviscid simulation conditions, i e , defining those operating conditions whereby the model nozzle exhaust plumes matched the prototype plume shapes. The effects of the viscous similarity parameter on plume similitude were then addressed qualitatively

In addressing the problem of simulating full-scale exhaust plume shapes in scale model tests, two basic problem areas must be considered: (1) defining the full-scale exhaust plume characteristics; and (2) selecting and applying the appropriate similarity criteria to determine model requirements. An exact definition of the full-scale exhaust plume shapes in the region where plume characteristics may influence the flow adjacent to the vehicle is an impossible task with state-of-the-art analytical tools This results primarily from the complexity of the approach flow which the plumes "see" and the interaction which occurs between the individual plumes. Both of these effects produce three-dimensional plume shapes which, in general, cannot be treated satisfactorily using analytical techniques. Further complications are imposed by the presence of solid particles in the SRM nozzle and exhaust plumes The particles give up heat to the surrounding flow and influence the gas plume via drag forces These effects combine to produce lower local Mach numbers in the two-phase medium than would be experienced in a similar single phase flow Simplifying assumptions are therefore required to generate full-scale plume shapes with existing analytical tools to use as the baseline for the simulation

The complexity of the gasdynamic phenomena associated with base pressure or the plume-induced separation problem negates a completely analytical treatment Therefore, a series of experimental programs was undertaken to define the power-on Space Shuttle launch vehicle aerodynamic characteristics Conducting a power-on experimental program requires scaling or simulating the effects of the full-scale propulsion system on the vehicle

Three basic techniques exist for simulation of the exhaust plumes These are:

1 Scale models flowing prototype combustion gases as the working fluid — denoted as "hot flow" testing

2 Scale models flowing simulant gases as the working fluid — denoted as "cold flow" testing, and

3 Scale models whose gaseous plumes are simulated with a solid shape.

Each of these techniques has been applied, and each has inherent advantages and disadvantages. Hot flow testing offers the advantage of matching the thermochemistry of the exhaust gas (gaseous only or two phase) comprising the plume but is complex and costly. Cold flow testing offers simplicity in gas handling but generally ignores simulation of thermochemistry effects.

A variation on this technique, "warm gas" testing, is possible where the simulant gas is heated in an effort to match the full-scale thermodynamic variation Finally, the simplest approach is to model the plume with a solid shape This approach has the disadvantage, however, of not reproducing the shear layer mixing between the freestream flow and the exhaust plume gases and is the least desirable simulation approach when near field plume effects are to be assessed. Additional discussion of the problems associated with scale model exhaust plume simulation is given in Refs. 1-1 through 1-7

The goal of the NASA-MSFC Plume Technology Program has been to select and design a set of carefully controlled experiments which will provide adequate data for a systematic investigation of the pertinent engineering parameters necessary for prototype ground testing These experimental results have been analyzed extensively to determine the simulation parameters which would provide the simplest and best variables for use in establishing prototype flowfield simulation

The plume technology experimental program is outlined in Table 1-1 and includes the overall scope of the program This report details the results of the analysis of tests MA 10F, MA 11F, FA 11, FA 20, FA 22 and FA 23 which addressed the problem of base pressure correlation through hot and cold testing of Freon, air and solid propellant exhaust gases for single and triple nozzle configurations and triple-body configurations

The data base resulting from the technology test series and shuttle scale model "hot" flow tests covered a somewhat narrow range of test parameters and, in addition, did not include Mach numbers between 1.46 and 3 48 This data base was subsequently augmented with analytical predictions of base pressures for a single nozzle, single body configuration at a freestream Mach number of 2.0

This report presents a detailed development of the base pressure similarity parameters and a description of the experimental data base utilized in correlation analysis. Also, the methods used to determine the nozzle exit flowfield properties used in the similarity parameter analysis are presented Finally, the methods of application of the base pressure similarity parameters to test procedures are discussed.

Table 1-1

PLUME TECHNOLOGY EXPERIMENTAL PROGRAM

Test No.	Test Type	Facility	Date
MA 10F	Freon and Air Base Pressure[a]	MSFC 14" TWT	09-73
MA 11F	Solid Propellant Base Pressure[a, e]	MSFC 14" TWT	12-73
FA 15	Completes the Test Matrix of MA 10F and MA 11F (First Use of Helium as a Simulant Gas)[c]	MSFC 14" TWT	04-77
FA 11	Triple Nozzle Base Pressure[a]	MSFC 14" TWT	02-74
FA 19	Freon and Air Flare Effects on Base Pressure[c]	MSFC 14" TWT	06-77
FA 6	Freon and Air Plume-Induced Separation (Single and Triple Body)[d]	Ames 6' x 6'	7-74
FA 20	Replaces FA 6 where Applicable (Triple-Body Only)[a]	AEDC 4T	10-75
FA 7	Solid Propellant Plume-Induced Separation[b]	Ames 6' x 6'	8-74
FA 22	Replaces FA 7 Base Pressure[a]	AEDC 4T	7-75
FA 12	Pilot Jet Interaction Flow Separation	MSFC 14" TWT	3-74
FA 13	Transverse Jet Interaction Flow Separation	MSFC 14" TWT	9-75
FA 23	Solid Propellant (Triple Body Only)[a]	Ames 11' x 11' (UPWT)	7-76

[a]Data analyzed in this report.

[b]Faulty transducers; all data considered questionable

[c]Qualitatively, data compare with data of MA 10F and MA 11F Quantitatively, data do not compare due to increased exhaust plume blockage that resulted from primary tunnel modifications

[d]All data for freestream Mach numbers ≤ 1.3 are questionable.

[e]All data for freestream Mach number ≤ 1.5 are questionable.

2 EVALUATION AND DEFINITION OF THE EXPERIMENTAL DATA BASE

This section presents a detailed definition of the experimental data base used in the similarity analysis. The basic objective is to provide a consistent data set for future investigators and outline the evaluation procedure used to arrive at the final data set presented

2 1 EVALUATION OF EXPERIMENTAL DATA BASE

Before an attempt can be made to develop a base pressure similarity parameter using experimental data, it is first necessary to arrive at an experimental data base that contains only reliable data Therefore, all data that are either "obviously" not correct or somewhat "questionable" must be discarded Some of the methods used to evaluate the experimental data will be discussed below It should be noted that the methods used were a function of the information available and that not all data were evaluated by the same methods

2 1.1 Examination of the "Basic Data"

The first method used to evaluate the experimental data is to examine the "basic data" for each of the nozzle geometries tested In this report, "basic data" refers to the variation of PB/P_{∞} with PC/P_{∞} (see Figs 2-1 through 2-4) Figure 2-1 presents an example of a "basic data" plot containing questionable data Figures 2-2 through 2-4 are the basic data after the questionable points have been removed The data in question are those points that do not fall along a smooth curve formed by most of the points for a given nozzle Such questionable points often indicate possible liquefaction in the exhaust plume, or a bad chamber pressure measurement CF_4 data with variable TC do not meet the "smooth curve" criteria This is attributed to real gas effects (γ vs TC) and for that reason the data are considered acceptable and were retained for development of the base pressure similarity parameters

Point 1 in Fig 2-1 corresponds to an experimental test run with a high chamber pressure and low chamber temperature Such a set of chamber conditions often result in liquefaction occurring in the nozzle This can be illustrated by referring to Fig 2-5 (exerpted from Ref. 2-1) which presents a P-T diagram for the isentropic expansion of air from several nozzle chamber conditions. Included on Fig 2-5 are the saturation curves for O_2, N_2 and air To the left of these curves condensation is possible Considering the nozzle expansion process from a given set of chamber conditions to some freestream or ambient pressure (base pressure) the nozzle isentrope can be followed from right to left. When this isentrope crosses the vapor pressure curves, supersaturation occurs and liquefaction of the gaseous exhaust plume may occur Whenever possible, the existance of liquefaction in the exhaust plume was verified by the comparison of schlieren photographs with analytical predictions of plume shape. (Confidence in such comparisons between analytical and experimental plume shapes has been gained during several previous studies performed by personnel in Lockheed-Huntsville's Fluid Technology & Application Section) Figure 2-6 is an example of a schlieren photograph in which liquefaction has taken place in the exhaust plume (Ref. 2-1). Liquefaction is indicated when the analytically predicted plume boundary and shock location do not agree with the experimental results As the chamber pressure is increased while maintaining a low chamber temperature, the amount of liquefaction increases and results in larger differences between the analytically calculated, and experimental plume shape. This is depicted in Figs 2-7, 2-8 and 2-9 Liquefaction changes the fundamental physical parameters which govern the base pressure and is therefore an additional parameter in the simulation analysis which we do not have data, or techniques to analyze. Therefore, all data determined to contain the effects of liquefaction were not used in the development of the base pressure similarity parameters

Point 2 in Fig. 2-1 corresponds to an experimental test run in which the pressure tubing leading to the chamber pressure transducer was subject to some form of blockage or leaking which resulted in a measured chamber pressure lower than actual Such anomalous pressure readings are often noted in the experimental run log and as such, represent further justification for deleting the data point from the analysis.

2 1 2 Examination of the Experimental Run Log

The experimental run log is very useful in gaining insight to what happens during a test. In addition to the usual information recorded such as test configuration and design test conditions, brief remarks on anomalies such as liquefaction, blocked or leaking pressure transducers, technicial errors, etc , are noted that normally would not appear in the Standard Operators Log and special Propellant Logs maintained by the tunnel staff Though these notes are not used as the sole justification for deleting a data point, they are often used as the final justification for deleting a data point that is determined to be questionable by some other method

2.1 3 Selection of Representative Data

Selection of data most representative of a particular experimental run requires the selection of a specific time interval during each run that represents a steady state condition The selection procedure may take any one of several forms The procedure may be: (a) purely mathematical as in the case of REMTECH's FA 23 data selection techniques (Ref 2-2); (b) a combination of the physical examination of strip charts and digital data, and mathematical techniques as in the case of REMTECH's MA 11F data selection techniques (Ref 3-3), or (c) a purely physical examination of strip charts and/or digital data (most often used in this study).

The selection procedure chosen is a function of: (1) the time available to analyze each experimental run, the amount of data available for each run (if only a small number of measurements are recorded a mathematical analysis becomes meaningless), and (3) the degree of accuracy desired

For this analytical study, the points determined most representative were chosen by physical examination of strip charts and/or digital data and whenever possible taken directly from work performed by REMTECH.

2.1 4 Physical Examination of Experimental Data

During an experimental run, questionable data are sometimes recorded but not noted in the experimental run log Some of these data are immediately apparent and can be deleted easily during a physical examination of strip charts and/or digital data The remaining questionable data are more difficult to identify When such questionable data are used in a similarity parameter analysis, the resulting plots are a combination of data that correlates and data that do not correlate The question then arises, "Is the similarity parameter not valid for this set of data; or are the data bad?" Such a question is difficult to address and can only be answered after a high degree of confidence in the similarity parameter has been established Though this confidence level has been established for the similarity parameters developed in this study, it should be noted that no data were deleted merely because it would not correlate Any data that have been deleted were deleted only after the reason for doing so has been justified.

2 1 5 Evaluation of the Experimental Test Apparatus

A document (Ref 2-4) summarizing the Space Shuttle aerodynamic/plume simulation data obtained during the various tests of the Plume Technology experimental program will be published by REMTECH in late 1978 This document discusses both qualitatively and quantitatively the experimental test apparatus and data of the plume technology experimental program (see Table 1-1 notes for example data analyses). As such, the document proved to be an invaluable guide in arriving at an experimental data base that contains only reliable data to be used in the development of a base pressure similarity parameter

2 2 DEFINITION OF EXPERIMENTAL DATA BASE

The following paragraphs present a detailed definition of the experimental data base used in the development of the base pressure similarity parameters This data base contains only reliable data, all data that are either "obviously" bad or "questionable" have been discarded By presenting this data base, it is hoped that future investigators will use the same experimental data base thereby: (1) eliminating the need for reevaluating the experimental data, (2) maintaining the continuity of this analytical investigation, and (3) eliminating the possibility of unwarranted conclusions based on erroneous data

2 2 1 Nozzle Geometry Definition and Data Accuracy

In the development of the base pressure similarity parameters, it is of paramount importance that the performance of the nozzles be accurately known for use in the data analysis. This was realized from the outset of the Plume Technology Program based on previous experience in testing small nozzles in the wind tunnel Therefore, a concerted effort was maintained to provide information from which accurate nozzle performance could be determined Procedures included conducting a complete mechanical inspection of the nozzle internal geometry, then each nozzle was calibrated by flowing air at various PC/P(INF) levels into a quiescent evacuated chamber while measuring PC, TC, nozzle internal wall pressures, and P(INF) Schlieren photos of the plumes were also recorded for reference purposes and comparisons with analytical predictions Table 2-1 presents a summary of the nozzle geometries, and pressure tap locations for each nozzle considered in this analysis To verify the analytical results for each nozzle it is necessary to compare the analytical predictions with the experimental nozzle wall pressure distribution Transducer accuracy is an important consideration in the analytical/experimental data comparison involving pressure measurements Table 2-2 presents a summary of the transducer accuracies for each test of the plume technology program considered in this analysis. The actual procedures followed to verify nozzle gasdynamic performance and to determine nozzle exit plane flowfield properties will be discussed in Section 3

2.2 2 Plume Technology Program Test Number MA 10F Experimental Data Base

The MA 10F test program was conducted in the Marshall Space Flight Center's 14 x 14-inch trisonic wind tunnel using two models, the first being a strut mounted cone-ogive-cylinder model with a fineness ratio of 9 Model surface pressures, model base pressures, model plenum chamber and model nozzle wall pressure data were obtained at Mach numbers of 0 9, 1 2, 1 46 and 3 48 The exhaust plumes were generated by using air as the simulant gas, or Freon-14 (CF_4) as the prototype gas, over a chamber pressure range from 0 to 2000 psia and a total temperature range from 50 to 600 F

Three single nozzles and one triple nozzle were used for the air tests, and one single and one triple nozzle were used for the CF_4 tests All of the nozzles were conical and ranged in area ratio from 3 5 to 8 0 with wall angles from 15 to 35 deg The location of each nozzle exit plane with respect to the model base and the ratio of exit diameter to the base diameter of each type (single or triple) nozzle was held constant

In addition to the strut model, a sting-mounted model of the same configuration was also tested prior to the gaseous plume test to assess strut and blockage effects Number 60 carborundum grit was used on each model to ensure a turbulent boundary layer. All the testing was conducted at a 0 degree angle of attack and yaw

A detailed definition of the test hardware, test conditions and data acquired during the MA 10F test program is presented in Ref 2-5 Tables 2-3 and 2-4 present a definition of the MA 10F single nozzle and triple nozzle experimental data base used in the development of the base pressure similarity parameters This data base contains only reliable data; all data that is either "obviously" bad or only "questionably" bad has been discarded. Tables 2-3 and 2-4 present both experimental data and analytical results determined from the data The values of base pressure presented were measured at the outermost base pressure tap away from the strut in an effort to minimize the effects of disturbances on base pressure measurements The nozzle exit plane flowfield properties and corresponding jet conditions presented in these tables are calculated following the procedures described in Section 3 Jet conditions are those conditions that exist on the plume boundary at the nozzle exit plane, and are calculated assuming that the jet pressure is equal to the model base pressure

2 2 3 Plume Technology Program Test Number FA11 Experimental Data Base

The FA 11 test program was conducted in the Marshall Space Flight Center's 14 x 14-inch trisonic wind tunnel using a strut-mounted cone-ogive, cylinder model with a fineness ratio of 9 Model surface pressures, model base pressures, model plenum chamber and model nozzle wall pressure data were obtained at Mach numbers of 0 5, 0 7, 0 9, 1 2 and 1 46 The exhaust plumes were generated by using air as the simulant gas over a chamber pressure range from 0 to 2000 psia and a total temperature range from 50 to 600 F

Two single nozzles and four triple nozzles were used for the tests Both single nozzles were conical, having area ratios of 3 5 and 6 5 Three triple nozzles were conical, having area ratios of 4.0, 6 0 and 8 0, and one contoured triple nozzle had an area ratio of 5 3 The location of each nozzle exit plane with respect to the model base and the ratio of exit diameter to the base diameter of each type (single or triple) nozzle was held constant

Number 60 carborundum grit was used to ensure a turbulent boundary layer All the testing was conducted at a 0 degree angle of attack and yaw

A detailed definition of the test hardware, test conditions and data acquired during the FA 11 test program is presented in Ref 2-6 Table 2-4 presents a definition of the FA 11 experimental data base used in the development of the base pressure similarity parameters This data base contains only reliable data, all data that are either "obviously" bad or only "questionably" bad have been discarded

Table 2-4 presents both experimental data and analytical results determined from the data The values of base pressure presented were measured at the outermost base pressure tap away from the strut in an effort to minimize the effects of any disturbances on base pressure measurements The nozzle exit plane flowfield properties and corresponding jet conditions presented in these tables are calculated following the procedures described in Section 3 Jet conditions are those conditions that exist on the plume boundary at the nozzle exit plane, and are calculated assuming the jet pressure is equal to the model base pressure. A definition of each of the variables is given in the nomenclature section of this report

2 2 4 Plume Technology Program Test Number MA 11F Experimental Data Base

The MA 11F test program was conducted in the MSFC's 14 x 14-inch trisonic wind tunnel using a variety of 15 deg half-angle conical nozzles in the base of a strut mounted ogive-cylinder body The MA 11F test program was conducted to measure the aerodynamic effects of plumes from hot combustion gases in the presence of an external flow field and to provide data to compare with the effects observed using cold gas plumes. Model surface pressures, model base pressures, model plenum chamber pressure, model nozzle wall pressure data, and (for transonic Mach numbers) pressures in the tunnel test section plenum surrounding the porous walls were obtained at nominal Mach numbers of 0 9, 1 2 and 1.5 Schlieren photographs were taken for all tests at Mach 3 5, and for all air calibration tests The exhaust plumes were generated using propellants containing 16% Aℓ (UTP-3001) and 2% Aℓ (ANB-3335) as the simulant gas over a chamber pressure range from 400 to 1800 psia

Three single nozzles were used for the test — two each with an area ratio of 8 and the third with an area ratio of 4 Nozzle area ratios of 4 and 8 were used to determine the effects of different plume shapes at constant pressure ratios The exhaust plume for the nozzle having an area ratio of 4 was generated using UTP-3001. The exhaust plumes for the nozzles having an area ratio of 8 were generated using both UTP-3001 and ANB-3335. The propellants containing 16% and 2% Aℓ were used to assess the effects of particles and different particle concentrations on plume aerodynamic interactions

A detailed definition of the test hardware, test conditions and data acquired during the MA 11F test program is presented in Ref 2-3 The data acquired during the MA 11F test program were evaluated and found to be very questionable (Ref 2-4) Steady state conditions could not be achieved during transonic testing because the controller for the plenum suction could not stabilize in less than 0 4 sec. Furthermore, for the case of M_∞ = 3 48, the accuracy of the pressure transducers used to measure base pressure was such (see Table 2-2) that the uncertainty in the ratio PB/P_∞ was too great to make any meaningful evaluation of our similarity parameters (see Fig 4-7) The MA 11F data were therefore determined to be of little value in the development of the base pressure similarity parameters Table 2-5 presents a definition of the MA 11F data base considered in the analysis These data are presented for completeness only and were not used in the development of the base pressure similarity parameters. Table 2-5 presents both experimental data and analytical results determined from the data The values of base pressure presented were measured at the outermost base pressure tap away from the strut in an effort to minimize the effects of any disturbances on base pressure measurements The nozzle exit plane flowfield properties and corresponding jet conditions presented in these tables are calculated following the procedures described in Section 3. Jet conditions are those conditions that exist on the plume boundary at the nozzle exit plane, and are calculated assuming that the jet pressure is equal to the model base pressure A definition of each of the variables is given in the nomenclature section of this report.

2 2 5 Plume Technology Program Test Number FA 22 Experimental Data Base

The FA 22 test program was conducted in the Aerodynamic Wind Tunnel (4T) of the AEDC Propulsion Wind Tunnel Facility (PWT) The FA 22 test program was conducted to replace the FA 7 base pressure data because those data were determined to be very questionable (Ref. 2-4) The FA 7 test program is reported on in Ref 2-7 The objectives of the FA 22 test program were to complete the test matrix originally planned for the MA 11F test program (where the Mach numbers 0.9 to 1 5 were omitted), and to expand upon the data base to higher values of plume pressure ratio (chamber pressure divided by freestream static pressure)

The model and support hardware were similar to the previously described test programs, with only small modifications made to the support strut to house the strain gage pressure transducers A total of 20 solid propellant rocket motor firings were made at freestream Mach numbers of 0 5, 0 9 and 1 2 The gas generator was operated in a short duration mode of approximately 300 msec with propellants containing 2% (ANB-3335) or 16% (UTP-3001) aluminum Conical nozzles of 15 deg half-angle were tested with area ratios of 4 and 8 at nominal chamber pressures from 300 to 1350 psia

A detailed definition of the test hardware, test conditions and data acquired during the FA 22 test program is presented in Ref 2-8 The data acquired during the FA 22 test program were evaluated Solid propellant contamination of the pressure tubing leading to the chamber pressure transducer was noted during some of the firings of the test program The degree of contamination that took place and its effect of reducing measured chamber pressure to some value lower than actual is not known for each of the firings This must be kept in mind when evaluating a prospective base pressure similarity parameter (see Figs 4-5 and 4-6) Table 2-6 presents a definition of the FA 22 experimental data base used in the development of the base pressure similarity parameter analysis. Table 2-6 presents both experimental data and analytical results determined from the data The values of base pressure presented were measured at the outermost base pressure tap away from the strut in an effort to minimize the effects of any disturbances on base pressure measurements The nozzle exit plane flowfield properties and corresponding jet conditions presented in these tables are calculated following the procedures described in Section 3 Jet conditions are those conditions that exist on the plume boundary at the nozzle exit plane, and are calculated assuming that the jet pressure is equal to the model base pressure A definition of each of the variables is given in the nomenclature section of this report.

2 2 6 Plume Technology Program Test Number FA 20 Experimental Data Base

The FA 20 test program was conducted in the Aerodynamic Wind Tunnel (4T) of the AEDC Propulsion Wind Tunnel Facility (PWT) The FA 20 test program was conducted to replace the FA 6 triple body base pressure data which were determined to be questionable (Ref. 2-4) As such, the FA 20 base pressure test data is the only reliable triple body data obtained to date in the Plume Technology Program

Cold flow Space Shuttle launch vehicle tests have shown that the ET base pressure is dominated by the SRB plumes The objective of the FA 20 test program was to determine the effects of the solid rocket exhaust plumes on the base pressure field of a configuration similar to the Space Shuttle ET/SRB combinations Pressure distributions on two external tank base configurations and rocket boosters were obtained at Mach numbers from 0 5 to 2 0 The exhaust plumes of the solid rocket boosters were generated by using heated, high pressure air or CF_4 over a chamber pressure range from 400 to 1500 psia and a total temperature range from 200 to 500 F

Three different pairs (left SRB and right SRB) of conical nozzles were used for the tests All of the nozzles were conical and ranged in area ratio from 5 to 8 with wall angles from 15 to 35 deg (see Table 2-1) All configurations were tested at a constant wind tunnel total pressure of 1440 psfa except for the $A/A^* = 8$ nozzles at 400 psia chamber pressure where the total pressure had to be reduced for Mach numbers below 1 2 to prevent flow separation in the nozzles

A detailed definition of the test hardware, test conditions and data acquired during the FA 20 test program is presented in Ref 2-9 Table 2-7 presents the FA 20 experimental data base used in the development of the base pressure similarity parameters. This data base contains only reliable test data; all data that are either "obviously" bad or questionable have been discarded

Table 2-7 presents both experimental data and analytical results determined from the data The values of base pressure presented were measured: (1) on the left SRB at the outermost base pressure tap away from the ET in an effort to minimize the effects of any disturbances on the base pressure measurements, and (2) at the center of the ET base The nozzle exit plane flowfield properties and corresponding jet conditions presented in these tables are calculated following the procedures described in Section 3 Jet conditions are those conditions that exist on the plume boundary at the SRB nozzle exit plane, and are calculated assuming that the jet pressure is equal to the SRB base pressure. A definition of each of the variables is given in the nomenclature section of this report

2.2 7 Plume Technology Program Test Number FA 23 Experimental Data Base

The FA 23 test program was conducted in the NASA-Ames Unitary 11 x 11-Foot Transonic Wind Tunnel. The objective of the FA 23 test program was to determine the effects of solid propellant exhaust plumes on the base pressure of the triple body configuration, and to provide data for comparison with the effects observed in the FA 20 (gaseous only exhaust plume) test program

Pressure distributions on the external tank configuration and the two solid rocket boosters were obtained at Mach numbers 0 5, 0 9, 1.05, 1 2 and and 1 3 at plume pressure ratios (chamber pressure divided by freestream static pressure) ranging from 11 to 89. A total of 28 solid propellant rocket motor test firings were made The gas generator was operated in a short duration mode of approximately 200 msec The propellant contained 16% aluminum (LPC-580C). This propellant is similar to that developed for the Space Shuttle SRBs Conical nozzles of 20 deg half-angle and an area ratio of 3 were tested at nominal chamber pressures of 125, 150 and 215 psia.

A detailed definition of the test hardware, test conditions and data acquired during the FA 23 test program is presented in Ref 2-10 The data acquired during the FA 23 test program were evaluated and found to be unusable in the development of the base pressure similarity parameter The data acquired during FA 23 testing appears to be acceptable when examined in terms of the overall operation of the model solid propellant rockets, instrumentation and data recording system However, because of lack of nozzle geometric information and probable plugging of the nozzle wall taps during the solid propellant runs, the gasdynamic performance of the nozzles tested could not be verified by comparing the analytical and experimental data. Table 2-8 presents a definition of the FA 23 data base considered in the analysis These data are presented for completeness only and were not used in the development of base pressure similarity parameters.

Table 2-8 presents both experimental data and analytical results determined from the data The values of base pressure presented were measured: (1) on the left SRB at the outermost base pressure tap away from the ET in an effort to minimize the effects of any disturbances on the base pressure measurements, and (2) at the center of the ET base The nozzle exit plane flowfield properties and corresponding jet conditions presented in these tables are calculated following the procedures described in Section 3 Jet conditions are those conditions that exist on the plume boundary at the SRB nozzle exit plane, and are calculated assuming that the jet pressure is equal to the model SRB base pressure A definition of each of the variables is given in the nomenclature section of this report

Table 2-1

NOZZLE GEOMETRIES AND PRESSURE TAP LOCATIONS USED IN THE ANALYTICAL CALCULATIONS OF THIS REPORT

Test No	Simulant Gas	Nozzle No	Area Ratio	θ_{lip} (deg)	R_t (in)	R_e (in)	R_c (in)	X_L (in)	X_1 (in)	X_2 (in)	X_3 (in)
MA10F	CF_4	1	7 967	15 12	1235	3486	780	9366	0547	3839	7289
MA10F	Air	2	3 571	25 03	1852	3500	750	5194	0548	1139	1728
MA10F	Air	4X	6 518	34 77	1365	3485	500	4619	0557	1057	1543
MA10F	CF_4	5A	8 291	15 03	0705	2030	390	5449	0693	0708	
FA11	Air	5R	8 296	14 83	0710	2045	385	5543	0632	0645	
MA10F	Air	6A	4 040	24 62	1005	2020	400	3088	0597	0619	
FA11	Air	8A	4 060	10 12	0995	2005	410	6022	0381	1734	
MA11F	UTP-3001	S/N-1	7 594	14 95	1265	3486	450	891	051	384	753
MA11F	UTP-3335	S/N-2	8 662	14 72	1265	3723	450	994	047	376	759
MA11F	UTP-3001	S/N-3	4 067	15 18	174	3509	660	740	043	263	542
FA22	UTP-3001 ANB-3335	5	8 003	15 00	124	3508	445	905	033	355	741
FA22	UTP-3001 ANB-3335	6	8 102	15 00	125	3558	430	918	030	356	743
FA22	UPT-3001	7	3 984	15 00	173	3453	660	730	030	252	508
FA20	Air	1-Left	8 091	35 00	1125	3200	4455	4368	041	136	251
FA20	Air	1-Right	8 040	35 30	1125	3190	4500	438	043	140	247
FA20	CF_4	2-Left	8 011	14 90	112	3170	4547	8299	049	383	734
FA20	CF_4	2-Right	7 986	15 00	112	3165	4446	819	047	433	726
FA20	Air	3-Left	4 918	25 20	1425	3160	570	4961	042	102	161
FA20	Air	3-Right	4 918	24 90	1425	3160	570	494	039	100	158
FA23	LPC-580C	21A	3 099	20 40	8785	1 5465	2 460	2 2524	0546	4159	7633
FA23	LPC-580C	21B	3 087	20 23	8787	1 5439	2 943	2 446	0649	4175	7741

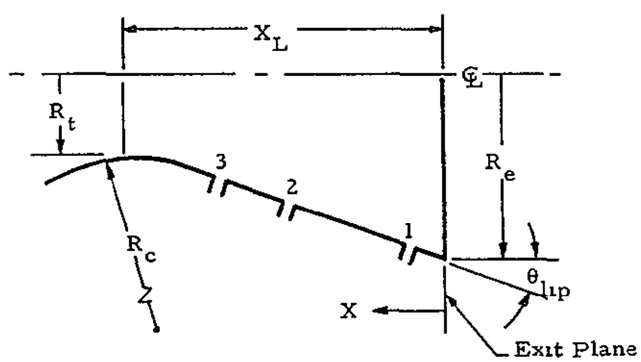

Table 2-2

ESTIMATED TRANSDUCER TOLERANCES FOR EACH TEST OF THE PLUME TECHNOLOGY PROGRAM CONSIDERED IN THIS ANALYSIS

(Tolerances shown are in ± psi, except those marked * shown in $\pm P/P_\infty$

Facility	AEDC 4T		MSFC 14" TWT			Ames 11'x11' (UPWT)
Test No	FA20	FA22	MA10F	MA11F	FA11	FA23
• Tunnel Conditions						
Freestream Total Pressure			050	050	05	
Freestream Static Pressure	020[a] 054[b]	020[a] 054[b]	015	015	015	
• Model Surface and Base Pressure	010[a] 020[b]	025	113[f] 038[g]	378	022	113
• Model Plenum Chamber Conditions	1 5*[a] 2 4*[b]	9 2	18 75	16 0	3 0[h] 750[i] 225[j]	7 5
• Nozzle Wall Pressures	2 0[c] 2[d] 1[e]	2 59[c] 1 25[d] 36[e]		3 47		375
No 1			3 75[c] 1 13[d] 227[e]			
No 4X & 5			227			
No 2 & 6			1 13			
No 5 & 8					045[k] 225[ℓ]	

a $M_\infty = 9$

b $M_\infty = 1\ 20$

c Upstream Tap

d Middle Tap

e Downstream Tap

f $M_\infty = 9, 1\ 2, 1\ 46$

g $M_\infty = 3\ 48$

h $500 \leq P_c \leq 2000$ psi

i $150 \leq P_c < 500$ psi

j $P_c < 150$ psi

k $P_c < 500$ psi

ℓ $1000 \leq P_c \leq 2000$

Table 2-3

MA 10F SINGLE NOZZLE CONFIGURATION EXPERIMENTAL DATA BASE

NOZZLE PARAMETERS- NOZZLE 1 - CF4, A/A*=7.967, THETA=15.12, M=.9

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
518/0	.8636	.8945	115.849	.9655	.4080	.0075	2.1165
519/0	.8572	.8929	105.703	.9600	.4329	.0081	1.9801
538/0	.9440	.9542	176.575	.9893	.2801	.0053	3.3708
539/0	.9134	.9309	148.417	.9812	.3311	.0062	2.7583
540/0	.8668	.8964	112.116	.9670	.4148	.0077	2.0897
541/0	.8268	.8756	79.601	.9443	.5518	.0104	1.4985
550/0	.8865	.9093	114.222	.9749	.3977	.0078	2.2291

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
518/0	694.8	1221.4	9.43	9.10	22.31	.448+00	689.2	69.62	2.994
519/0	774.6	1120.3	9.46	9.09	20.99	.369+00	721.7	69.54	2.982
538/0	885.5	1876.6	10.14	10.03	35.82	.540+00	796.3	69.02	2.979
539/0	887.2	1569.3	9.84	9.66	29.17	.451+00	785.3	69.73	2.990
540/0	865.7	1188.2	9.50	9.19	22.15	.350+00	763.6	69.79	2.983
541/0	861.7	853.5	9.39	8.87	16.07	.252+00	752.3	70.03	2.977
550/0	1000.3	1224.0	9.74	9.50	23.89	.312+00	819.2	69.63	2.957

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(0) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
518/0	.909	974.5	18.00	10.54	.185-02	557.8	478.7	.515+07
519/0	.904	969.5	18.00	10.60	.186-02	557.3	479.0	.515+07
538/0	.901	969.0	17.99	10.63	.185-02	559.7	481.5	.511+07
539/0	.906	973.8	18.00	10.57	.184-02	559.9	480.9	.512+07
540/0	.904	972.3	18.01	10.60	.185-02	560.1	481.4	.512+07
541/0	.894	962.2	18.02	10.72	.187-02	559.1	482.0	.511+07
550/0	.893	963.0	18.00	10.72	.186-02	560.9	483.7	.508+07

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
.8636	9.105	328.2	.711-02	474.0	1628.6	3.436	82.37	27.87	2.835
.8572	9.085	399.1	.582-02	517.1	1749.9	3.384	81.71	27.28	2.853
.9440	10.033	450.8	.569-02	546.2	1952.4	3.574	87.33	33.43	3.051
.9134	9.658	464.8	.531-02	553.8	1940.6	3.504	85.68	31.07	2.999
.8668	9.186	467.4	.502-02	555.3	1886.0	3.397	82.75	28.08	2.909
.8268	8.865	488.4	.463-02	566.5	1844.7	3.257	78.96	24.05	2.800
.8865	9.500	573.5	.423-02	609.6	2060.5	3.380	83.50	28.99	2.946

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Table 2-3 (Continued)

NOZZLE PARAMETERS- NOZZLE 2 - AIR, A/A*=3.571, THETA=25.03, M=.9

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
352/0	1.0375	1.0429	149.807	.9948	.2256	.0069	4.5996
353/0	.9939	1.0049	114.896	.9891	.2791	.0087	3.5611
354/0	.9393	.9593	81.738	.9792	.3674	.0115	2.5566
356/0	.8457	.8916	43.163	.9485	.6199	.0196	1.3643
357/0	.9333	.9520	78.663	.9804	.3790	.0119	2.4623
358/0	.9954	1.0051	116 057	.9983	.2768	.0086	3.5955
359/0	1.0292	1.0341	141.205	.9953	.2369	.0073	4.3447

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
352/0	712.0	1583.9	11.03	10.97	48.63	.187+00	1308.1	48.20	2.920
353/0	707.8	1217.1	10.64	10.53	37.72	.144+00	1?04.2	48.08	2.914
354/0	701.6	865.0	10.15	9.94	27.06	.103+00	1298.5	47.96	2.908
356/0	958.5	465.5	9.62	9.12	14.71	.407-01	1517.7	47.82	2.901
357/0	966.2	836.5	10.12	9.92	26.18	.726-01	1523.8	47.95	2.907
358/0	989.4	1234.4	10.69	10.59	38.24	.105+00	1542.0	48.08	2.914
359/0	982.8	1500.7	10.99	10.94	46.17	.128+00	1536.8	48.17	2.919

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(O) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
352/0	.907	975.0	18.01	10.57	.184-02	560.5	481.4	.512+07
353/0	.905	974.0	18.02	10.59	.184-02	561.1	482.1	.511+07
354/0	.906	975.0	18.02	10.58	.184-02	561.3	482.1	.511+07
356/0	.888	959 8	18.01	10.78	.186-02	562.8	486.1	.505+07
357/0	901	972.7	18.01	10.63	.184-02	563.6	484.8	.507+07
358/0	.901	970.5	18.00	10.64	.185-02	561.9	483.5	.508+07
359/0	.902	972.1	18.01	10.63	.184-02	562.6	483.9	.508+07

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
1.0375	10.969	172.0	.535-02	642.9	2547.3	3.962	65.30	42.13	2.830
.9939	10.528	182.2	.485-02	661.7	2513.1	3.798	63.03	39.98	2.713
.9393	9.940	195.8	.426-02	686.0	2465.2	3.593	60.00	37.07	2.567
.8457	9.121	311.6	.246-02	865.4	2788.0	3.222	53.87	31.08	2.301
.9333	9.925	272.2	.306-02	808.8	2887 8	3.571	59.65	36.73	2.550
.9954	10.587	254.0	.350-02	781.3	2972.6	3.804	63.12	40.07	2.717
1.0292	10.938	240.9	.381-02	760.8	2985.8	3.924	64.78	41.64	2.803

Table 2-3 (Continued)

NOZZLE PARAMETERS- NOZZLE 4X- AIR, A/A*=6.518, THETA=34.77, M=.9

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
115/0	.7745	.8525	38.638	.9085	2.3015	.0200	.3365
116/0	.8207	.8727	71.577	.9404	1.3567	.0115	.6049
117/0	.8854	.9097	105.477	.9733	1.0252	.0084	.8636
118/0	.9340	.9469	138.395	.9864	.8492	.0067	1.0999
119/0	.9814	.9836	172.364	.9978	.7364	.0057	1.3327
150/0	.9622	.9700	163.885	.9920	.7542	.0059	1.2757
151/0	.9283	.9417	133.754	.9858	.8691	.0069	1.0681
152/0	.8888	.9110	101.420	.9756	1.0670	.0088	.8330
153/0	.8417	.8799	79.160	.9566	1.2689	.0106	.6634
154/0	.7750	.8516	35.556	.9101	2.4958	.0218	.3105
155/0	.7757	.8520	34.860	.9104	2.5464	.0223	.3046
156/0	.8272	.8740	69.732	.9465	1.4033	.0119	.5895
157/0	.8924	.9159	106.824	.9743	1.0228	.0084	.8725
158/0	.9397	.9515	141.685	.9876	.8368	.0066	1.1229
159/0	.9712	.9783	172.203	.9927	.7300	.0056	1.3303
190/0	.9681	.9748	172.335	.9931	.7273	.0056	1.3310
191/0	.9289	.9513	138.947	.9765	.8407	.0067	1.1049
192/0	.8859	.9270	109.424	.9557	.9920	.0081	.8930
193/0	.8222	.8716	69.634	.9433	1.3965	.0118	.5888
194/0	.7678	.8497	38.193	.9036	2.3073	.0201	.3328
195/0	.7668	.8424	36.906	.9103	2.3819	.0208	.3219
196/0	.8205	.8653	72.397	.9482	1.3425	.0113	.6112
197/0	.8873	.9069	105.849	.9784	1.0242	.0084	.8664
198/0	.9277	.9380	133.515	.9890	.8693	.0069	1.0672
199/0	.9734	.9741	174.167	.9993	.7238	.0056	1.3448

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Table 2-3 (Continued)

NOZZLE PARAMETERS- NOZZLE 4X- AIR, A/A*=6.518, THETA=34.77, M=.9

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
115/0	659.9	410.8	9.06	8.23	3.58	.527-01	1259.3	62.96	3.793
116/0	701.6	752.9	9.18	8.63	6.36	.900-01	1298.5	63.2[illegible]	3.815
117/0	686.1	1123.4	9.69	9.43	9.20	.137+00	1284.1	63.60	3.838
118/0	684.2	1483.9	10.15	10.01	11.79	.182+00	1282.3	63.90	3.860
119/0	666.4	1825.5	10.42	10.39	14.11	.230+00	1265.5	64.19	3.881
150/0	762.5	1740.6	10.30	10.22	13.55	.191+00	1353.7	64.13	3.876
151/0	759.8	1425.5	10.04	9.89	11.38	.157+00	1351.3	63.86	3.857
152/0	756.9	1086.6	9.76	9.52	8.92	.120+00	1348.7	63.57	3.836
153/0	760.3	850.8	9.46	9.05	7.13	.939-01	1351.7	63.[illegible]	3.821
154/0	744.9	380.3	9.11	8.29	3.32	.428-01	1338.0	62.9	3.791
155/0	808.1	373.9	9.14	8.32	3.27	.388-01	1393.6	62.92	3.791
156/0	836.3	750.3	9.40	8.90	6.34	.753-01	1417.7	63.27	3.815
157/0	848.2	1153.4	9.89	9.64	9.42	.114+00	1427.7	63.62	3.840
158/0	856.0	1517.6	10.19	10.07	12.03	.149+00	1434.3	63.93	3.862
159/0	856.7	1836.0	10.43	10.35	14.18	.180+00	1434.9	64.19	3.881
190/0	942.7	1839.2	10.40	10.33	14.20	.164+00	1505.1	64.20	3.881
191/0	926.2	1476.6	10.11	9.87	11.78	.134+00	1491.9	63.90	3.860
192/0	922.0	1162.4	9.85	9.41	9.49	.106+00	1488.5	63.63	3.841
193/0	900.6	747.6	9.36	8.88	6.32	.696-01	1471.2	63.27	3.815
194/0	872.0	406.6	9.05	8.17	3.54	.391-01	1447.6	62.9[illegible]	3.793
195/0	992.3	393.9	8.99	8.18	3.44	.333-01	1544.2	62.9[illegible]	3.792
196/0	1026.2	765.5	9.15	8.68	6.46	.626-01	1570.4	63.[illegible]	3.816
197/0	1037.0	1128.1	9.67	9.46	9.23	.913-01	1578.6	63.60	3.839
198/0	1041.1	1413.4	9.93	9.82	11.30	.114+00	1581.8	63.85	3.856
199/0	1050.4	1842.3	10.30	10.30	14.23	.147+00	1588.8	64.20	3.882

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Table 2-3 (Continued)

NOZZLE PARAMETERS- NOZZLE 4X- AIR, A/A*=6.518, THETA=34.77, M=.9

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(O) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
115/0	.901	971.1	18.01	10.63	.185-02	561.6	483.1	.509+07
116/0	.911	979.4	18.01	10.52	.183-02	560.8	480.9	.512+07
117/0	.899	968.2	18.00	10.65	.185-02	560.6	482.5	.510+07
118/0	.893	962.3	18.00	10.72	.186-02	560.4	483.3	.509+07
119/0	.905	978.7	18.00	10.59	.182-02	567.0	487.2	.504+07
150/0	.901	970.3	17.99	10.62	.185-02	560.7	482.3	.510+07
151/0	.899	967.9	18.00	10.66	.185-02	560.7	482.7	.510+07
152/0	.894	963.3	18.00	10.71	.186-02	560.6	483.3	.509+07
153/0	.891	960.7	18.01	10.75	.186-02	560.4	483.5	.509+07
154/0	.896	964.3	18.00	10.70	.186-02	560.1	482.7	.510+07
155/0	.893	962.4	18.00	10.73	.186-02	561.0	483.9	.508+07
156/0	.889	959.2	17.99	10.76	.186-02	560.8	484.2	.507+07
157/0	.887	956.1	18.00	10.80	.187-02	560.9	484.3	.507+07
158/0	.894	963.7	18.00	10.71	.186-02	561.1	483.8	.508+07
159/0	.899	968.4	18.00	10.66	.185-02	561.6	483.5	.509+07
190/0	.898	967.2	18.02	10.67	.186-02	560.4	482.5	.510+07
191/0	.902	970.4	18.01	10.63	.185-02	560.5	482.1	.511+07
192/0	.902	971.0	18.01	10.62	.185-02	560.5	482.0	.511+07
193/0	.892	961.6	18.01	10.74	.186-02	560.3	483.3	.509+07
194/0	.900	968.8	18.01	10.65	.185-02	560.3	482.2	.511+07
195/0	.897	968.2	18.00	10.67	.185-02	562.6	484.5	.507+07
196/0	.907	976.0	18.01	10.57	.184-02	561.9	482.6	.510+07
197/0	.899	968.6	18.00	10.66	.185-02	561.8	483.7	.508+07
198/0	.905	974.9	18.01	10.59	.184-02	561.8	482.7	.510+07
199/0	.906	975.7	18.01	10.58	.184-02	562.1	482.8	.510+07

Table 2-3 (Continued)

NOZBLE PARAMETERS- NOZZLE 4X- AIR, A/A*=6.518, THETA=34.77, M=.9

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
.7745	8.234	215.9	.320-02	720.4	2309.7	3.206	53.59	25.32	2.290
.8207	8.633	195.7	.370-02	685.8	2465.5	3.595	60.03	31.52	2.568
.8854	9.430	175.1	.452-02	648.7	2478.0	3.820	63.34	34.51	2.729
.9340	10.015	164.0	.512-02	627.9	2500.0	3.982	65.55	36.42	2.844
.9814	10.394	152.2	.573-02	604.8	2485.7	4.110	67.22	37.81	2.936
.9622	10.219	175.7	.488-02	649.8	2655.4	4.087	66.92	37.58	2.919
.9283	9.893	183.6	.452-02	664.3	2631.2	3.961	65.28	36.19	2.829
.8888	9.523	195.5	.409-02	685.5	2597.2	3.789	62.89	34.10	2.706
.8417	9.047	207.6	.366-02	706.3	2577.1	3.649	60.84	32.25	2.606
.7750	8.289	249.7	.279-02	774.6	2439.4	3.149	52.57	24.30	2.250
.7757	8.320	272.4	.256-02	809.2	2537.0	3.135	52.31	24.04	2.240
.8272	8.900	235.6	.317-02	752.4	2686.7	3.571	59.65	31.15	2.551
.8924	9.635	216.1	.374-02	720.7	2755.8	3.824	63.39	34.54	2.731
.9397	10.065	204.2	.413-02	700.5	2798.5	3.995	65.73	36.57	2.853
.9712	10.355	195.1	.445-02	684.8	2819.4	4.117	67.31	37.89	2.941
.9681	10.332	214.5	.404-02	717.9	2958.1	4.120	67.35	37.93	2.943
.9289	9.871	221.5	.374-02	729.5	2910.0	3.989	65.65	36.52	2.849
.8859	9.411	232.9	.339-02	748.1	2877.6	3.847	63.71	34.85	2.748
.8222	8.827	253.3	.292-02	780.3	2788.8	3.574	59.70	31.20	2.553
.7678	8.174	285.6	.240-02	828.4	2654.5	3.204	53.56	25.29	2.289
.7668	8.184	328.1	.209-02	887.9	2825.1	3.182	53.15	24.89	2.273
.9205	8.676	285.3	.255-02	828.1	2983.7	3.603	60.15	31.64	2.574
.8873	9.457	264.5	.300-02	797.3	3046.6	3.821	63.36	34.52	2.729
.9277	9.821	251.7	.327-02	777.7	3079.8	3.966	65.26	36.19	2.829
.9734	10.296	238.6	.362-02	757.3	3123.2	4.124	67.40	37.97	2.946

Table 2-3 (Continued)

NOZZLE PARAMETERS- NOZZLE 1 - CF4, A/A*=7.967, THETA=15.12, M=1.2

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
517/0	.7251	.9191	166.711	.7889	.2391	.0043	3.0332
520/0	.7216	.9070	153.633	.7956	.2524	.0047	2.8589
533/0	.5685	.9019	68.249	.6303	.4412	.0083	1.2885
534/0	.6671	.9023	115.773	.7393	.3064	.0058	2.1776
536/0	.8070	.9099	209.497	.8869	.2070	.0039	3.8981
537/0	.8675	.9298	258.394	.9330	.1755	.0034	4.9421
549/0	.7724	.9160	168.124	.8432	.2356	.0046	3.2781

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
517/0	693.3	1215.6	6.78	5.29	22.12	.447+00	688.3	69.72	2.997
520/0	770.3	1134.0	6.69	5.33	21.10	.375+00	720.3	69.65	2.987
533/0	845.1	510.3	6.74	4.25	9.63	.154+00	737.4	69.88	2.976
534/0	859.5	857.2	6.68	4.94	16.12	.254+00	751.5	69.98	2.977
536/0	886.8	1559.3	6.77	6.01	29.01	.448+00	784.8	69.69	2.988
537/0	883.3	1911.4	6.88	6.42	36.56	.552+00	796.9	68.92	2.977
549/0	997.1	1241.9	6.77	5.71	24.22	.318+00	818.5	69.66	2.959

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(0) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
517/0	1.213	1234.6	18.00	7.29	.142-02	557.9	431.0	.547+07
520/0	1.204	1226.9	18.00	7.38	.143-02	557.4	432.1	.548+07
533/0	1.195	1222.2	18.01	7.48	.144-02	559.9	435.5	.545+07
534/0	1.202	1226.9	18.01	7.40	.143-02	558.9	433.6	.546+07
536/0	1.198	1224.4	18.00	7.44	.144-02	559.8	435.0	.544+07
537/0	1.202	1228.6	18.00	7.40	.143-02	560.3	434.6	.544+07
549/0	1.204	1230.2	18.00	7.39	.142-02	561.0	435.0	.543+07

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
.7251	5.287	295.9	.458-02	453.3	1682.0	3.711	89.19	34.60	3.019
.7216	5.326	361.4	.377-02	495.0	1807.7	3.652	88.83	34.30	3.043
.5685	4.251	464.7	.233-02	554.0	1861.7	3.360	82.02	27.16	2.874
.6671	4.939	446.6	.282-02	544.1	1923.6	3.535	87.08	32.22	3.012
.8070	6.007	433.3	.354-02	536.7	1999.8	3.726	91.77	37.20	3.166
.8675	6.417	418.1	.392-02	528.2	2005.3	3.797	93.20	39.40	3.215
.7724	5.706	532.5	.273-02	589.3	2134.1	3.621	90.63	36.10	3.136

Table 2-3 (Continued)

NOZZLE PARAMETERS- NOZZLE 2 - AIR, A/A*=3.571, THETA=25.03, M=1.2

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
328/0	1.0574	1.0282	198.615	1.0284	.1730	.0053	6.1109
329/0	.9934	.9900	165.918	1.0034	.1933	.0060	5.1379
349/0	.8728	.9399	116.011	.9286	.2405	.0075	3.6295
350/0	.9790	.9823	163.530	.9966	.1931	.0060	5.0693
351/0	1.0744	1.0458	218.127	1.0273	.1606	.0049	6.6918
360/0	1.0917	1.0586	220.280	1.0313	.1616	.0050	6.7573
361/0	.9935	.9917	167.133	1.0018	.1918	.0059	5.1792
362/0	.8644	.9269	114.865	.9326	.2422	.0076	3.5688
363/0	.7093	.9115	60.279	.7782	.3721	.0118	1.9060

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
328/0	901.3	1502.3	7.78	8.00	46.22	.140+00	1471.7	48.17	2.919
329/0	891.8	1251.3	7.47	7.49	38.75	.118+00	1464.0	48.09	2.914
349/0	704.2	855.5	6.93	6.44	26.77	.102+00	1300.9	47.95	2.908
350/0	710.7	1210.8	7.27	7.25	37.53	.143+00	1306.9	48.07	2.914
351/0	708.2	1615.5	7.75	7.96	49.56	.191+00	1304.6	48.21	2.921
360/0	1021.4	1618.6	7.78	8.02	49.65	.133+00	1566.7	48.21	2.921
361/0	1009.7	1223.9	7.26	7.28	37.93	.102+00	1557.7	48.08	2.914
362/0	983.8	853.9	6.94	6.47	26.72	.728-01	1537.6	47.95	2.908
363/0	949.9	451.3	6.82	5.31	14.27	.399-01	1510.9	47.81	2.901

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(0) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
328/0	1.186	1217.4	18.02	7.56	.145-02	561.9	438.5	.542+07
329/0	1.189	1219.2	18.02	7.54	.144-02	561.8	438.0	.542+07
349/0	1.206	1231.8	18.02	7.37	.142-02	560.9	434.6	.543+07
350/0	1.203	1229.4	18.02	7.40	.143-02	560.8	434.9	.544+07
351/0	1.203	1230.4	18.02	7.41	.143-02	561.9	435.9	.542+07
360/0	1.208	1234.3	18.01	7.35	.142-02	561.4	434.5	.543+07
361/0	1.211	1236.5	18.00	7.32	.141-02	561.7	434.4	.542+07
362/0	1.194	1223.8	18.01	7.49	.144-02	562.2	437.5	.541+07
363/0	1.194	1224.9	18.01	7.49	.143-02	563.2	438.3	.540+07

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
1.0574	7.998	201.9	.332-02	696.6	2898.9	4.161	67.87	44.72	2.972
.9934	7.492	206.6	.304-02	704.7	2869.3	4.072	66.73	43.68	2.908
.8728	6.436	174.2	.310-02	647.0	2523.7	3.901	64.46	41.54	2.786
.9790	7.249	164.7	.369-02	629.1	2561.5	4.072	66.73	43.69	2.909
1.0744	7.957	155.2	.430-02	610.7	2577.8	4.221	68.60	45.42	3.015
1.0917	8.022	224.2	.300-02	734.0	3095.0	4.216	68.55	45.36	3.012
.9935	7.275	233.5	.261-02	749.0	3054.0	4.077	66.80	43.75	2.912
.8644	6.471	243.8	.223-02	765.5	2981.9	3.895	64.39	41.47	2.782
.7093	5.310	267.0	.167-02	801.0	2864.6	3.577	59.74	36.96	2.555

Table 2-3 (Continued)

NOZZLE PARAMETERS- NOZZLE 4X- AIR, A/A*=6.518, THETA=34.77, N=1.2

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
120/0	.9521	.9566	243.567	.9953	.5051	.0039	1.8850
121/0	.8817	.9301	198.655	.9480	.5577	.0044	1.5810
122/0	.8058	.9176	152.852	.8782	.6456	.0053	1.2481
123/0	.7120	.9098	103.269	.7826	.8165	.0069	.8720
124/0	.5714	.9032	51.970	.6326	1.2596	.0110	.4536
145/0	.5578	.9007	50.801	.6193	1.2568	.0110	.4438
146/0	.7124	1.2495	107.663	.5701	.7861	.0066	.9062
147/0	.7915	.9116	151.129	.8683	.6391	.0052	1.2385
148/0	.8637	.9212	196.353	.9376	.5523	.0044	1.5639
149/0	.9332	.9458	244.566	.9867	.4936	.0038	1.8908
160/0	.9396	.9507	245.713	.9883	.4952	.0038	1.8975
161/0	.8674	.9234	190.919	.9394	.5692	.0045	1.5239
162/0	.7867	.9069	145.472	.8675	.6585	.0054	1.1948
163/0	.7164	.9021	107.215	.7941	.7936	.0067	.9027
164/0	.5639	.8984	51.492	.6277	1.2542	.0110	.4496
185/0	.5702	.9006	52.588	.6331	1.2429	.0108	.4588
186/0	.7172	.9042	108.304	.7932	.7869	.0066	.9115
187/0	.8053	.9339	155.367	.8623	.6341	.0052	1.2700
188/0	.8756	.9313	201.793	.9402	.5460	.0043	1.6036
189/0	.9479	.9563	251.561	.9912	.4888	.0038	1.9391
200/0	.9372	.9429	245.034	.9940	.4949	.0038	1.8936
201/0	.8621	.9149	196.272	.9423	.5515	.0044	1.5633
202/0	.7990	.9009	153.931	.8869	.6350	.0052	1.2582
203/0	.7051	.8899	105.805	.7923	.7910	.0067	.8915
204/0	.5585	.8864	51.586	.6301	1.2402	.0108	.4503

Table 2-3 (Continued)

NOZZLE PARAMETERS- NOZZLE 4X- AIR, A/A*=6.518, THETA=34.77, M=1.2

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
120/0	666.4	1813.9	7.12	7.09	14.04	.228+00	1265.5	64.18	3.880
121/0	669.9	1466.6	6.87	6.51	11.67	.184+00	1268.8	63.89	3.859
122/0	674.6	1125.5	6.77	5.95	9.21	.140+00	1273.3	63.60	3.839
123/0	676.0	762.4	6.72	5.26	6.44	.946-01	1274.6	63.28	3.816
124/0	672.4	386.6	6.72	4.25	3.37	.482-01	1271.2	62.94	3.79
145/0	737.3	376.6	6.68	4.14	3.29	.428-01	1331.1	62.93	3.791
146/0	755.8	799.7	9.28	5.29	6.73	.888-01	1347.7	63.31	3.818
147/0	758.1	1112.9	6.71	5.83	9.12	.123+00	1349.8	63.59	3.838
148/0	764.1	1457.1	6.84	6.41	11.61	.160+00	1355.1	63.88	3.859
149/0	769.9	1826.6	7.06	6.97	14.12	.199+00	1360.2	64.19	3.881
160/0	855.4	1840.6	7.12	7.04	14.22	.181+00	1433.8	64.20	3.882
161/0	848.7	1430.3	6.92	6.50	11.42	.141+00	1428.1	63.86	3.857
162/0	842.8	1087.1	6.78	5.88	8.93	.108+00	1423.2	63.57	3.836
163/0	841.1	796.0	6.70	5.32	6.70	.794-01	1421.7	63.31	3.818
164/0	824.1	382.9	6.68	4.19	3.34	.390-01	1407.3	62.93	3.791
185/0	881.4	392.4	6.72	4.25	3.42	.373-01	1455.4	62.94	3.792
186/0	904.5	801.7	6.69	5.31	6.74	.743-01	1474.3	63.32	3.818
187/0	917.5	1144.0	6.88	5.93	9.35	.105+00	1484.9	63.62	3.840
188/0	906.8	1485.0	6.85	6.44	11.80	.137+00	1476.2	63.91	3.860
189/0	933.5	1864.0	7.09	7.02	14.37	.168+00	1497.0	64.22	3.883
200/0	1034.4	1831.8	7.05	7.01	14.16	.149+00	1576.7	64.19	3.881
201/0	1031.0	1456.5	6.79	6.40	11.60	.119+00	1574.1	63.88	3.859
202/0	1034.9	1143.9	6.69	5.94	9.35	.927-01	1577.0	63.62	3.840
203/0	1025.3	788.1	6.63	5.25	6.64	.645-01	1569.7	63.30	3.817
204/0	993.6	385.5	6.62	4.17	3.37	.325-01	1545.2	62.94	3.792

Table 2-3 (Continued)

NOZZLE PARAMETERS- NOZZLE 4X- AIR, A/A*=6.518, THETA=34.77, M=1.2

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(0) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
120/0	1.198	1233.2	18.02	7.45	.142-02	567.6	441.0	.535+07
121/0	1.204	1236.5	17.99	7.38	.141-02	566.6	439.3	.535+07
122/0	1.205	1238.1	18.03	7.38	.141-02	566.8	439.2	.536+07
123/0	1.204	1236.6	17.99	7.38	.141-02	566.7	439.4	.535+07
124/0	1.198	1232.2	17.99	7.44	.142-02	566.9	440.5	.535+07
145/0	1.201	1226.8	18.00	7.41	.143-02	559.6	434.3	.545+07
146/0	1.200	1225.4	18.00	7.43	.143-02	559.4	434.4	.545+07
147/0	1.206	1230.3	18.00	7.36	.143-02	559.3	433.3	.545+07
148/0	1.200	1225.6	18.00	7.42	.143-02	559.3	434.2	.545+07
149/0	1.195	1221.7	18.00	7.47	.144-02	559.1	434.8	.545+07
160/0	1.193	1222.8	18.00	7.49	.144-02	562.0	437.5	.541+07
161/0	1.193	1222.7	18.00	7.49	.144-02	561.7	437.2	.542+07
162/0	1.195	1223.8	18.00	7.47	.144-02	561.5	436.8	.542+07
163/0	1.200	1228.1	18.00	7.42	.143-02	561.8	436.2	.542+07
164/0	1.199	1227.7	18.00	7.44	.143-02	562.3	436.8	.541+07
185/0	1.196	1223.2	18.01	7.46	.144-02	559.7	435.1	.545+07
186/0	1.203	1228.2	18.01	7.40	.143-02	559.6	434.0	.545+07
187/0	1.207	1231.0	18.01	7.36	.143-02	559.4	433.2	.545+07
188/0	1.207	1231.3	18.02	7.36	.143-02	559.3	433.1	.546+07
189/0	1.201	1226.4	18.00	7.41	.143-02	559.1	433.9	.545+07
200/0	1.195	1224.3	18.01	7.48	.143-02	561.9	437.1	.542+07
201/0	1.201	1227.9	18.01	7.42	.143-02	561.0	435.4	.543+07
202/0	1.200	1228.2	18.02	7.43	.143-02	561.9	436.3	.542+07
203/0	1.198	1226.4	18.01	7.45	.143-02	561.7	436.5	.542+07
204/0	1.195	1225.0	18.01	7.47	.143-02	562.2	437.3	.542+07

Table 2-3 (Continued)

NOZZLE PARAMETERS- NOZZLE 4X- AIR, A/A*=6.518, THETA=34.77, M=1.2

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
.9521	7.091	136.7	.435-02	573.2	2522.9	4.402	70.74	41.33	3.144
.8817	6.509	142.5	.383-02	585.2	2517.4	4.302	69.58	40.46	3.073
.8058	5.949	150.8	.331-02	602.1	2508.7	4.167	67.94	39.11	2.976
.7120	5.256	163.1	.270-02	626.0	2482.6	3.966	65.34	36.83	2.833
.5714	4.251	185.3	.192-02	667.4	2419.2	3.625	60.48	32.31	2.589
.5578	4.135	203.1	.171-02	698.7	2533.4	3.626	60.50	32.34	2.590
.7124	5.292	180.2	.246-02	658.1	2629.9	3.996	65.75	37.21	2.855
.7915	5.829	169.1	.289-02	637.4	2660.4	4.174	68.02	39.20	2.981
.8637	6.409	162.1	.332-02	624.2	2689.5	4.309	69.66	40.55	3.078
.9332	6.970	156.8	.373-02	613.9	2714.1	4.421	70.96	41.54	3.158
.9396	7.039	174.4	.339-02	647.3	2860.6	4.419	70.94	41.51	3.157
.8674	6.498	181.7	.300-02	660.9	2830.9	4.284	69.36	40.27	3.060
.7867	5.879	189.7	.260-02	675.2	2801.4	4.149	67.72	38.92	2.964
.7164	5.319	201.1	.222-02	695.2	2773.1	3.989	65.65	37.11	2.849
.5639	4.193	226.9	.155-02	738.4	2678.8	3.628	60.53	32.36	2.591
.5702	4.255	242.C	.147-02	762.6	2771.9	3.635	60.63	32.46	2.596
.7172	5.306	215.7	.206-02	720.0	2876.9	3.996	65.74	37.20	2.854
.8053	5.930	204.0	.244-02	700.2	2928.0	4.182	68.12	39.28	2.987
.8756	6.444	191.6	.282-02	678.6	2931.4	4.320	69.79	40.65	3.085
.9479	7.024	189.5	.311-02	674.8	2990.0	4.431	71.07	41.62	3.165
.9372	7.006	210.9	.279-02	711.9	3145.7	4.419	70.94	41.52	3.156
.8621	6.398	218.6	.245-02	724.9	3124.3	4.310	69.67	40.56	3.079
.7990	5.938	230.2	.216-02	743.8	3109.5	4.181	68.11	39.26	2.986
.7051	5.252	244.9	.180-02	767.2	3062.1	3.991	65.68	37.15	2.851
.5585	4.174	272.7	.128-02	809.5	2943.2	3.636	60.65	32.48	2.597

Table 2-3 (Continued)

NOZZLE PARAMETERS- NOZZLE 1 - CF4, A/A*=7.967, THETA=15.12, M=1.46

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
516/0	.7533	.9675	218.688	.7786	.1880	.0034	4.0063
521/0	.7686	.9688	222.955	.7934	.1866	.0034	4.1190
528/0	.9194	.9748	373.878	.9432	.1289	.0025	7.1318
529/0	.8686	.9636	308.827	.9014	.1520	.0028	5.7141
530/0	.7878	.9668	223.145	.8149	.1895	.0035	4.1563
531/0	.7180	.9543	161.757	.7524	.2360	.0044	3.0426
532/0	.6001	.9478	93.216	.6332	.3376	.0064	1.7774
548/0	.8285	.9706	247.258	.8536	.1713	.0034	4.8356

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
516/0	699.9	1122.9	4.97	3.87	20.57	.409+00	687.5	69.63	2.995
521/0	768.4	1144.5	4.97	3.95	21.14	.380+00	719.8	69.75	2.990
528/0	875.4	1875.1	4.89	4.61	35.77	.546+00	792.4	68.97	2.979
529/0	877.1	1554.0	4.85	4.37	28.75	.452+00	780.7	69.65	2.989
530/0	868.8	1146.1	4.97	4.05	21.36	.336+00	763.6	69.84	2.983
531/0	855.6	840.8	4.96	3.73	15.82	.251+00	749.4	69.95	2.976
532/0	809.8	495.6	5.04	3.19	9.45	.156+00	721.8	72.33	2.973
548/0	1004.7	1259.3	4.94	4.22	24.63	.320+00	822.0	69.64	2.958

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(O) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
516/0	1.468	1421.0	18.00	5.13	.110-02	558.2	390.1	.533+07
521/0	1.468	1420.5	18.00	5.13	.110-02	557.8	389.8	.533+07
528/0	1.484	1435.5	17.99	5.02	.108-02	561.2	389.6	.527+07
529/0	1.482	1433.9	17.99	5.03	.108-02	561.1	389.9	.527+07
530/0	1.467	1423.9	17.99	5.14	.110-02	560.9	392.1	.529+07
531/0	1.459	1418.6	17.99	5.20	.111-02	561.0	393.4	.530+07
532/0	1.444	1408.0	18.02	5.32	.113-02	560.7	395.6	.532+07
548/0	1.473	1426.6	17.99	5.09	.109-02	559.8	390.3	.530+07

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
.7533	3.868	289.4	.342-02	449.1	1720.6	3.832	92.02	37.51	3.106
.7686	3.945	341.1	.295-02	482.6	1837.5	3.808	92.64	38.01	3.150
.9194	4.611	392.7	.300-02	513.6	2028.2	3.949	96.88	43.03	3.320
.8686	4.371	405.5	.275-02	521.1	2021.9	3.880	95.57	41.04	3.274
.7878	4.046	418.3	.247-02	528.4	1991.2	3.769	93.05	38.32	3.189
.7180	3.732	426.8	.223-02	533.2	1951.1	3.659	90.41	35.58	3.103
.6001	3.191	420.5	.194-02	529.7	1848.8	3.490	87.96	30.74	2.955
.8285	4.220	515.7	.209-02	580.8	2186.9	3.765	94.74	40.22	3.252

Table 2-3 (Continued)

NOZZLE PARAMETERS- NOZZLE 2 - AIR, A/A*=3.571, THETA=25.03, M=1.46

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
344/0	1.0883	1.0395	314.616	1.0469	.1127	.0035	9.6574
345/0	1.0121	1.0069	238.801	1.0052	.1367	.0042	7.4043
346/0	.9191	.9807	169.560	.9372	.1733	.0054	5.3047
347/0	.7662	.9601	88.513	.7980	.2738	.0087	2.7981
364/0	.7697	.9696	89.832	.7938	.2723	.0086	2.8271
365/0	.9240	.9736	168.528	.9491	.1752	.0055	5.2738
366/0	1.0352	1.0092	249.925	1.0288	.1337	.0041	7.7408
367/0	1.1040	1.0513	318.823	1.0501	.1128	.0035	9.7861

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
344/0	709.5	1593.4	5.26	5.51	48.91	.188+00	1305.8	48.20	2.920
345/0	716.5	1201.8	5.07	5.09	37.26	.141+00	1312.2	48.07	-.914
346/0	729.6	857.1	4.96	4.65	26.81	.985-01	1324.1	47.95	2.908
347/0	737.3	460.7	5.00	3.99	14.56	.524-01	1331.1	47.82	2.901
364/0	931.7	460.2	4.99	3.96	14.55	.414-01	1496.3	47.82	2.901
365/0	961.1	846.5	4.89	4.64	26.49	.739-01	1519.8	47.95	2.908
366/0	990.4	1243.9	5.02	5.15	38.53	.105+00	1542.8	48.09	2.914
367/0	992.8	1595.0	5.26	5.52	48.96	.135+00	1544.6	48.20	2.920

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(0) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
344/0	1.478	1429.7	18.01	5.06	.109-02	559.7	389.5	.530+07
345/0	1.482	1432.6	18.01	5.03	.109-02	559.7	388.8	.530+07
346/0	1.480	1432.7	18.02	5.05	.109-02	561.3	390.4	.528+07
347/0	1.459	1420.5	18.01	5.20	.111-02	562.6	394.6	.528+07
364/0	1.468	1431.1	18.05	5.15	.109-02	566.0	395.5	.524+07
365/0	1.484	1441.6	18.03	5.02	.107-02	565.7	392.7	.522+07
366/0	1.491	1444.5	18.02	4.98	.107-02	564.7	391.0	.523+07
367/0	1.487	1446.1	18.04	5.00	.107-02	567.6	393.5	.520+07

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
1.0883	5.812	140.5	.329-02	581.2	2614.7	4.499	71.84	48.66	3.214
1.0121	5.094	150.4	.284-02	601.2	2608.1	4.338	70.00	46.96	3.099
.9191	4.646	164.3	.237-02	628.4	2606.2	4.147	67.69	44.77	2.962
.7662	3.988	189.8	.176-02	675.4	2564.9	3.798	63.02	40.24	2.713
.7697	3.961	239.5	.139-02	758.6	2884.1	3.802	63.08	40.30	2.716
.9240	4.641	217.2	.179-02	722.4	2989.8	4.139	67.59	44.67	2.956
1.0352	5.152	206.5	.209-02	704.5	3069.0	4.356	70.21	47.16	3.111
1.1040	5.523	196.7	.236-02	687.6	3092.8	4.498	71.83	48.65	3.213

Table 2-3 (Continued)

NOZZLE PARAMETERS- NOZZLE 4X- AIR, A/A*=6.518, THETA=34.77, M=1.46

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
125/0	.6528	.9576	89.072	.6817	.8450	.0073	.7725
126/0	.7784	.9615	160.104	.8096	.5786	.0049	1.3452
127/0	.8673	.9625	233.420	.9011	.4558	.0037	1.9028
128/0	.9527	.9744	313.545	.9777	.3853	.0030	2.4725
129/0	.9946	.9871	365.691	1.0076	.3517	.0027	2.8276
165/0	.6331	.9585	78.552	.6605	.9251	.0081	.6844
166/0	.7686	.9584	147.026	.8020	.6191	.0052	1.2415
167/0	.8663	.9714	225.122	.8918	.4708	.0038	1.8401
168/0	.9484	.9793	309.541	.9684	.3879	.0031	2.4450
169/0	.9998	.9949	371.775	1.0049	.3487	.0027	2.8671
205/0	.5760	.9358	62.265	.6155	1.0549	.0093	.5460
206/0	.7540	.9672	147.340	.7796	.6056	.0051	1.2450
207/0	.8199	.9405	203.752	.8718	.4897	.0040	1.6742
208/0	.9069	.9441	285.172	.9606	.4004	.0032	2.2648
209/0	.9683	.9655	357.550	1.0029	.3514	.0027	2.7552

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
125/0	707.1	458.1	4.92	3.36	3.97	.543-01	1303.6	63.00	3.796
126/0	705.6	820.2	4.93	3.99	6.89	.975-01	1302.2	63.33	3.819
127/0	684.6	1176.5	4.85	4.37	9.59	.144+00	1282.7	63.64	3.842
128/0	695.9	1579.7	4.91	4.80	12.46	.190+00	1293.2	63.98	3.866
129/0	711.0	1824.9	4.93	4.96	14.11	.215+00	1307.2	64.18	3.881
165/0	835.4	407.0	4.97	3.28	3.55	.409-01	1416.9	62.96	3.793
166/0	847.0	762.8	4.97	3.99	6.44	.755-01	1426.7	63.28	3.816
167/0	851.6	1143.9	4.94	4.40	9.35	.113+00	1430.6	63.62	3.840
168/0	861.3	1559.1	4.93	4.78	12.32	.152+00	1438.7	63.97	3.865
169/0	870.5	1858.1	4.97	5.08	14.33	.179+00	1446.4	64.21	3.883
205/0	991.0	334.5	5.03	3.09	2.93	.283-01	1543.2	62.89	3.788
206/0	1016.0	754.4	4.95	3.86	6.37	.623-01	1562.6	63.27	3.815
207/0	1044.9	1081.3	4.99	4.35	8.89	.868-01	1584.6	63.56	3.836
208/0	1046.6	1492.4	4.94	4.75	11.85	.120+00	1585.9	63.91	3.861
209/0	1057.8	1868.2	5.04	5.06	14.40	.148+00	1594.4	64.22	3.883

Table 2-3 (Continued)

NOZZLE PARAMETERS- NOZZLE 4X- AIR, A/A*=6.518, THETA=34.77, M=1.46

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(0) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
125/0	1.467	1424.5	18.01	5.14	.110-02	561.4	392.4	.529+07
126/0	1.470	1425.5	18.01	5.12	.110-02	56[illegible].7	391.5	.530+07
127/0	1.481	1434.4	18.01	5.04	.108-02	561.7	390.4	.527+07
128/0	1.482	1434.3	18.01	5.04	.108-02	561.4	390.1	.528+07
129/0	1.488	1440.1	18.01	4.99	.107-02	562.5	389.8	.525+07
165/0	1.462	1422.7	18.01	5.18	.110-02	562.7	394.2	.528+07
166/0	1.461	1421.8	18.01	5.19	.110-02	562.4	394.1	.528+07
167/0	1.476	1431.4	18.01	5.08	.109-02	562.3	391.7	.527+07
168/0	1.482	1437.2	18.03	5.04	.108-02	563.3	391.3	.525+07
169/0	1.487	1440.2	18.01	5.00	.107-02	563.1	390.4	.525+07
205/0	1.437	1406.2	18.01	5.37	.113-02	563.4	398.8	.530+07
206/0	1.471	1429.7	18.01	5.12	.109-02	563.7	393.5	.526+07
207/0	1.445	1410.5	18.01	5.31	.112-02	562.1	396.4	.530+07
208/0	1.455	1418.5	18.01	5.23	.111-02	563.2	395.7	.528+07
209/0	1.456	1419.0	18.01	5.23	.111-02	563.0	395.3	.528+07

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
.6528	3.357	173.6	.162-02	645.9	2531.9	3.920	64.73	36.50	2.800
.7784	3.988	154.0	.217-02	608.4	2574.4	4.231	68.73	40.16	3.022
.8673	4.371	138.4	.265-02	576.7	2561.8	4.442	71.20	42.32	3.173
.9527	4.800	132.8	.303-02	565.0	2601.1	4.604	72.97	43.76	3.288
.9946	4.963	131.5	.317-02	562.1	2638.8	4.694	73.93	44.51	3.353
.6331	3.280	210.7	.131-02	711.6	2739.7	3.850	63.76	35.58	2.750
.7686	3.988	188.8	.177-02	673.6	2812.3	4.175	68.04	39.53	2.982
.8663	4.402	173.9	.212-02	646.5	2853.6	4.414	70.88	42.04	3.153
.9484	4.777	164.8	.243-02	629.3	2892.9	4.597	72.90	43.70	3.284
.9998	4.997	160.5	.261-02	621.0	2920.9	4.704	74.02	44.58	3.360
.5760	3.094	260.0	.998-03	790.5	2963.7	3.749	62.33	34.21	2.678
.7540	3.861	225.1	.144-02	735.5	3082.8	4.192	68.24	39.74	2.994
.8199	4.351	216.1	.169-02	720.7	3155.7	4.379	70.48	41.68	3.128
.9069	4.746	202.4	.197-02	697.4	3184.9	4.567	72.58	43.43	3.262
.9683	5.059	195.4	.217-02	685.2	3219.1	4.698	73.96	44.51	3.356

Table 2-3 (Continued)

NOZZLE PARAMETERS- NOZZLE 1 - CF4, A/A*=7.967, THETA=15.12, M=3.48

RUN/PT	PB/P(INF)	PS/P(INF)	PC/R(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
515/0	.6613	.9749	958.217	.6783	.0374	.0007	17.6824
522/0	.6766	.9746	948.027	.6942	.0383	.0007	17.6639
523/1	.4776	.9718	343.625	.4915	.0725	.0014	6.5837
524/0	.6397	.9712	659.698	.6587	.0512	.0010	12.4921
525/0	.7282	.9738	1014.838	.7478	.0392	.0007	18.5948
526/0	8097	.9787	1281.089	.8273	.0333	.0006	24.3243
527/0	.8511	.9803	1478.801	.8682	.0304	.0006	27.9680
546/0	.7466	.9723	982.297	.7679	.0361	.0008	20.6864
547/0	.7925	.9712	1003.551	.8160	.0402	.0008	19.7382

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
515/0	703.2	1164.5	1.18	.80	21.49	.422+00	690.7	69.56	2.992
522/0	757.8	1150.8	1.18	.82	21.44	.389+00	713.4	69.55	2.986
523/1	815.2	417.6	1.18	.58	8.00	.131+00	722.9	69.98	2.971
524/0	915.4	800.8	1.18	.78	15.16	.223+00	783.5	70.32	2.972
525/0	839.7	1231.9	1.18	.88	22.57	.374+00	753.9	69.91	2.992
526/0	845.9	1555.1	1.19	.98	29.53	.469+00	768.0	69.16	2.977
527/0	828.7	1795.1	1.19	1.03	33.95	.552+00	771.0	68.97	2.982
546/0	900.4	1192.[illegible]	1.18	.91	25.11	.338+00	778.2	68.09	2.927
547/0	1027.6	1218.2	1.18	.96	23.96	.302+00	829.7	69.64	2.953

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(0) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
515/0	3.480	2179.5	90.10	1.22	.624-03	558.8	163.3	.107+08
522/0	3.480	2179.9	90.02	1.21	.623-03	559.0	163.3	.107+08
523/1	3.480	2180.2	90.05	1.22	.624-03	559.2	163.4	.107+08
524/0	3.480	2179.5	90.01	1.21	.624-03	558.8	163.3	.107+08
525/0	3.480	2179.5	90.02	1.21	.624-03	558.8	163.3	.107+08
526/0	3.480	2179.3	90.02	1.21	.624-03	558.7	163.2	.107+08
527/0	3.480	2179.7	90.02	1.21	.624-03	558.9	163.3	.107+08
546/0	3.480	2180.5	90.03	1.21	.623-03	559.3	163.4	.107+08
547/0	3.480	2186.1	90.03	1.21	.620-03	562.2	164.3	.106+08

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHO J (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
.6613	.804	207.9	.988-03	390.0	1848.3	4.739	108.76	54.32	3.658
.6766	.821	243.2	.862-03	416.9	1946.3	4.668	109.32	54.90	3.689
.4776	.530	330.8	.447-03	476.4	2026.1	4.253	104.10	49.24	3.502
.6397	.777	373.6	.530-03	502.6	2206.0	4.389	108.92	53.73	3.667
.7282	.884	300.0	.752-03	456.5	2098.5	4.597	110.37	55.57	3.740
.8097	.983	293.8	.853-03	452.3	2110.9	4.667	111.44	57.41	3.786
.8511	1.033	274.7	.960-03	439.3	2080.8	4.736	111.87	58.02	3.808
.7466	.906	344.8	.670-03	485.1	2196.4	4.528	110.68	57.71	3.747
.7925	.962	433.7	.565-03	537.2	2388.4	4.446	111.84	57.32	3.775

Table 2-3 (Continued)

NOZZLE PARAMETERS- NOZZLE 2 - AIR, A/A*=3.571, THETA=25.03, M=3.48

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
308/1	.6963	.9855	422.526	.7065	.0522	.0016	13.3384
340/0	.6647	.9964	354.898	.6671	.0592	.0019	11.2276
370/0	.8359	.9837	700.476	.8498	.0381	.0012	21.9182
376/0	.6738	.9799	353.162	.6876	.0603	.0019	11.1735
377/0	1.0402	.9894	1254.975	1.0513	.0270	.0008	38.5915
379/0	.8334	.9957	711.680	.8370	.0374	.0012	22.2609
380/0	.9634	.9968	1004.050	.9665	.0310	.0010	31.1171
381/0	1.0222	1.0055	1242.783	1.0166	.0267	.0008	38.2310

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
308/1	726.7	512.9	1.20	.85	16.19	.592-01	1321.5	47.83	2.902
340/0	674.6	431.3	1.21	.81	13.64	.536-01	1273.3	47.81	2.900
370/0	971.6	850.3	1.19	1.01	26.61	.734-01	1528.0	47.95	2.908
376/0	943.4	428.7	1.19	.82	13.56	.381-01	1505.7	47.80	2.900
377/0	981.5	1523.4	1.20	1.26	46.85	.130+00	1535.8	48.18	2.919
379/0	860.7	863.9	1.21	1.01	27.02	.842-01	1438.2	47.96	2.908
380/0	859.3	1220.2	1.21	1.17	37.82	.119+00	1437.0	48.08	2.914
381/0	844.4	1508.6	1.22	1.20	46.41	.150+00	1424.5	48.18	2.919

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(0) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
308/1	3.480	2187.1	90.02	1.21	.619-03	562.7	164.4	.105+08
340/0	3.480	2187.2	90.07	1.22	.620-03	562.8	164.5	.106+08
370/0	3.480	2191.4	90.02	1.21	.617-03	564.9	165.1	.105+08
376/0	3.480	2188.2	90.02	1.21	.619-03	563.3	164.6	.105+08
377/0	3.480	2188.6	90.02	1.21	.618-03	563.5	164.7	.105+08
379/0	3.480	2188.1	90.02	1.21	.619-03	563.2	164.6	.105+08
380/0	3.480	2188.1	90.04	1.22	.619-03	563.3	164.6	.105+08
381/0	3.480	2188.2	90.00	1.21	.619-03	563.3	164.6	.105+08

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
.6963	.845	116.5	.609-03	529.0	2707.9	5.118	78.02	55.22	3.656
.6647	.808	112.1	.604-03	519.1	2599.7	5.008	77.01	54.23	3.577
.8359	1.015	142.0	.599-03	584.2	3157.3	5.405	80.49	57.57	3.861
.6738	.818	157.7	.435-03	615.5	3072.7	4.992	76.86	54.08	3.566
1.0402	1.263	129.3	.819-03	557.3	3200.1	5.742	83.12	59.97	4.101
.8334	1.012	125.1	.678-03	548.3	2973.0	5.422	80.63	57.70	3.873
.9634	1.171	118.0	.832-03	532.5	2984.5	5.605	82.08	59.84	4.003
1.0222	1.241	111.0	.938-03	516.4	2968.7	5.749	83.18	60.03	4.106

Table 2-3 (Continued)

NOZZLE PARAMETERS- NOZZLE 4X- AIR, A/A*=6.518; THETA=34.77, M=3.48

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
130/0	.9899	.9939	1524.604	.9960	.0841	.0006	11.7645
131/0	.9071	.9942	1216.475	.9124	.0938	.0007	9.6714
132/0	.8222	.9969	951.091	.8248	.1059	.0009	7.7659
133/0	.7178	.9929	635.904	.7229	.1338	.0011	5.3649
134/0	.5579	.9943	313.262	.5611	.2039	.0018	2.7357
210/0	.5846	.9658	353.993	.6053	.1899	.0017	3.0778
211/0	.7251	.9639	661.495	.7523	.1303	.0011	5.5658
212/0	.8223	.9767	979.365	.8419	.1031	.0008	7.9743
213/0	.9109	.9785	1254.069	.9309	.0917	.0007	9.9353
214/0	.9670	.9846	1508.128	.9821	.0830	.0006	11.6558

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
130/0	730.3	1850.7	1.21	1.20	14.28	.213+00	1324.8	64.21	3.882
131/0	723.5	1479.2	1.21	1.10	11.76	.172+00	1318.6	63.90	3.860
132/0	702.4	1156.5	1.21	1.08	9.44	.138+00	1299.2	63.63	3.840
133/0	736.7	772.8	1.21	.87	6.52	.880-01	1330.6	63.29	3.816
134/0	704.0	380.7	1.21	.68	3.32	.454-01	1300.7	62.93	3.791
210/0	999.3	430.2	1.17	.71	3.74	.361-01	1549.7	62.98	3.794
211/0	1022.8	803.9	1.17	.88	6.76	.659-01	1567.8	63.32	3.818
212/0	1026.2	1190.2	1.19	1.00	9.69	.973-01	1570.4	63.66	3.843
213/0	1019.5	1522.3	1.19	1.11	12.06	.125+00	1565.3	63.94	3.863
214/0	1018.8	1830.7	1.20	1.17	14.15	.151+00	1564.7	64.19	3.881

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(0) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
130/0	3.480	2191.2	90.03	1.21	.617-03	564.8	165.0	.105+08
131/0	3.480	2202.4	90.15	1.22	.612-03	570.6	166.7	.103+08
132/0	3.480	2191.3	90.12	1.22	.618-03	564.9	165.1	.105+08
133/0	3.480	2203.0	90.04	1.22	.611-03	571.0	166.9	.103+08
134/0	3.480	2191.8	90.05	1.22	.617-03	565.2	165.2	.105+08
210/0	3.480	2182.9	90.06	1.22	.622-03	560.6	163.8	.106+08
211/0	3.480	2183.3	90.09	1.22	.622-03	560.8	163.9	.106+08
212/0	3.480	2183.7	90.04	1.22	.622-03	561.0	164.0	.106+08
213/0	3.480	2184.0	90.03	1.21	.621-03	561.1	163.9	.106+08
214/0	3.480	2183.8	90.03	1.21	.621-03	561.0	163.9	.106+08

Table 2-3 (Concluded)

NOZZLE PARAMETERS- NOZZLE 4X- AIR, A/A*=6.518, THETA=34.77, M=3.48

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
.9899	1.202	89.7	.112-02	464.3	2774.4	5.976	84.80	55.37	4.268
.9071	1.103	92.4	.100-02	471.3	2753.7	5.842	83.86	54.73	4.173
.8222	1.000	93.6	.896-03	474.3	2704.6	5.702	82.83	53.97	4.073
.7178	.872	106.0	.691-03	504.6	2753.0	5.455	80.90	52.38	3.897
.5579	.678	115.4	.493-03	526.5	2659.5	5.051	77.41	49.25	3.608
.5646	.710	160.3	.372-03	620.6	3175.2	5.117	78.01	49.80	3.655
.7251	.881	145.9	.507-03	592.1	3246.0	5.482	81.12	52.57	3.916
.8223	.999	135.6	.618-03	570.9	3271.2	5.729	83.03	54.15	4.092
.9109	1.106	129.3	.717-03	557.4	3270.6	5.867	84.04	54.87	4.191
.9670	1.174	124.7	.790-03	547.4	3277.7	5.988	84.89	55.47	4.277

Table 2-4

FA 11 AND MA 10F TRIPLE NOZZLE CONFIGURATION EXPERIMENTAL DATA BASE

NOZZLE PARAMETERS- NOZZLE 58 - CF4, A/A*=8.291, THETA=15.03, M=.9, MA10F

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
607/0	.8548	.9837	142.942	.8690	.3577	.0060	2.3899
615/0	.7734	.8673	77.411	.8917	.5608	.0100	1.3791
616/0	.8136	.8840	107.626	.9204	.4226	.0076	1.9254
617/0	.8693	.9128	146.530	.9523	.3350	.0059	2.5946
618/0	.9056	.9378	175.449	.9657	.2885	.0052	3.1389
634/0	.8951	.9269	152.612	.9657	.3200	.0059	2.7968

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
607/0	754.4	1512.9	10.41	9.05	25.30	.511+00	728.4	70.90	3.039
615/0	839.2	829.7	9.30	8.29	14.78	.252+00	742.0	70.76	3.004
616/0	848.3	1144.5	9.40	8.65	20.48	.344+00	754.8	70.89	3.003
617/0	870.3	1556.2	9.71	9.24	27.59	.456+00	778.1	70.40	3.012
618/0	870.0	1866.1	9.97	9.63	33.39	.547+00	789.9	69.93	3.008
634/0	1030.6	1619.7	9.84	9.50*	29.68	.401+00	842.9	70.25	2.992

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(0) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
607/0	.906	974.4	18.02	10.58	.184-02	560.6	481 5	.512+07
615/0	.894	960.0	18.00	10.72	.187-02	557.1	480.4	.513+07
616/0	.901	967.2	18.01	10.63	.186-02	557.3	479.4	.515+07
617/0	.901	968.2	18.01	10.63	.186-02	558.4	480.4	.513+07
618/0	.901	968.0	18.01	10.64	.186-02	558.3	480.3	.513+07
634/0	.902	978.4	18.00	10.61	.182-02	569.2	489.5	.500+07

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
.8548	9.047	358.5	.646-02	492.9	1742.4	3.535	85.27	29.20	2.946
.7734	8.289	468.3	.452-02	555.8	1820.7	3.276	79.32	23.39	2.806
.8136	8.652	452.6	.488-02	547.3	1865.7	3.409	83.46	27.40	2.910
.8693	9.244	449.1	.526-02	545.3	1921.5	3.524	86.08	30.52	3.006
.9056	9.632	436.5	.564-02	538.3	1933.8	3.592	87.63	32.53	3.056
.8951	9.500	572.9	.423-02	609.3	2138.9	3.510	87.01	31.59	3.059

Table 2-4 (Continued)

NOZZLE PARAMETERS- NOZZLE 5A - AIR, A/A*=8.296, THETA=14.83, M=.9, FA11

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
58/0	.8510	.8872	23.084	.9592	3.5650	.0369	.2387
59/0	.8530	.8804	46.122	.9689	1.7973	.0185	.4746
64/0	.8510	.8756	45.997	.9719	1.7977	.0185	.4734
73/0	.7960	.8613	93.925	.9242	.8316	.0085	.9572
74/0	.7940	.8580	93.041	.9254	.8372	.0085	.9484
79/0	.8140	8643	139.818	.9418	.5766	.0058	1.4118
80/0	8230	.8671	138.281	.9491	.5894	.0060	1.3964
35/0	.8400	.8764	187.162	.9585	.4488	.0045	1.8718
86/0	.8420	.8814	186.935	.9553	.4503	.0045	1.8699

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
58/0	646.2	242.9	9.34	8.95	2.51	.315-01	1246.2	61.14	3.669
59/0	667.8	495.2	9.45	9.16	5.10	.622-01	1266.8	61.20	3.672
64/0	868.1	489.1	9.31	9.05	5.03	.473-01	1444.4	61.20	3.672
73/0	651.9	1001.6	9.19	8.49	10.21	.129+00	1251.7	61.30	3.679
74/0	848.2	989.4	9.12	8.44	10.09	.979-01	1427.7	61.30	3.679
79/0	867.7	1484.4	9.18	8.64	14.99	.144+00	1444.0	61.40	3.686
80/0	662.9	1482.1	9.29	8.82	14.97	.188+00	1262.2	61.40	3.686
85/0	653.2	1996.4	9.35	8.96	19.97	.256+00	1252.9	61.50	3.693
86/0	844.7	1984.5	9.36	8.94	19.85	.197+00	1424.8	61.50	3.693

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(0) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
58/0	.910	977.8	18.00	10.52	.184-02	560.0	480.4	.513+07
59/C	.892	960.7	18.00	10.74	.186-02	560.0	483.2	.509+07
64/0	.901	969.4	18.01	10.63	.185-02	560.0	481.8	.511+07
73/0	.898	966.4	18.00	10.67	.186-02	560.0	482.2	.510+07
74/0	.901	968.9	18.00	10.63	.185-02	560.0	481.8	.511+07
79/0	.902	970.4	18.00	10.62	.185-02	560.0	481.6	.511+07
80/0	.893	962.2	18.00	10.72	.186-02	560.0	482.9	.509+07
85/0	.898	966.4	18.00	10.67	.186-02	560.0	482.2	.510+07
86/0	.903	970.7	18.00	10.62	.185-02	560.0	481.5	.511+07

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
.8510	8.954	251.7	.298-02	777.7	2177.3	2.800	45.75	-.93	2.000
.853C	9.158	213.6	.360-02	716.4	2336.3	3.261	54.56	8.17	2.329
.8510	9.049	277.6	.273-02	816.8	2663.6	3.261	54.56	8.17	2.329
.7960	8.490	166.8	.427-02	633.1	2414.3	3.813	63.24	16.77	2.724
7940	8.443	217.5	.326-02	722.9	2753.0	3.808	63.17	16.70	2.720
.8140	8.642	199.4	.363-02	692.3	2833.7	4.093	67.31	20.44	2.924
.8230	8.821	153.3	.483-02	607.0	2474.5	4.076	66.79	20.22	2.912
.8400	8.960	139.4	.539-02	578.8	2484.7	4.293	69.47	22.80	3.067
.8420	8.939	180.4	.416-02	658.5	2825.2	4.290	69.44	22.77	3.065

Table 2-4 (Continued)

NOZZLE PARAMETERS- NOZZLE 6A - AIR, A/A*=4.040, THETA=24.62, M=.9, MA10F

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PF	PB/PC	PE/P(INF)
420/0	.9850	.9946	154.546	.9903	.2460	.0064	4.0040
421/0	9444	.9627	125.091	.9810	.2894	.0075	3.2628
422/0	.8701	.9114	85.885	.9547	.3850	.0101	2.2601
423/0	.7669	.8637	44.810	.8879	.6442	.0171	1.1904
425/0	.9077	.9339	96.718	.9719	.3575	.0094	2.5390
452/0	.9814	.9910	155.320	.9903	.2440	.0063	4.0229
454/0	.8609	.9035	78.426	.9529	.4165	.0110	2.0670
455/0	.7698	.8648	45.972	.8901	.6305	.0167	1.2209
457/0	.8813	.9151	87.964	.9631	.3810	.0100	2.3132
459/0	.9616	.9928	151.999	.9887	.2492	.0065	3.9396

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
420/0	685.8	1635.5	10.53	10.42	42.37	.200+00	1283.8	50.40	3.033
421/0	684.7	1321.8	10.17	9.98	34.48	.162+00	1282.8	50.32	3.029
422/0	676.9	910.2	9.66	9.22	23.95	.113+00	1275.4	50.20	3.023
423/0	679.2	477.1	9.20	8.17	12.67	.589-01	1277.6	50.08	3.016
425/0	517.3	1023.4	9.88	9.60	26.87	.166+00	1115.0	50.23	3.024
452/0	833.6	1649.2	10.52	10.42	42.72	.166+00	1415.4	50.40	3.033
454/0	833.9	839.7	9.67	9.22	22.13	.845-01	1415.6	50.18	3.022
455/0	815.2	489.7	9.21	8.20	13.01	.504-01	1399.7	50.08	3.017
457/0	1001.1	942.8	9.81	9.45	24.79	.790-01	1551.1	50.21	3.023
459/0	1009.8	1617.1	10.56	10.44	41.91	.134+00	1557.8	50.40	3.033

Table 2-4 (Continued)

NOZZLE PARAMETERS- NOZZLE 6A - AIR, A/A*=4.040, THETA=24.62, M=.9, MA10F

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(0) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
420/0	.905	975.1	17.99	10.58	.184-02	562.6	483.4	.509+07
421/0	.907	976.8	18.01	10.57	.184-02	562.4	482.9	.510+07
422/0	.904	973.8	18.00	10.60	.184-02	562.0	483.0	.509+07
423/0	.900	969.5	18.00	10.65	.185-02	561.8	483.5	.508+07
425/0	.905	974.5	18.00	10.58	.184-02	561.4	482.3	.510+07
452/0	.902	968.5	18.00	10.62	.186-02	557.8	479.7	.514+07
454/0	.895	965.7	18.01	10.71	.185-02	562.6	484.9	.507+07
455/0	.899	969.9	18.00	10.65	.184-02	562.7	484.4	.507+07
457/0	.893	962.3	18.00	10.72	.186-02	560.3	483.2	.509+07
459/0	.900	969.2	18.00	10.64	.185-02	560.6	482.4	.510+07

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
.9850	10.424	161.8	.541-02	623.5	2509.3	4.025	66.12	40.34	2.875
.9444	9.979	169.5	.494-02	638.2	2488.1	3.898	64.43	38.73	2.784
.8701	9.221	182.3	.424-02	661.8	2437.9	3.684	61.36	35.78	2.631
.7669	8.165	212.4	.322-02	714.5	2368.2	3.314	55.48	30.02	2.367
.9077	9.605	136.3	.591-02	572.3	2139.7	3.739	62.18	36.56	2.671
.9814	10.421	196.1	.446-02	686.6	2767.6	4.031	66.21	40.42	2.879
.8609	9.218	229.7	.337-02	743.1	2694.3	3.626	60.50	34.94	2.590
.7698	8.200	253.4	.271-02	780.4	2598.2	3.329	55.74	30.27	2.378
.8813	9.446	268.7	.295-02	803.6	2966.5	3.692	61.48	35.89	2.637
.9816	10.443	239.1	.366-02	758.0	3043.2	4.015	65.99	40.22	2.868

Table 2-4 (Continued)

NOZZLE PARAMETERS- NOZZLE 8A - AIR, A/A*=4.060, THETA=10.12, M=.9, FA11

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
111/0	.8750	.9792	14.349	.8936	1.9899	.0610	.4397
112/0	.8570	.9748	23.929	.8792	1.1723	.0358	.7310
116/0	.8130	.9752	46.872	.8337	.5720	.0173	1.4214
119/0	.8170	.9782	46.613	.8352	.5779	.0175	1.4137
122/0	.8610	.9789	23.321	.8796	1.2083	.0369	.7126
124/0	.8680	.9729	16.419	.8922	1.7264	.0529	.5028
128/1	.8760	.9776	95.508	.8961	.3073	.0092	2.8508
132/0	.9220	.9814	139.768	.9395	.2241	.0066	4.1145
135/0	.8740	.9767	94.124	.8949	.3109	.0093	2.8111
138/0	.9230	.9807	140.459	.9412	.2233	.0066	4.1341

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
111/0	653.7	152.7	10.42	9.31	4.68	.196-01	1253.4	48.23	2.921
112/0	663.8	253.8	10.34	9.09	7.75	.321-01	1263.0	48.27	2.923
116/0	647.8	495.8	10.32	8.60	15.04	.642-01	1247.7	48.36	2.928
119/0	917.1	492.9	10.34	8.64	14.95	.451-01	1484.6	48.36	2.928
122/0	896.3	247.4	10.38	9.13	7.56	.232-01	1467.6	48.26	2.923
124/0	892.4	175.2	10.38	9.26	5.37	.165-01	1464.4	48.24	2.922
128/1	895.9	1022.0	10.46	9.37	30.51	.957-01	1467.3	48.57	2.939
132/0	904.7	1489.5	10.46	9.83	43.85	.138+00	1474.5	48.75	2.948
135/0	644.4	1003.2	10.41	9.32	29.96	.131+00	1244.4	48.56	2.938
138/0	665.6	1495.5	10.44	9.83	44.02	.188+00	1264.7	48.76	2.948

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Table 2-4 (Continued)

NOZZLE PARAMETERS- NOZZLE 8A - AIR, A/A*=4.060, THETA=10.12, M=.9, FA11

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(O) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
111/0	.900	968.4	18.00	10.64	.185-02	560.0	481.9	.511+07
112/0	.903	971.2	18.00	10.61	.185-02	560.0	481.5	.511+07
115/0	.906	974.2	18.02	10.58	.184-02	560.0	481.0	.513+07
119/0	.906	974.3	18.01	10.57	.184-02	560.0	481.0	.512+07
122/0	.904	971.9	18.02	10.61	.185-02	560.0	481.4	.512+07
124/0	.899	967.1	18.02	10.67	.186-02	560.0	482.1	.511+07
128/1	.896	964.5	18.02	10.70	.186-02	560.0	482.5	.510+07
132/0	.900	981.0	18.02	10.66	.181-02	575.0	494.9	.494+07
135/0	.900	975 8	18.02	10.66	.183-02	569.0	489.7	.501+07
138/0	.900	968.7	18.02	10.65	.185-02	560.0	481.9	.511+07

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
.8750	9.311	294.0	.266-02	840.5	2079.1	2.474	38.51	.37	1.767
.8570	9.090	256.4	.297-02	785.0	2212.5	2.819	46.14	7.99	2.013
.8130	8.600	203.4	.355-02	699.1	2310.8	3.305	55.32	17.08	2.361
.8170	8.639	288.8	.251-02	833.1	2747.6	3.298	55.20	16.96	2.356
.8610	9.134	349.2	.219-02	916.f	2563.9	2.799	45.73	7.58	1.999
.8680	9.262	385.3	.202-02	962.2	2468.5	2.565	40.64	2.51	1.632
.8760	9.374	234.5	.335-02	750.7	2819.1	3.756	62.42	23.97	2.683
.9220	9.826	215.5	.382-02	719.6	2877.7	3.999	65.78	27.15	2.856
.8740	9.315	169.3	.462-02	637.8	2389.4	3.747	62.29	23.84	2.676
.9230	9.827	158.4	.521-02	616.9	2468.8	4.002	65.82	27.18	2.858

Table 2-4 (Continued)

NOZZLE PARAMETERS- NOZZLE 5B - CF4, A/A*=8.291, THETA=15.03, M= [illegible]

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
608/0	.7604	.9293	216.718	.8398	.2070	.0036	3.7700
619/0	.8310	.9352	256.267	.8886	.1844	.0032	4.5059
620/0	.7863	.9215	209.567	.8533	.2099	.0038	3.7463
621/0	.7300	.9155	165.070	.7974	.2474	.0044	2.9508
622/0	.6407	.9105	110.056	.7037	.3250	.0058	1.9717
633/0	.8190	.9292	214.544	.8814	.2095	.0038	3.9090

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
608/0	795.4	1585.5	6.80	5.71	27.58	.508+00	748.6	70.30	3.018
619/0	836.6	1880.0	6.86	6.10	33.06	.573+00	777.7	70.07	3.017
620/0	867.0	1552.4	6.83	5.82	27.75	.456+00	776.5	70.21	3.006
621/0	856.9	1224.5	6.79	5.42	21.89	.364+00	761.0	70.37	3.003
622/0	847.9	824.5	6.82	4.80	14.77	.248+00	745.6	70.70	3.000
633/0	1028.7	1606.1	6.96	6.13	29.26	.398+00	841.8	70.32	2.993

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(O) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
608/0	1.212	1234.8	18.02	7.32	.142-02	559.3	432.3	.546+07
619/0	1.210	1232.8	18.02	7.34	.142-02	559.0	432.4	.546+07
620/0	1.202	1225.7	18.01	7.41	.144-02	558.0	432.9	.547+07
621/0	1.201	1224.5	18.01	7.42	.144-02	557.8	432.9	.547+07
622/0	1.193	1217.5	18.01	7.49	.145-02	556.8	433.4	.548+07
633/0	1.193	1231.2	18.00	7.49	.142-02	569.4	443.2	.532+07

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
.7804	5.709	358.6	.407-02	493.2	1864.2	3.780	91.91	36.44	3.147
.8310	6.096	380.7	.409-02	506.5	1935.8	3.822	93.22	37.98	3.234
.7863	5.825	416.3	.357-02	527.2	1973.6	3.744	91.99	36.61	3.168
.7300	5.415	423.0	.327-02	531.0	1945.1	3.663	90.36	34.52	3.105
.6407	4.800	438.7	.279-02	539.9	1906.8	3.533	86.86	30.99	3.005
.8190	6.131	540.1	.290-02	593.1	2198.5	3.707	92.72	37.23	3.214

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Table 2-4 (Continued)

NOZZLE PARAMETERS- NOZZLE 6A - AIR, A/A*=4.040, THETA=24.62, M=1.2 MA10F

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
416/0	6646	.9129	66.095	.7280	.3786	.0101	1.7553
417/0	.8016	.9219	123.155	.8695	.2474	.0065	3.2407
418/0	.8943	.9436	177.238	.9478	.1934	.0050	4.6237
419/0	.9591	.9722	215.507	.9865	.1716	.0045	5.5883
448/0	.6263	.9132	53.433	.6858	.4404	.0117	1.4220
449/0	.8060	.9212	123.661	.8749	2477	.0065	3.2537
450/0	.9042	.9439	177.870	.9579	.1949	.0051	4.6390
451/0	.9302	.9594	196.022	.9696	.1825	.0047	5.0973
460/0	.9776	.9777	225.096	.9999	.1677	.0043	5.8286
462/0	.7991	.9296	121.232	.8596	.2503	.0066	3.1920

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
416/0	661.2	489.7	6.76	4.92	13.01	.621-01	1260.5	50.08	3.017
417/0	676.4	912.8	6.83	5.94	24.02	.113+00	1275.0	50.20	3.023
418/0	684 8	1313.9	7.00	6.63	34.28	.161+00	1282.8	50.31	3.028
419/0	688.5	1594.9	7.19	7.10	41.36	.194+00	1286.3	50.39	3.032
448/0	799.5	394.4	6.74	4.62	10.50	.414-01	1386.1	50.06	3.015
449/0	843.7	918.1	6.84	5.98	24.16	.913-01	1423.9	50.20	3.023
450/0	878.1	1325.5	7.03	6.74	34.57	.127+00	1452.7	50.32	3.029
451/0	872.1	1463.9	7.16	6.95	38.07	.141+00	1447.7	50.35	3.031
460/0	1002.7	1661.8	7.22	7.22	43.03	.139+00	1552.3	50.41	3.033
462/0	976.0	885.5	6.79	5.84	23.32	.761-01	1531.5	50.19	3.022

Table 2-4 (Continued)

NOZZLE PARAMETERS- NOZZLE 6A - AIR, A/A*=4.040, THETA=24.67, M=1.2 MA10F

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(O) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
416/0	1.201	1232.2	18.00	7.41	.142-02	564.4	438.0	.538+07
417/0	1.201	1231.4	18.00	7.41	.142-02	563.8	437.5	.539+07
418/0	1.201	1231.0	18.00	7.41	.142-02	563.4	437.2	.540+07
419/0	1.202	1231.4	18.00	7.40	.142-02	562.9	436.6	.541+07
448/0	1.204	1232.5	18.00	7.38	.142-02	562.4	435.9	.541+07
449/0	1.200	1227.0	18.00	7.42	.143-02	560.7	435.3	.543+07
450/0	1.197	1224.6	18.00	7.45	.143-02	560.7	435.8	.543+07
451/0	1.195	1223.5	18.00	7.47	.144-02	560.9	436.3	.543+07
460/0	1.204	1230.8	18.01	7.38	.142-02	560.9	434.8	.543+07
462/0	1.212	1237.1	18.00	7.30	141-02	560.8	433.4	.543+07

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
.6646	4 924	177.7	.233-02	653.4	2410.4	3.689	61.44	35.98	2.635
.8016	5.941	160.5	.311-02	621.1	2489.8	4.009	65.91	40.33	2.863
.8943	6.630	151.1	.368-02	602.6	2532.4	4.202	68.38	42.68	3.002
.9591	7.098	146.6	.406-02	593.5	2551.8	4.300	69.55	43.78	3.071
.6263	4 623	224.4	.173-02	734.4	2628.7	3.579	59.78	34.35	2.557
.8060	5.984	200.3	.251-02	693.8	2780.5	4.008	65.90	40.32	2.863
.9042	6.738	194.2	.291-02	683.1	2866.7	4.197	68.31	42.61	2.998
.9302	6.947	189.1	.308-02	674.1	2864.8	4.250	68.95	43.22	3.036
.9776	7.217	212.0	.286-02	713.7	3082.4	4.319	69.78	43.99	3.085
7991	5.837	232.4	.211-02	747.4	2989.1	3.999	65.79	40.21	2.857

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Table 2-4 (Continued)

NOZZLE PARAMETERS- NOZZLE 8A - AIR, A/A*=4.060, THETA=10.12, M=1.2 FAll

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
109/2	.6225	1.0114	16.830	.6155	1.2060	.0370	.5162
110/1	.6431	1.0048	16.061	.6400	1.3053	.0400	.4927
113/0	.5227	1.0108	34.294	.5171	.4989	.0152	1.0477
117/0	.6279	1.0068	66.777	.6237	.3101	.0094	2.0249
118/0	.6361	1.0135	67.095	.6276	.3127	.0095	2.0345
123/0	.5218	1.0150	33.085	.5141	.5161	.0158	1.0110
129/0	.7883	1.0142	133.105	.7773	.1982	.0059	3.9765
133/0	.8909	1.0060	202.980	.8856	.1491	.0044	5.9740
134/0	.7752	1.0018	132.579	.7738	.1958	.0058	3.9601
139/1	.8868	1.0296	202.178	.8613	.1491	.0044	5.9494

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
109/2	891.0	125.2	7.52	4.63	3.84	.118-01	1463.3	48.22	2.92[illegible]
110/1	658.5	119.7	7.49	4.79	3.67	.152-01	1258.0	48.21	2.921
113/0	664.3	253.8	7.48	3.87	7.75	.321-01	1263.5	48.27	2.923
117/0	661.6	497.3	7.50	4.68	15.08	.631-01	1260.9	48.36	2.928
118/0	915.3	497.9	7.52	4.72	15.10	.456-01	1483.1	48.36	2.928
123/0	905.6	245.2	7.52	3.87	7.49	.227-01	1475.2	48.26	2.923
129/0	909.1	993.2	7.57	5.88	29.67	.916-01	1478.1	48.56	2.938
133/0	915.3	1497.4	7.42	6.57	44.07	.137+00	1483.1	48.76	2.948
134/0	677.5	998.3	7.54	5.84	29.82	.124+00	1276.0	48.56	2.938
139/1	654.6	1503.0	7.65	6.59	44.23	.193+00	1254.2	48.76	2.948

Table 2-4 (Continued)

NOZZLE PARAMETERS- NOZZLE 8A - AIR, A/A*=4.060, THETA=10.12, M=1.2 FA11

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(O) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
109/2	1.199	1225.6	18.02	7.44	.143-02	560.0	434.9	.545+07
110/1	1.197	1224.2	18.01	7.45	.144-02	560.0	435.2	.544+07
113/0	1.202	1228.1	18.00	7.40	.143-02	560.0	434.4	.544+07
117/0	1.198	1224.9	18.02	7.45	.144-02	560.0	435.1	.545+07
118/0	1.201	1227.0	18.02	7.42	.143-02	560.0	434.6	.545+07
123/0	1.202	1227.8	18.02	7.41	.143-02	560.0	434.5	.545+07
129/0	1.196	1223.5	18.01	7.46	.144-02	560.0	435.4	.544+07
133/0	1.205	1240.5	18.02	7.38	.140-02	569.0	440.9	.533+07
134/0	1.190	1227.8	18.01	7.53	.142-02	569.0	443.5	.533+07
139/1	1.200	1226.2	18.02	7.43	.143-02	560.0	434.8	.545+07

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
.6225	4.631	347.3	.112-02	913.6	2555.9	2.798	45.70	7.61	1.998
.6431	4.793	262.6	.153-02	794.4	2181.1	2.746	44.51	6.52	1.961
.5227	3.868	201.0	.161-02	695.0	2359.4	3.395	56.83	18.68	2.425
.6279	4.676	174.4	.225-02	647.4	2419.5	3.737	62.16	23.91	2.670
.6361	4.720	241.8	.164-02	762.3	2844.7	3.732	62.07	23.82	2.665
.5218	3.867	276.7	.117-02	815.5	2748.9	3.371	56.43	18.29	2.408
.7883	5.882	210.0	.235-02	710.4	2898.4	4.080	66.84	28.40	2.914
.8909	6.572	194.1	.284-02	682.9	2943.8	4.311	69.68	31.04	3.079
.7752	5.837	155.9	.314-02	612.1	2503.5	4.090	66.96	28.52	2.921
.8868	6.592	138.8	.399-02	577.5	2489.6	4.311	69.69	31.05	3.079

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Table 2-4 (Continued)

NOZZLE PARAMETERS- NOZZLE 5B - CF4, A/A*=8.291, THETA=15.03, M 1.46 HA10F

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
612/0	.8255	.9709	233.561	.8502	.1922	.0035	4.2945
623/0	.7116	.9649	161 541	.7375	.2470	.0044	2.8813
624/0	.8002	.9643	232.970	.8298	.1909	.0034	4.1909
625/0	.8638	.9791	302.686	.8822	.1589	.0029	5.4355
626/0	.9216	.9862	377.350	.9345	.1371	.0024	6.7214

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
612/0	1014.9	1210.3	5.03	4.28	22.25	.304+00	824.5	70.71	2.985
623/0	850.9	848.2	5.07	3.74	15.13	.254+00	747.5	70.79	3.003
624/0	840.4	1212.9	5.02	4.17	21.82	.368+00	753.6	70.30	3.003
625/0	842.4	1556.1	5.03	4.44	27.94	.471+00	766.6	70.03	3.004
626/0	848.0	1916.1	5.01	4.68	34.13	.576+00	783.7	69.83	3.010

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(0) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
612/0	1.462	1419.8	18.01	5.18	.111-02	560.5	392.6	.531+07
623/0	1.453	1410.7	18.01	5.25	.112-02	558.2	392.5	.535+07
624/0	1.459	1414.7	18.01	5.21	.112-02	558.2	391.5	.534+07
625/0	1.467	1420.8	18.00	5.14	.110-02	558.4	390.3	.533+07
626/0	1.476	1427.5	18.01	5.08	.109-02	558.9	389.2	.531+07

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
.8255	4.278	527.4	.207-02	586.8	2193.9	3.739	94.21	38.33	3.235
.7116	3.736	422.4	.226-02	530.7	1945.5	3.666	90.50	34.54	3.105
.8002	4.166	394.4	.270-02	514.7	1950.1	3.789	93.08	37.61	3.187
.8638	4.441	380.4	.298-02	506.4	1965.9	3.882	95.09	39.90	3.253
.9216	4.680	371.2	.322-02	500.9	1984.2	3.961	96.68	41.68	3.310

Table 2-4 (Continued)

NOZZLE PARAMETERS- NOZZLE 6A - AIR, A/A*=4.040, THETA=24.62, M=1.46, MA10F

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
412/0	1.0467	1.0319	312.020	1.0143	.1294	.0034	8.0915
413/0	.9724	.9921	246.009	.9801	.1514	.0040	6.4230
414/0	.8774	.9759	176.838	.8991	.1886	.0050	4.6532
415/0	.7145	.9640	88.798	.7412	.3028	.0080	2.3593
444/0	1.0539	1.0226	316.882	1.0306	.1283	.0033	8.2115
445/0	.9806	.9975	260.323	.9831	.1445	.0038	6.7866
446/0	.8857	.9728	180.712	.9105	.1863	.0049	4.7532
447/0	.7348	.9566	97.213	.7681	.2848	.0076	2.5805
465/0	1.0526	1.0320	317.852	1.0200	.1278	.0033	8.2346
467/0	.8871	.9760	177.456	.9089	.1900	.0050	4.6695

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
412/0	744.5	1591.3	5.26	5.34	41.27	.179+00	1337.6	50.39	3.032
413/0	705.5	1276.0	5.15	5.04	33.31	.152+00	1302.1	50.30	3.028
414/0	692.7	914.4	5.05	4.54	24.06	.111+00	1290.2	50.20	3.023
415/0	671.4	470.2	5.10	3.78	12.49	.587-01	1270.2	50.08	3.016
444/0	858.4	1626.0	5.25	5.41	42.14	.159+00	1436.3	50.40	3.033
445/0	855.4	1345.0	5.15	5.07	35.06	.132+00	1433.8	50.32	3.029
446/0	890.8	932.8	5.02	4.57	24.54	.878-01	1463.1	50.21	3.023
447/0	907.1	512.8	5.05	3.88	13.61	.474-01	1476.5	50.09	3.017
465/0	986.7	1637.6	5.32	5.42	42.43	.139+00	1539.9	50.40	3.033
467/0	982.6	913.9	5.03	4.57	24.05	.780-01	1536.7	50.20	3.023

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Table 2-4 (Continued)

NOZZLE PARAMETERS- NOZZLE 6A - AIR, A/A*=4.040, THETA=24.62, M=1.46 MA10F

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(0) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
412/0	1.473	1432.2	18.01	5.10	.109-02	564.3	393.5	.525+07
413/0	1.461	1424.4	17.99	5.19	.110-02	564.8	395.9	.525+07
414/0	1.463	1426.0	18.00	5.17	.110-02	564.7	395.4	.525+07
415/0	1.446	1413.6	18.00	5.30	.112-02	564.0	397.6	.527+07
444/0	1.469	1422.8	18.00	5.13	.110-02	559.3	390.8	.531+07
445/0	1.464	1420.3	18.00	5.17	.111-02	559.9	391.9	.531+07
446/0	1.464	1421.2	18.00	5.16	.110-02	560.3	392.1	.533+07
447/0	1.449	1410.5	18.00	5.27	.112-02	560.0	394.3	.532+07
465/0	1.466	1422.5	18.00	5.15	.110-02	560.6	392.1	530+07
467/0	1.466	1422.9	18.01	5.15	.110-02	560.7	392.1	.530+07

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
1.0467	5.338	146.2	.306-02	592.7	2681.3	4.524	72.11	46.34	3.231
.9724	5.044	145.2	.291-02	590.7	2594.8	4.393	70.64	44.96	3.138
.6774	4.537	152.1	.250-02	604.6	2548.7	4.215	68.54	42.95	3.011
.7145	3.783	169.3	.188-02	637.8	2456.3	3.851	63.78	38.32	2.751
1.0539	5.408	168.1	.270-02	635.7	2880.0	4.531	72.18	46.40	3.236
.9806	5.066	173.6	.245-02	645.9	2862.2	4.431	71.07	45.37	3.165
.8857	4.572	194.9	.197-02	684.4	2891.6	4.225	68.65	43.06	3.018
.7348	3.876	224.6	.145-02	734.8	2863.6	3.897	64.42	38.94	2.784
1.0526	5.423	193.0	.236-02	681.1	3088.1	4.534	72.22	46.44	3.239
.8871	4.569	216.2	.177-02	720.9	3034.6	4.210	68.46	42.88	3.007

Table 2-4 (Continued)

NOZZLE PARAMETERS- NOZZLE 8A - AIR, A/A*=4.060, THETA=10.12, M=1.46 FA11

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
140/0	.9647	.9764	275.196	.9880	.1191	.0035	8.0982
141/C	.8561	.9820	187.612	.8718	.1529	.0046	5.5998
142/0	.8678	.9846	182.920	.8814	.1588	.0047	5.4635
143/0	.9673	.9487	276.885	1.0196	.1187	.0035	8.1486
144/1	.6741	.9793	89.648	.6883	.2479	.0075	2.7188
145/1	.5549	.9764	45.402	.5683	.4000	.0122	1.3872
146/0	5473	.9709	45.418	.5637	.3944	.0121	1.3877
147/0	.6731	.9745	90.934	.6907	.2441	.0074	2.7572
148/0	.6189	.9776	15.378	.6331	1.3105	.0402	.4722
149/0	5961	.9795	15.572	.6086	1.2466	.0383	.4782

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
140/0	652.4	1502.3	5.33	5.27	44.21	.193+00	1252.1	48.76	2.948
141/0	667.8	1023.4	5.36	4.67	30.55	.129+00	1266.8	48.57	2.939
142/0	911.8	1000.6	5.39	4.75	29.89	.921-01	1480.3	48.56	2.938
143/0	901.2	1499.6	5.14	5.24	44.13	.140+00	1471.6	48.76	2.948
144/1	913.1	493.5	5.39	3.71	14.97	.453-01	1481.3	48.36	2.928
145/1	913.1	249.3	5.36	3.05	7.62	.229-01	1481.3	48.27	2.923
146/0	662.5	249.8	5.34	3.01	7.63	.316-01	1261.8	48.27	2.923
147/0	666.0	500.2	5.36	3.70	15.17	.630-01	1265.1	48.37	2.928
148/0	669.1	84.1	5.35	3.38	2.58	.105-01	1268.1	48.20	2.920
149/0	871.6	84.9	5.34	3.25	2.61	.817-02	1447.3	48.20	2.920

Table 2-4 (Continued)

NOZZLE PARAMETERS- NOZZLE 8A - AIR, A/A*=4.060, THETA=10.12,M=1.46 FA11

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(O) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
140/0	1.499	1444.1	20.01	5.46	.119-02	560.0	386.4	.586+07
141/0	1.499	1444.3	20.01	5.45	.118-02	560.0	386.3	.586+07
142/0	1.498	1443.3	20.02	5.47	.119-02	560.0	386.6	.586+07
143/0	1.505	1447.8	20.02	5.42	.118-02	560.0	385.5	.585+07
144/1	1.493	1440.3	20.02	5.50	.119-02	560.0	387.3	.587+07
145/1	1.495	1441.4	20.01	5.49	.119-02	560.0	387.0	.586+07
146/0	1.494	1440.5	20.00	5.50	.119-02	560.0	387.2	.586+07
147/0	1.494	1440.5	20.01	5.50	.119-02	560.0	387.2	.587+07
148/0	1.498	1443.4	20.02	5.47	.119-02	560.0	386.5	.586+07
149/0	1.500	1444.7	20.01	5.45	.118-02	560.0	386.2	.586+07

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
.9647	5.266	129.7	.341-02	558.3	2506.1	4.488	71.72	33.08	3.206
.8561	4.670	143.2	.274-02	586.6	2510.7	4.280	69.32	30.87	3.057
.8678	4.747	197.7	.201-02	689.2	2929.3	4.250	68.96	30.51	3.036
.9673	5.239	179.0	.245-02	655.9	2945.8	4.491	71.75	33.11	3.208
.6741	3.711	225.8	.138-02	736.6	2873.8	3.901	64.47	26.23	2.787
.5549	3.047	259.4	.985-03	789.6	2802.6	3.550	59.32	21.18	2.535
.5473	3 010	187.5	.135-02	671.2	2389.2	3.560	59.48	21.33	2.543
.6731	3.703	164 0	.189-02	627.7	2456.1	3.913	64.63	26.38	2.795
.6189	3 385	267.2	.106-02	801.3	2197.5	2.742	44.54	6.46	1.959
.5961	3.250	343.1	.795-03	908.1	2519.9	2.775	45.23	7.15	1.982

Table 2-4 (Continued)

NOZZLE PARAMETERS- NOZZLE 5B - CF4, A/A*=8.291, THETA=15.03, 3.48, MA10F

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
610/0	1.1127	.9937	1250.085	1.1198	.0508	.0009	21.9077
611/0	1.1593	1.0097	1201.675	1.1482	.0527	.0010	22.0037
627/0	1.2463	1.0331	1476.617	1.2064	.0472	.0008	26.3833
628/0	1.1275	9980	1206.041	1.1298	.0524	.0009	21.5333
629/0	1.0013	.9840	974.674	1.0176	.0587	.0010	17.0718
630/0	8153	.9779	669.312	.8337	.0684	.0012	11.9281
631/0	1.2512	1.0346	1333.071	1.2094	.0521	.0009	24.0146

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
610/0	796.6	1519.2	1.21	1.35	26.62	.486+00	746.3	70.24	3.015
611/0	924.4	1458.7	1.23	1.41	26.71	.402+00	796.5	70.22	2.995
627/0	854.9	1794.5	1.26	1.51	32.06	.535+00	781.1	69.93	3.008
628/0	856.8	1464.0	1.21	1.37	26.14	.436+00	769.1	70.31	3.008
629/0	842.0	1184.5	1.20	1.22	20.75	.359+00	753.4	71.38	3.014
630/0	858.6	813.4	1.19	.99	14.50	.242+00	750.0	70.87	3.003
631/0	1012.2	1618.2	1.26	1.52	29.15	.408+00	835.9	70.44	3.000

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(O) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
610/0	3.480	2193.6	90.04	1.22	.616-03	566.1	165.5	.105+08
611/0	3.480	2196.0	90.03	1.21	.614-03	567.3	165.8	.104+08
627/0	3.480	2193.0	90.06	1.22	.617-03	565.8	165.4	.105+08
628/0	3.480	2195.2	90.03	1.21	.615-03	566.9	165.6	.104+08
629/0	3.480	2195.7	90.04	1.22	.615-03	567.2	165.8	.104+08
630/0	3.480	2195.7	90.04	1.22	.615-03	567.2	165.8	.104+08
631/0	3.480	2197.9	90.02	1.21	.613-03	568.3	166.1	.104+08

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
1.1127	1.352	279.6	.123-02	442.6	1996.2	4.510	107.40	51.98	3.635
1.1593	1.407	373.4	.961-03	502.5	2207.9	4.394	108.23	52.84	3.671
1.2463	1.515	314.1	.123-02	465.6	2097.6	4.505	108.45	53.35	3.687
1.1275	1.369	324.5	.108-02	472.3	2099.9	4.446	107.74	52.26	3.653
1.0013	1.217	322.5	.962-03	471.1	2073.9	4.403	107.51	50.97	3.615
.8153	.991	348.1	.726-03	487.1	2095.6	4.302	105.66	49.62	3.565
1.2512	1.519	431.4	.898-03	535.9	2343.5	4.373	109.16	53.55	3.711

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Table 2-4 (Continued)

NOZZLE PARAMETERS- NOZZLE 6A - AIR, A/A*=4.040, THETA=24.62, M=3.48, MA10F

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
406/0	.9398	1.0048	404.320	.9353	.0875	.0023	10.7377
409/0	1.2207	1.0309	738.124	1.1841	.0628	.0017	19.4303
410/0	1.4388	1.1080	1063.378	1.2986	.0518	.0014	27.7537
411/0	1.5807	1.1666	1349.239	1.3550	.0452	.0012	34.9534
440/0	.9364	1.0083	377.876	.9287	.0932	.0025	10.0424
441/0	1.2423	1.0379	756.330	1.1969	.0624	.0016	19.9000
442/0	1.3988	1.1037	1022.561	1.2674	.0524	.0014	26.7182
443/0	1.5644	1.1669	1358.197	1.3406	.0445	.0012	35.1787
468/0	1.5873	1.1845	1383.323	1.3401	.0443	.0011	35.8062
469/0	1.4462	1.1361	1061.135	1.2730	.0522	.0014	27.6976
470/0	1.1976	1.0324	677.410	1.1600	.0671	.0018	17.8606
471/0	.8823	1.0008	321.446	.8816	.1031	.0027	8.5556

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
408/0	695.7	490.6	1.22	1.14	13.03	.592-01	1293.0	50.08	3.017
409/0	696.9	896.0	1.25	1.48	23.59	.108+00	1294.1	50.20	3.022
410/0	684.1	1292.3	1.35	1.75	33.73	.158+00	1282.2	50.31	3.028
411/0	678.1	1639.7	1.42	1.92	42.48	.203+00	1276.6	50.40	3.033
440/0	818.1	458.7	1.22	1.14	12.19	.470-01	1402.2	50.08	3.016
441/0	819.8	918.1	1.26	1.51	24.16	.939-01	1403.6	50.20	3.023
442/0	821.1	1241.3	1.34	1.70	32.43	.127+00	1404.7	50.29	3.027
443/0	827.7	1648.7	1.42	1.90	42.70	.167+00	1410.4	50.40	3.033
468/0	978.4	1679.2	1.44	1.93	43.46	.144+00	1533.4	50.41	3.034
469/0	986.7	1288.1	1.38	1.76	33.62	.110+00	1539.9	50.31	3.028
470/0	970.3	822.3	1.25	1.45	21.68	.711-01	1527.0	50.18	3.021
471/0	926.8	390.2	1.21	1.07	10.39	.353-01	1492.4	50.06	3.015

Table 2-4 (Concluded)

NOZZLE PARAMETERS- NOZZLE 6A - AIR, A/A*=4.040, THETA=24.62, M=3.48, MA10F

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(O) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
408/0	3.480	2180.7	90.02	1.21	.623-03	559.4	163.5	.106+08
409/0	3.480	2180.5	90.02	1.21	.623-03	559.3	163.4	.106+08
410/0	3.480	2180.5	90.04	1.22	.624-03	559.4	163.5	.107+08
411/0	3.480	2181.1	90.05	1.22	.623-03	559.7	163.6	.106+08
440/0	3.480	2183.6	90.03	1.21	.621-03	560.9	163.9	.106+08
441/0	3.480	2184.4	90.02	1.21	.621-03	561.3	164.0	.106+08
442/0	3.480	2180.8	89.99	1.21	.623-03	559.5	163.5	.106+08
443/0	3.480	2181.6	90.00	1.21	.622-03	559.9	163.6	.106+08
468/0	3.480	2184.7	89.97	1.21	.621-03	561.5	164.1	.106+08
469/0	3.480	2184.0	90.02	1.21	.621-03	561.1	163.9	.106+08
470/0	3.480	2184.0	90.03	1.21	.621-03	561.1	163.9	.106+08
471/0	3.480	2183.8	90.02	1.21	.621-03	561.0	163.9	.106+08

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	PJ/GAMMA
.9398	1.141	123.0	.778-03	543.7	2623.2	4.825	75.25	49.78	3.446
1.2207	1.482	111.8	.111-02	518.3	2651.5	5.115	77.99	52.42	3.654
1.4388	1.749	103.6	.142-02	499.0	2641.0	5.292	79.54	53.86	3.780
1.5807	1.921	98.6	.163-02	486.7	2638.8	5.422	80.63	54.84	3.873
.9364	1.137	147.3	647-03	595.0	2839.0	4.771	74.71	49.26	3.408
1.2423	1.508	131.3	.964-03	561.6	2876.3	5.121	78.05	52.46	3.658
1.3988	1 698	124.8	.114-02	547.6	2892.6	5.282	79.46	53.79	3.773
1.5644	1,899	119 7	.133-02	536.4	2916.6	5.437	80.75	54.97	3.884
1.5873	1.927	141.4	.114-02	582.9	3171.3	5.440	80.78	54.99	3.886
1.4462	1.756	149.8	.983-03	600.0	3171.2	5.286	79.49	53.80	3.775
1.1976	1.454	158.7	.769-03	617.5	3122.9	5.057	77.47	51.91	3.612
.8823	1.071	171.8	.523-03	642.6	3011.9	4.687	73.85	48.41	3.348

Table 2-5

MA11F (TWO-PHASE) SINGLE NOZZLE CONFIGURATION EXPERIMENTAL DATA BASE

NOZZLE PARAMETERS – NOZZLE S/N-1 – 16% Aℓ – A/A = 7 594, THETA = 14 95, M = 3 48, MA11F

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
1/1	597	1 007	259 10	593	132	0023	4 529
2/0	824	1 025	586 79	804	078	0014	10 527
3/0	1 005	996	897 98	1 009	055	0010	18 285
4/2	1 032	1 032	1371 13	1 000	040	0008	26 108

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	GAMMAE	ME
1/1	5936 4	349 06	1 356	804	6 10	462-02	3518 0	1 300	2 976
2/0	6003 7	790 54	1 381	1 110	14 18	1 030-02	3535 0	1 298	2 958
3/0	6086 1	1331 08	1 342	1 354	24 63	1 725-02	3555 8	1 296	2 936
4/2	6165 0	1849 09	1 392	1 392	35 22	2 391-02	3575 8	1 294	2 914

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(O) (DEG-R)	T(INF) (DEG-R)	R N (/FT)
1/1	3 48	2194 8	99 88	1 347	685-03	564 4	165 0	1170+08
2/0	3 48	2188 8	99 88	1 347	689-03	561 2	164 1	1180+08
3/0	3 48	2192 8	99 88	1 347	686-03	563 1	164 7	1174+08
4/2	3 48	2182 2	99 98	1 349	694-03	557 7	163 1	1193+08

RUN/PT	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	DELTA(J) (DEG)	MJ/ GAMMA
1/1	804	1659 1	27249-04	2382 6	10100 0	4 239	38 70	3 165
2/0	1 110	1486 9	41305-04	2258 4	10329 8	4 574	43 77	3 398
3/0	1 354	1395 5	54105-04	2188 3	10486 5	4 792	47 09	3 552
4/2	1 392	1317 6	59835-04	2127 4	10624 1	4 994	50 01	3 694

Table 2-5 (Continued)

NOZZLE PARAMETERS – NOZZLE S/N-2 - 2% Aℓ – A/A* = 8 662, THETA = 14 72, M = 3 48, MA11F

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
136/0	505	958	309 00	527	122	0016	4 154
137/0	708	952	849 41	744	061	0008	11 512
138/0	812	949	1371 78	856	043	0006	18 746
237/0	1 536	1 352	3634 98	1 136	031	0004	49 377

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	GAMMAE	ME
136/0	5396 4	416 51	1 291	681	5 60	572-02	3470 8	1 256	3 24
137/0	5475 0	1145 50	1 284	955	15 53	1 546-02	3499 3	1 254	3 24
138/0	5551 2	1849 51	1 280	1 095	25 27	2 490-03	3526 9	1 252	3 23
237/0	5483 8	1225 97	456	518	16 64	1 655-02	3502 5	1 254	3 24

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(O) (DEG-R)	T(INF) (DEG-R)	R N (/FT)
136/0	3 48	2162 7	99 93	1 348	706-03	547 9	160 2	1226+08
137/0	3 48	2162 0	99 98	1 349	707-03	547 7	160 1	1228+08
138/0	3 48	2162 0	99 95	1 348	706-03	547 7	160 1	0307+08
237/0	3 48	2162 7	25 01	337	177-03	547 8	160 2	1227+08

RUN/PT	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	DELTA(J) (DEG)	MJ/ GAMMA
136/0	681	1584 4	30915-04	2023 0	9095 2	4 496	38 73	3 480
137/0	955	1378 7	49372-04	1891 3	9354 6	4 946	45 11	3 786
138/0	1 095	1291 8	46246-04	1831 1	9494 5	5 185	48 23	3 965
237/0	518	1176 4	31402-04	1755 1	9542 3	5 437	50 76	4 134

Table 2-5 (Concluded)

NOZZLE PARAMETERS — NOZZLE S/N-3 - 16% Aℓ — A/A* = 4 067, THETA = 15 18, M = 3 48, MA11F

RUN/PT	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
163/0	1 187	972	651 07	1 221	041	0018	28 666

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	GAMMAE	ME
163/0	6069 6	878 02	1 311	1 601	38 67	1 146-02	3551 8	1 284	2 432

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(O) (DEG-R)	T(INF) (DEG-R)	R N (/FT)
163/0	3 48	2188 2	99 98	1 349	690-03	561 0	164 0	1182+08

RUN/PT	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	DELTA(J) (DEG)	MJ/ GAMMA
163/0	1 601	1611 4	56013-04	2343 9	10254 4	4 375	55 48	3 266

Table 2-6

FA22 (TWO-PHASE) SINGLE NOZZLE CONFIGURATION EXPERIMENTAL DATA BASE

FA22, M_∞ = 9, UTP-3001 16% Aℓ

RUN/NOZZLE	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
13/5	8567	8701	87 75	9846	5516	0098	1 553
14/7	9042	8951	34 69	1 0102	5605	0261	1 613
15/6	9802	9814	201 39	9988	2791	0049	3 511

RUN/NOZZLE	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	GAMMAE	ME
13/5	5936 4	351 0	3 4804	3 4268	6 212	465-02	3518 3	1 256	2 921
14/7	5967 0	425 0	10 9650	11 0765	19 763	561-02	3525 6	1 240	2 388
15/6	6015 6	596 1	2 9049	2 9014	10 394	783-02	3538 1	1 260	2 932

RUN/NOZZLE	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(O) (DEG-R)	T(INF) (DEG-R)	R N (/FT)
13/5	903	967 6	6 79	4 00	705-03	553 9	476 2	1947+07
14/7	898	980 1	20 68	12 25	208-02	573 8	494 1	5658+07
15/6	899	963 1	5 00	2 96	521-03	553 0	476 0	1434+07

RUN/NOZZLE	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	DELTA(J) (DEG)	MJ/ GAMMA
13/5	3 4268	2754 2	719-04	2948 9	9589 1	3 2517	23 329	2 564
14/7	11 0765	3357 9	190-03	3235 1	8757 8	2 7071	24 679	2 167
15/6	2 9014	2359 4	709-04	2734 5	10049 7	3 6752	31 780	2 888

Note See Table 2-1 for definition of A/A* and THETA

Table 2-6 (Continued)

FA22, M_∞ = 9, AND-3335 2% Aℓ

RUN/NOZZLE	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
4/6	8471	8691	71 89	9747	8032	0118	1 055
5/5	9176	9185	161 84	9990	3766	0057	2 437

RUN/NOZZLE	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	GAMMAE	ME
4/6	5400 0	430 6	5 206	5 0741	6 3172	591-02	3472 1	1 254	3 195
5/5	5414 4	483 9	2 746	2 7436	7 2856	663-02	3477 0	1 254	3 180

RUN/NOZZLE	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(O) (DEG-R)	T(INF) (DEG-R)	R N (/FT)
4/6	898	969 1	10 10	5 99	104-02	561 0	483 1	2846+07
5/5	898	963 9	5 04	2 99	525-03	555 0	477 9	1440+07

RUN/NOZZLE	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	DELTA(J) (DEG)	MJ/ GAMMA
4/6	5 0741	2425 8	151-03	2469 2	8190 4	3 317	17.92	2 638
5/5	2 7436	2081 2	948-04	2297 9	8591 7	3 739	27 38	2 942

Note See Table 2-1 for definition of A/A* and THETA

Table 2-6 (Continued)

FA22, M_{∞} = 1 2, UTP-3001 16% Aℓ

RUN/NOZZLE	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
16/5	6264	8592	62 58	7291	5673	0100	1 104
17/7	7824	8680	56 05	9014	3001	0140	2 607
18/6	6797	8807	84 12	7718	4640	0081	1 465

RUN/NOZZLE	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	GAMMAE	ME
16/5	5947 2	373 0	5 121	3 7333	6 5812	493-02	3520 7	1 256	2 923
17/7	5968 8	432 7	6 701	6 0401	20 128	.571-02	3526 2	1 241	2 388
18/6	5934 6	343 2	3 593	2 7732	5 9765	455-02	3517 4	1 256	2 931

RUN/NOZZLE	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(O) (DEG-R)	T(INF) (DEG-R)	R N (/FT)
16/5	1 201	1248 5	14 47	5 96	112-02	577 4	448 3	4177+07
17/7	1 20	1259 9	18 71	7 72	142-02	588 9	457 2	5262+07
18/6	1 20	1230 0	9 89	4 08	786-03	561 3	435 8	2961+07

RUN/NOZZLE	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	DELTA(J) (DEG)	MJ/GAMMA
16/5	3 7333	2766 4	779-04	2955 5	9573 0	3 239	22 97	2 554
17/7	6 0401	2961 7	118-03	3052 5	9304 0	3 048	34 01	2 413
18/6	2 7732	2645 4	605-04	2893 3	9724 4	3 361	25 58	2 643

Note See Table 2-1 for definition of A/A^* and THETA

Table 2-6 (Concluded)

FA22, M_{∞} = 1 2, ANB-3335 2% Aℓ

RUN/NOZZLE	PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)		
6/6	6423	8835	74 35	7270	5866	0086	1 095		
RUN/NOZZLE	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	GAMMAE	ME
6/6	5403 6	442 4	5 2568	3 8217	6 515	607-02	3473 4	1 254	3 1928
RUN/NOZZLE	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(O) (DEG-R)	T(INF) (DEG-R)	R N (/FT)	
6/6	1 20	1248 4	14 44	5 95	863-03	578 2	448 9	4159+07	
RUN/NOZZLE	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	DELTA(J) (DEG)	MJ/ GAMMA	
6/6	3 8217	2273 4	121-03	2394 5	8370 8	3 4958	22 01	2 769	

Note See Table 2-1 for definition of A/A* and THETA

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Table 2-7

FA 20 TRIPLE BODY CONFIGURATION EXPERIMENTAL DATA BASE

NOZZLE PARAMETERS- FA20 NOZZLE CF4 A/A* = 8.011 THETA=14.9 (LEFT MOTOR), M=.9

RUN/PT	ET PB/P(INF)	SRB PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
129	.9820	.8910	.9516	94.182	.9369	.5113	.0095	1.7427
136	1.0010	.9670	.9590	142.520	1.0083	.3612	.0068	2.6769
139	1.0340	1.0460	.9890	216.286	1.0576	.2567	.0048	4.0744

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
129	847.1	392.1	3.96	3.71	7.26	.118+00	736.2	70.28	2.983
136	960.0	847.7	5.70	5.75	15.92	.225+00	792.9	70.39	2.974
139	960.0	1284.8	5.87	6.21	24.20	.341+00	805.2	69.95	2.976

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(O) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
129	.899	951.5	7.03	4.16	.748-03	542.3	466.9	.208+07
136	.896	972.1	10.02	5.95	.102-02	568.3	489.6	.278+07
139	.896	958.2	10.00	5.94	.105-02	552.9	476.5	.288+07

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
.8910	3.709	476.3	.199-02	560.2	1849.5	3.301	80.33	24.94	2.830
.9670	5.752	535.6	.274-02	590.9	2034.7	3.444	85.46	29.98	2.984
1.0460	6.214	507.3	.312-02	576.4	2077.6	3.604	89.66	34.61	3.109

Table 2-7 (Continued)

NOZZLE PARAMETERS- FA20 NOZZLE AIR A/A* = 8.091 THETA=35.0 (LEFT MOTOR), M=.9

RUN/PT	ET PB/P(INF)	SRB PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
41	1.0310	1.0620	1.0000	260.466	1.0620	.6529	.0041	1.6266
48	1.0140	1.0240	.9820	205.198	1.0428	.8080	.0050	1.2673
51	.9930	.9630	.9640	143.293	.9990	1.1018	.0067	.8740
60	.9810	.9010	.9700	99.778	.9289	1.5025	.0090	.5997
64	.9780	.9150	.9620	111.298	.9511	1.3654	.0082	.6701
71	.9940	.9680	.9650	149.647	1.0031	1.0591	.0065	.9140
74	1.0190	1.0360	.9890	221.762	1.0475	.7540	.0047	1.3741
85	1.0370	1.0720	1.0040	275.237	1.0677	.6218	.0039	1.7239

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
41	892.1	1547.6	5.94	6.31	9.66	.146+00	1464.2	66.32	4.040
48	935.6	1220.5	5.84	6.09	7.54	.109+00	1499.5	66.43	4.048
51	909.9	851.0	5.73	5.72	5.19	.785-01	1478.7	66.55	4.058
60	854.5	405.0	3.94	3.66	2.43	.398-01	1433.0	66.70	4.069
64	682.4	459.8	3.97	3.78	2.77	.565-01	1280.6	66.68	4.068
71	663.2	89[illegible].4	5.74	5.76	5.44	.113+00	1262.5	66.54	4.057
74	665.3	1318.1	5.88	6.16	8.17	.166+00	1264.4	66.40	4.046
85	649.0	1634.6	5.96	6.37	10.24	.211+00	1248.9	66.29	4.038

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Table 2-7 (Continued)

NOZZLE PARAMETERS- FA20 NOZZLE AIR A/A* = 6.C91 THETA=35.0 (LEFT MOTOR), M=.9

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(O) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
41	.895	950.2	10.00	5.94	.106-02	543.9	468.7	.294+07
48	.897	954.4	10.03	5.95	.106-02	546.9	471.1	.293+07
51	.898	953.9	10.02	5.94	.106-02	545.8	470.0	.294+07
60	.907	961.2	6.92	4.06	.729-03	544.1	467.2	.205+07
64	.899	952.1	6.98	4.13	.742-03	542.4	466.9	.206+07
71	.899	958.2	10.05	5.95	.105-02	549.6	473.2	.292+07
74	.900	959.1	10.05	5.94	.105-02	549.6	473.0	.292+07
85	.898	954.0	10.02	5.94	.106-02	545.9	470.1	.294+07

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
1.0620	6.310	185.2	.286-02	667.2	2914.4	4.368	70.36	39.03	3.120
1.0240	6.091	205.8	.248-02	703.2	2961.3	4.211	68.48	37.05	3.008
.9630	5.719	217.9	.220-02	723.6	2883.6	3.985	65.60	34.04	2.846
.9010	3.657	222.7	.138-02	731.5	2755.4	3.767	62.58	30.88	2.691
.9150	3.780	173.1	.183-02	645.0	2473.8	3.835	63.56	31.87	2.740
.9680	5.760	157.1	.308-02	614.4	2466.0	4.014	65.98	34.44	2.867
1.0360	6.158	143.6	.360-02	587.4	2503.7	4.262	69.10	37.70	3.044
1.0720	6.366	133.0	.402-02	565.3	2490.0	4.405	70.77	39.48	3.146

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Table 2-7 (Continued)

NOZZLF PARAMETERS- FA20 NOZZLF AIP A/A* = 4.918 THETA=25.2 (LEFT MOTOR), M=.9

RUN/PT	ET PB/P(INF)	SRB PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
110	1.0470	1.0870	1.0070	236.354	1.0794	.2393	.0046	4.5420
111	1.0220	1.0300	.9820	163.345	1.0489	.3309	.0063	3.1129
113	.9890	.9320	.9520	86.329	.9790	.5713	.0108	1.6314

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
110	891.4	1419.6	6.05	6.53	27.28	.134+00	1463.6	54.10	3.235
111	700.0	968.5	5.82	6.11	18.46	.116+00	1297.0	54.20	3.241
113	700.0	509.7	5.62	5.50	9.63	.611-01	1297.0	54.30	3.246

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(0) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
110	.892	948.4	10.07	6.01	.107-02	545.6	470.7	.295+07
111	.900	956.5	10.03	5.93	.106-02	546.2	470.0	.294+07
113	.901	958.0	10.00	5.90	.105-02	546.7	470.3	.293+07

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
1.0870	6.529	191.5	.286-02	678.5	2899.9	4.274	69.25	40.35	3.353
1.0300	6.107	164.6	.311-02	629.0	2536.4	4.033	66.23	37.23	2.881
.9320	5.503	191.9	.240-02	679.2	2470.8	3.638	60.68	31.58	2.599

Table 2-7 (Continued)

NOZZLE PARAMETEPS- FA?? NOZZLE CF4 A/A* = 8.011 THETA=14.9 (LEFT MOTOR), M=1.2

RUN/PT	ET PB/P(INF)	SRB PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
131	.8460	.7520	.9110	96.137	.8255	.4148	.0078	1.8127
134	.9440	.9570	.9210	196.967	1.0391	.2562	.0049	3.7348
142	1.0400	1.1430	.9720	311.988	1.1759	.1944	.0037	5.8784
146	1.0680	1.2030	.9980	386.202	1.2054	.1646	.0031	7.3108

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOE (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
131	906.1	398.5	3.78	3.12	7.51	.112+00	760.9	70.44	2.971
134	960.0	815.5	3.81	3.96	15.46	.217+00	792.1	70.21	2.968
142	960.0	1288.9	4.02	4.72	24.29	.342+00	805.3	69.94	2.976
146	989.9	1596.3	4.13	4.97	30.22	.411+00	826.7	70.06	2.977

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(0) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
131	1.199	1214.8	10.04	4.15	.814-03	550.2	427.3	.311+07
134	1.197	1234.0	10.00	4.14	.785-03	569.3	442.5	.296+07
142	1.198	1222.4	9.99	4.13	.799-03	558.0	433.6	.303+07
146	1.197	1221.7	9.99	4.13	.800-03	557.6	433.3	.304+07

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	NU(J) (DEG)	DELTA(J) (DEG)	MJ/GAMMA
.7520	3.117	509.0	.156-02	577.4	1952.1	3.381	83.49	27.95	2.916
.9570	3.962	512.2	.197-02	579.0	2082.8	3.597	89.98	34.67	3.104
1.1430	4.722	488.1	.247-02	566.4	2114.2	3.733	93.21	38.17	3.207
1.2030	4.972	496.7	.255-02	570.9	2173.0	3.806	95.48	40.32	3.276

Table 2-7 (Continued)

NOZZLE PARAMETERS- FA20 NOZZLE AIR A/A* = 8.091 THETA=35.0 (LEFT MOTOR), M=1.2

RUN/PT	ET PB/P(INF)	SRB PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
43	1.0460	1.1420	.9910	360.862	1.1524	.5078	.0032	2.2488
46	1.0080	1.0810	.9670	291.950	1.1179	.5999	.0037	1.8021
53	.9420	.9820	.9380	203.045	1.0469	.7932	.0048	1.2379
56	.8540	.7980	.9250	102.255	.8627	1.2978	.0078	.6149
66	.8580	.8010	.9240	111.524	.8669	1.1928	.0072	.6715
69	.9460	.9940	.9390	212.241	1.0586	.7670	.0047	1.2959
76	1.0170	1.1060	.9730	317.124	1.1367	.5630	.0035	1.9646
79	1.0630	1.1790	1.0090	397.881	1.1685	.4728	.0030	2.4938

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
43	922.6	1486.8	4.08	4.71	9.27	.135+00	1489.8	66.34	4.042
46	973.0	1204.9	3.99	4.46	7.44	.104+00	1529.1	66.44	4.049
53	945.2	837.7	3.87	4.05	5.11	.743-01	1507.1	66.56	4.058
56	931.0	421.8	3.82	3.29	2.54	.380-01	1495.8	66.69	4.069
66	663.4	460.5	3.82	3.31	2.77	.582-01	1262.6	66.68	4.068
69	673.7	880.8	3.90	4.13	5.38	.110+00	1272.4	66.54	4.057
76	670.7	1313.2	4.03	4.58	8.14	.164+00	1269.6	66.40	4.046
79	676.6	1654.8	4.20	4.90	10.37	.205+00	1275.1	66.29	4.037

Table 2-7 (Continued)

NOZZLE PARAMETERS- FA2C NOZZLE AIR A/A* = 8.091 THETA=35.0 (LEFT MOTOR), M=1.2

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(O) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
43	1.201	1216.3	10.00	4.12	.809-03	550.4	427.2	.309+07
46	1.200	1217.7	10.01	4.13	.808-03	552.1	428.6	.308+07
53	1.200	1214.5	10.00	4.13	.811-03	549.5	426.7	.310+07
56	1.199	1217.4	9.99	4.12	.806-03	552.6	429.2	.307+07
66	1.201	1216.5	10.03	4.13	.811-03	550.2	427.0	.310+07
69	1.199	1215.4	10.05	4.15	.814-03	550.8	427.8	.311+07
76	1.198	1215.7	10.01	4.14	.810-03	552.1	429.0	.308+07
79	1.197	1219.3	10.05	4.16	.808-03	555.6	431.8	.307+07

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	DELTA(J) (DEG)	MJ/GAMMA
1.1420	4.705	178.2	.222-02	654.3	2990.8	4.571	41.28	3.265
1.0810	4.461	196.5	.190-02	687.2	3054.5	4.445	39.79	3.175
.9820	4.051	206.0	.165-02	703.7	2980.2	4.235	37.22	3.025
.7980	3.292	232.7	.119-02	747.8	2896.7	3.874	32.40	2.767
.8010	3.307	161.9	.171-02	623.8	2454.8	3.935	33.25	2.811
.9940	4.125	145.5	.238-02	591.4	2519.2	4.260	37.53	3.043
1.1060	4.580	133.2	.289-02	565.7	2541.4	4.493	40.36	3.209
1.1790	4.903	128.2	.321-02	555.1	2566.9	4.624	41.90	3.303

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Table 2-7 (Concluded)

NOZZLE PARAMETERS- FA20 NOZZLE AIR A/A* = 4.918 THETA=25.2 (LEFT MOTOR), M=1.2

RUN/PT	ET PB/P(INF)	SRB PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
116	.8940	.8900	.9170	119.186	.9706	.3598	.0075	2.4736
119	1.0040	1.0920	.9593	235.066	1.1387	.2217	.0046	4.9265

RUN/PT	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	NU(EXIT) (DEG)	ME
116	670.F	492.8	3.79	3.68	10.23	~~.617-01~~	~~1268.9~~	-53.17	3.183
119	990.2	978.3	3.99	4.54	20.50	.829-01	1542.6	53.05	3.176

RUN/PT	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(0) (DEG-R)	T(INF) (DEG-R)	R.N. (/FT)
116	1.200	1213.5	10.03	4.13	.815-03	548.2	425.6	.312+07
119	1.198	1220.1	10.06	4.16	.808-03	556.1	432.2	.307+07

PB/PINF	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	DELTA(J) (DEG)	MJ/GAMMA
.8900	3.680	165.4	.187-02	630.4	2462.5	3.906	36.57	2.790
1.0920	4.545	213.4	.179-02	716.1	3055.2	4.266	41.31	3.047

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Table 2-8

FA23 (TWO-PHASE) TRIPLE BODY CONFIGURATION EXPERIMENTAL DATA BASE

NOZZLE PARAMETERS – NOZZLE 21B-LPC-580C – A/A = 3 087, THETA = 20 23 (LEFT MOTOR), M = 9, FA23

RUN	ET PB/P(INF)	SRB PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
8	1 0866	1 1497	1 0372	48 74	1 1085	3674	0236	3 1297
24	1 0117	1 0150	9804	22 73	1 0353	6944	0447	1 4616
25	1 0739	1 1312	1 0255	44 05	1 1031	4004	0257	2 8252

RUN	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	ME	GAMMAE
8	5857 2	212 26	4 517	5 007	13 63	283-02	3498 4	2 206	1 229
24	5819 4	167 95	7 244	7 500	10 80	225-02	3488 8	2 205	1 226
25	5810 4	159 81	3 721	4 104	10 25	215-02	3486 9	2 206	1 226

RUN	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(O) (DEG-R)	T(INF) (DEG-R)	R N (/FT)
8	902	957 1	7 38	4 355	782-03	543 0	467 0	217+07
24	902	956 2	12 52	7 389	133-02	542 0	466 1	369+07
25	901	954 4	6 14	3 628	654-03	541 0	465 4	182+07

RUN	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	DELTA(J) (DEG)	MJ/GAMMA
8	5.007	3305 0	908-04	3188 1	8847 0	2 775	37 91	2 229
24	7 500	3727 1	113-03	3389 4	8178 8	2 413	27 01	1 957
25	4 104	3364 6	687-04	3226 3	8756 1	2 714	36 18	2 186

Table 2-8 (Concluded)

NOZZLE PARAMETERS-NOZZLE 21B-LPC-580C-A/A* = 3 087, THETA = 20 23, (LEFT MOTOR) M = 1 2, FA23

RUN	ET PB/P(INF)	SRB PB/P(INF)	PS/P(INF)	PC/P(INF)	PB/PS	PB/PE	PB/PC	PE/P(INF)
9	9924	1 0801	1 0173	36 57	1 0617	4604	0295	2 3463
10	8659	8210	9774	14 43	8400	8210	0569	1 0
11	1 1822	1 3834	1 1085	78 97	1 2480	2737	0175	5 0542
22	8976	8923	9970	20 64	8950	6712	0432	1 3294
23	1 0568	1 1959	1 0246	51 37	1 1672	3620	0233	3 3040

RUN	TC (DEG-R)	PC (PSI)	PS (PSI)	PB (PSI)	PE (PSI)	RHOC (SCF)	AC (FPS)	ME	GAMMAE
9	5810 4	158 61	4 412	4 685	10 176	213-02	3486 5	2 206	1 226
10	5769 0	124 33	8 421	7 074	8 616	168-02	3476 4	2 205	1 223
11	5866 2	224 26	3 148	3 929	14 354	299-02	3500 7	2 207	1 229
22	5765 4	121 51	5 869	5 253	7 826	164-02	3475 4	2 205	1 223
23	5814 0	163 06	3 252	3 796	10 487	219-02	3487 5	2 205	1 226

RUN	M	V (FPS)	H (PSI)	P (PSI)	RHO (SCF)	T(O) (DEG-R)	T(INF) (DEG-R)	R N (/FT)
9	1 20	1214 2	10 55	4 337	856-03	547 0	424 7	327+07
10	1 20	1238 4	20 83	8 616	164-02	569 0	441 8	613+07
11	1 20	1208 7	6 89	2 840	566-03	542 0	420 8	216+07
22	1 20	1220 9	14 19	5 887	115-02	553 0	429 3	433+07
23	1 20	1208 7	7 72	3 174	632-03	542 0	420 8	242+07

RUN	PJ (PSI)	TJ (DEG-R)	RHOJ (SCF)	AJ (FPS)	UJ (FPS)	MJ	DELTA(J) (DEG)	MJ/GAMMA
9	4 685	3454 1	770-04	3268 3	8618 6	2 637	33 93	2 129
10	7 074	3911 4	104-03	3465 5	7852 9	2 266	22 27	1 849
11	3 929	3119 4	715-04	3116 6	9113 0	2 924	41 99	2 337
22	5 253	3671 7	783-03	3397 9	8260 2	2 431	27 63	2 227
23	3 796	3300 3	664-04	3197 0	8852 4	2 769	37 80	1 974

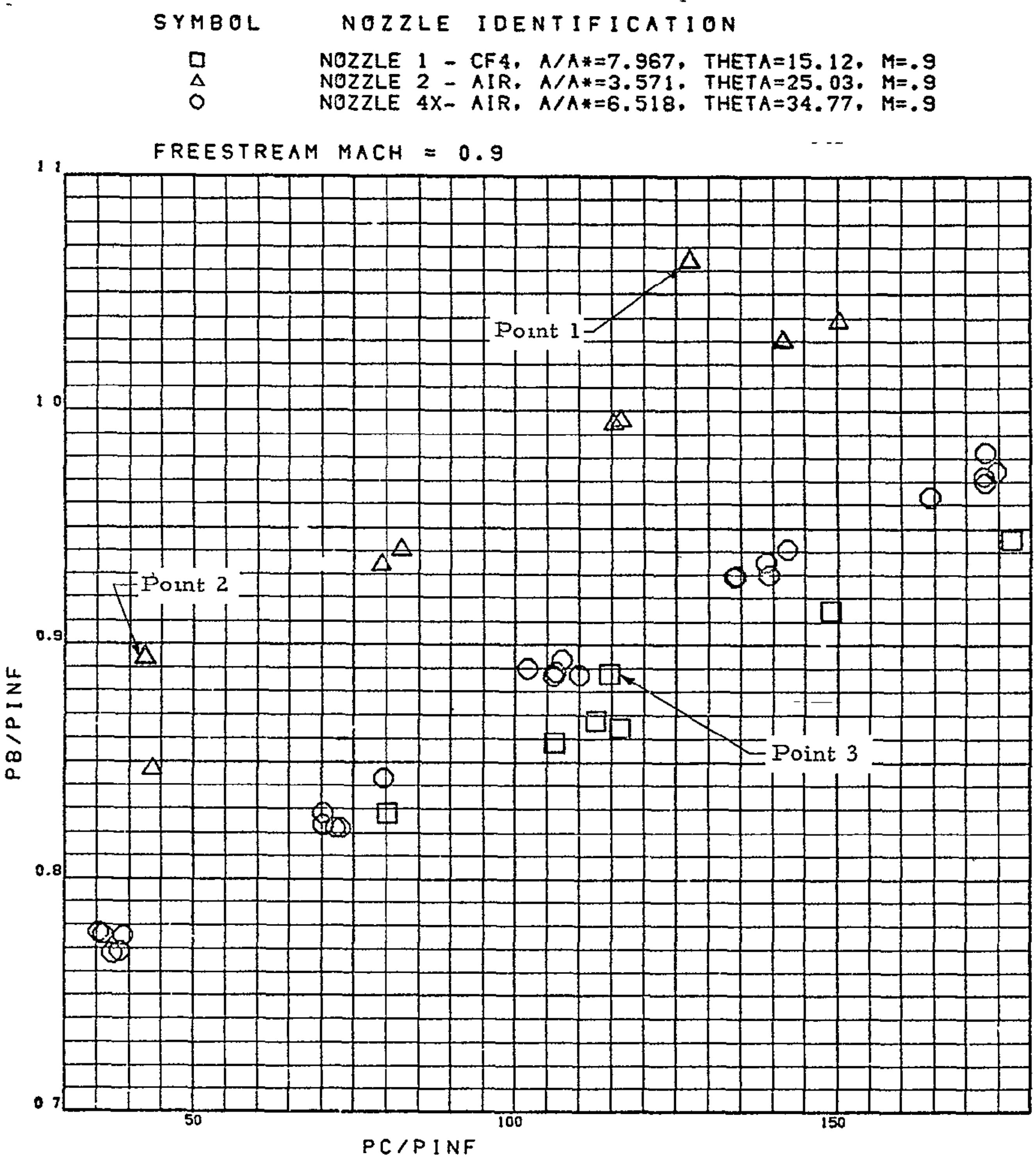

Fig. 2-1 - Basic Data for a Single Nozzle Configuration Flowing Air and CF_4
M_∞ = 0.9 (Test No. MA 10F)

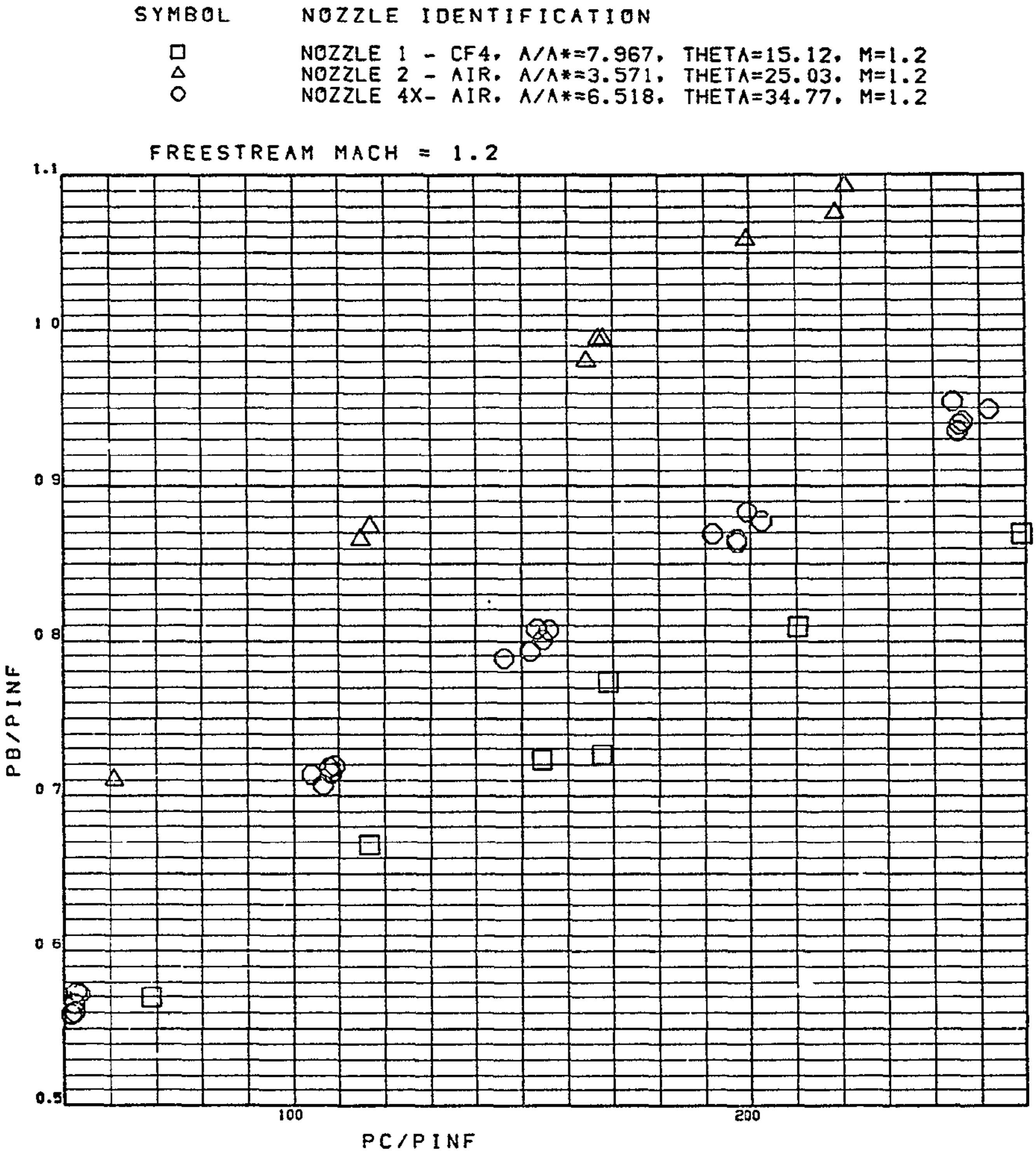

Fig. 2-2 - Basic Data for a Single Nozzle Configuration Flowing Air and CF_4 $M_\infty = 1.2$ (Test No. MA 10F)

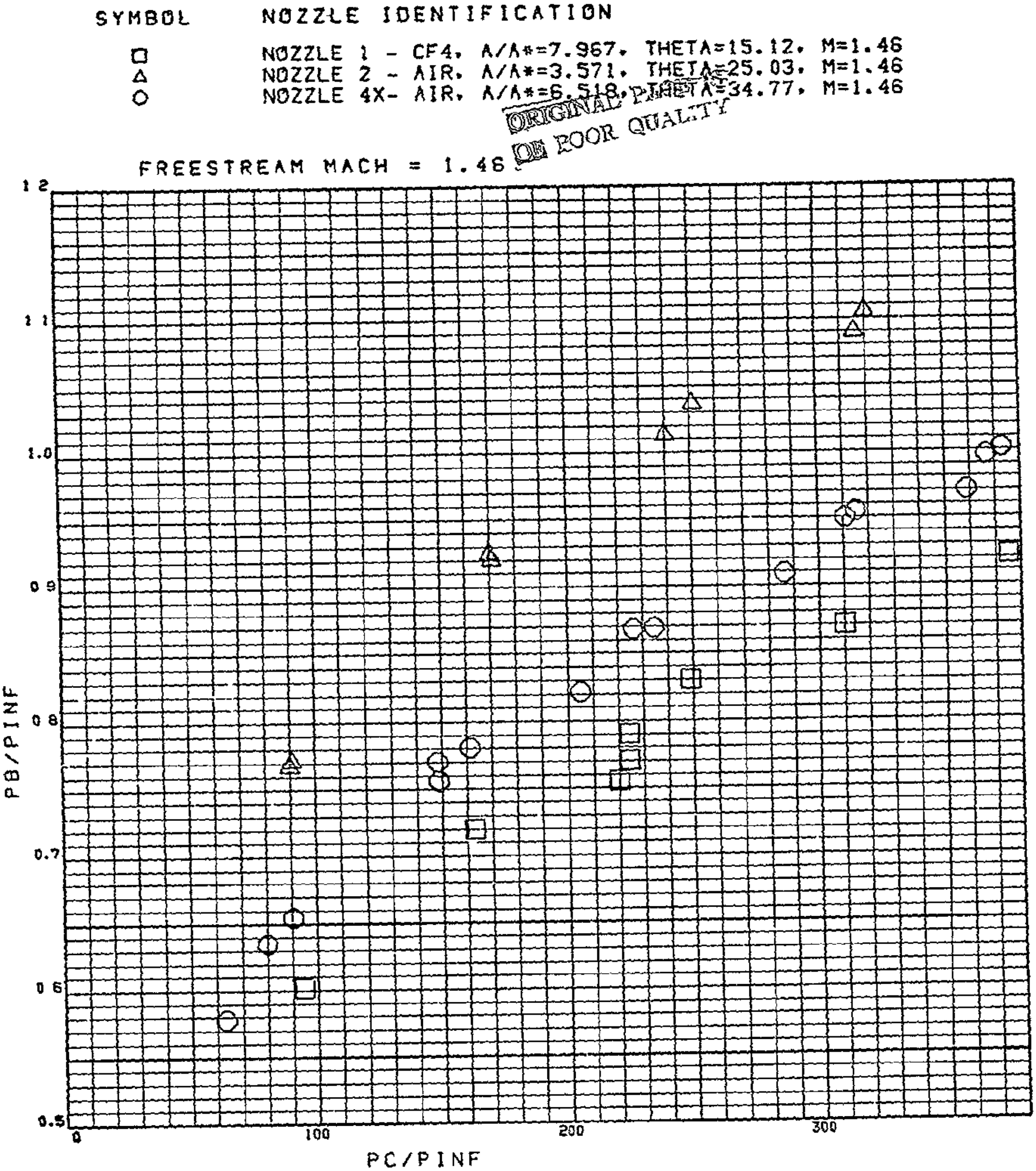

Fig. 2-3 - Basic Data for a Single Nozzle Configuration Flowing Air and CF_4 $M_\infty = 1.46$ (Test No. MA 10F)

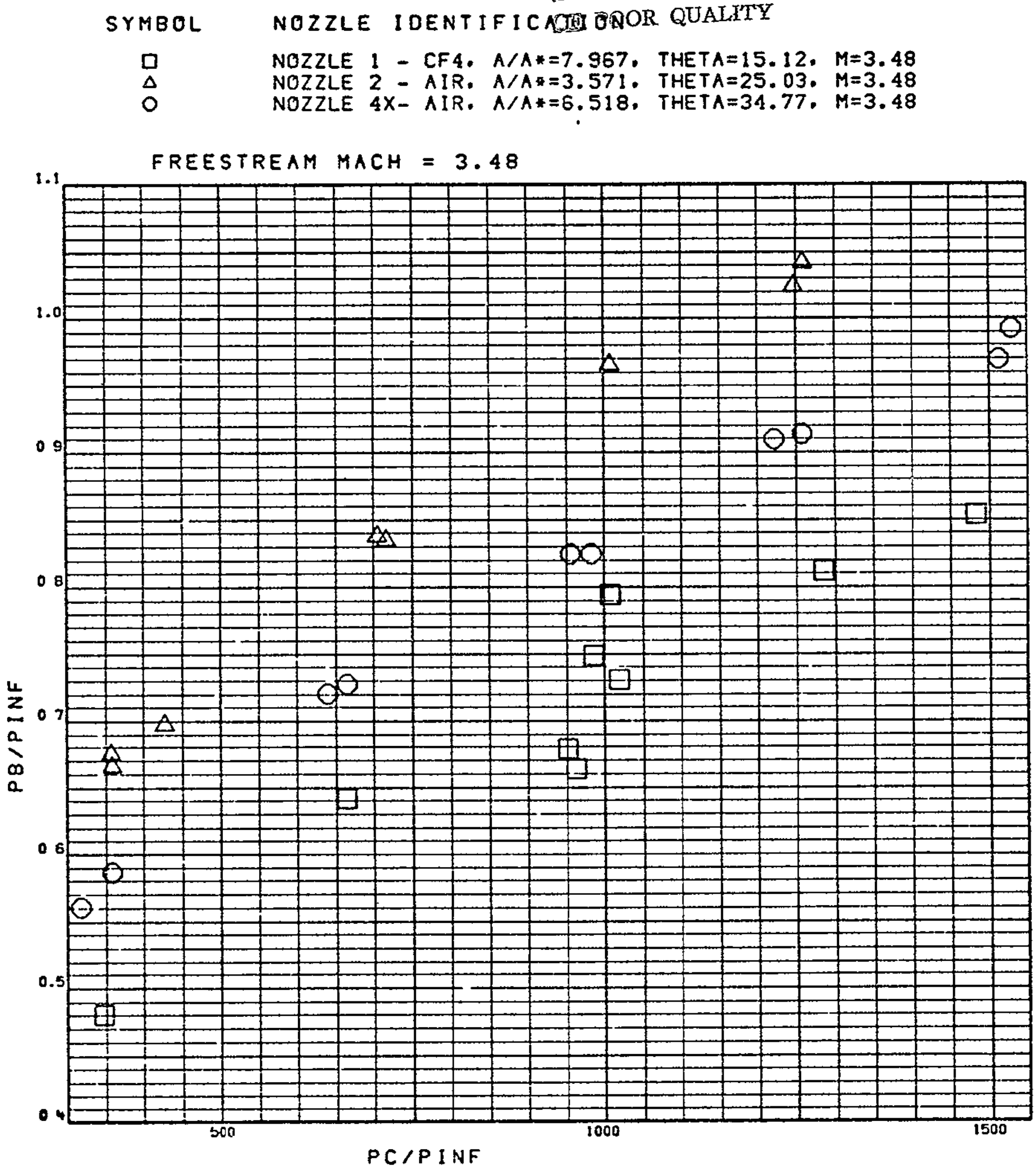

Fig. 2-4 - Basic Data for a Single Nozzle Configuration Flowing Air and CF_4 $M_\infty = 3.48$ (Test No. MA 10F)

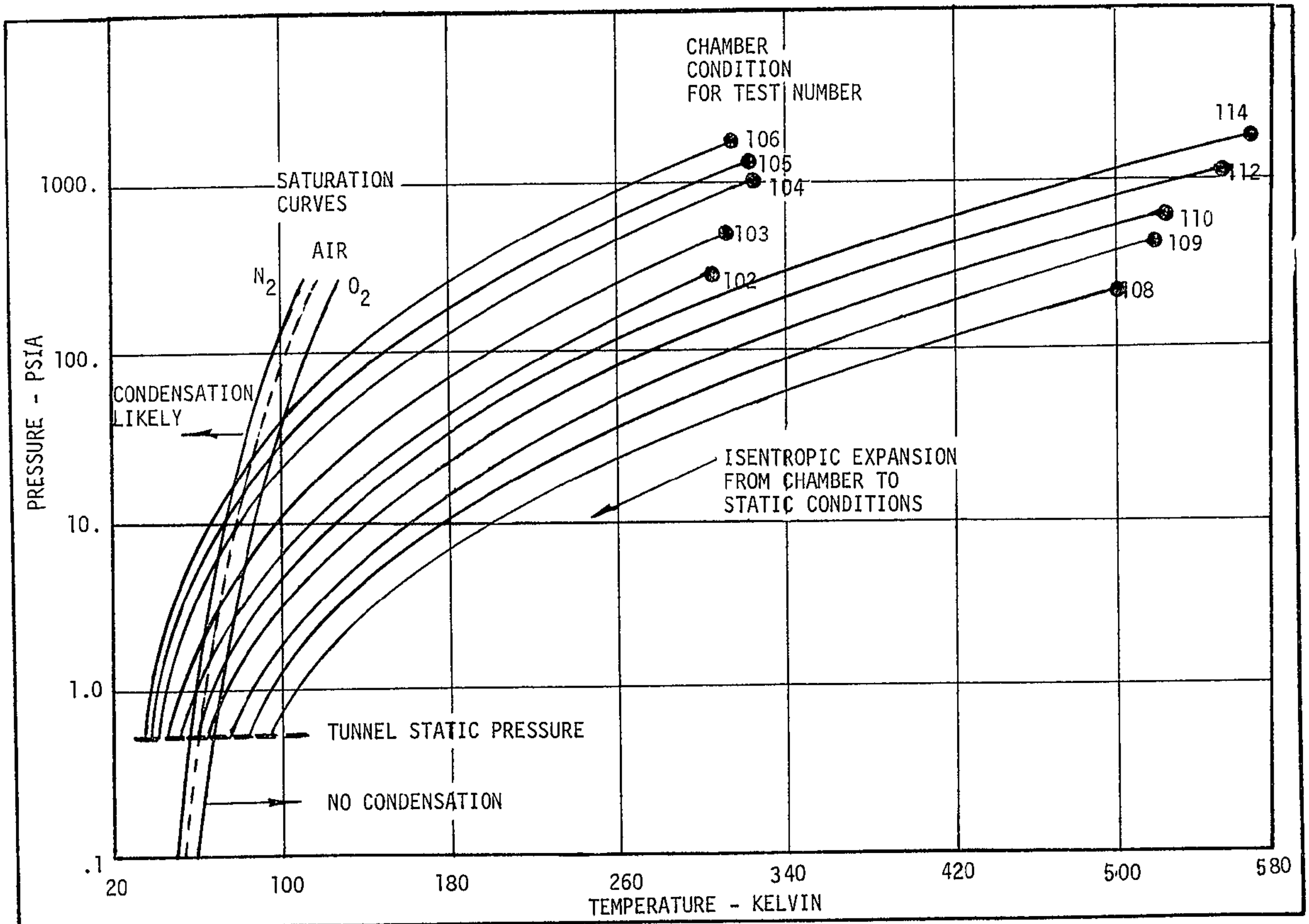

Fig. 2-5 - Isentropic Expansions for Nozzle 4X Flowing Air M_∞ = 0.0 (Calibration Runs) (Test No. MA 10F)

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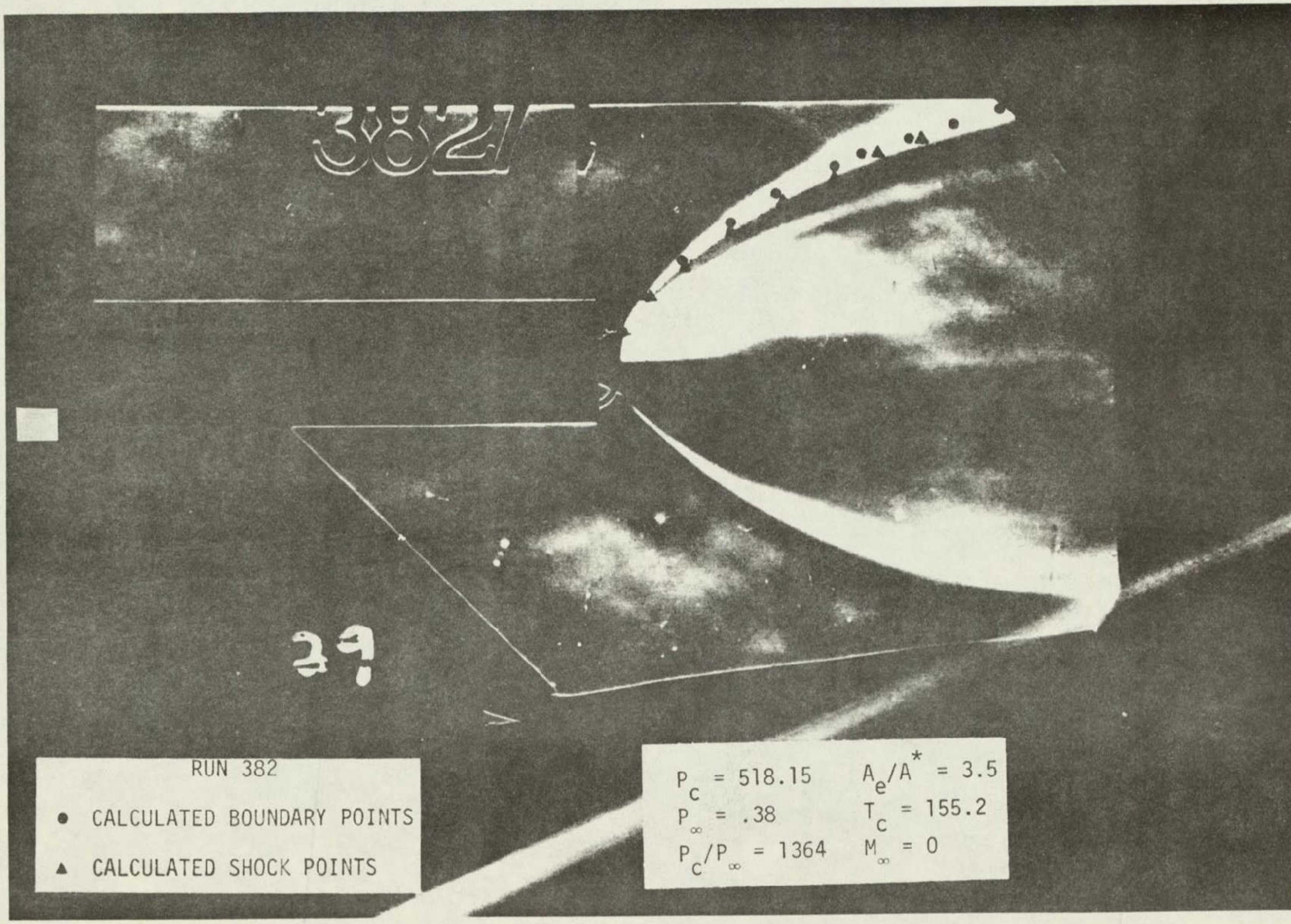

Fig. 2-6 - A Comparison of the Analytical Plume Boundary and Shock Location with Experimental Results (Test No. MA 10F)

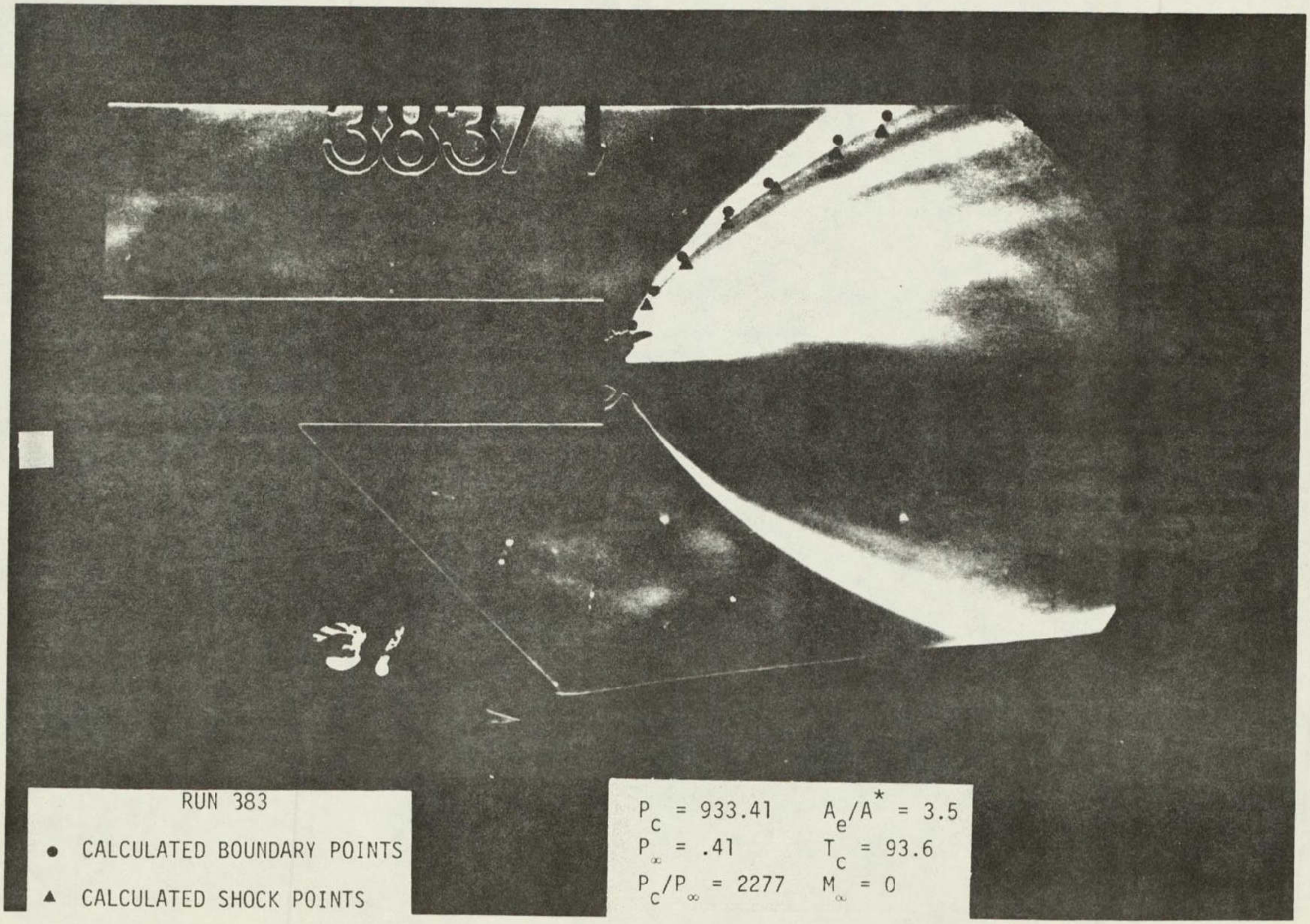

Fig. 2-7 - A Comparison of the Analytical Plume Boundary and Shock Location with Experiment Results (Test No. MA 10F)

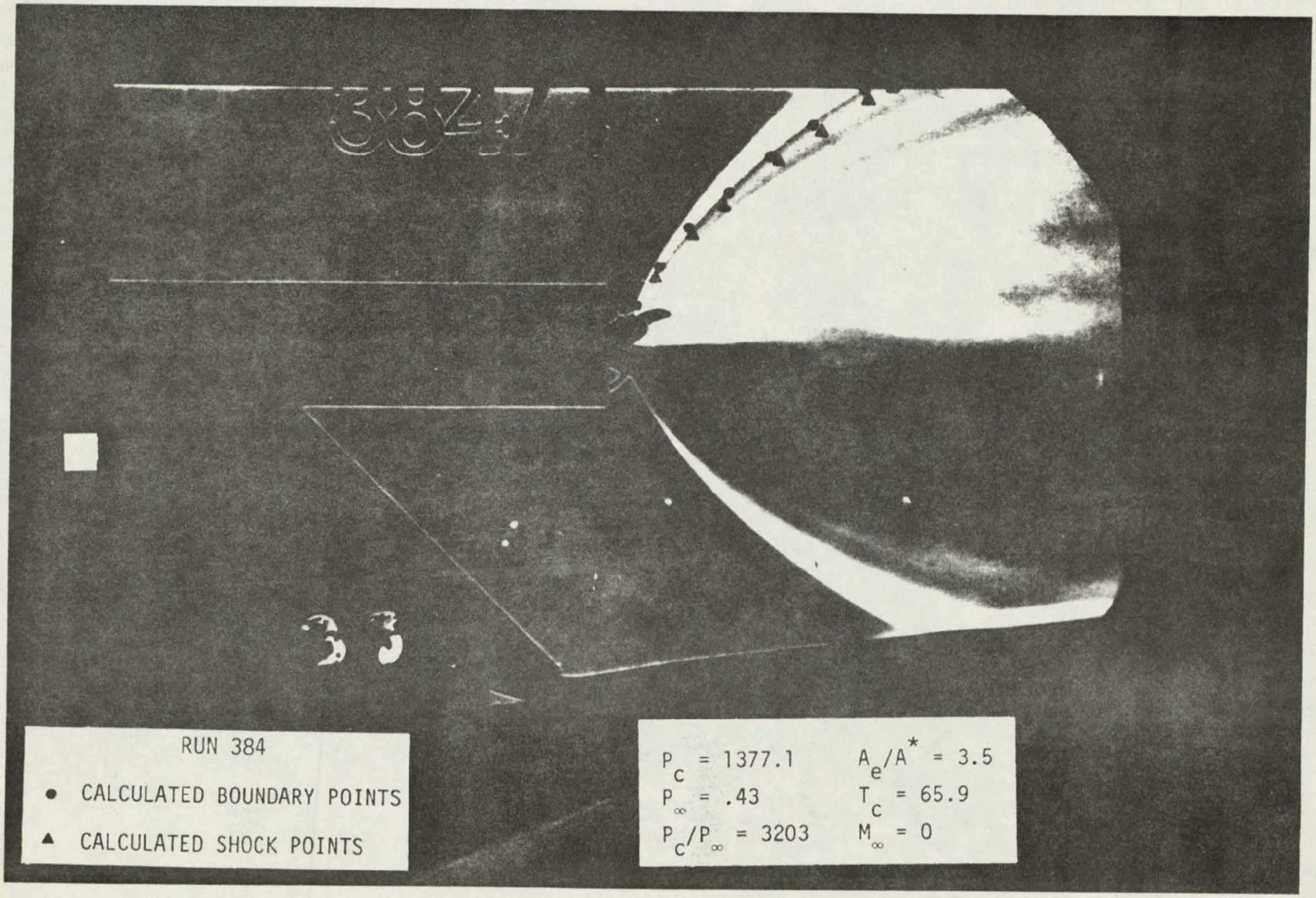

Fig. 2-8 - A Comparison of the Analytical Plume Boundary and Shock Location with Experimental Results (Test No. MA 10F)

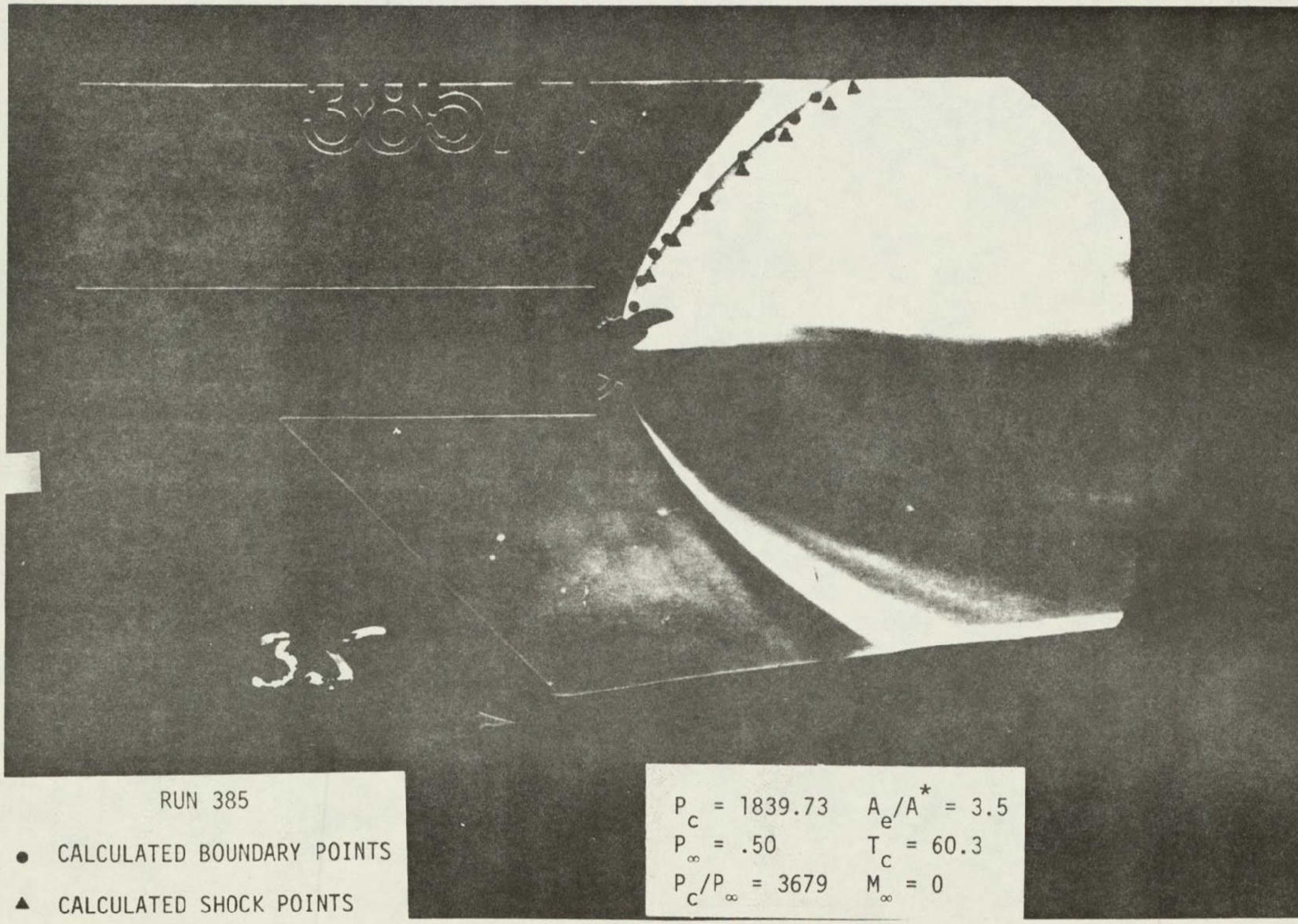

Fig. 2-9 - A Comparison of the Analytical Plume Boundary and Shock Location with Experimental Results (Test No. MA 10F)

nozzle chamber pressure and nozzle wall pressure measurements according to the following equation (see Appendix A for derivation):

$$\delta \left(\frac{PC}{PW}\right) = \frac{\delta\ PC}{PW} + \frac{PC}{PW} * \frac{\delta\ PW}{PW}$$

where

δ PC = uncertainty in nozzle chamber pressure, $\pm$ psia

δ PW = uncertainty in nozzle wall static pressure, $\pm$ psia (see Table 2-2 for δ PC and δ PW values)

PC = measured value of nozzle chamber pressure, psia

PW = measured value of nozzle wall static pressure, psia

All non-quiescent nozzle wall static pressure test data points are then plotted; test runs whose nozzle wall static pressure points fall within the uncertainty band are accepted for use in the base pressure similarity parameter analysis, while all other runs are discarded. (In this case, the test point 1 would be discarded.)

To determine the nozzle exit plane flowfield properties and corresponding jet conditions to be used in the base pressure similarity parameter analysis the nozzle exit plane pressure is first calculated for a given PC using the equation:

$$\left.\frac{PC}{PW}\right)_{\text{exit plane}} = \left.\frac{PC}{PW}\right)_{\text{downstream tap}} + \Delta\left(\frac{PC}{PW}\right)_{\text{ideal gas}} \qquad (3\ 1)$$

where

Δ(PC/PW) is the change in PC/PW from the downstream nozzle pressure tap to the nozzle exit plane determined from the analytically predicted wall pressure distribution for an ideal gas (see Fig 3-2)

and

$$\left.\frac{PC}{PW}\right)_{\text{downstream tap}} = m * PC + b \qquad (3\ 2)$$

where m and b are the slope and y intercept of the "best" straight line drawn through the calibration data of Fig. 3-1

Once the value of $PC/PW)_{exit}$ is determined, the remaining exit plane properties are calculated using the ideal gas equation of state and isentropic relationships.

The corresponding jet conditions are then determined from the measured nozzle wall angle, PC/PB and γ_e using the ideal gas method-of-characteristics (MOC) plume calculation.

Figure 3-3 presents a plot of the nozzle 4x calibration data Unlike the nozzle 2 calibration data, discrepancies do exist between the pressure taps located at the same axial distance from the nozzle throat For such a case, the nozzle exit plane pressure is determined in the same manner described above but, the values of "m" and "b" in Eq 3-2 are for the "best" straight line drawn through the non-quiescent test data for only one pressure tap rather than for the "best" straight line drawn through the root-mean-square values of the calibration data. This discrepancy in nozzle wall pressure leaves some question as to the accuracy of the calculated nozzle exit plane properties and their corresponding jet conditions. This must be kept in mind when evaluating a prospective base pressure similarity parameter.

3.2 NOZZLES FLOWING CF_4 OR SOLID PROPELLANT COMBUSTION GASES AS THE SIMULANT EXHAUST GAS

Initially, it was felt that the procedures followed to verify the gas-dynamic performance of the air nozzles could also be followed for the nozzles of test MA 10F flowing CF_4 as the simulant exhaust gas, Fig 3-4 presents just such an attempt Examination of Fig. 3-4 indicated that real gas effects were such that each data point had to be analyzed individually to decide if a particular test run would be accepted for use in the base pressure similarity parameter analysis The same situation was found to hold true for the nozzles flowing solid propellant combustion gases as the simulant exhaust gas.

To determine the nozzle exit plane flowfield properties for the case when real gas effects must be considered, the assumption was made that: if the experimental nozzle wall static pressure at the tap location nearest the nozzle exit plane could be predicted analytically, the corresponding experimental exit plane properties and jet conditions would also be predicted correctly Any test data that could not be analytically predicted would be discarded as unusable because the nozzle exit plane properties were unknown

The nozzle wall static pressure distributions for the CF_4 nozzles were determined using the Gaseous Only Method-of-Characteristics (MOC) Computer Code described in Ref 3-1 The CF_4 real gas properties used in the MOC computer code were determined using the computer code described in Ref 3-2 Figure 3-5 presents a typical example of the analytical and experimental data comparison for the CF_4 runs of test MA 10F No CF_4 data were discarded as unusable.

The nozzle wall static pressure distributions for the solid propellant nozzles were determined using the two-phase RAMP computer code described in Ref 3-3 The thermodynamic properties used in the RAMP computer code were determined using the modified TRAN72 computer code described in Ref 3-4. Verification of the gasdynamic performance of nozzles flowing solid propellant combustion gases (tests MA 11F, FA 22 and FA 23) was not as straight forward a procedure as the gaseous-only nozzles discussed earlier in this section. This is a direct result of solid propellant contamination of the pressure tubing leading to the chamber pressure transducers and nozzle wall pressure transducers. (This effect was noted during the FA 22 tests described in Ref 2-8.) Such solid propellant contamination results in a measured pressure lower than actual. The degree to which this contamination takes place, is not known and for that reason it was impossible to assess how well the analytical nozzle wall static pressure distributions and corresponding jet conditions are when compared to the "real" (non-contaminated) experimental conditions

Figures 3-6 through 3-9 present a comparison of analytical and experimental results for several of the MA 11F test runs. Solid propellant contamination was not noted during this test program, this is not to say that contamination did not occur to any degree. Figures 3-10 through 3-14 present similar comparisons of analytical and experimental results for several of the FA 22 runs Solid propellant contamination was noted during the FA 22 test program, the degree to which contamination occurred is not known. Examination of Figs. 3-6 through 3-9 indicates a satisfactory agreement between the analytical and experimental results The analytical predictions for MA 11F fall into the uncertainty band for all test data except for run 4, and the experimental data always fall above the analytical prediction which is to be expected if solid propellant contamination takes place. Examination of Figs. 3-10 through 3-14, on the other hand, indicates a very poor agreement between the analytical and experimental results of the FA 22 tests Based upon the confidence gained in the analytical predictions of the MA 11F experimental test data, it was felt that the discrepancies between the analytical and experimental results of the FA 22 data could largely be attributed to solid propellant contamination of the pressure tubing leading to the chamber pressure transducers and nozzle wall pressure transducers It was therefore decided to accept the analytical predictions of the nozzle exit conditions and corresponding jet conditions as correct and acceptable for use in the development of the base pressure similarity parameters. It should be noted at this time that the measured chamber pressures for the FA 22 tests had to be accepted as correct (though PC measured was known to be lower than actual due to solid propellant contamination) and as such introduced an error into the calculation of the nozzle exit conditions and corresponding jet conditions. This effect will be seen in the plots of the final base pressure similarity parameters

The verification of the gasdynamic performance of the FA 23 nozzles was, in brief, not accomplished to any degree of satisfaction and for that reason, all data obtained during the FA 23 test program were considered unusable in the development of the base pressure similarity parameters.

C-2

Figure 3-15 presents a comparison of the analytical and experimental calibration data results for the FA 23 design nozzle contours Considering how well all previous analytical and experimental data compared, the very poor agreement between the analytical and experimental data in this case was cause for a low confidence level in obtaining an accurate analytical prediction of the gasdynamic performance of the same nozzles flowing the LPC-380C propellant combustion gases If this problem were not enough, the FA 23 nozzle data were made more questionable when, "during this pretest period, replacement of the SRB nozzle pressure tubes (which had been damaged during the 9 x 7 tests) was performed in the Ames machine shop. As a result of overheating the nozzle during the soldering processes, severe warping of the nozzle contour was experienced This nozzle distortion was satisfactorily corrected, however, by remolding the nozzle over a 20 deg conical aluminum mandrel," (taken directly from Ref. 2-10). The degree to which the contour was corrected, in particular what happened to the nozzle throat due to warping is not known. Furthermore, the effect of remolding the nozzles on the previously obtained calibration data is not known Therefore, prior to actual solid propellant testing little was known about the gasdynamic performance of the nozzles to be tested

In addition to the above problems, one more error was introduced into the test program when the location (left or right) of the nozzles being used in the test were not recorded in the run log. Therefore, the actual geometries that correspond to the experimental nozzle wall pressures and SRB base pressures is not known Figure 3-16 presents a comparison of the analytical and experimental results for several of the FA 23 test runs assuming that nozzle 21B was identified as the left nozzle during testing As can be seen the analytical prediction overpredicts the experimental data, and does not fall into any of the uncertainty bands This is further justification for considering the FA 23 data to be unusable Furthermore, had there been a favorable comparison, the question would still remain as to whether or not the correct base pressure was being used In view of all of these problems, the FA 23 data were discarded as unusable in this analysis

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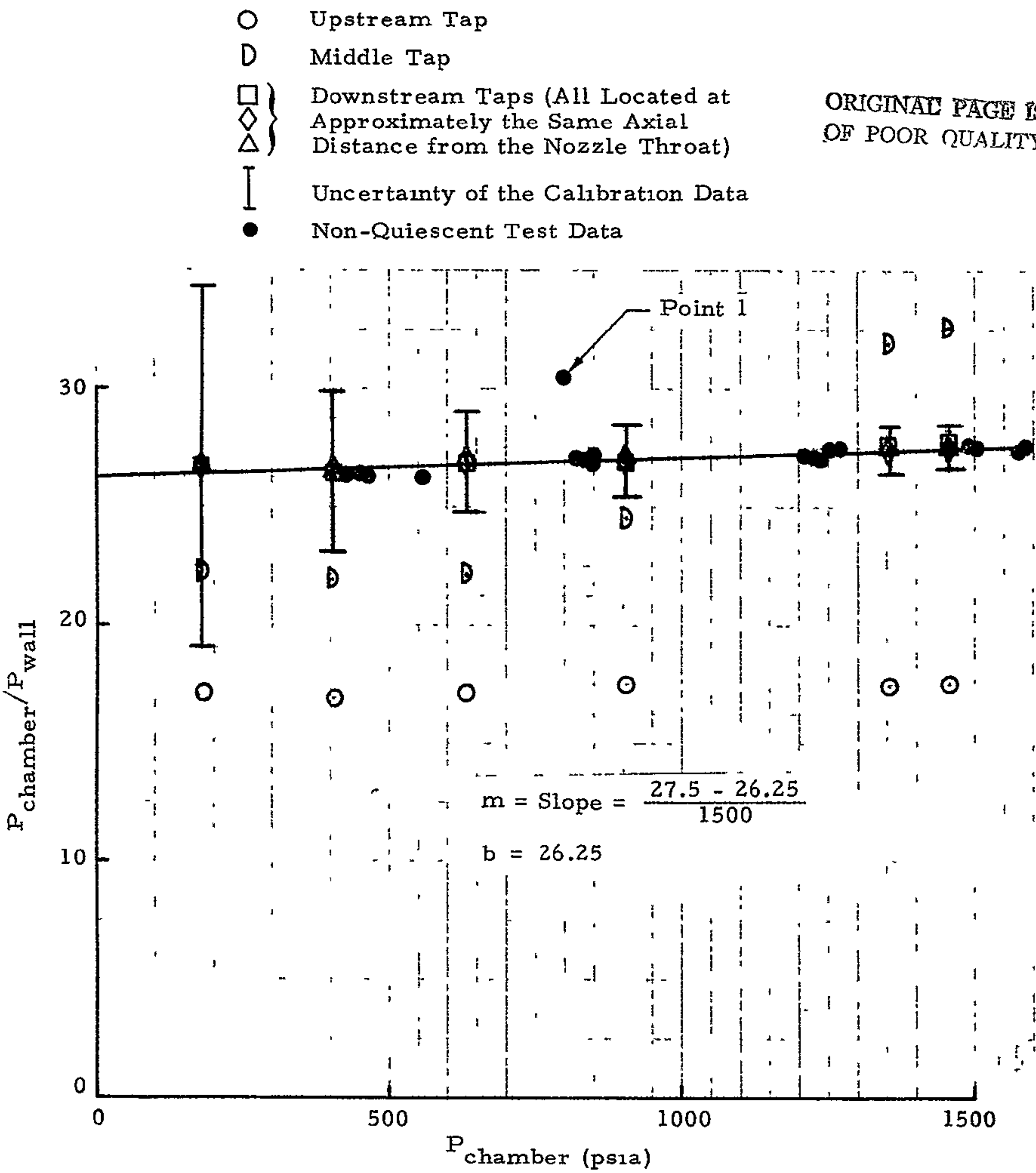


Fig. 3-1 - Nozzle 2 Calibration Data Using Air as the Simulant Exhaust Gas (Test MA10F)

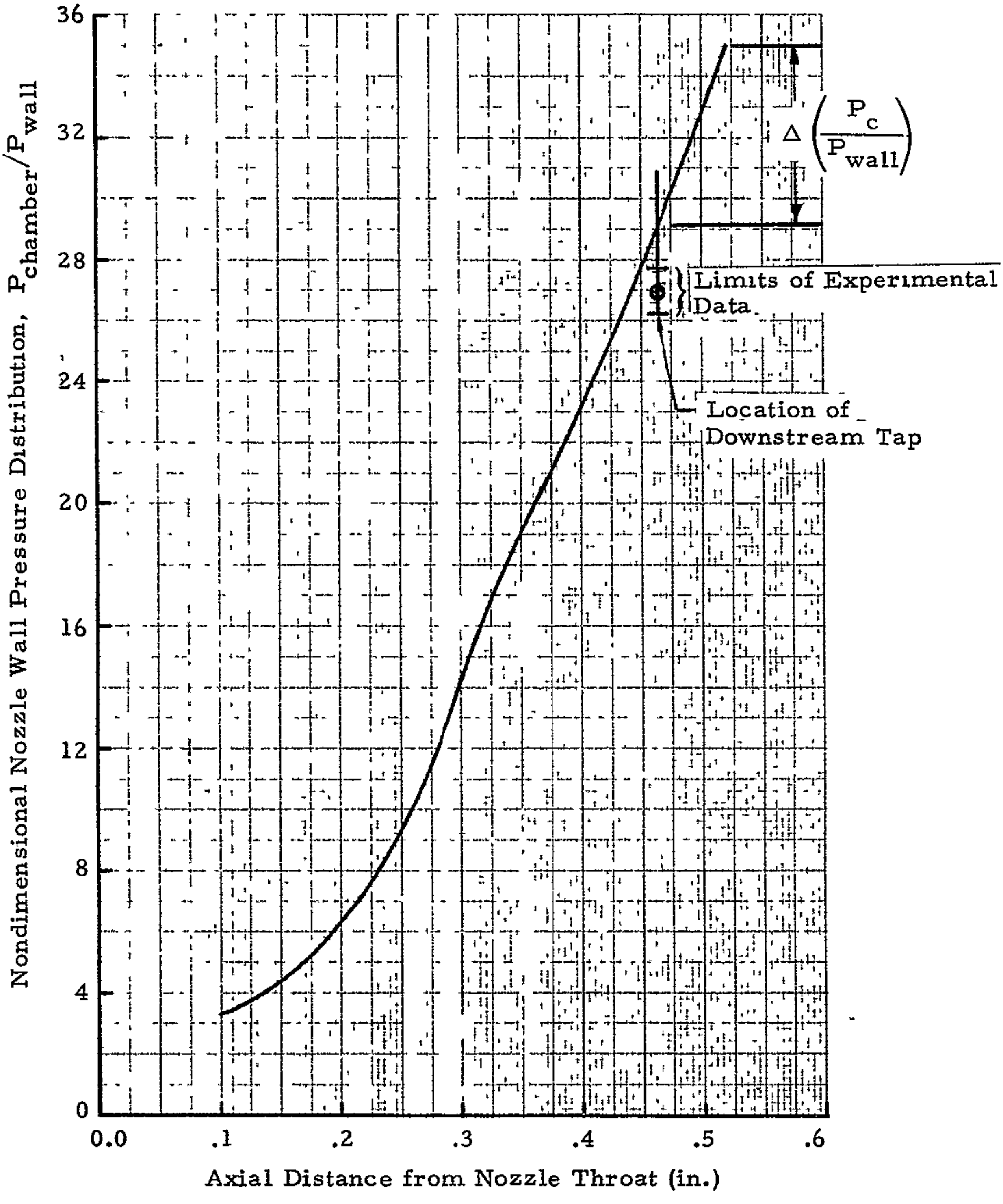


Fig. 3-2 - Nozzle Wall Pressure Distribution for Nozzle 2 (Test MA10F) Flowing Air as the Simulant Exhaust Gas

○ Upstream Tap
D Middle Tap
□ } Downstream Taps (All Located
◇ } at Approximately the Same Axial
△ } Distance from the Nozzle Throat)
I Uncertainty of the Calibration Data
● Non-Quiescent Test Data

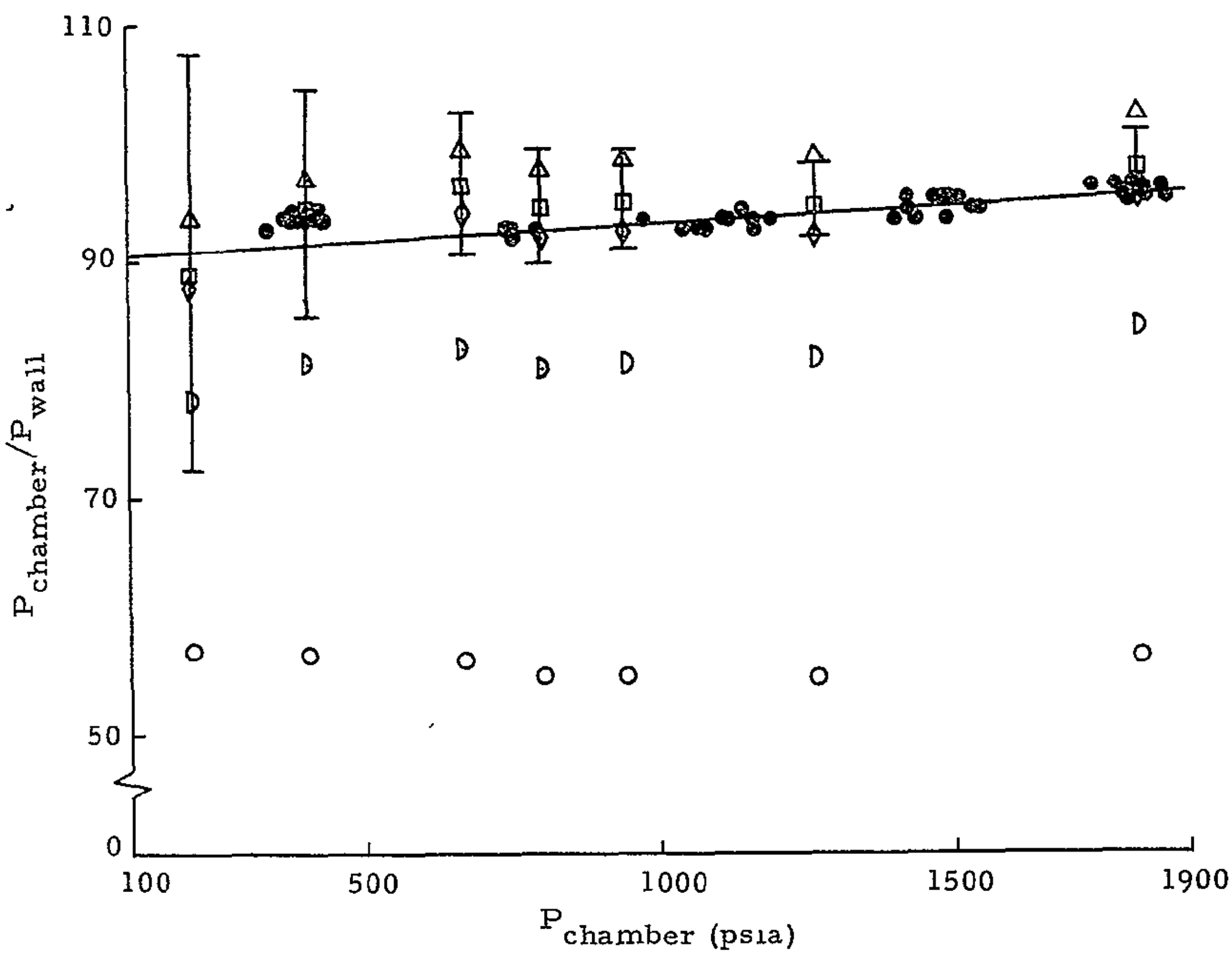


Fig. 3-3 - Nozzle 4X Calibration Data Using Air as the Simulant Exhaust Gas (Test MA10F)

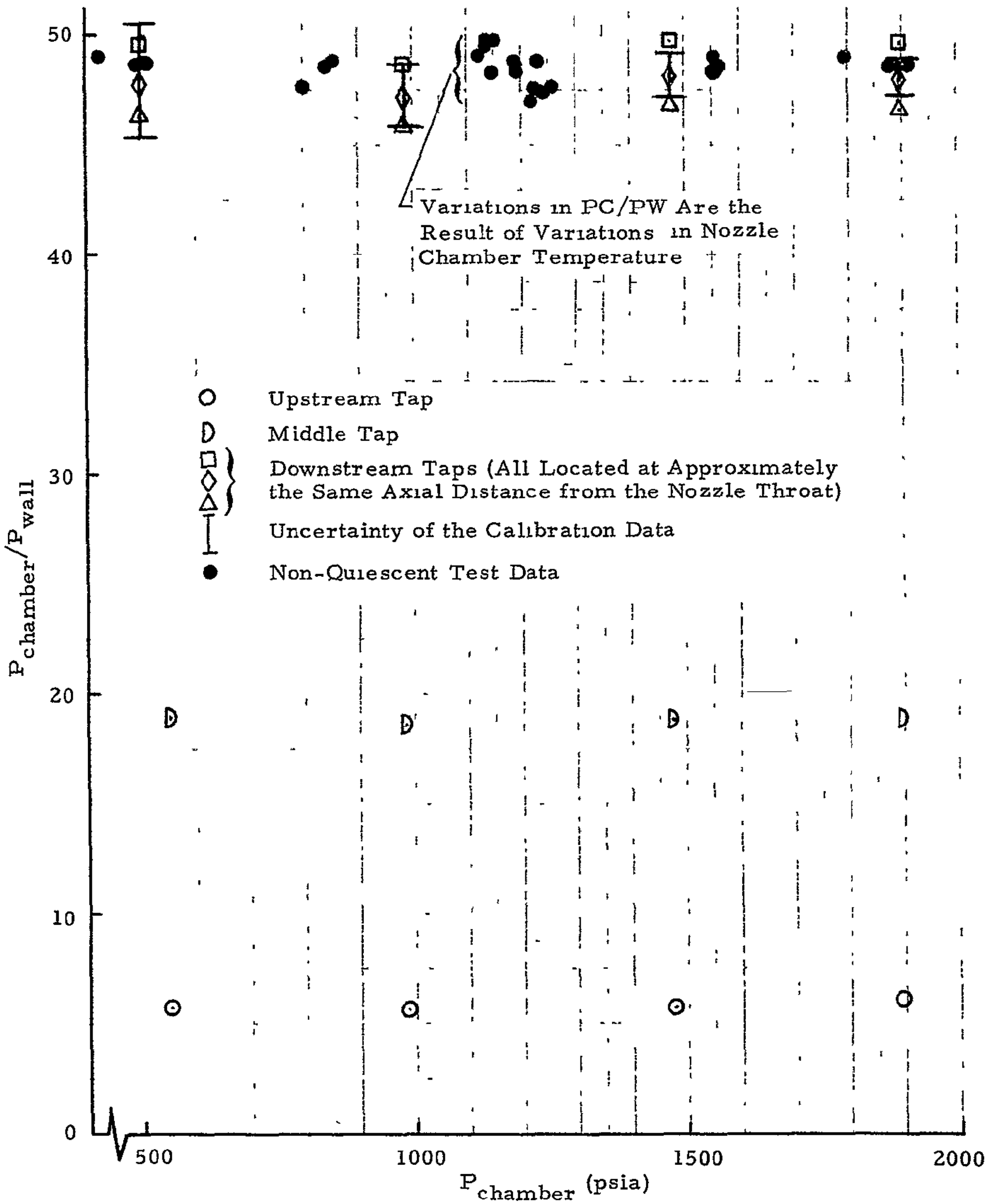


Fig. 3-4 - Nozzle 1 Calibration Data Using CF_4 as the Simulant Exhaust Gas (Test MA 10F)

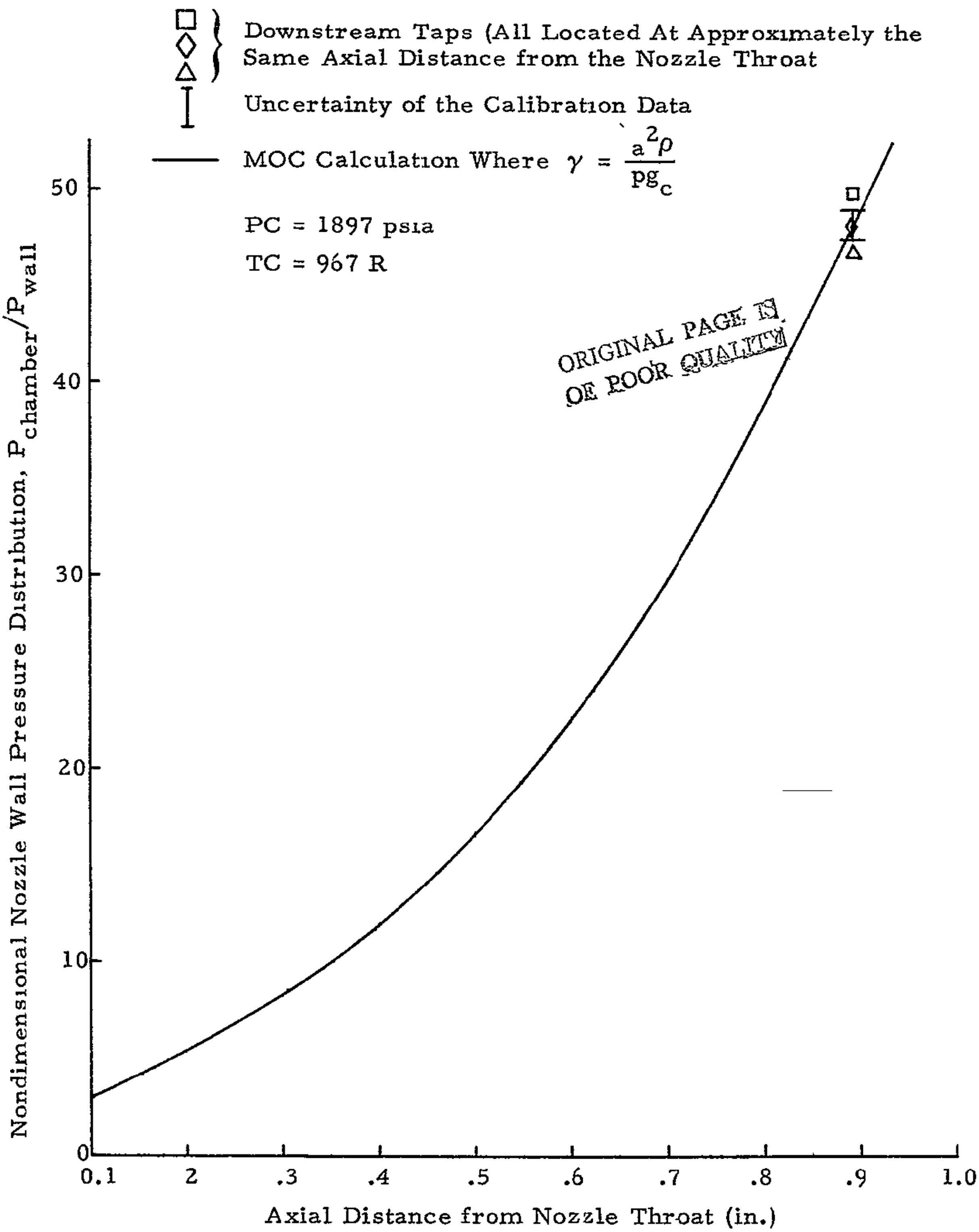


Fig. 3-5 - Nozzle Wall Pressure Distribution for Nozzle 1 (Test MA10F) Flowing CF_4 as the Simulant Exhaust Gas

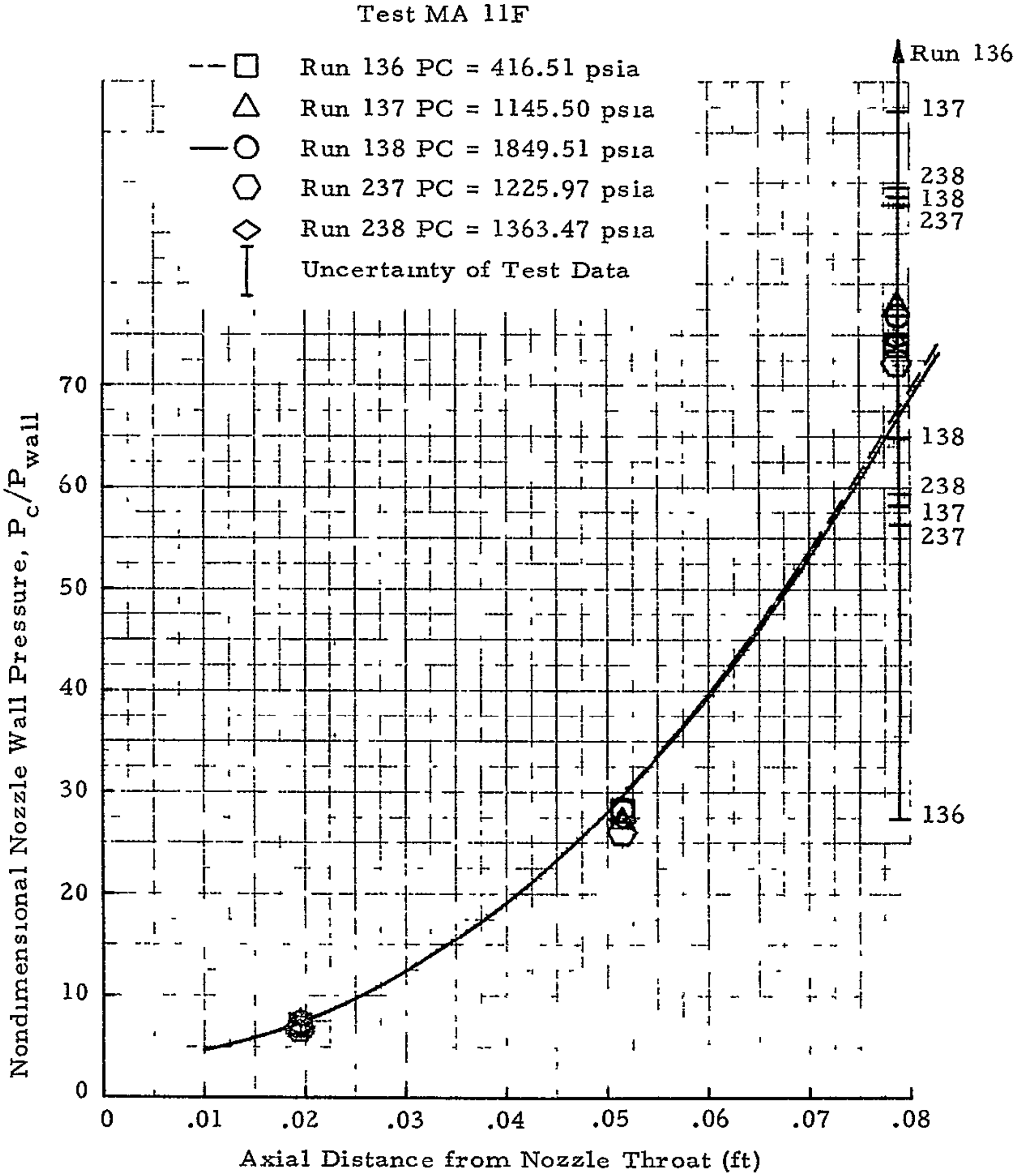


Fig. 3-6 - Nozzle Wall Pressure Distribution for Nozzle S/N 2 Flowing ANB-3335 Propellant with 2% Aluminum Loading

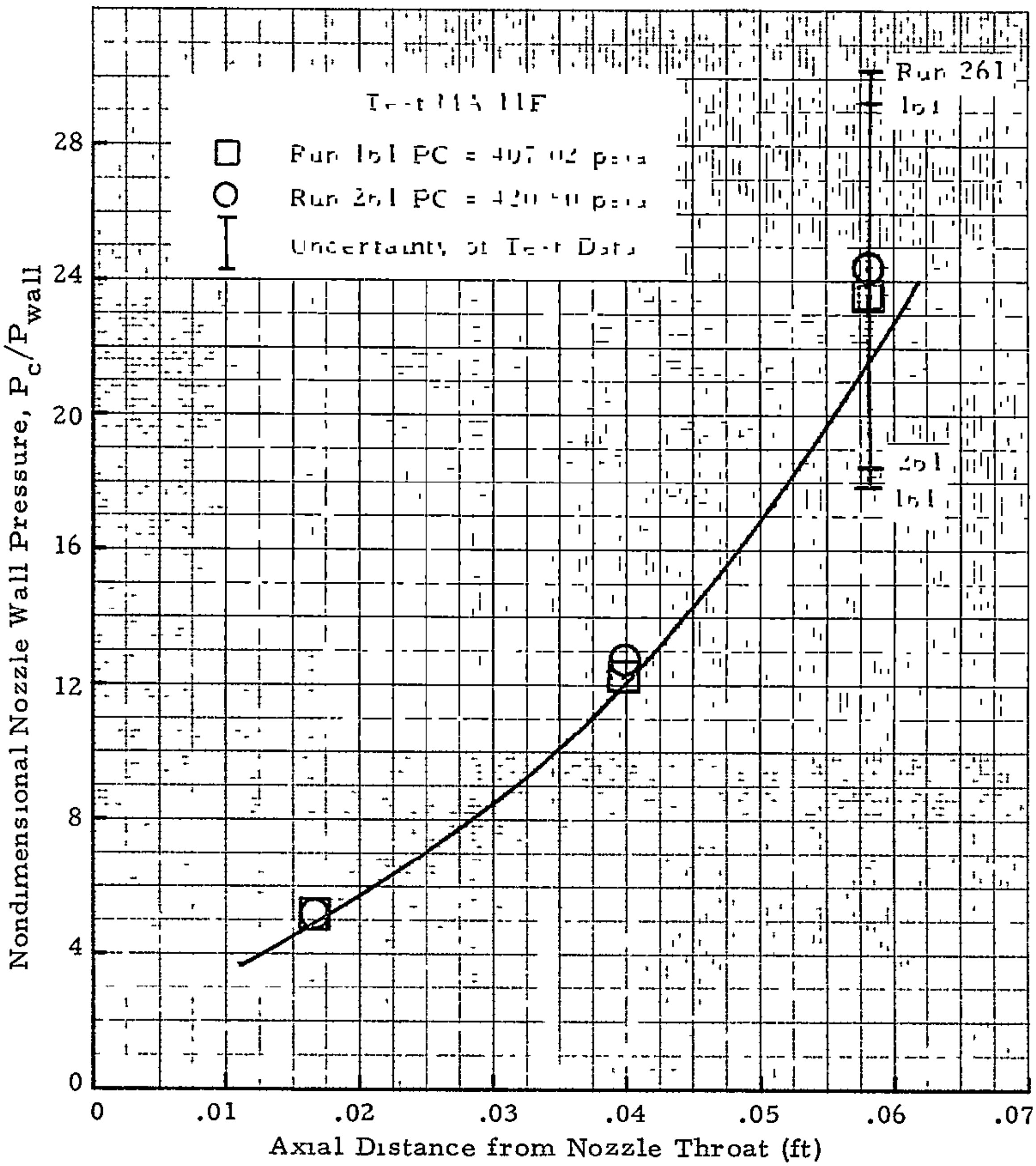


Fig. 3-7 - Nozzle Wall Pressure Distribution for Nozzle S/N 3 Flowing ANB-3335 Propellant with 2% Aluminum Loading

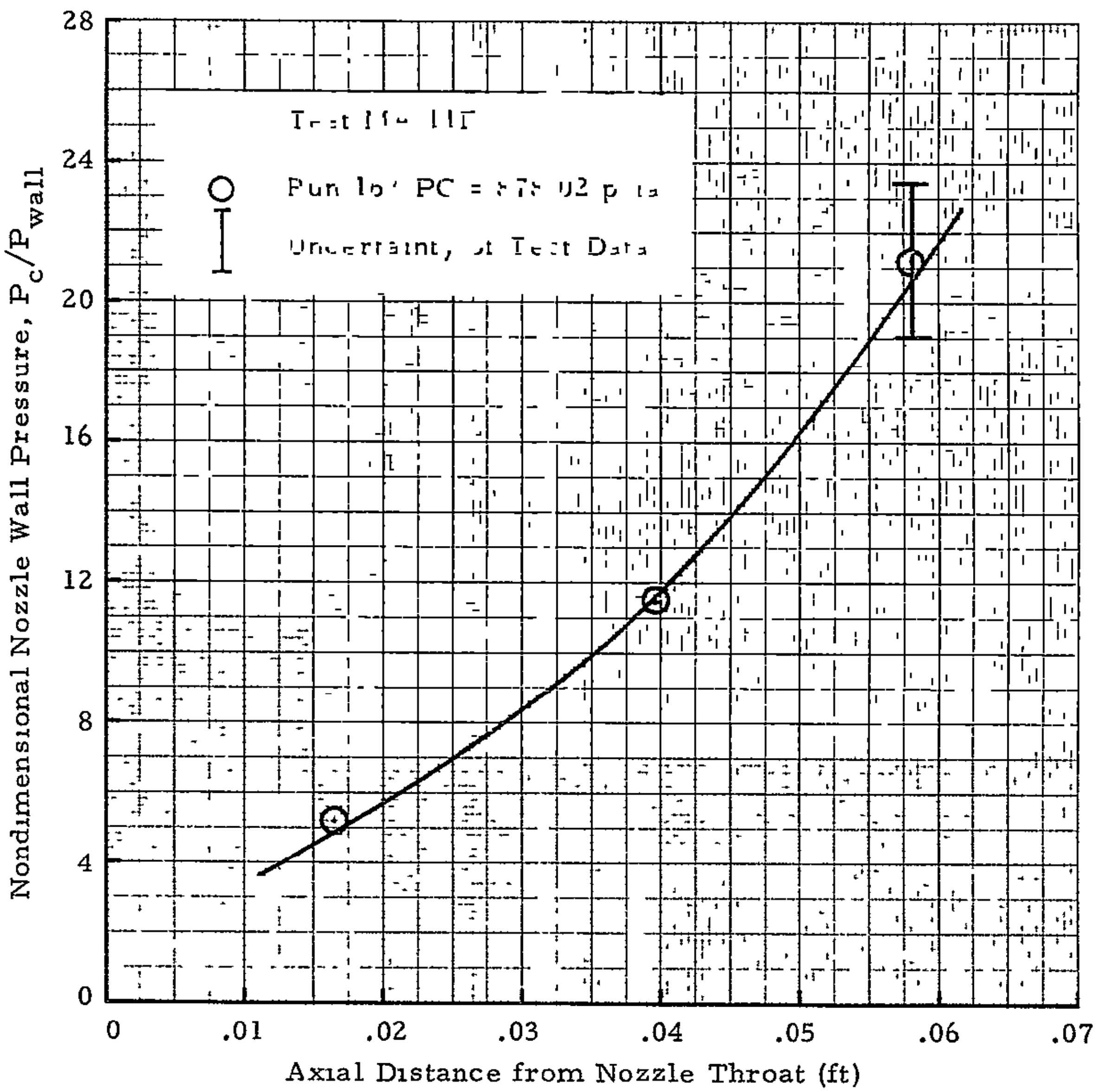


Fig. 3-8 - Nozzle Wall Pressure Distribution for Nozzle S/N 3 Flowing UTP 3001 Propellant with 16% Aluminum Loading

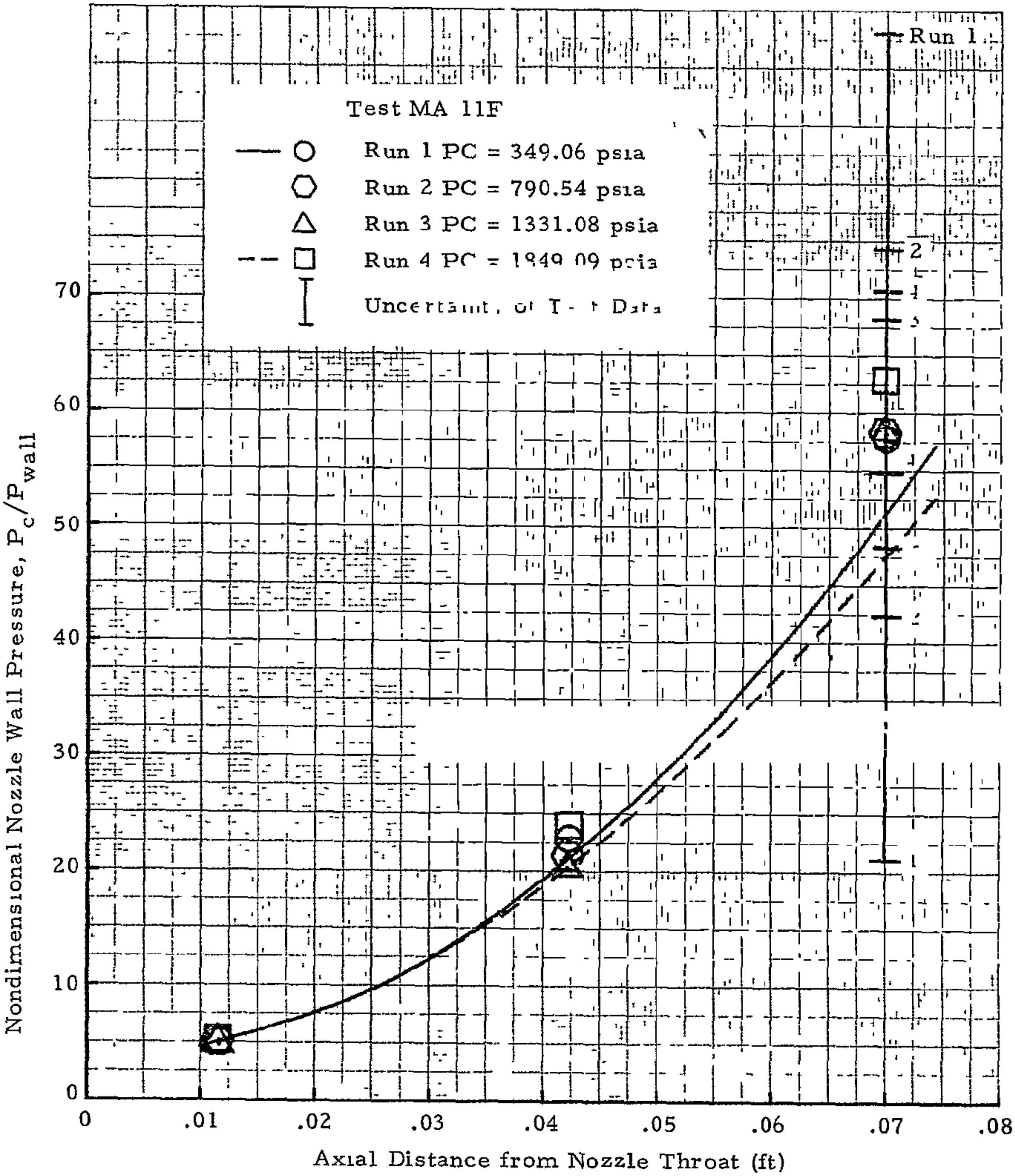


Fig 3-9 - Nozzle Wall Pressure Distribution for Nozzle S/N 1 Flowing UTP 3001 Propellant with 16% Aluminum Loading

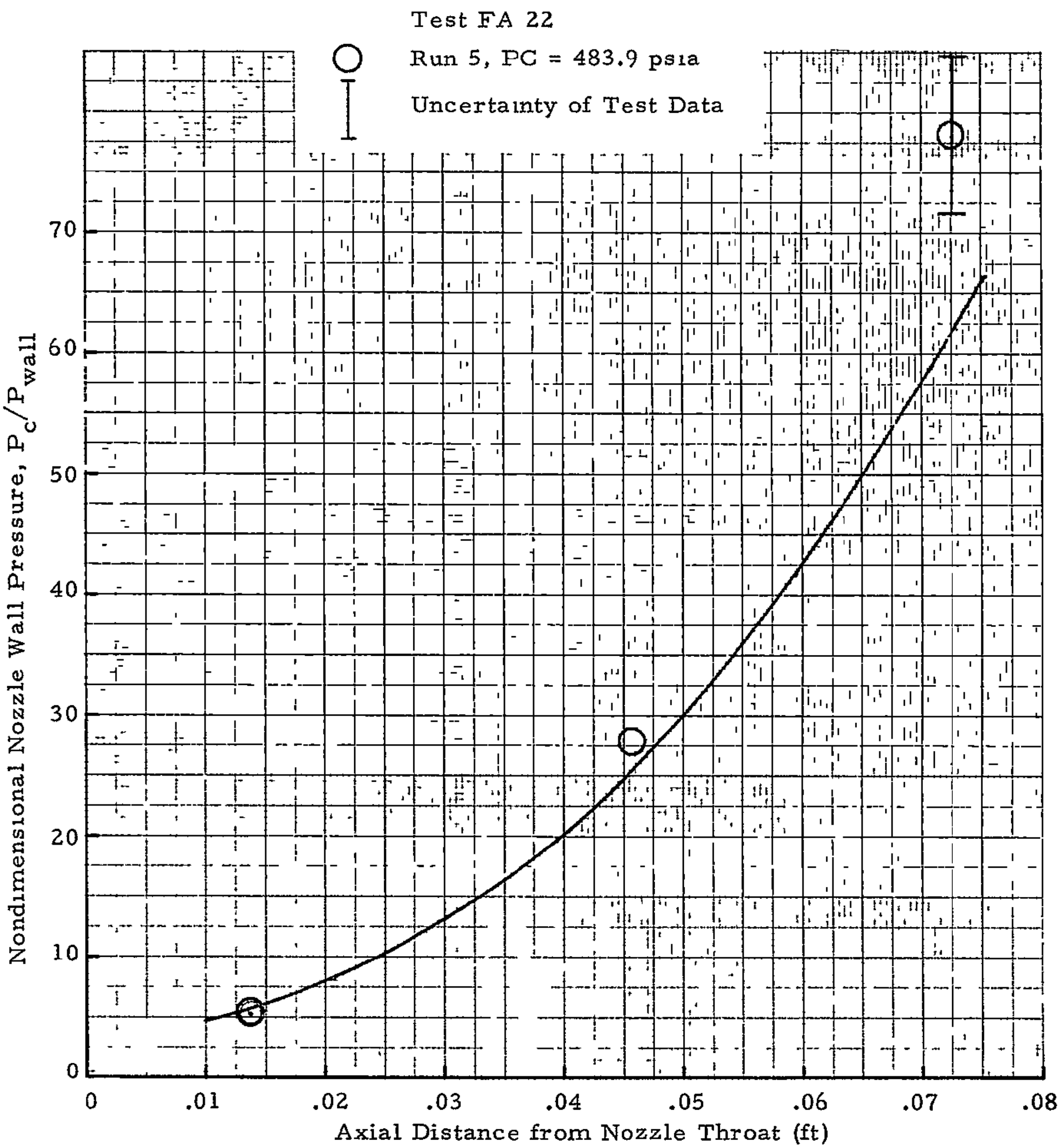


Fig. 3-10 - Nozzle Wall Pressure Distribution for Nozzle S/N 5 Flowing ANB 3335 Propellant with 2% Aluminum Loading

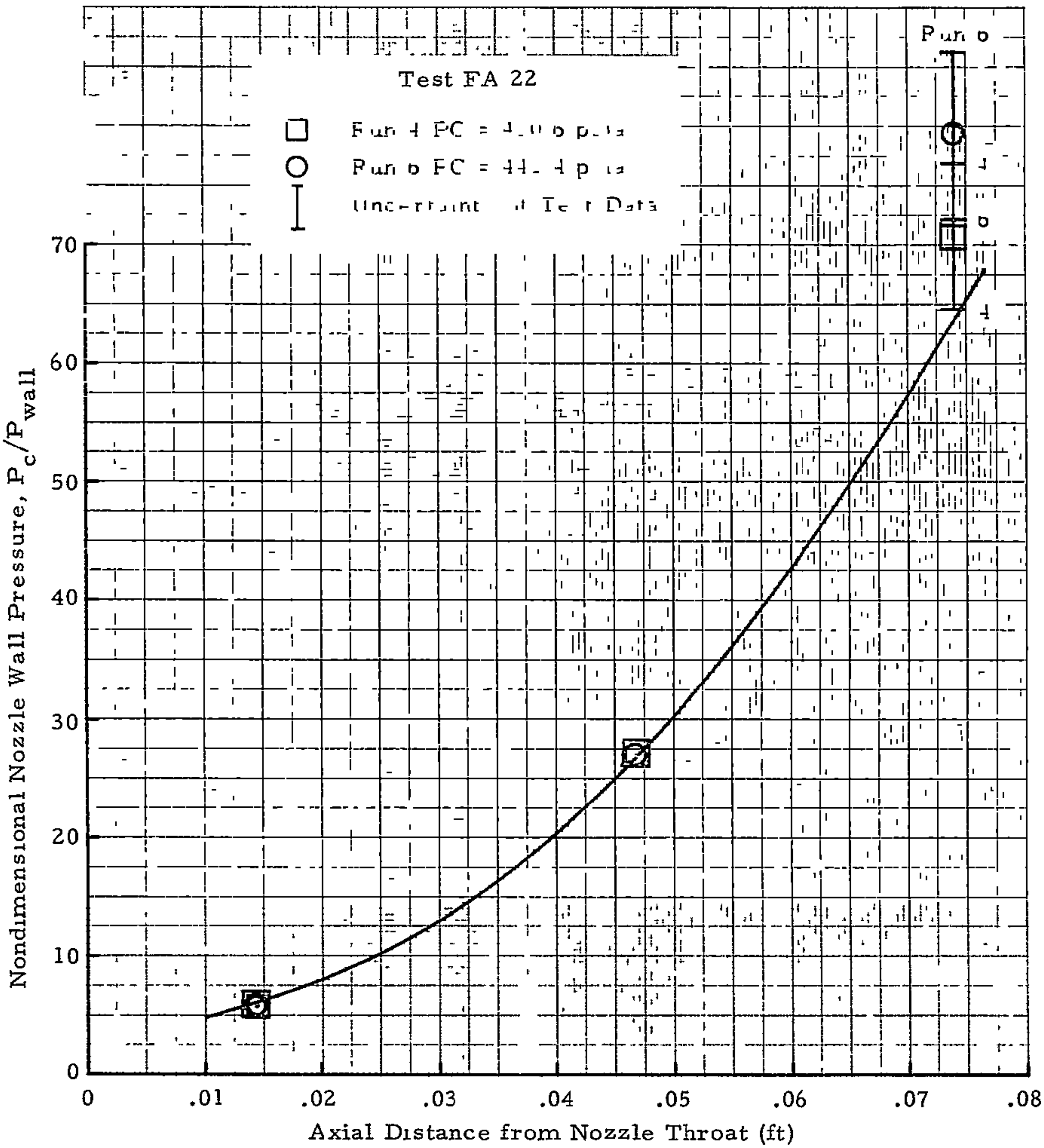


Fig. 3-11 - Nozzle Wall Pressure Distribution for Nozzle S/N 6 Flowing ANB 3335 Propellant with 2% Aluminum Loading

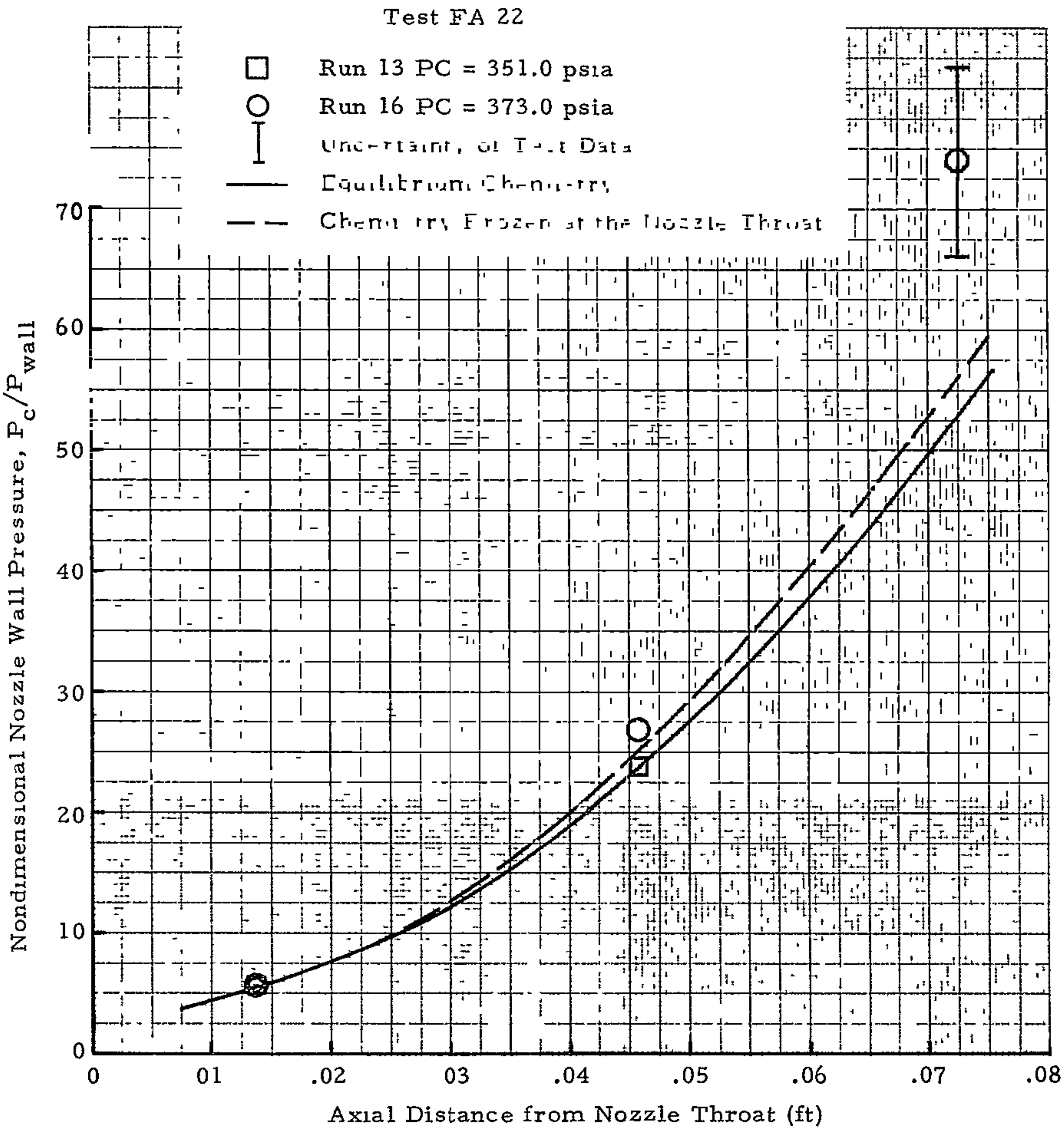


Fig. 3-12 - Nozzle Wall Pressure Distribution for Nozzle S/N 5 Flowing UTP-3001 Propellant with 16% Aluminum Loading

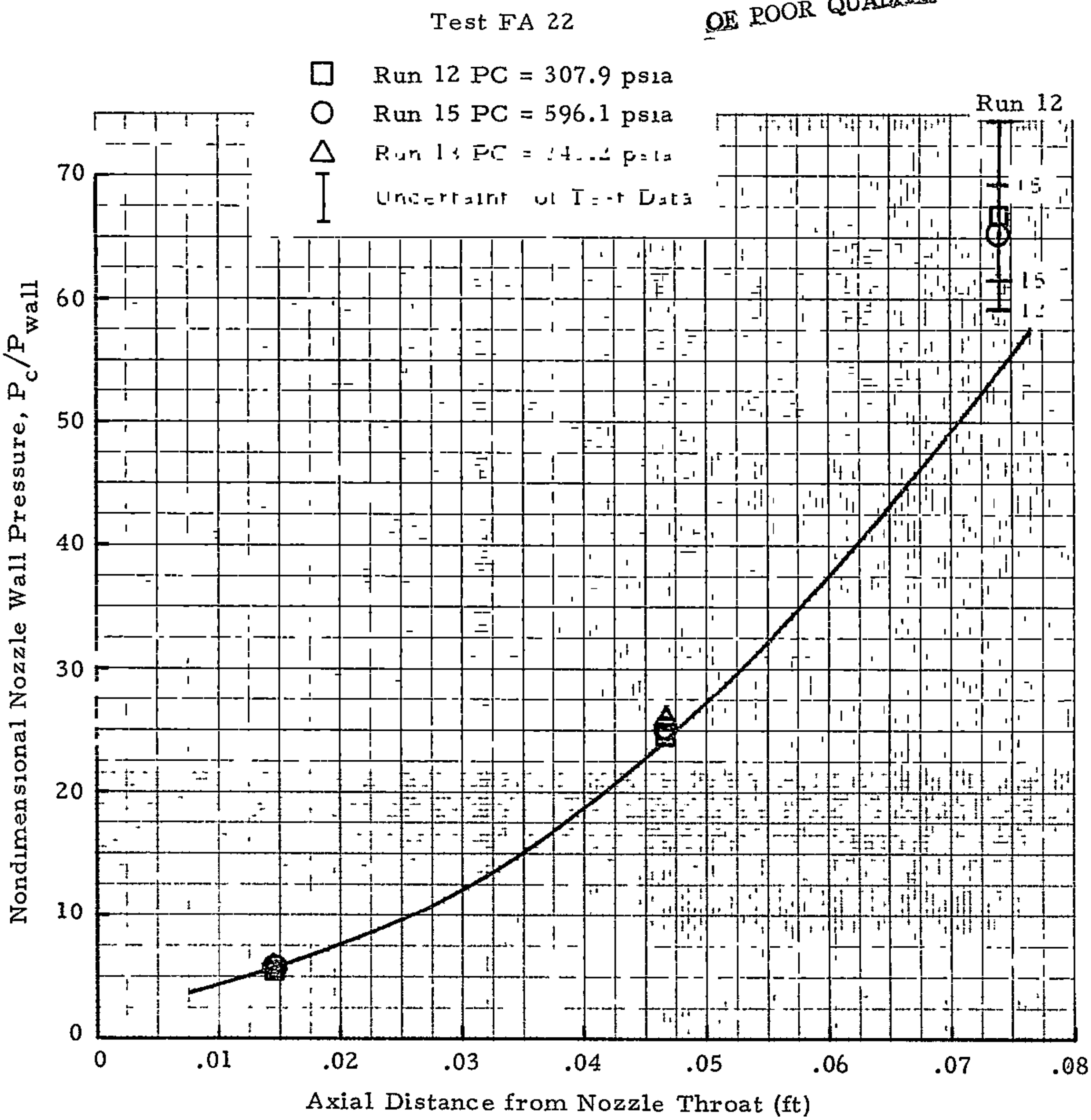


Fig. 3-13 - Nozzle Wall Pressure Distribution for Nozzle S/N 6 Flowing UTP-3001 Propellant with 16% Aluminum Loading

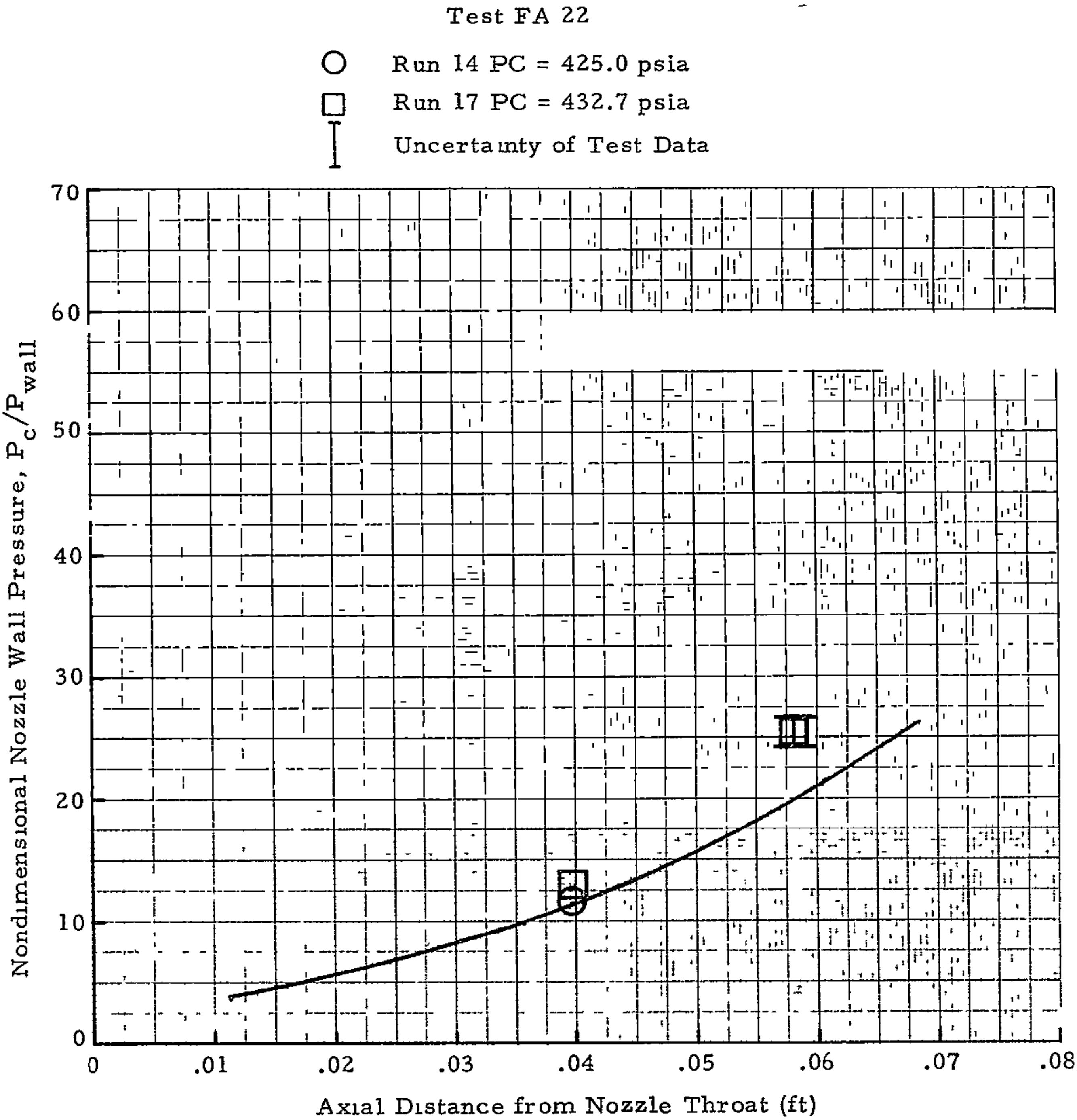


Fig. 3-14 - Nozzle Wall Pressure Distribution for Nozzle S/N 7 Flowing UTP-3001 Propellant with 16% Aluminum Loading

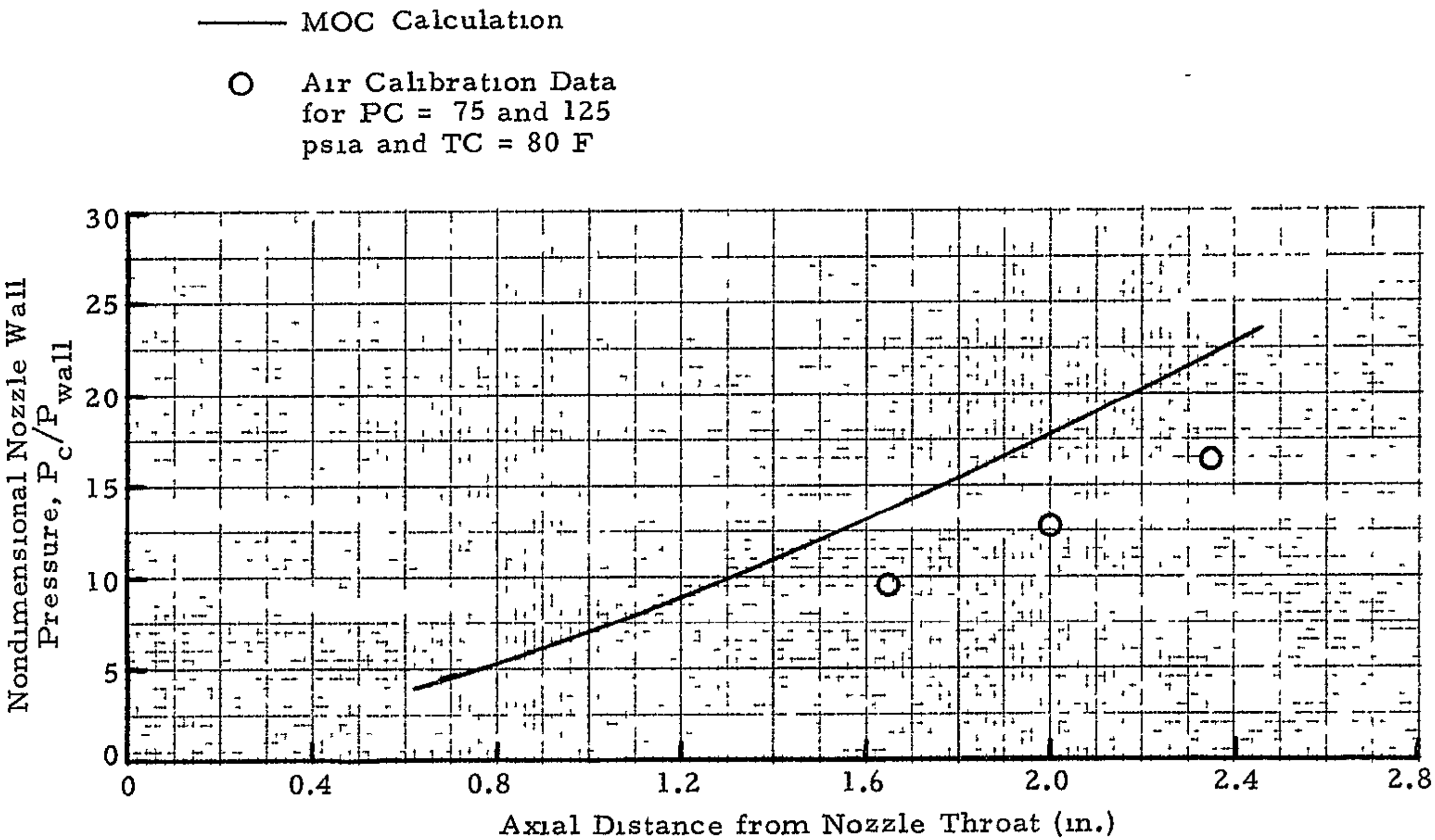


Fig. 3-15 - FA-23 Nondimensional Nozzle Pressure Distribution Based on Design Nozzle Contours

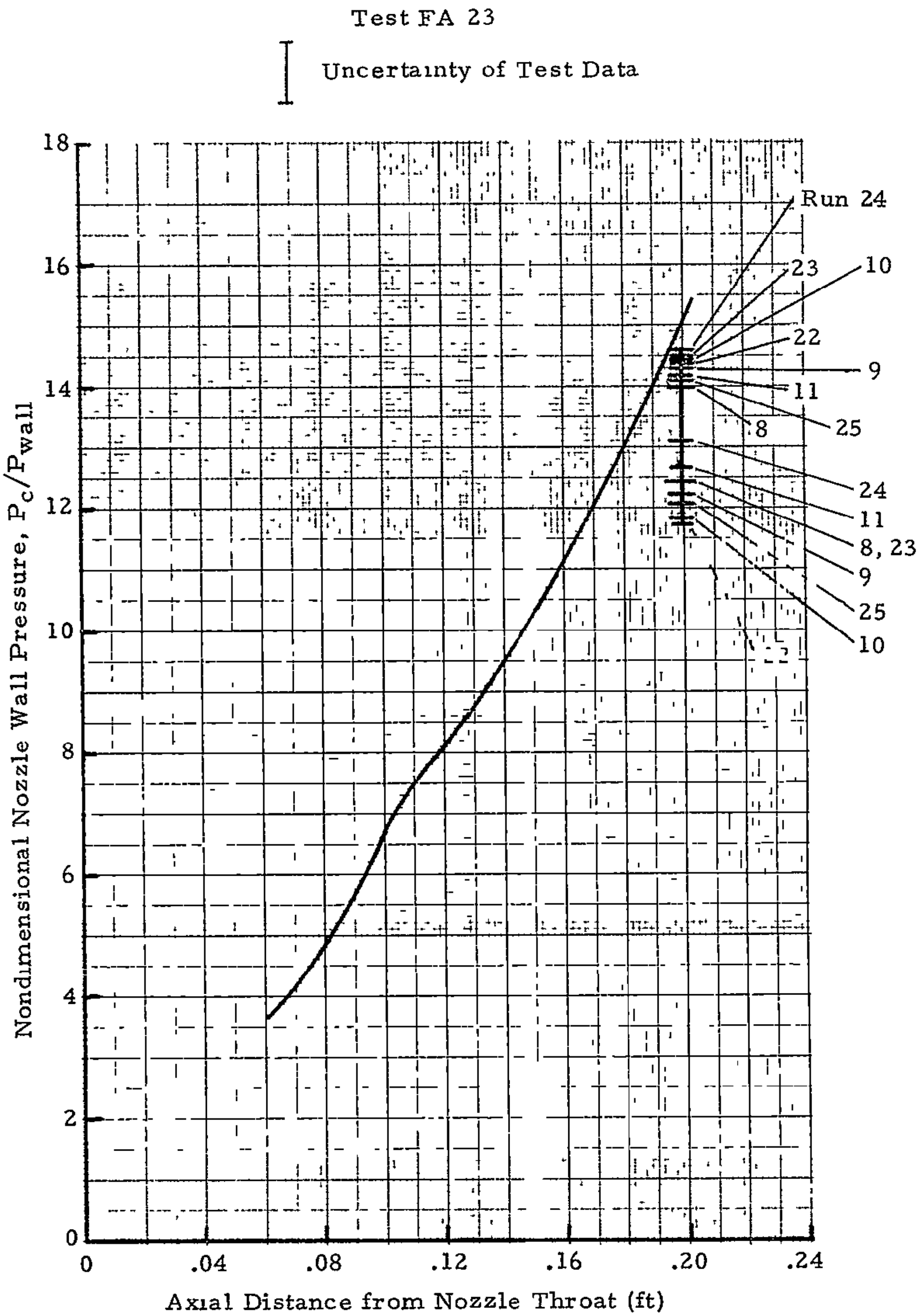


Fig. 3-16 - Nozzle Wall Pressure Distribution for Nozzle 21B Flowing LPC-580C Propellant with 16% Aℓ Loading

4 DEVELOPMENT OF THE BASE PRESSURE SIMILARITY PARAMETERS

This section describes the procedure used to develop the base pressure similarity parameters and presents the final form of those parameters found to correlate the existing data base Limitations to be placed upon the use of the base pressure similarity parameters are also discussed

4 1 SIMILARITY PARAMETER ANALYSIS

At the onset of this investigation, a literature search was conducted to identify existing similarity parameters A preliminary analysis was performed to determine their applicability to the Space Shuttle launch vehicle power-on aerodynamic testing As a result of the preliminary analysis the similarity parameters presented by R D. Herron for the correlation of exhaust plume blockage (Ref 3-5) and M Pindzola for the correlation of exhaust plume entrainment (Ref. 3-6) were consequently chosen as a "starting point" to derive the similarity parameters that may be applied to the experimental data base discussed in the previous section

The Data Management code described in Ref 2-1 was modified extensively to allow for both the evaluation of existing and new similarity parameters, and to create new similarity parameters based on inputs by the program user Use of the computer code identified "correlating trends" which, in turn, made it possible to limit the investigation to a few (5 to 10) promising similarity parameters Utilizing the knowledge gained by identifying certain "correlating trends," a matrix of variables was constructed Each variable of this matrix was then examined for potential use as a base pressure similarity parameter Table 4-1 presents the matrix from which all other matrices were constructed Table 4-2 is an example of a matrix constructed from the matrix of Table 4-1, and presents the results of the similarity parameter analysis for the single nozzle configuration (Tests MA 10F, MA 11F and FA 22) data base

Use of Tables 4-1 and 4-2: Starting with the matrix of Table 4-1, the variable PB/P_∞ is arbitrarily chosen to be plotted as the dependent variable on the vertical axis. The independent variable to be plotted on the horizontal axis is then determined by taking the product of the variables at the intersection of a particular row and column The degree to which the data is correlated when plotted is indicated by "no," "no-fair," "fair," "fair-yes," and "yes." As an example (see Table 4-2), the variable $\gamma_J M_J^2/\gamma_\infty M_\infty^2$ is multiplied by momentum$)_e$ and plotted on the horizontal axis with PB/P_∞ on the vertical axis. The result is a parameter that does correlate (indicated by "yes") the experimental data base This parameter is then non-dimensionalized by dividing by momentum$)_\infty$ and is recommended as the base pressure similarity parameter found to best correlate the existing data base for the single nozzle configuration (Tests MA 10F, MA 11F and FA 22) data base. It should be noted at this time, that for a given set of wind tunnel freestream conditions momentum$)_\infty$ is a constant and therefore non-dimensionalizing by dividing by a constant has no effect on the results of Table 4-2.

In addition to the matrix presented in Table 4-2, other similar matrices were constructed using all of the remaining variables taken one at a time, products of variables taken two at a time and products of variables taken three at a time and plotted on the vertical axis as the dependent variable The result was several hundred plots that led to the conclusion: for the data base defined under this contract PB/P_∞ was the best parameter to be plotted as the dependent parameter The intent of presenting this matrix of variables, is for future investigators to continue on from this point in the investigation rather than spend time reevaluating variables found not to be as good as the ones presented in this report.

Table 4-3 is the same matrix as is in Table 4-2, and presents the results of the similarity parameter analysis for the triple nozzle configuration (Tests MA 10F and FA 11) data base. The variable $M_J \delta_j/\gamma_J$ * Momentum$)_e$/ Momentum$)_\infty$ was determined to be the base pressure similarity parameter to best correlate the existing data base for the triple nozzle configuration A similar analysis was performed for the triple body configuration (Tests

FA 20 and FA 23) data base The variable $M_j \delta_j/\gamma_j$ * Momentum)$_e$/Momentum)$_\infty$ was again determined to be the base pressure similarity parameter to best correlate the existing data base for the triple body configuration

<u>Summary:</u> The following is a summary of those base pressure similarity parameters found to best correlate the existing data base:

a. Best parameter for the single nozzle configuration (MA 10F, MA 11F and FA 22 data base)

$$\frac{PB}{P_\infty} \text{ vs } \frac{\text{Momentum})_e}{\text{Momentum})_\infty} * \frac{\gamma_j M_j^2}{\gamma_\infty M_\infty^2}$$

b Best parameter for the triple nozzle configuration and the triple body configuration (MA10F, FA 11, FA 20 and FA 23 data base)

$$\frac{PB}{P_\infty} \text{ vs } \frac{\text{Momentum})_e}{\text{Momentum})_\infty} * \frac{M_j \delta_j}{\gamma_j}$$

Examination of Tables 4-2 and 4-3 indicate that other combinations of variables also correlate the data to some extent The above parameters were chosen because they correlated the data to a greater degree than did the other parameters

4 2 EXAMINATION OF BASE PRESSURE SIMILARITY PARAMETER PLOTS

Figures 4-1 through 4-13 present the results of applying the final base pressure similarity parameters to the experimental data base The following paragraphs discuss briefly some of the questions that may arise upon examination of these figures

4 2.1 Correlation of the Single Nozzle Configuration Experimental Data Base

The experimental data base for the single nozzle configuration consists of data taken from the MA 10F, FA 22 and MA 11F test programs (see Table 1-1) Figures 4-1 through 4-4 present the base pressure similarity parameter plots for the data obtained during the MA 10F test program; all data were taken for gaseous-only exhaust plumes. The effects of solid propellant exhaust gases on base pressure were studied in Tests FA 22 and MA 11F, the resultant base pressure similarity parameter plots are presented in Figs 4-5 through 4-7

The uncertainty of each of the experimental test values of PB/PINF was determined as a function of the uncertainty of the model base pressure and freestream static pressure measurements according to the following equation (see Appendix A for derivation):

$$\delta\left(\frac{PB}{PINF}\right) = \frac{\delta\ PB}{PINF} + \frac{PB}{PINF} * \frac{\delta\ PINF}{PINF}$$

where

δ PB = uncertainty in model base pressure, $\pm$psia

δ PINF = uncertainty in freestream static pressure, $\pm$psia (see Table 2-2 for δ PB and δ PINF values)

PB = measured value of model base pressure, psia

PINF = measured value of freestream static pressure, psia

The uncertainty of each data point is then plotted and represented as Examination of Figs 4-1, 4-2 and 4-3 indicate a very good correlation of data Figure 4-4, on the other hand, gives the initial impression that the data do not correlate as well as the data in Figs 4-1, 4-2 and 4-3. Upon closer examination, however, it is noted that the uncertainty bands on the data are larger, and that all uncertainty bands overlap, which indicates that the base pressure similarity parameter successfully correlated within the uncertainty of the data It is felt that if the accuracy of the freestream static pressure transducers were changed to reflect the need to measure a lower pressure at M_∞ = 3 48 the data of Fig 4-4 would have correlated to a greater degree. If, on the other hand, the uncertainty bands were to have increased further in size, the uncertainty in the ratio of PB/PINF would be too great to make any meaningful evaluation of the base pressure similarity parameter An example of this situation can best be seen in Fig. 4-7 for the correlation of the MA 10F and MA 11F (two-phase) test data Examination of this figure indicates that the uncertainty bands overlap, but the bands are so large that any meaningful evaluation of the base pressure similarity parameter is not possible (the uncertainty band of point 1 is so large that it exceeds the limits of the figure) As such, the MA 11F test data were determined to be of little value in the development of the base pressure similarity parameters (see Section 2 2 4)

Figures 4-5 and 4-6 present the base pressure similarity parameter plots for the MA 10F and FA 22 (two-phase) test data Close examination of these figures indicates that in most cases the FA 22 test data is slightly to the left of the MA 10F test data This is a direct result of the solid propellant contamination of the pressure tubing leading to the chamber pressure transducers Such contamination results in a measured chamber pressure lower than actual (see Section 2 2.5). Points 1 in both of these figures were not discarded so that the effect of contamination can be seen. It is felt that if solid propellant contamination had not occurred the FA 22 test data would shift to the right causing the MA 10F and FA 22 data to correlate to a greater degree.

4.2.2 Correlation of the Triple Body Configuration Experimental Data Base

The experimental data base for the triple nozzle configuration consists of data taken from the MA 10F and FA 11 test programs (see Table 1-1) The experimental data base for the triple body configuration consists of data taken from the FA 20 and FA 23 test programs (see Table 1-1). Figures 4-8 through 4-11 present the base pressure similarity parameter plots for the triple nozzle data obtained during the MA 10F and FA 11 test programs. Each of the plots indicate a very good correlation of the data with the recommended base pressure similarity parameter for the triple nozzle configuration

Figures 4-12 and 4-13 present the base pressure similarity parameter plots for the triple body data obtained during the FA 20 and FA 23 test programs Note that the jet conditions used in the determination of the base pressure similarity parameter values are those conditions that exist on the plume boundary at the SRB nozzle exit plane, and are calculated assuming that the pressure on the jet boundary is equal to the measured model SRB base pressure

It should be noted that Figs 4-12 and 4-13 contain FA 23 test data which has been determined unusable in the development of the base pressure similarity parameter (see Section 3 2). The FA 23 data were included in these figures to give the reader some insight into some of the difficulties involved in both the experimental and analytical aspect of the development of the base pressure similarity parameter Examining only the FA 20 data presented in these figures, it is seen that the FA 20 data do not correlate as well as the data for the single or triple nozzle configurations This is especially true for the freestream Mach number = 1.2 data This lesser degree of correlation is attributed to the inability to verify the gasdynamic performance of each of the three pairs (left and right) of nozzles. As was the case with the FA 23 nozzle performance data (see Section 3 2), the reason for this is only speculation Based on the fact that most of the FA 20 data did correlate together with the high confidence level already established for use of this parameter leaves no choice but to recommend that the same base pressure similarity parameter be used for both the triple nozzle and triple body configurations

4 3 LIMITATIONS OF THE BASE PRESSURE SIMILARITY PARAMETER

The most obvious limitation of the use of the base pressure similarity parameter is that of nozzle configuration (single or triple) being analyzed The parameter recommended to correlate the single nozzle configuration data base is by no means as acceptable when applied to the triple nozzle or triple body configuration data base The same holds true for the parameter recommended to best correlate the triple nozzle and triple body configuration data base

The base pressure similarity parameters developed in this study were derived for the data base obtained during the various tests of the Plume

Technology Program and as such are subject to certain limitations Ideally, the base pressure data base would be infinitely large and the derived base pressure similarity parameter would be such that it would correlate the entire data base These conditions obviously do not exist in this case

Table 4-4 presents the range of operating conditions which were used to generate the data base for the Plume Technology Program There is a fairly wide range of operating conditions as well as nozzle geometric conditions (A/A^*, θ_{lip}) These conditions and the resulting base pressures result in a corresponding range of values for the recommended correlation parameters which were used to collapse the data Within the range of values of the correlation parameters the collapse of the data was excellent Analysis of the analytical data base (see Section 5) using the experimentally derived single nozzle correlation parameter showed that variable wall angle effects for nozzles with constant exit plane properties are not correlated Thus, it is certain that the present single nozzle correlation parameter is not universally applicable Further, it was found that the present correlation parameter will correlate the data from any of the different analytical nozzles when values of M_J are approximately constant at constant values of P_B/P_∞ This implies that the present similarity parameter requires $M_{J_{model}} \approx M_{J_{prototype}}$ Analysis of the analytical data base is not complete enough to identify any other possible restriction or to determine a more complete similarity parameter than the one determined from the experimental data

A few of the geometric parameters of the Space Shuttle Main and SRB engines are beyond the range of the nozzle geometries of the data base The more important geometric considerations such as the spacing of the nozzles and the height of the exit plane above the base for the Space Shuttle are consistent with the data base geometries. The actual values of the correlation parameters when applied to the Space Shuttle vehicle fall within the range of the Plume Technology data base It is thus concluded that the similarity parameters derived in this study can be applied to the Space Shuttle vehicle for all those conditions for which the similarity parameters fall within the range of values of the Plume Technology data base

	PB/P_∞	δ_j	M_j/γ_j	δ_j/γ_j	$\frac{\gamma_j M_j^2}{\sqrt{M_j^2 - 1}}$	PC/P_∞	$1/\gamma_\infty M_\infty^2$	Momentum$)_e$	$(M_j \gamma_j)^{\gamma_j}$	$\frac{\gamma_j M_j^2}{\gamma_\infty M_\infty^2}$	δ_j Momentum$)_e$	$M_j \delta_j/\gamma_j$	Momentum$)_\infty$	$\left(\frac{R_\infty}{R_j}\right)^{1/3}\left(\frac{\gamma_j}{\gamma_\infty}\right)$
PB/P_∞														
δ_j														
M_j/γ_j														
δ_j/γ_j														
$\gamma_j M_j^2/\sqrt{M_j^2 - 1}$														
PC/P_∞														
$1/\gamma_\infty M_\infty^2$														
Momentum$)_e$														
$(M_j \gamma_j)^{\gamma_j}$														
$\gamma_j M_j^2/\gamma_\infty M_\infty^2$														
f_j Momentum$)_e$														
$M_j \delta_j/\gamma_j$														
Momentum$)_\infty$														
$(R_\infty/R_j)^{1/3} (\gamma_j/\gamma_\infty)$														

Note: See discussion in text for application of this matrix

Table 4-1 - Matrix of Variables Used to Arrive at the Final Base Pressure Similarity Parameters

PB/P_∞	δ_j	M_j/γ_j	δ_j/γ_j	$\gamma_j M_j^2/\sqrt{M_j^2-1}$	PC/P_∞	$1/\gamma_\infty M_\infty^2$	Momentum)$_e$	$(M_j \gamma_j)^{\gamma_j}$	$\frac{\gamma_j M_j^2}{\gamma_\infty M_\infty^2}$	δ_j Momentum)$_e$	$\frac{M_j \delta_j}{\gamma_j}$	Momentum)$_\infty$	$\left(\frac{R_\infty}{R_j}\right)^{1/3}\left(\frac{\gamma_j}{\gamma_\infty}\right)$
1	No-Fair	No	Fair-Yes	No	No	No	No	No	No	Fair-Yes	Fair	No	No
M_j/γ_j	No-Fair												
δ_j/γ_j	No	No											
$\gamma_j M_j^2/\sqrt{M_j^2-1}$	No	No	No										
PC/P_∞	No	No	No	No									
$1/\gamma_\infty M_\infty^2$	No	No	Fair-Yes	No	No								
Momentum)$_e$	Fair	No	No-Fair	Yes	No	No-Fair							
$(M_j \gamma_j)^{\gamma_j}$	No	No	No	No	No	No	Fair						
$\gamma_j M_j^2/\gamma_\infty M_\infty^2$	No	No	No	No	No	No	Yes	No					
δ_j Momentum)$_e$	Fair-Yes	Fair-Yes	Fair-Yes	Yes	Fair	Fair-Yes	No-Fair	No-Fair	Yes				
$M_j \delta_j/\gamma_j$	No	No	Fair	No	No	No	Fair-Yes	No	No	Yes			
Momentum)$_\infty$	No	No	Fair	No	No	No	No	No	No	Fair-Yes	Fair		
$(R_\infty/R_j)^{1/3}(\gamma_j/\gamma_\infty)$	No-Fair	No	No	No	No	No	No	No	No	No-Fair	No	No	

Note See discussion in text for application of this matrix

Table 4-2 - Results of the Similarity Parameter Analysis for the Single Nozzle Configuration (MA 10F, MA 11F, and FA 22 Data Base)

PB/P_∞	δ_j	M_j/γ_j	δ_j/γ_j	$\frac{\gamma_j M_j^2}{\sqrt{M_j^2-1}}$	PC/P_∞	$1/\gamma_\infty M_\infty^2$	Momentum)$_e$	$(M_j\ \gamma_j)^{\gamma_j}$	$\frac{\gamma_j M_j^2}{\gamma_\infty M_\infty^2}$	δ_j Momentum)$_e$	$M_j\ \delta_j/\gamma_j$	Momentum)$_\infty$	$\left(\frac{R_\infty}{R_j}\right)^{1/3}\left(\frac{\gamma_j}{\gamma_\infty}\right)$
1	No-Fair	No	No-Fair	No	No	No	No-Fair	No	No	Fair-Yes	Fair	No	No
M_j/γ_j	Fair												
δ_j/γ_j	No	No											
$\gamma_j M_j^2/\sqrt{M_j^2-1}$	No	No	No-Fair										
PC/P_∞	No	No	No	No									
$1/\gamma_\infty M_\infty^2$	No	No	No-Fair	No	No								
Momentum)$_e$	Fair	No	Fair-Yes	No	No	No-Fair							
$(M_j\ \gamma_j)^{\gamma_j}$	No	No	No	No	No	No	No						
$\gamma_j M_j^2/\gamma_\infty M_\infty^2$	No	No	No-Fair	No	No	No	No	No					
δ_j Momentum)$_e$	Fair	No-Fair	Fair-Yes	No-Fair	No-Fair	Fair-Yes	No-Fair	No-Fair	No-Fair				
$M_j\ \delta_j/\gamma_j$	No-Fair	No-Fair	No-Fair	No-Fair	No	Fair	Yes	No	No-Fair	Fair-Yes			
Momentum)$_\infty$	No	No	No-Fair	No	No	No	No-Fair	No	No	No-Fair	Fair		
$(R_\infty/R_j)^{1/3}(\gamma_j/\gamma_\infty)$	Fair	No	No	No	No	No	No	No	No	Fair-Yes	No	No	

Note See discussion in text for application of this matrix

Table 4-3 - Results of the Similarity Parameter Analysis for the Triple Nozzle Configurations (MA 10F and FA 11) Data Base

Table 4-4

APPROXIMATE LIMITATIONS OF TEST CONDITIONS FOR A GIVEN CONFIGURATION AND FREESTREAM MACH NUMBER

	M_∞	$M_J)_{min}$	$M_J)_{max}$	$\delta_J)_{min}$	$\delta_J)_{max}$	$\gamma_J)_{min}$	$\gamma_J)_{max}$	$M_e)_{min}$	$M_e)_{max}$	$P_e)_{min}$	$P_e)_{max}$	$P_\infty)_{min}$	$P_\infty)_{max}$
Single Nozzle Configuration (Gaseous Only and Two Phase Flow)	0 9	2 7	4 1	17 9	42 1	1 15	1 40	2 4	3 9	3 3	48 6	3 0	12 3
	1 2	3 0	4 4	22 0	45 4	1 15	1 40	2 4	3 9	3 3	49 7	4 1	7 7
	1 46	3 5	4 7	30 7	48 7	1 16	1 40	2 9	3 9	2 9	49 0	5 0	5 4
	3 48	4 3	6 0	49 2	60 0	1 18	1 40	2 9	3 9	3 3	46 9	1 21	1 22
Triple Nozzle Configuration	0 9	2 5	4 3	0 4	69 5	1 15	1.40	2 9	3 7	2 5	44 0	10 5	10 7
	1 2	2 7	4 3	6 5	44 0	1 15	1 40	2 9	3 0	3 7	44 2	7 3	7 5
	1 46	3 6	4 5	6 5	46 4	1 16	1 40	2 9	3 0	2 6	44 2	5 1	5 5
	3 48	4 3	5 4	48 4	55 0	1 15	1 40	3 9	3 0	10 4	43 5	1 2	1 4
Triple Body Configuration (Gaseous Only Flow)	0 9	3 3	4 4	23 6	40 7	1 15	1 40	3 0	4 1	2 4	27 3	4 2	6 0
	1 2	3 3	4 7	26 3	42 8	1 16	1 40	3 0	4 1	2 5	30 2	4 1	4 2

Symbol	Nozzle Identification
□	Nozzle 1 – CF4, A/A = 7 967, Theta = 15 12, M = 9
△	Nozzle 2 – Air, A/A^* = 3 571, Theta = 25 03, M = 9
○	Nozzle 4X – Air, A/A^* = 6 518, Theta = 34 77, M = .9
I	Uncertainty of Test Data

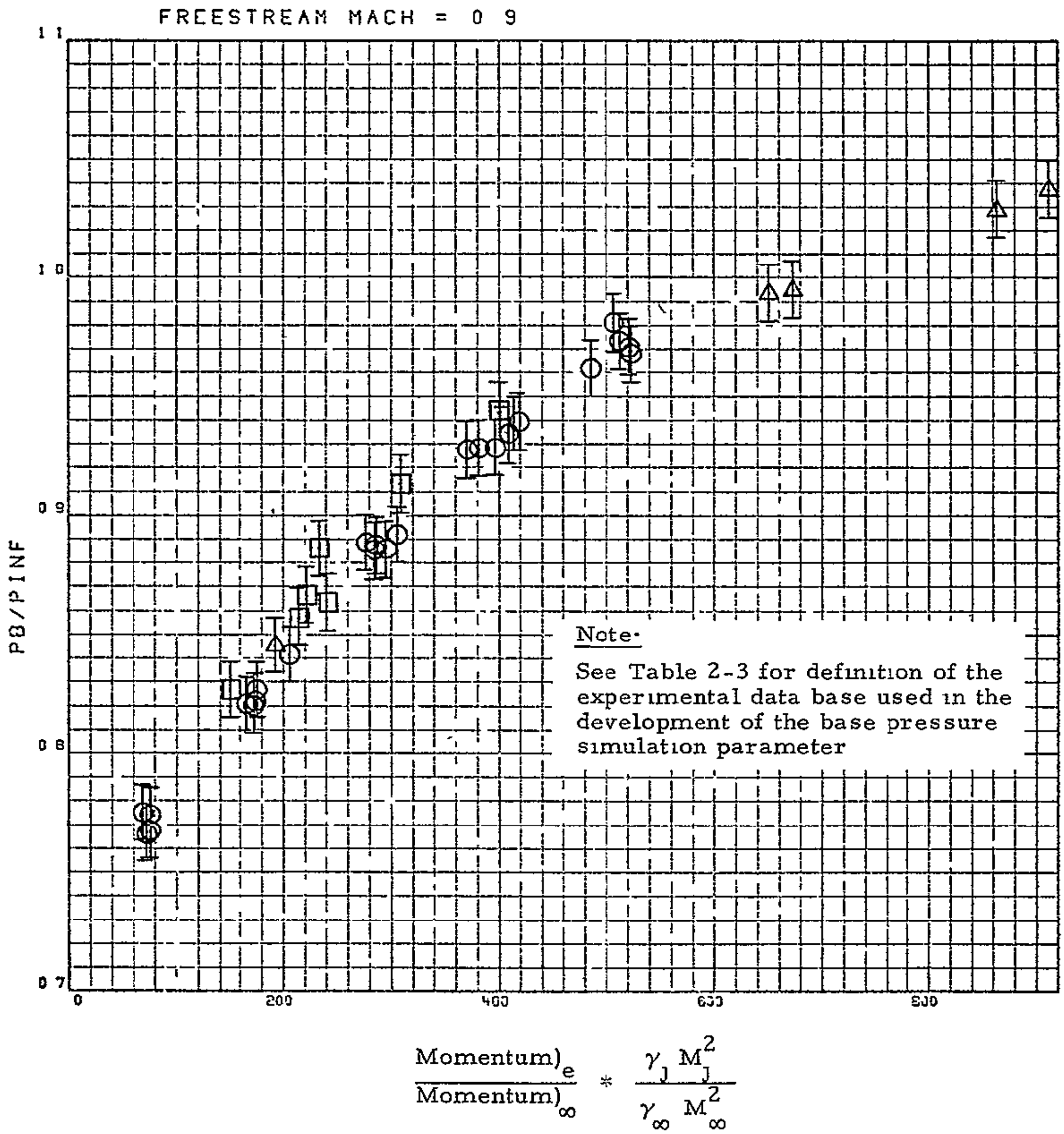


Fig 4-1 - Correlation of the MA 10F Single Nozzle Configuration Experimental Data Base (Freestream Mach Number = 0 9)

Symbol	Nozzle Identification
□	Nozzle 1 – CF4, A/A^* = 7 967, Theta = 15 12, M = 1 2
△	Nozzle 2 – Air, A/A^* = 3 571, Theta = 25.03, M = 1 2
○	Nozzle 4X – Air, A/A^* = 6 518, Theta = 34 77, M = 1 2
I	Uncertainty of Test Data

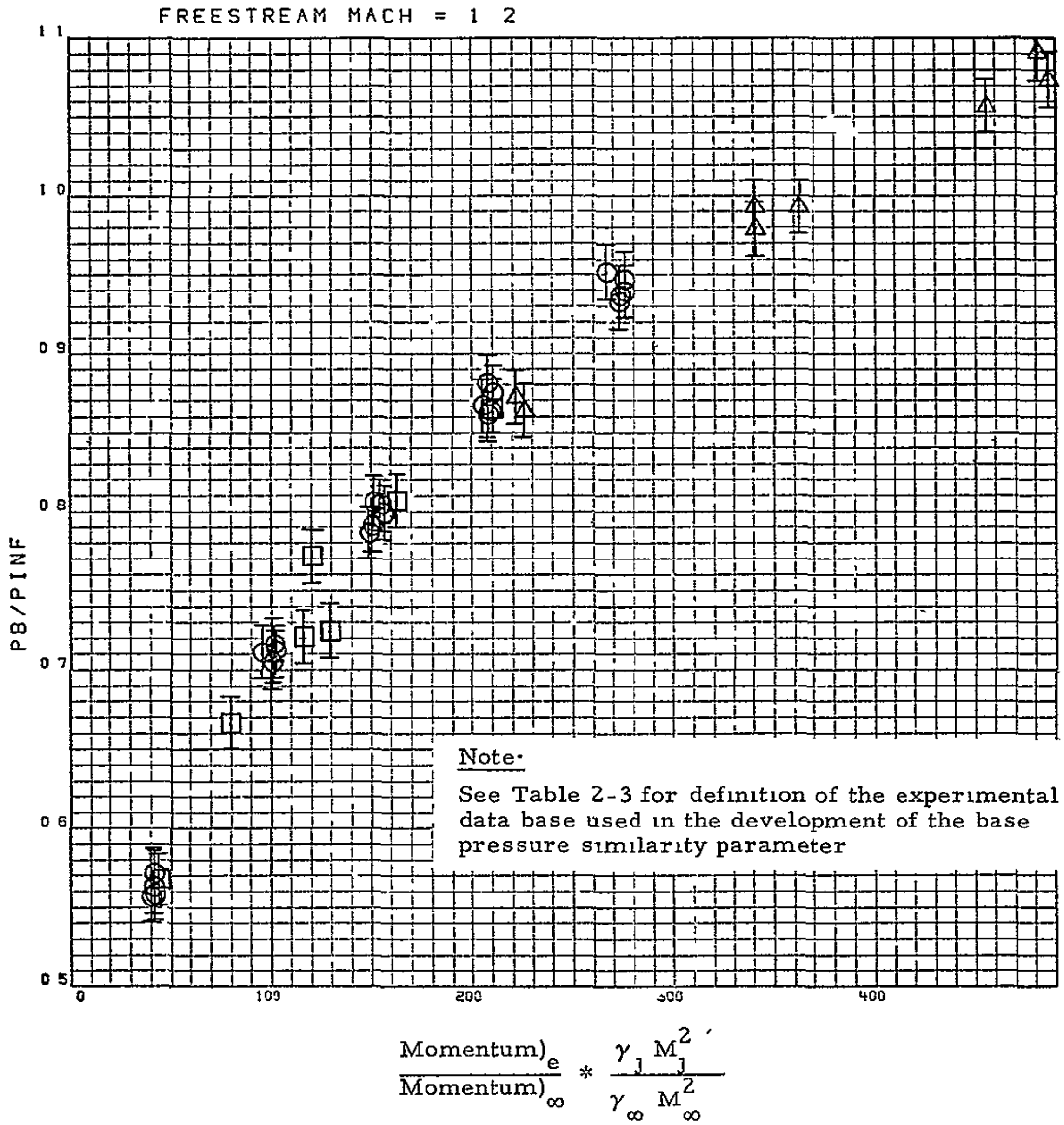
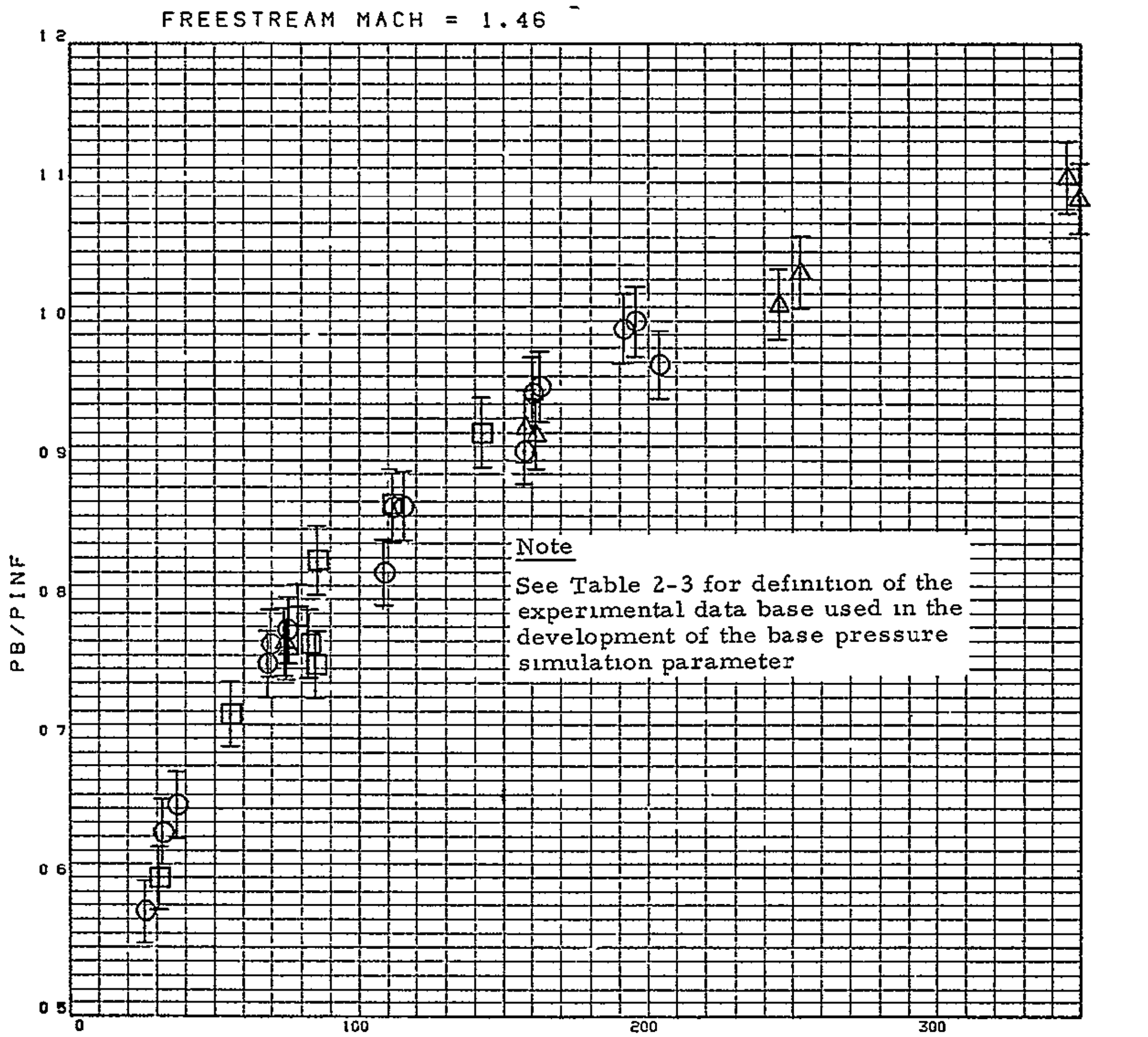


Fig 4-2 - Correlation of the MA 10F Single Nozzle Configuration Experimental Data Base (Freestream Mach Number = 1 2)

Symbol	Nozzle Identification
◘	Nozzle 1 – CF_4, A/A^* = 7 967, Theta = 15 12, M = 1 46
▲	Nozzle 2 – Air, A/A^* = 3 571, Theta = 25 03, M = 1 46
○	Nozzle 4X – Air, A/A^* = 6 518, Theta = 34.77, M = 1 46
I	Uncertainty of Test Data



$$\frac{\text{Momentum})_e}{\text{Momentum})_\infty} * \frac{\gamma_J M_J^2}{\gamma_\infty M_\infty^2}$$

Fig 4-3 - Correlation of the MA10F Single Nozzle Configuration Experimental Data Base (Freestream Mach Number = 1 46)

Symbol	Nozzle Identification
■	Nozzle 1 – CF4, $A/A^* = 7.967$, Theta = 15.12, M = 3.48
▲	Nozzle 2 – Air, $A/A^* = 3.571$, Theta = 25.03, M = 3.48
●	Nozzle 4X – Air, $A/A^* = 6.518$, Theta = 34.77, M = 3.48
I	Uncertainty of Test Data

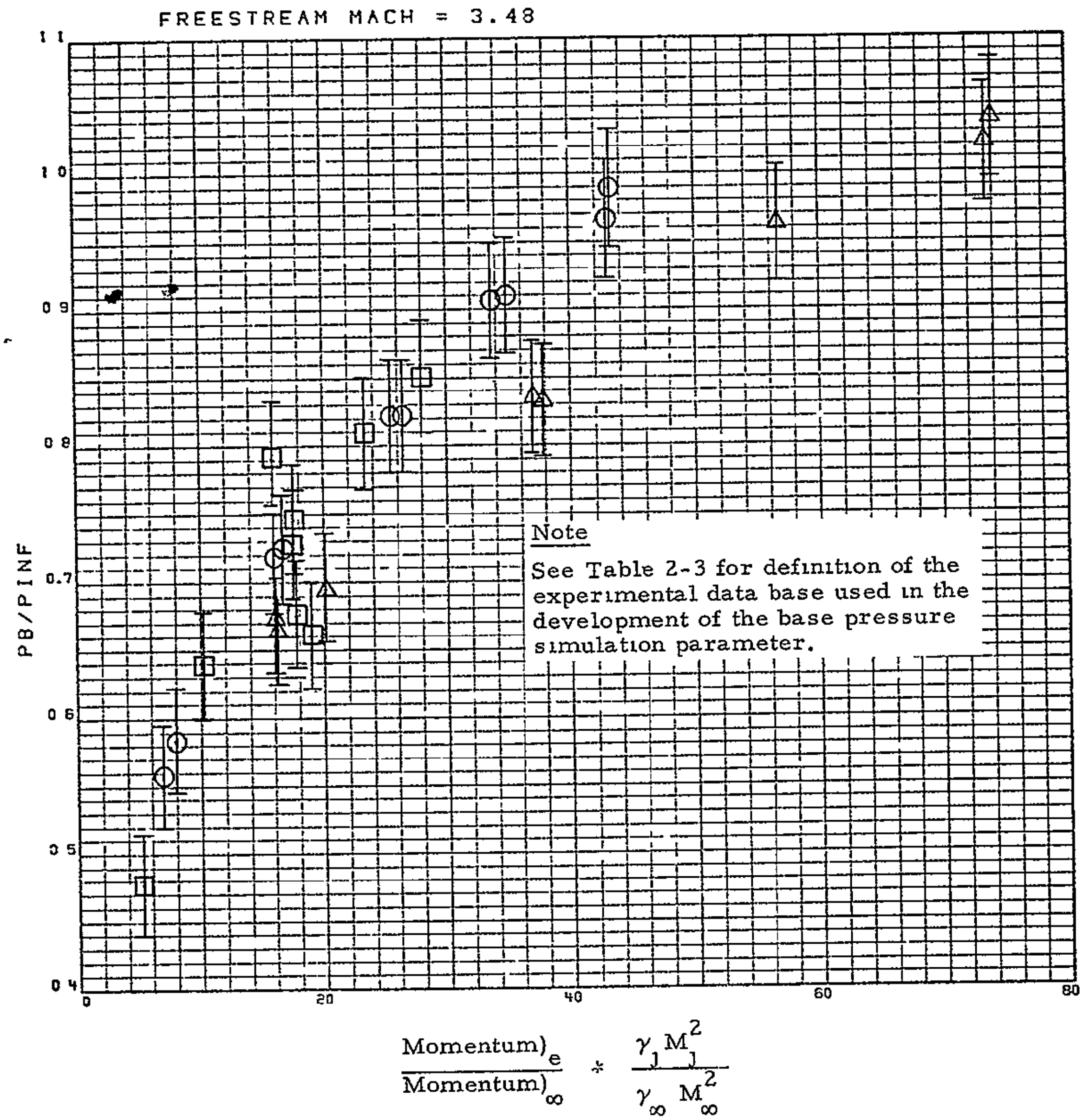
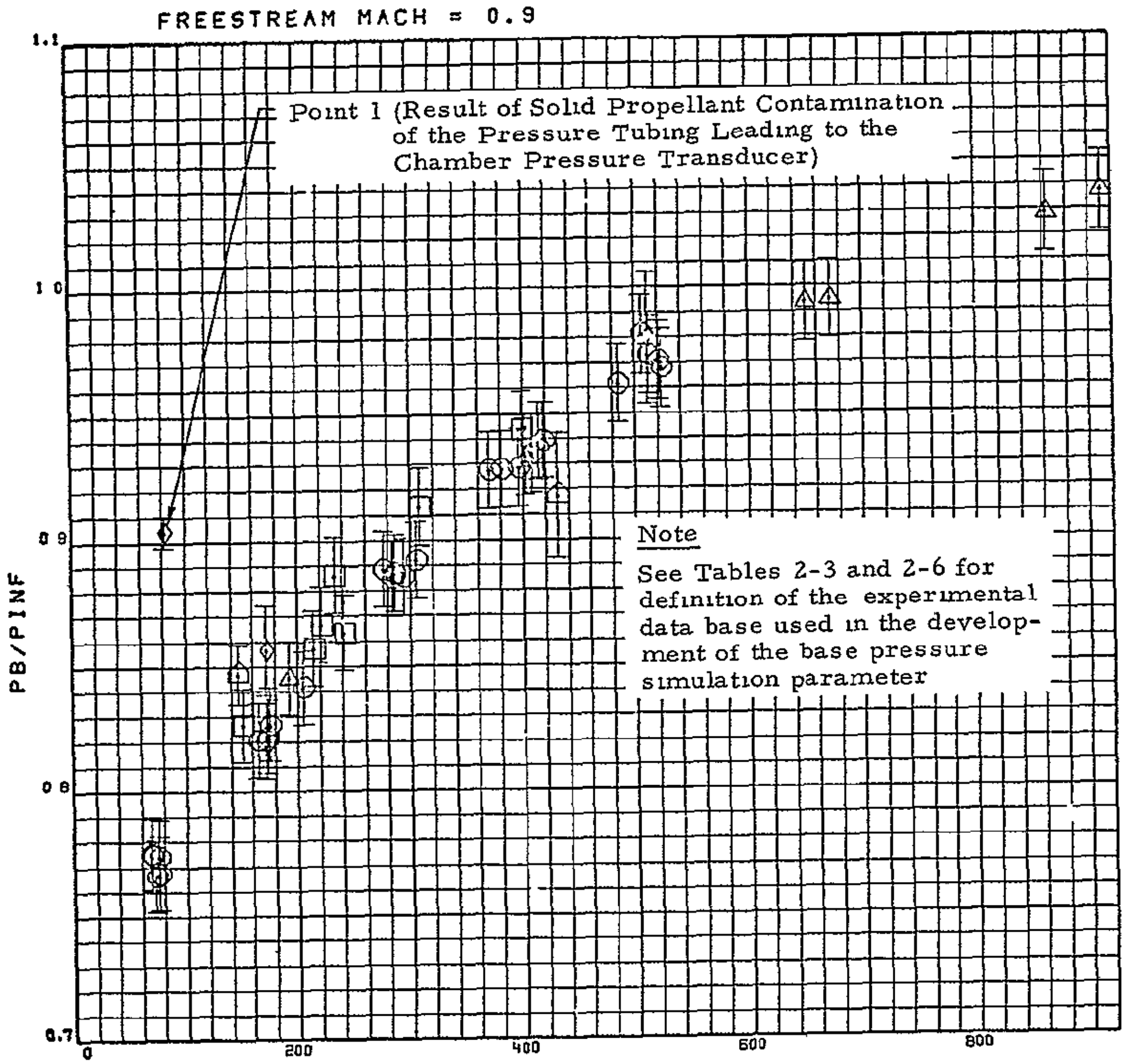


Fig 4-4 - Correlation of the MA10F Single Nozzle Configuration Experimental Data Base (Freestream Mach Number = 3.48)

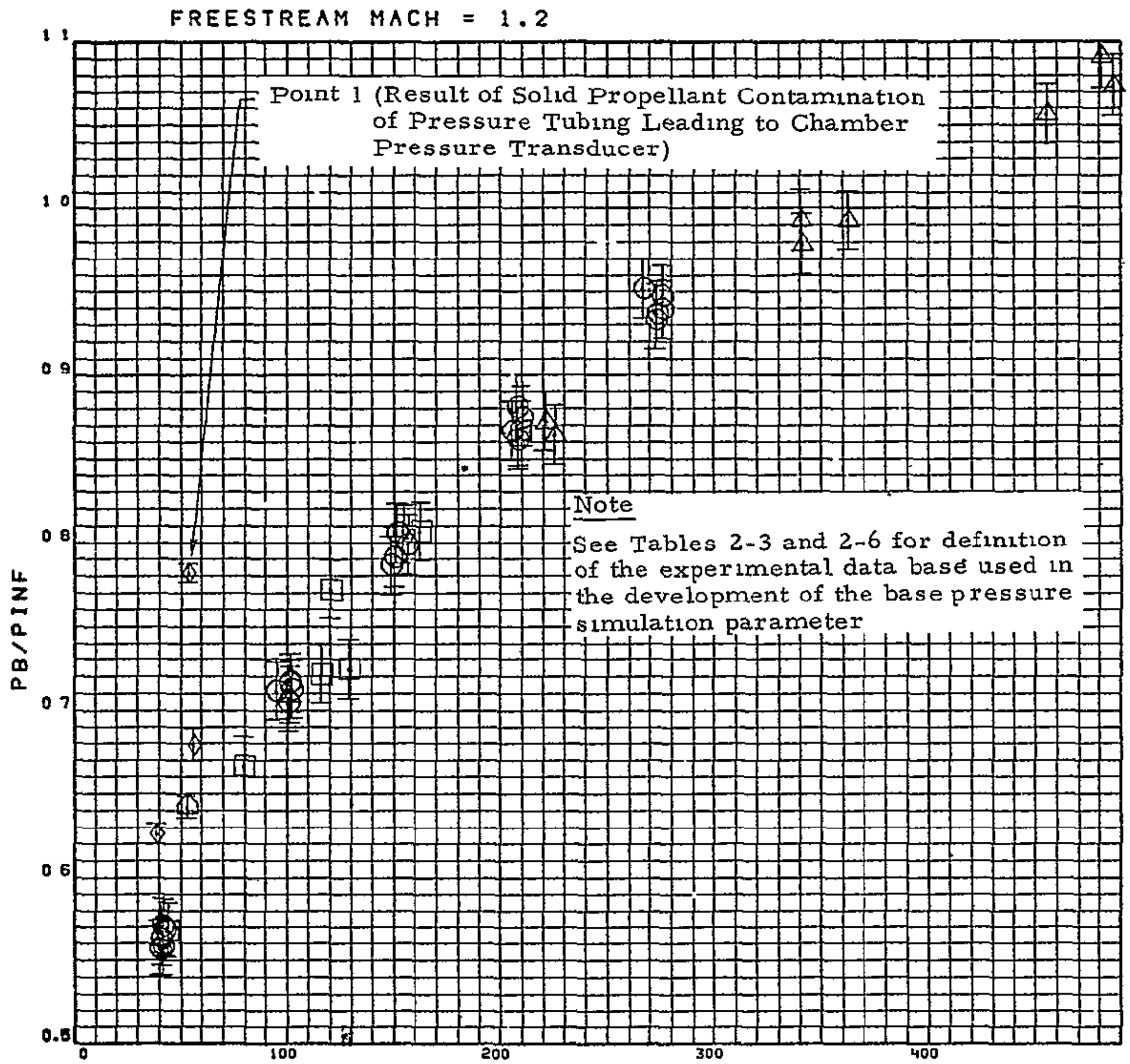
Symbol	Nozzle Identification
□	Nozzle 1 – CF4, $A/A^* = 7.967$, Theta = 15.12, M = 9
△	Nozzle 2 – Air, A/A^* = 3 571, Theta = 25 03, M = 9
○	Nozzle 4X – Air, A/A^* = 6 518, Theta = 34 77, M = 9
◇	FA22 UTP-3001 16% AL, M = 90
⌂	FA22 ANB-3335 2% AL, M = 90
I	Uncertainty of Test Data



$$\frac{\text{Momentum})_e}{\text{Momentum})_\infty} * \frac{\gamma_j M_j^2}{\gamma_\infty M_\infty^2}$$

Fig 4-5 - Correlation of the MA10F and FA22 (Two-Phase) Single Nozzle Configuration Experimental Data Base (Freestream Mach Number = 0 9)

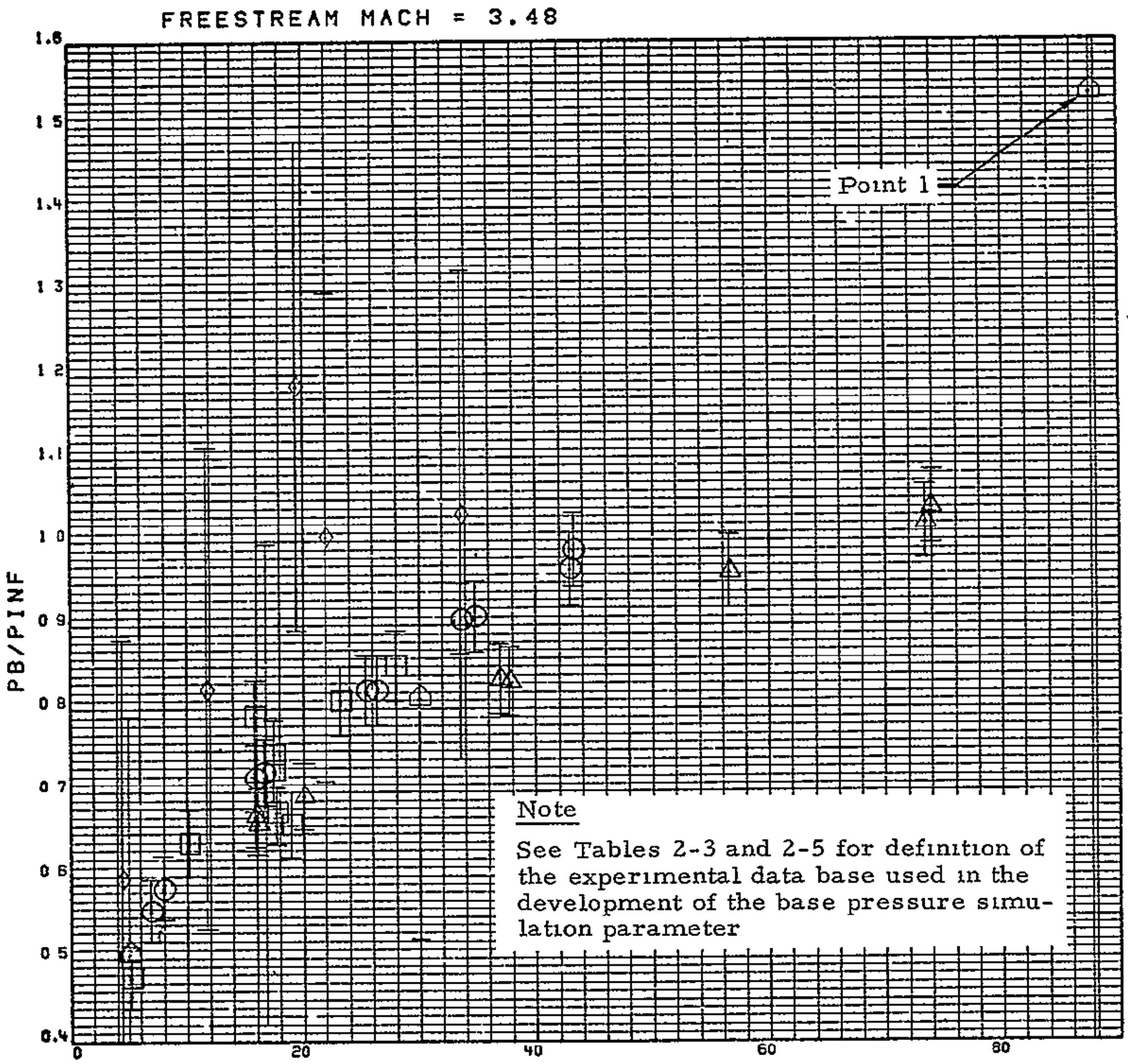
Symbol	Nozzle Identification
□	Nozzle 1 – CF4, A/A^* = 7 967, Theta = 15 12, M = 1 2
△	Nozzle 2 – Air, A/A^* = 3 571, Theta = 25 03, M = 1 2
○	Nozzle 4X – Air, A/A^* = 6 518, Theta = 34 77, M = 1 2
◇	FA22 UTP-3001 16% AL, M = 1 20
⌂	FA22 ANB-3335 2% AL, M = 1 20
I	Uncertainty of Test Data



$$\frac{\text{Momentum})_e}{\text{Momentum})_\infty} * \frac{\gamma_j M_j^2}{\gamma_\infty M_\infty^2}$$

Fig 4-6 - Correlation of the MA10F and FA22 (Two-Phase) Single Nozzle Configuration Experimental Data Base (Freestream Mach Number = 1 2)

Symbol	Nozzle Identification
□	Nozzle 1 – CF_4, $A/A^* = 7.967$, Theta = 15 12, M = 3 48
△	Nozzle 2 – Air, $A/A^* = 3\ 571$, Theta = 25 03, M = 3 48
○	Nozzle 4X – Air, $A/A^* = 6\ 518$, Theta = 34 77, M = 3 48
◇	MA11F UTP-3001 16% Aℓ, M = 3 48
⌂	MA11F ANB-3335 2% Aℓ, M = 3 48
I	Uncertainty of Test Data



$$\frac{\text{Momentum})_e}{\text{Momentum})_\infty} * \frac{\gamma_J M_J^2}{\gamma_\infty M_\infty^2}$$

Fig 4-7 - Correlation of the MA10F and MA11F (Two-Phase) Single Nozzle Configuration Experimental Data Base (Freestream Mach Number = 3 48)

Symbol	Nozzle Identification
□	Nozzle 5B – CF4, A/A^* = 8.291, Theta = 15 03, M = 9, MA10F
△	Nozzle 5A – Air, A/A^* = 8.296, Theta = 14 83, M = 9, FA11
○	Nozzle 6A – Air, A/A^* = 4 040, Theta = 24 62, M = .9, MA10F
◇	Nozzle 8A – Air, A/A^* = 4.060, Theta = 10 12, M = 9, FA11
I	Uncertainty of Test Data

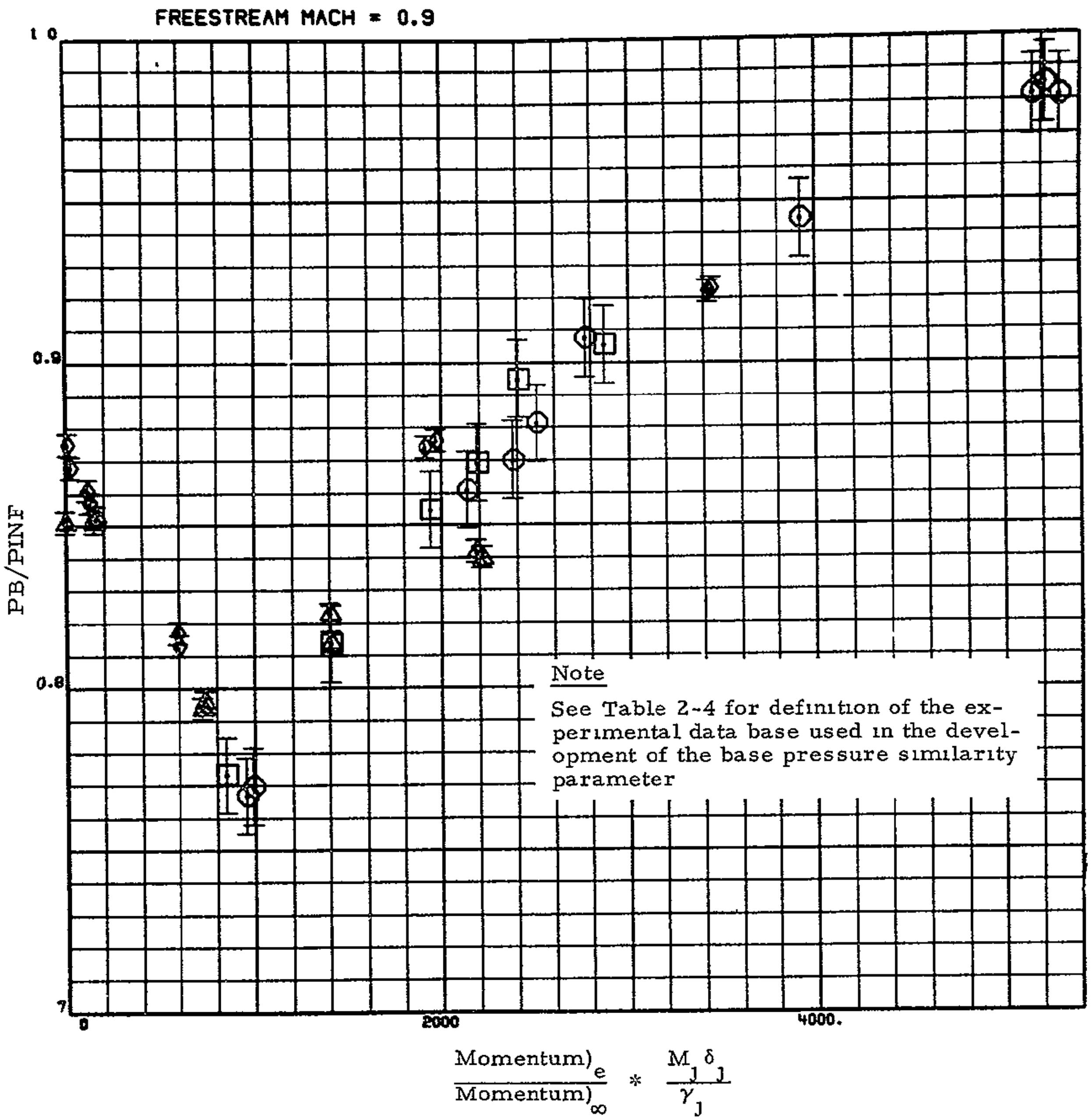


Fig 4-8 - Correlation of the MA10F and FA11 Triple Nozzle Configuration Experimental Data Base (Freestream Mach Number = 0 9)

Symbol	Nozzle Identification
□	Nozzle 5B – CF4, A/A^* = 8 291, Theta = 15 03, M = 1 2, MA10F
△	Nozzle 6A – Air, A/A^* = 4.040, Theta = 24 62, M = 1 2, MA10F
○	Nozzle 8A – Air, A/A^* = 4 060, Theta = 10 12, M = 1 2, FA11
I	Uncertainty of Test Data

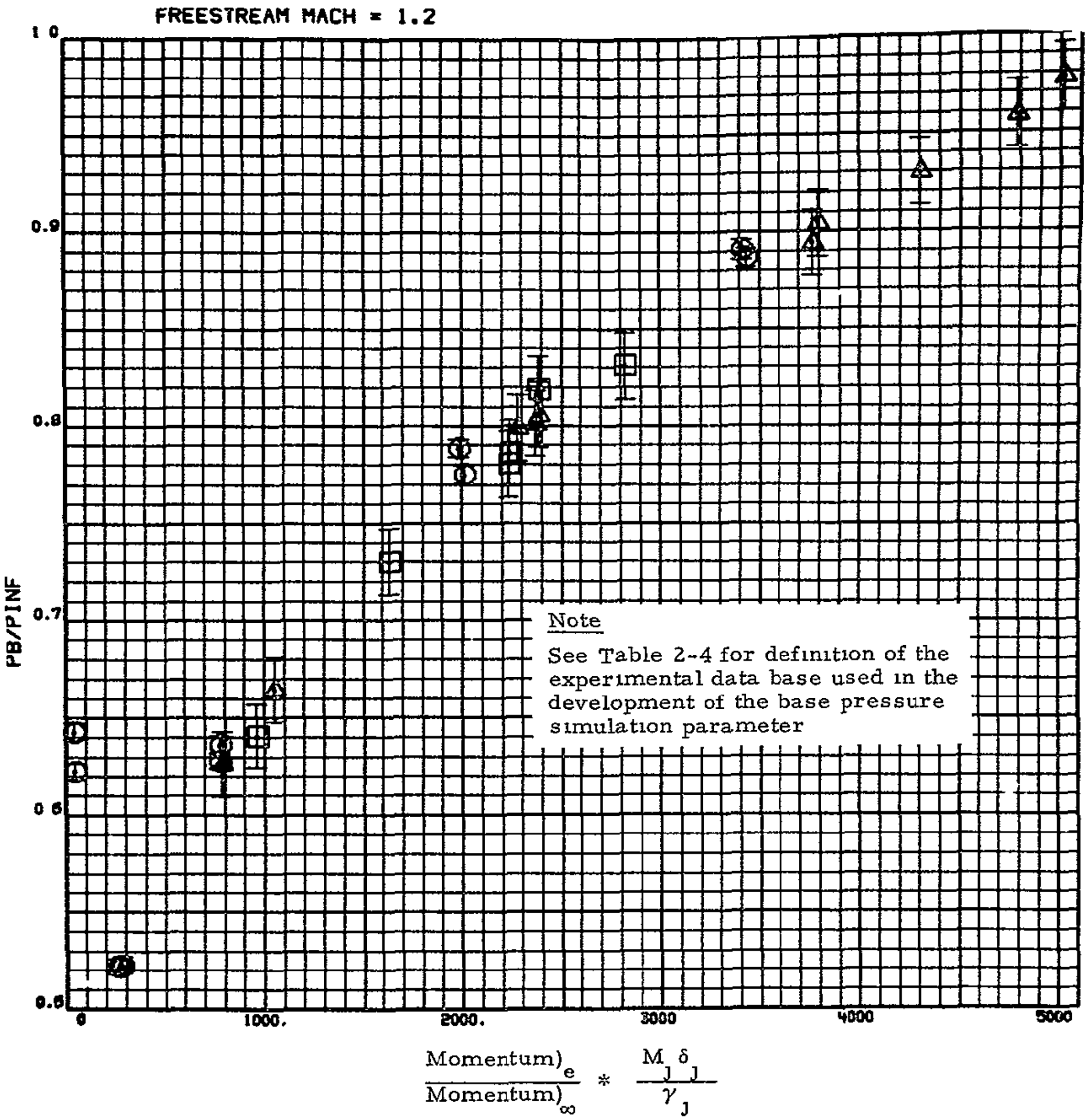
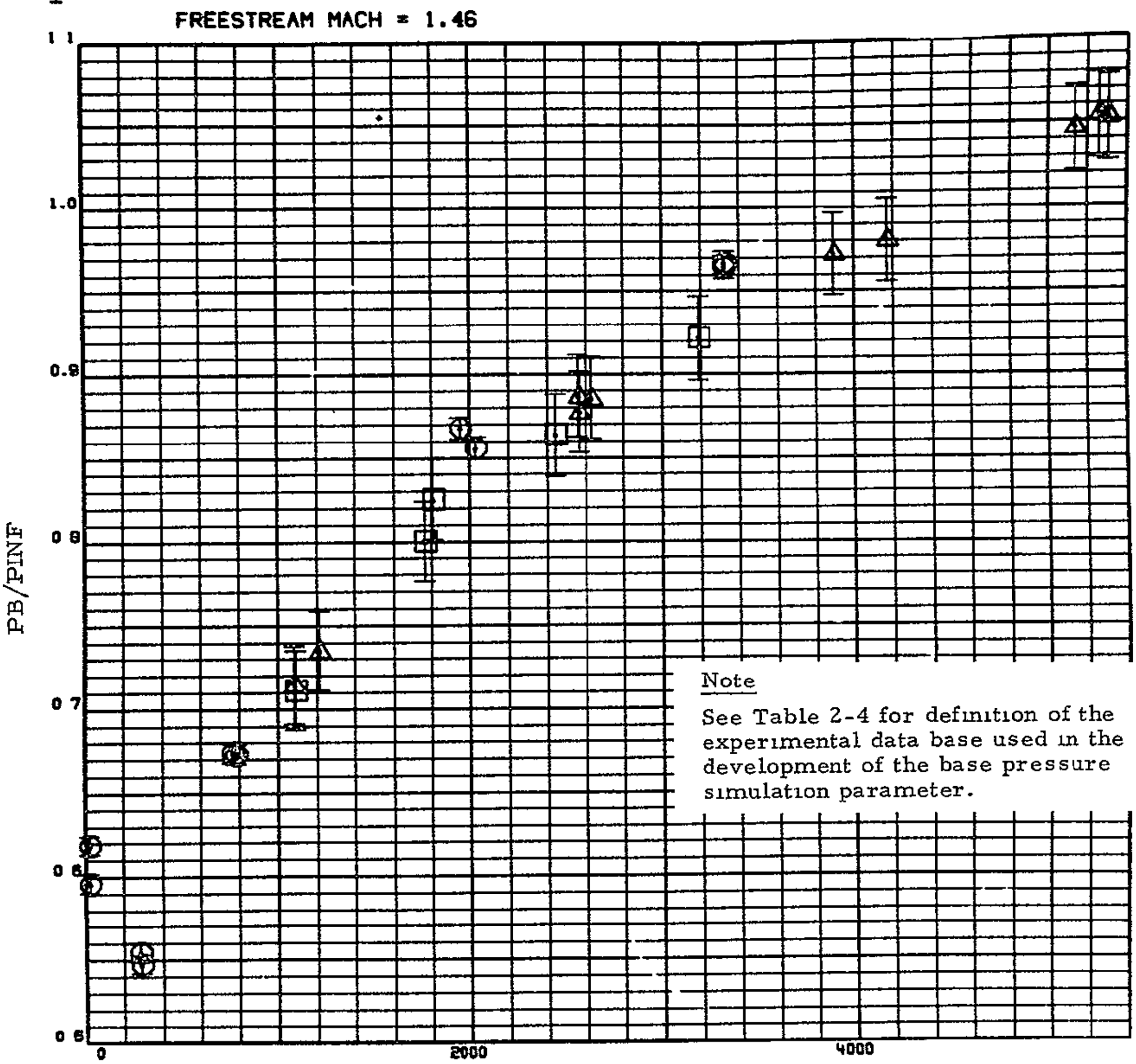


Fig 4-9 - Correlation of the MA10F and FA11 Triple Nozzle Configuration Experimental Data Base (Freestream Mach Number = 1.2)

Symbol	Nozzle Identification
□	Nozzle 5B – CF4, $A/A^* = 8.291$, Theta = 15 03, M = 1.46, MA10F
△	Nozzle 6A – Air, $A/A^* = 4\ 040$, Theta = 24 62, M = 1 46, MA10F
○	Nozzle 8A – Air, $A/A^* = 4\ 060$, Theta = 10 12, M = 1.46, FA11
I	Uncertainty of Test Data



$$\frac{\text{Momentum})_e}{\text{Momentum})_\infty} \approx \frac{M_J \delta_J}{\gamma_J}$$

Fig 4-10 - Correlation of the MA10F and FA11 Triple Nozzle Configuration Experimental Data Base (Freestream Mach Number = 1 46)

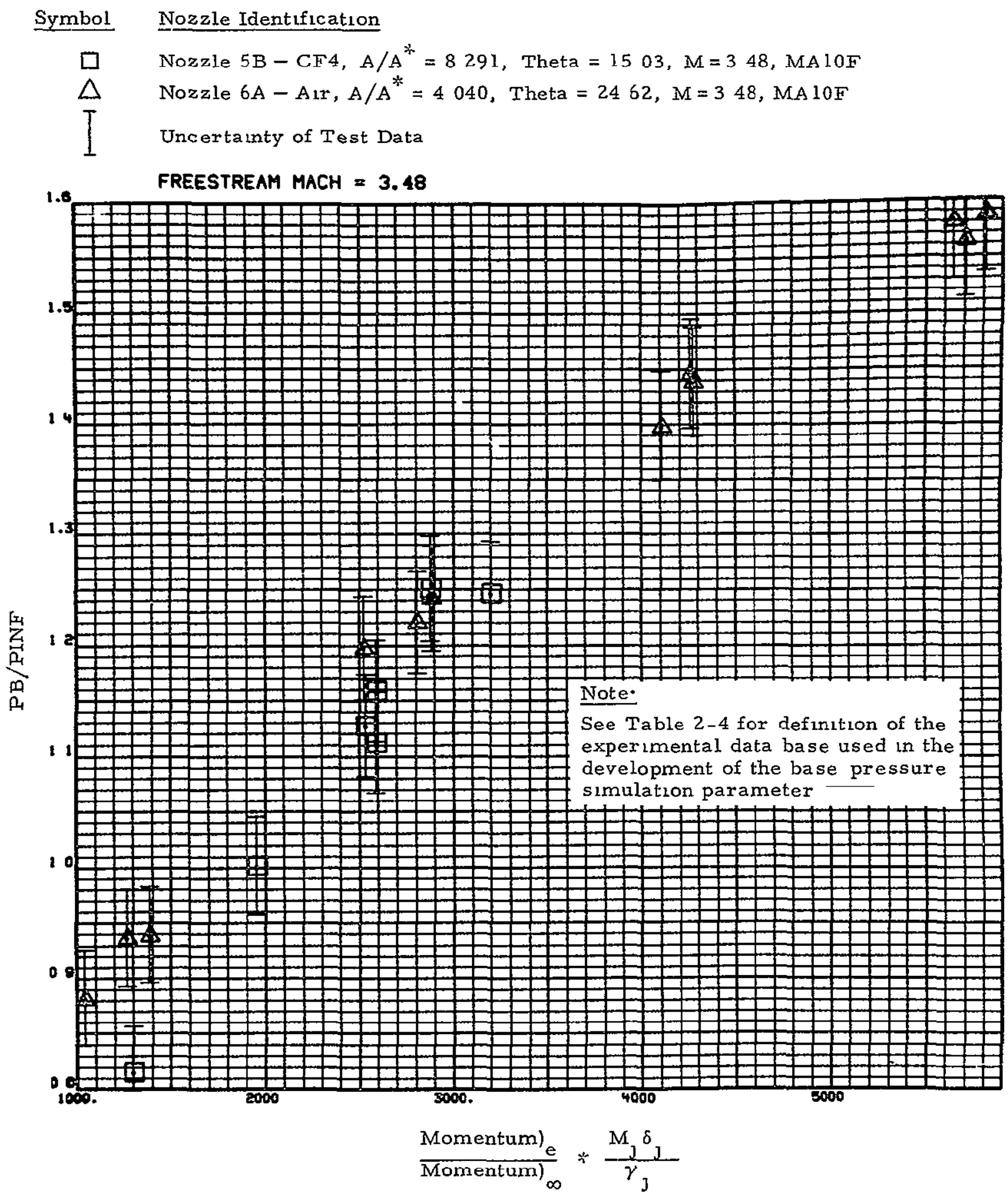
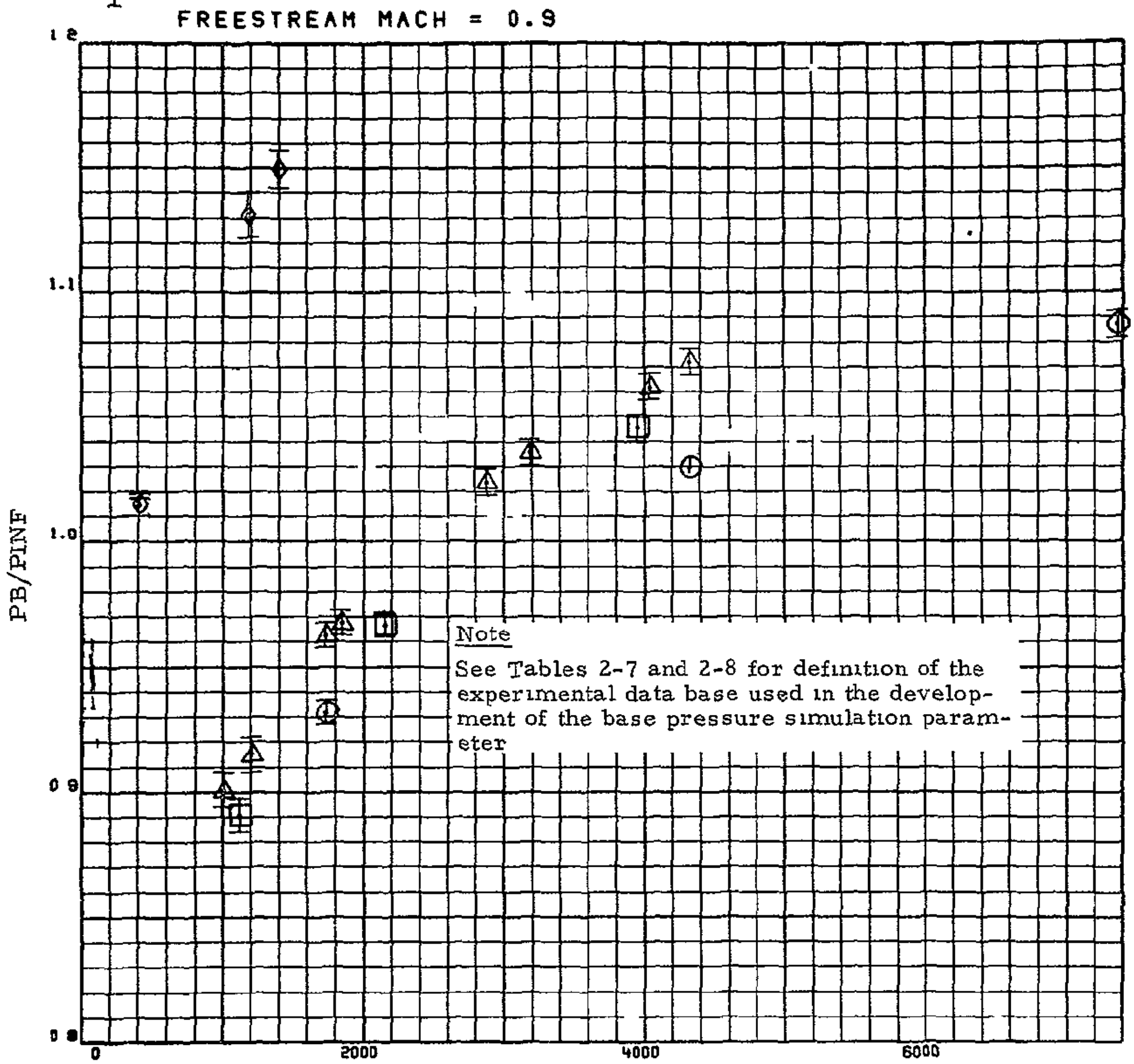


Fig 4-11 - Correlation of the MA10F and FA11 Triple Nozzle Configuration Experimental Data Base (Freestream Mach Number = 3 48)

Symbol	Nozzle Identification
□	FA20 Nozzle CF4 A/A^* = 8.011, Theta = 14 9 (Left Motor), M = 9
△	FA20 Nozzle Air A/A^* = 8.091, Theta = 35 0 (Left Motor), M = 9
○	FA20 Nozzle Air A/A^* = 4 918, Theta = 25.2 (Left Motor), M = 9
◇	Nozzle 3-LPC-580C, A/A^* = 3 087, Theta = 20 23, M = 9 (See text for discussion)
I	Uncertainty of Test Data



$$\frac{\text{Momentum})_e}{\text{Momentum})_\infty} * \frac{M_j \delta_j}{\gamma_j}$$

Fig 4-12 - Correlation of the FA20 and FA23 (Two-Phase) Triple Body Configuration Experimental Data Base (Base pressure measured on left motor Freestream Mach number = 0 9)

Symbol	Nozzle Identification
□	FA20 Nozzle CF4 A/A^* = 8 011, Theta = 14 9 (Left Motor), M = 9
△	FA20 Nozzle Air A/A^* = 8.091, Theta = 35 0 (Left Motor), M = 9
○	FA20 Nozzle Air A/A^* = 4.918, Theta = 25 2 (Left Motor), M = 9
◇	Nozzle 3-LPC-580C, A/A^* = 3.087, Theta = 20 23, M = 9 (See text for discussion)
I	Uncertainty of Test Data

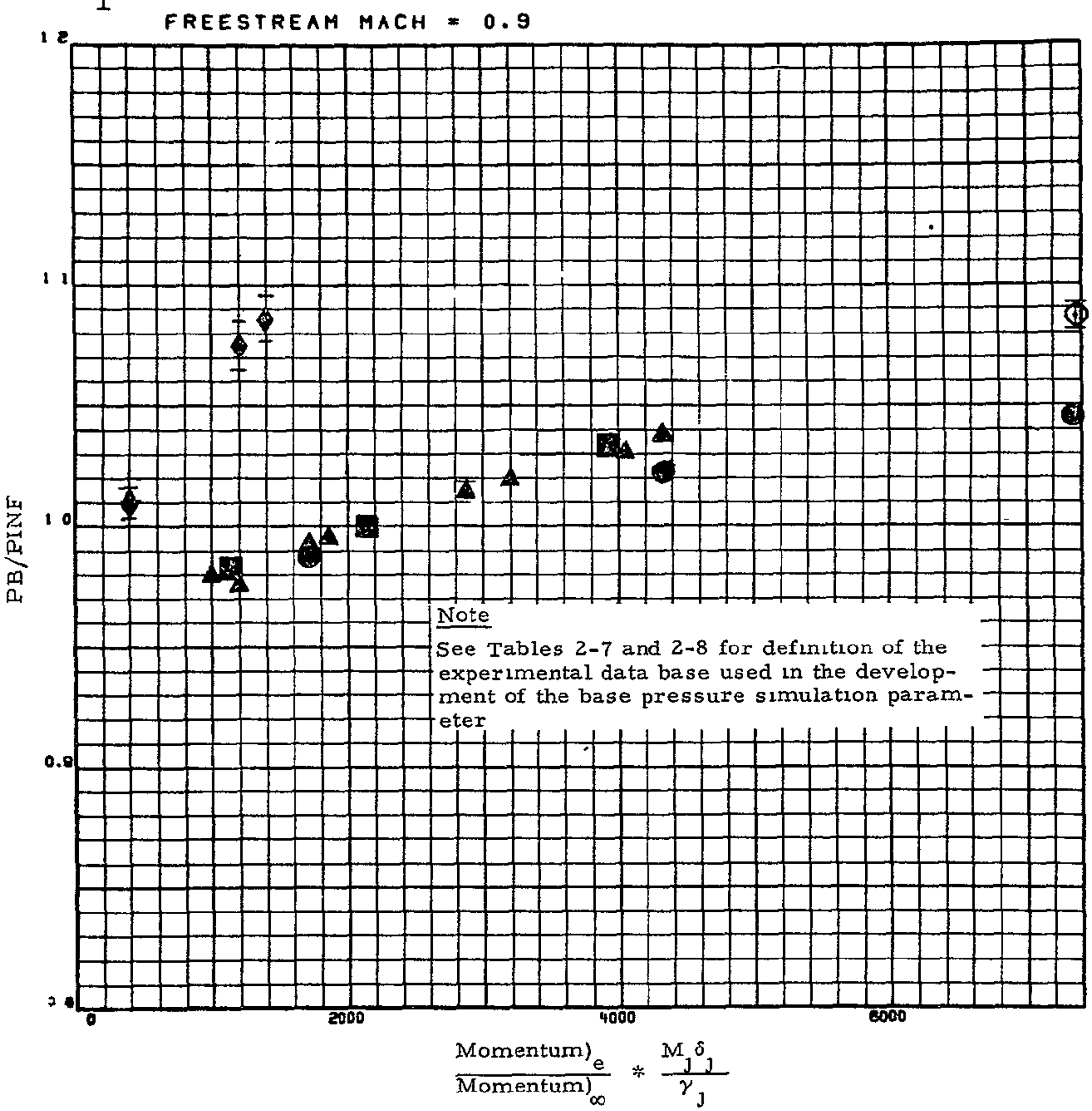
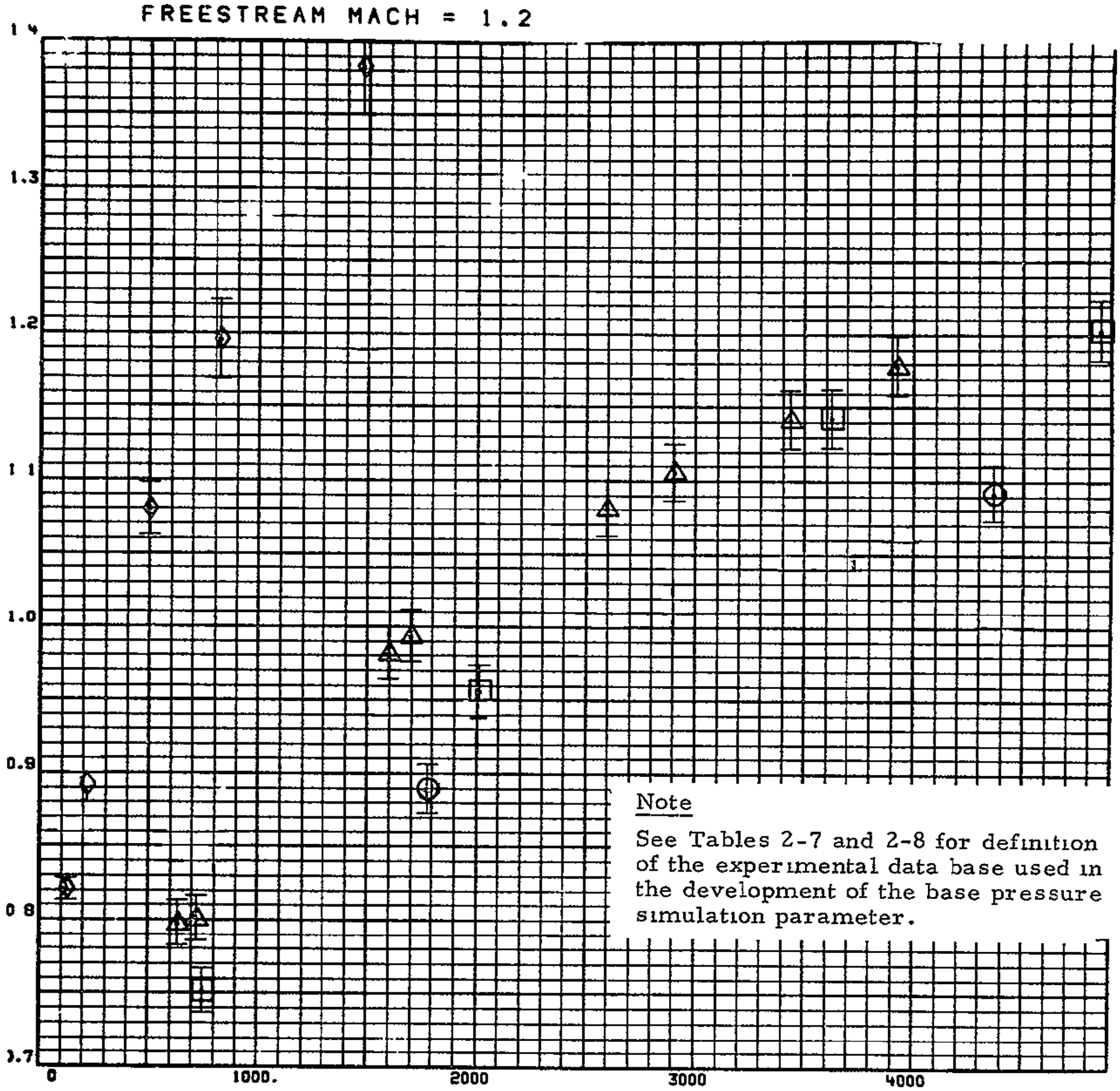


Fig 4-12a - Correlation of the FA20 and FA23 (Two-Phase) Triple Body Configuration Experimental Data Base (Base pressure measured on external tank Freestream Mach Number = 0 9)

Symbol	Nozzle Identification
□	FA20 Nozzle CF4 A/A^* = 8 011, Theta = 14 9 (Left Motor), M = 1 2
△	FA20 Nozzle Air A/A^* = 8 091, Theta = 35.0 (Left Motor), M = 1.2.
○	FA20 Nozzle Air A/A^* = 4 918, Theta = 25 2 (Left Motor), M = 1 2
◇	Nozzle 3-LPC-580C, A/A^* = 3 087, Theta = 20 23, M = 1 2 (See text for discussion)
I	Uncertainty of Test Data



$$\frac{\text{Momentum})_e}{\text{Momentum})_\infty} * \frac{M_j \delta_j}{\gamma_j}$$

Fig 4-13 - Correlation of the FA 20 and FA 23 (Two Phase) Triple Body Configuration Experimental Data Base (Base pressure measured on left motor. Freestream Mach number = 1 2)

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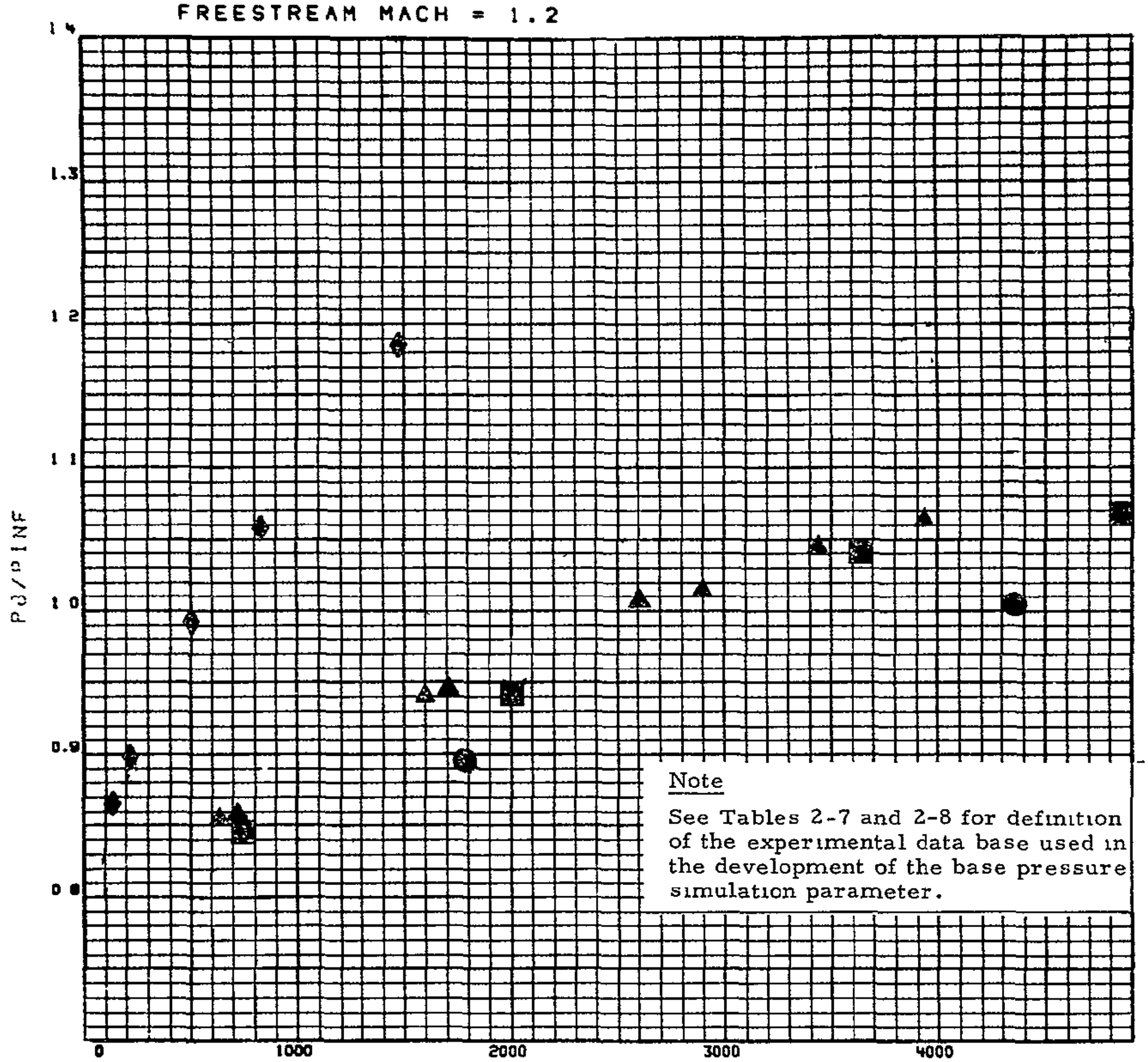
Symbol	Nozzle Identification
□	FA20 Nozzle CF4 A/A^* = 8 011, Theta = 14 9 (Left Motor), M = 1 2
△	FA20 Nozzle Air A/A^* = 8 091, Theta = 35 0 (Left Motor), M = 1 2
○	FA20 Nozzle Air A/A = 4.918, Theta = 25.2 (Left Motor), M = 1 2
◇	Nozzle 3-LPC-580C, A/A^* = 3.087, Theta = 20 23, M = 1 2 (See text for discussion)
I	Uncertainty of Test Data



$$\frac{\text{Momentum})_e}{\text{Momentum})_\infty} * \frac{M_j \delta_j}{\gamma_j}$$

Fig 4-13a - Correlation of the FA 20 and FA 23 (Two-Phase) Triple Body Configuration Experimental Data Base (Base pressure measured on external tank Freestream Mach number = 1 2)

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5 EXTENSION OF THE EXPERIMENTAL DATA BASE BY ANALYTICAL MEANS

During the analysis of the experimental data it was recognized that the limited data base may not be adequate to determine a complete similarity parameter. As a result of this realization, a fast, economical means of supplementing the data base was sought This resulted in acquisition and use of a computer program (described in Refs. 5-1 and 5-2) for the calculation of supersonic power-on base pressure This computer program is an adaptation of the Korst component method to axisymmetric bodies of revolution and is applicable only to cases where both the external stream and nozzle flow fields are always supersonic Furthermore, the program has limited capability where either stream has a low supersonic Mach number since the wake recompression tends to cause the flow to go subsonic which then causes the computer program to stop

One of the major improvements of this computer program over earlier component type programs is the use of an empirical recompression factor to define the overall pressure ratio across the wake recompression zone. This recompression factor has been established by a correlation of experimental data The results of the study which determined this criteria are published in Ref 5-3 An exhaustive comparison of experimental data and calculations from the computer program has been published in Ref 5-4 These two references show that experimental to predicted base pressure differences vary somewhat randomly and appear to be caused by: (1) lack of definition of experimental conditions, (2) measurement accuracy, and (3) inapplicability of the program to the real gas flow fields found in hot firing data However, this experience has shown that general trends and the functional dependence of base pressure upon the governing variables can be predicted by the flow model in this computer code Therefore, it was decided that this computer code could be used to provide a supplementary data base to the experimental data base

Initially, an attempt was made to run cases at a freestream Mach number of 1 46 to compare with and supplement the MA 10F experimental data base at this Mach number Very few of these cases could be computed because the wake recompression caused the external stream to go subsonic which stopped the calculation The cases that did run produced base pressure ratios that agreed very well with the experimental data. On this basis data were computed for nozzles 2 and 4 over the range of base pressure ratios from 0 4 to 1 1 This analytical data at a Mach number of 2 0 correlated in the same manner as the experimental data at a Mach number of 1 46 using the initial plume angle as the similarity parameter Since the program generated self-consistent results for the two nozzles with completely different physical characteristics, it should generate self-consistent results for parametric families of nozzles.

On this basis, parametric nozzle variations of single nozzle variables were devised using the three experimental nozzles as a base for the variation For example, a family of nozzles was formed around nozzle 2 with the conical wall angle varying from 15 to 35 degrees while holding all other parameters constant This is physically possible since for conical nozzles the wall angle effect on the two-dimensional flow effects may be offset by small changes in nozzle area ratio while holding the exit diameter constant In an analogous manner, calculations were performed to demonstrate the effect of the other nozzle flow parameters on the variation of the base pressure

It should be noted that the computer code could not reproduce any of the single nozzle test results (MA 10F) at M = 3.48 However, it was concluded that the M = 2.0 results were acceptable for evaluation of trends since the empirical recompression factor had been defined using test data obtained in the range of M = 2 0

Once an analytical data base had been established, the base pressure similarity parameter recommended for a single nozzle configuration was applied Figures 5-1 through 5-5 present the resultant base pressure similarity parameter plots It is immediately obvious that the data base does not correlate to any degree of satisfaction This further emphasizes the importance of the limitations placed upon the similarity parameters in Section 4 3

Further investigation was conducted to determine why the analytical base pressure data did not correlate It was found that the recommended single nozzle correlation parameter will correlate base pressure data for a set of nozzles whose operating range produce corresponding equal M_j and δ_j at fixed P_B/P_∞ pressure ratios This is shown in Fig. 5-6. The basic conclusion is that the recommended similarity parameters are not universally applicable

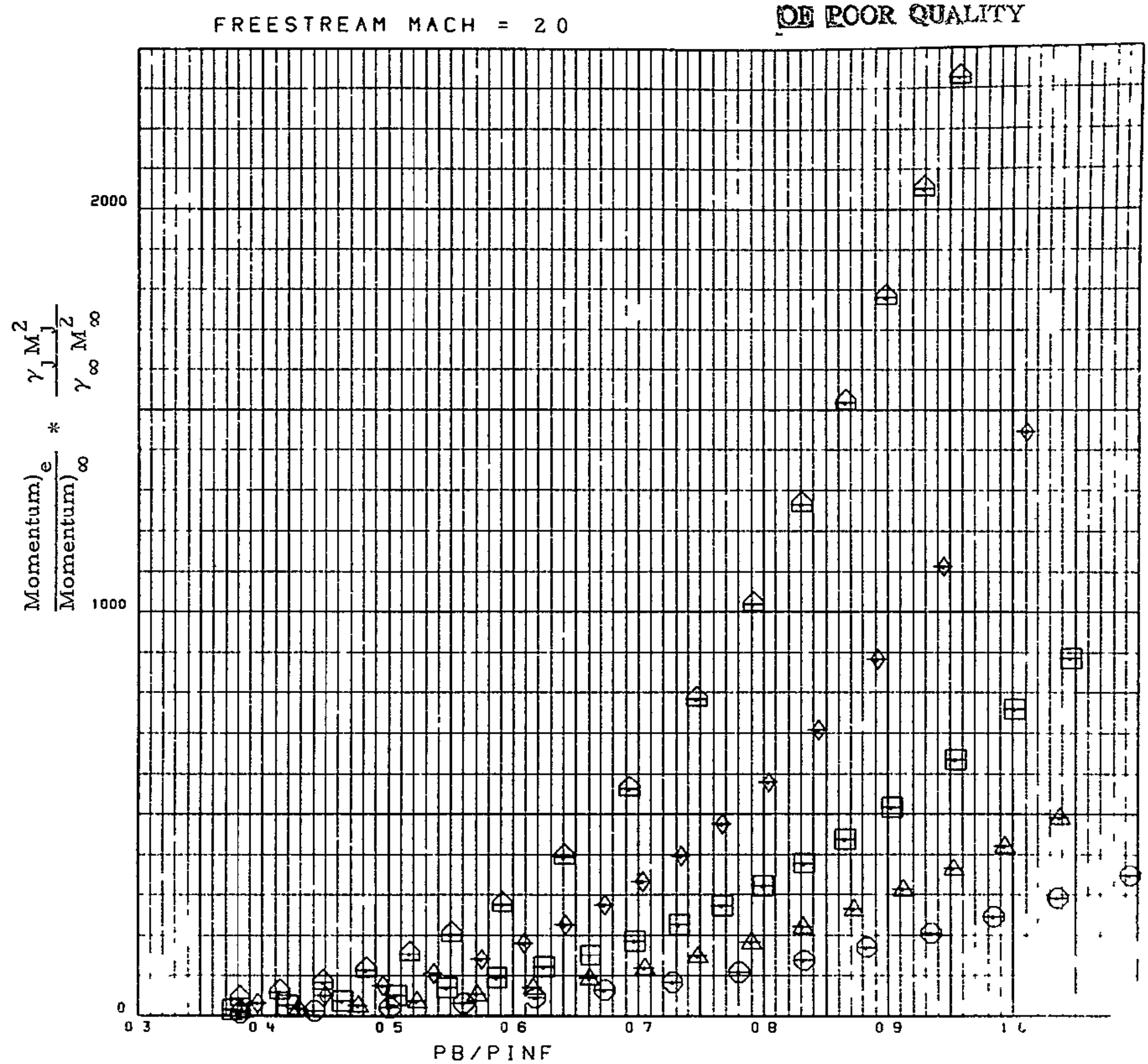

Fig 5-1 - Correlation of MA 10F Nozzle 1 Analytical Data for a Family of Nozzles with Different Wall Angles

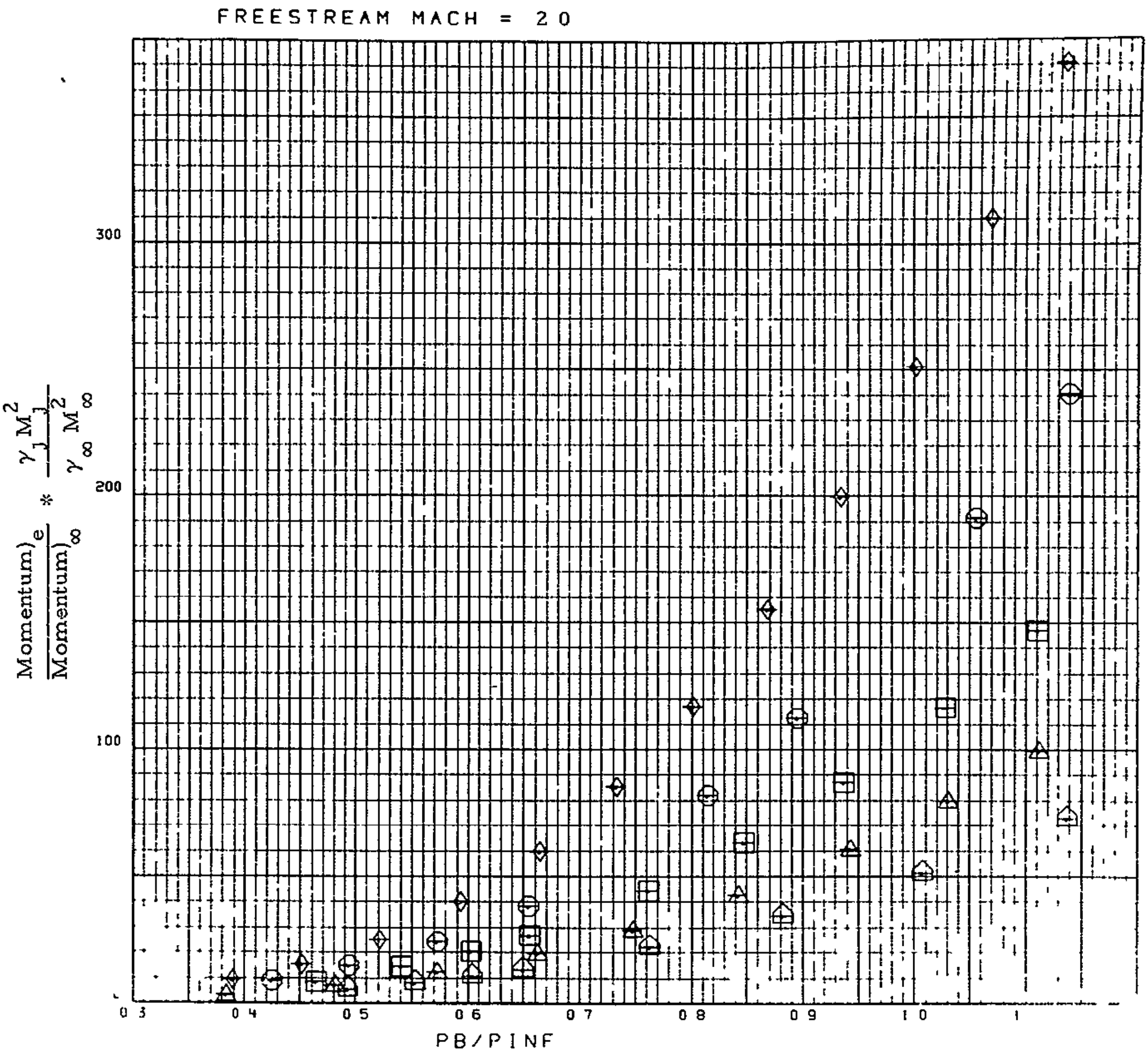

Fig 5-2 - Correlation of MA 10F Nozzle 2 Analytical Data for a Family of Nozzles with Different Wall Angles

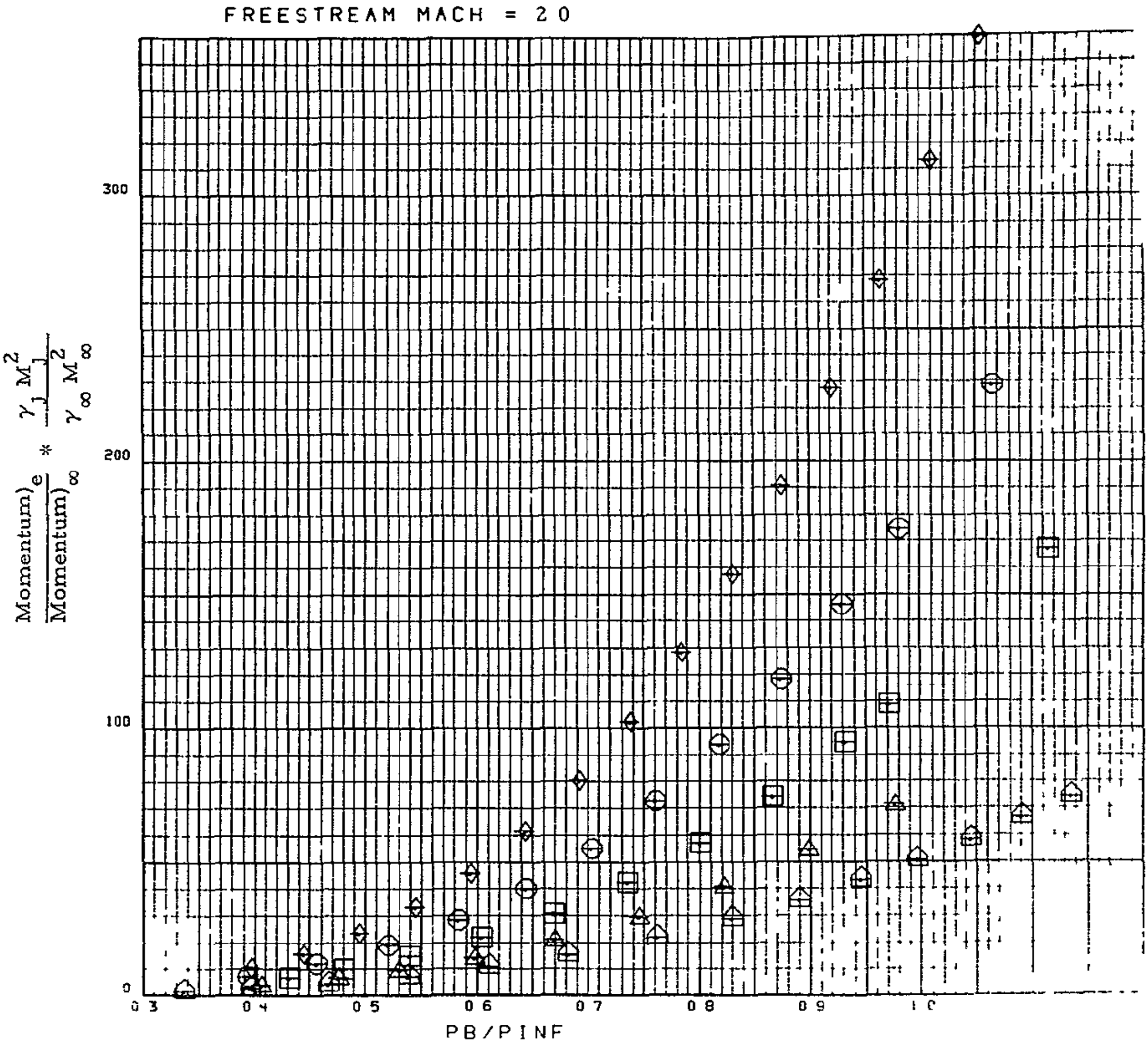

Fig. 5-3 - Correlation of MA 10F Nozzle 4X Analytical Data for a Family of Nozzles with Different Wall Angles

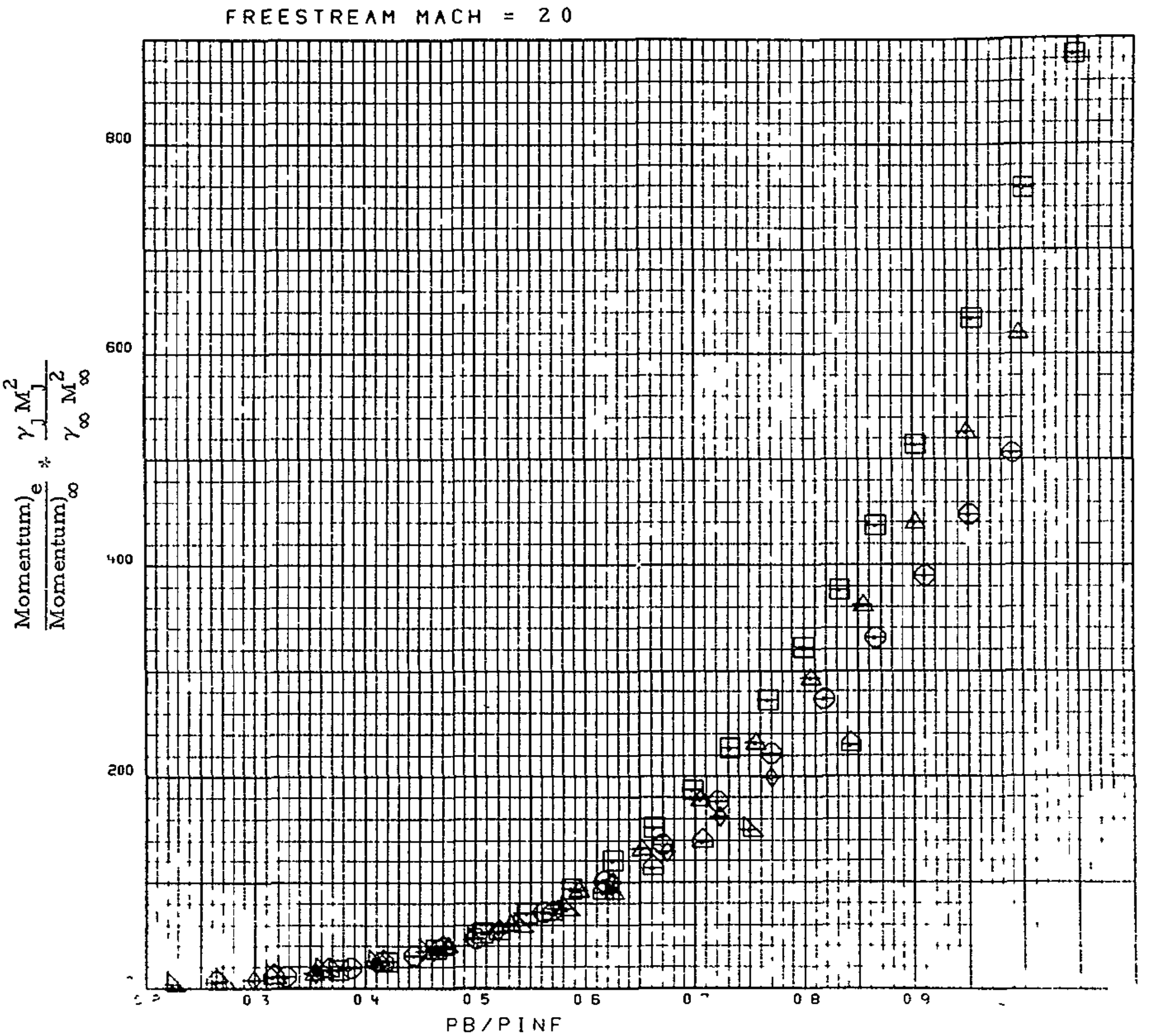

Fig 5-4 - Correlation of MA 10F Nozzle 1 Analytical Data for a Family of Nozzles with a Constant Exit Mach Number and Variable γ Exhaust Gas

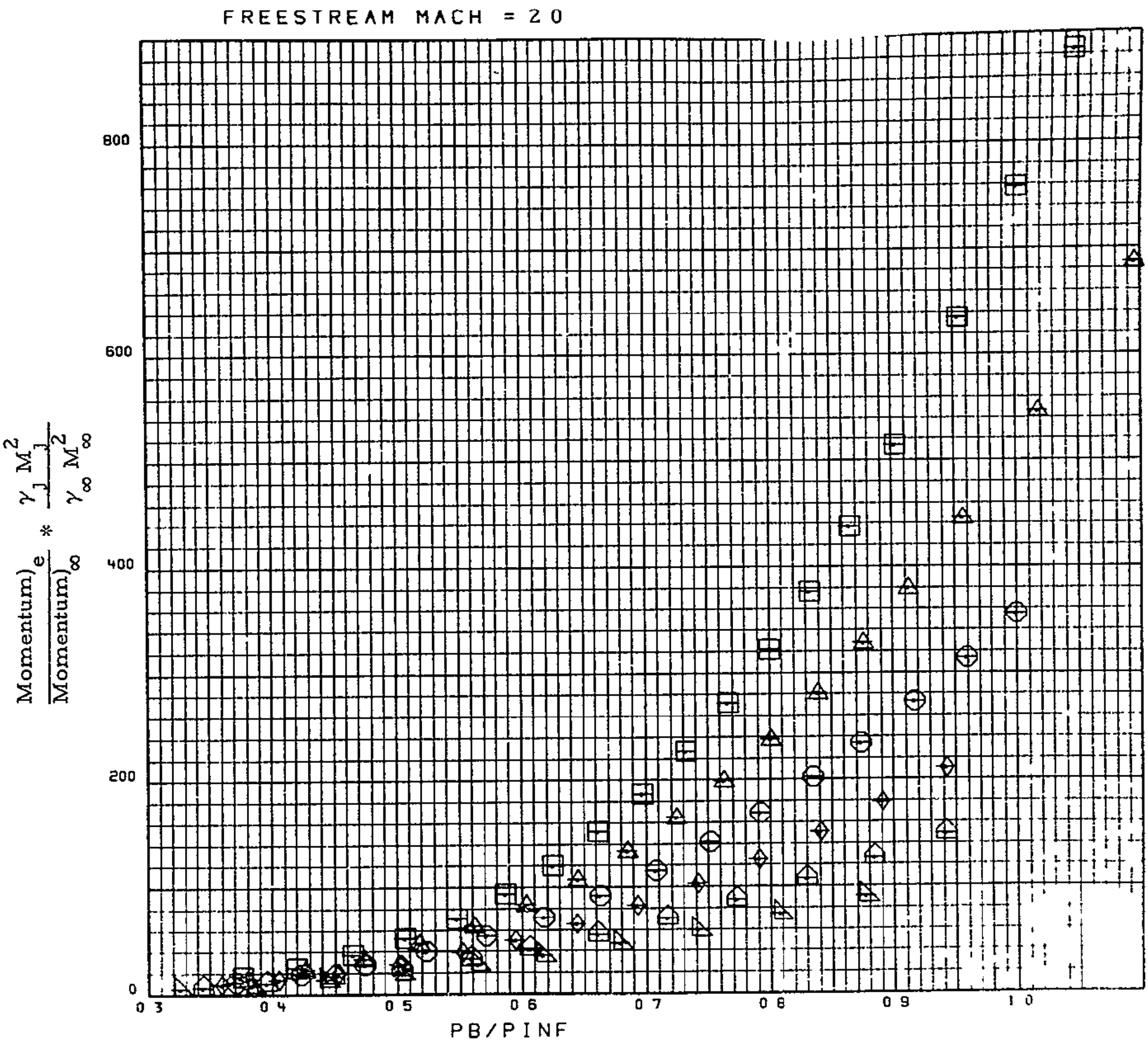

Fig 5-5 - Correlation of MA 10F Nozzle 1 Analytical Data for a Family of Nozzles with a Constant Area Ratio and Variable γ Exhaust Gas

Symbol	Nozzle Identification
□	Nozzle 1 – M_j and δ_j do not correlate data
△	Nozzle 2 – M_j and δ_j correlate data by themselves
○	Nozzle 4

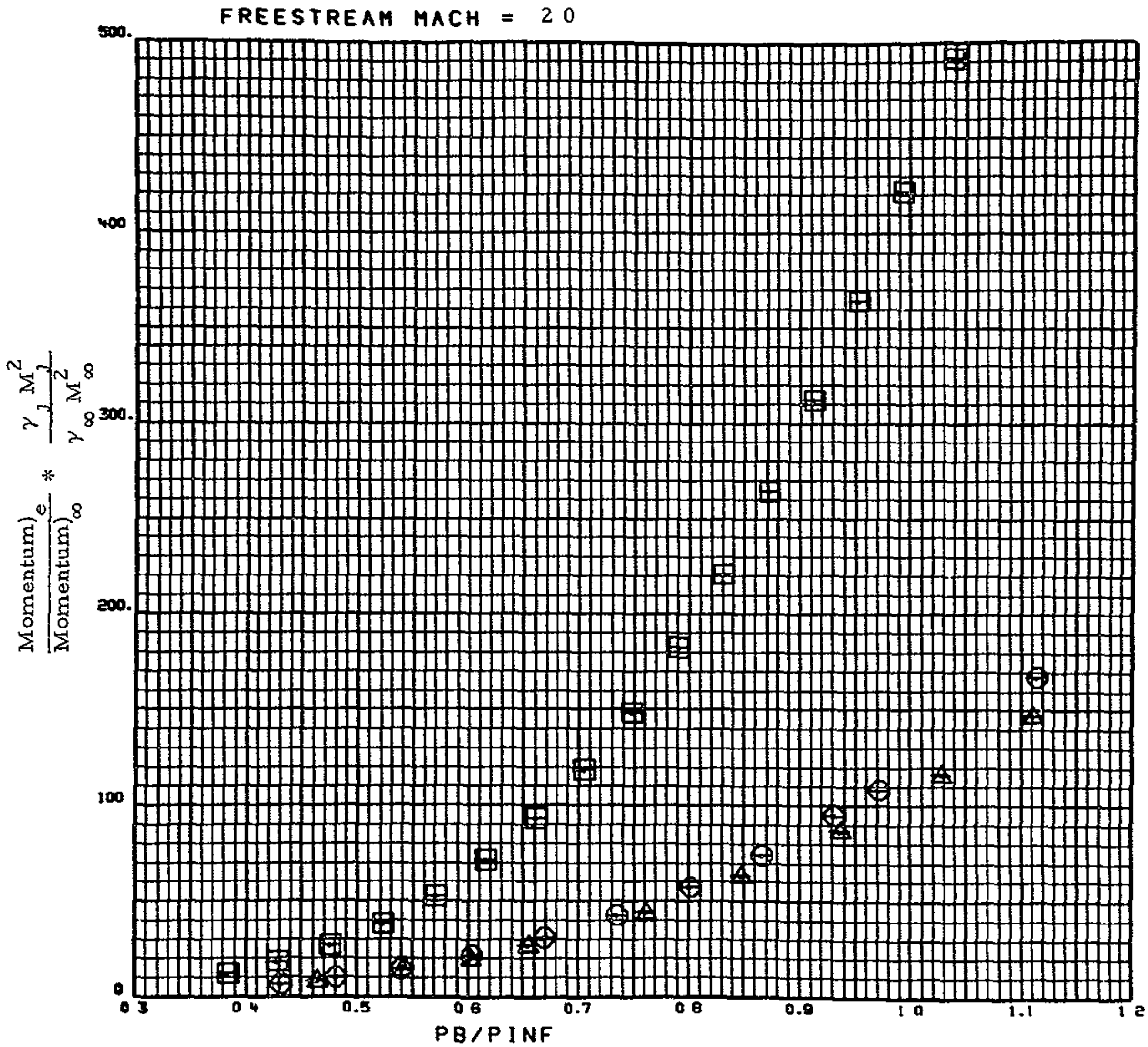

Fig 5-6 - Correlation of MA 10F Nozzle 1 (θ_{lip} = 20 deg), 2 and 4X Analytical Data

6 APPLICATION OF THE BASE PRESSURE SIMILARITY PARAMETERS TO SPACE SHUTTLE LAUNCH VEHICLE POWER-ON AERODYNAMIC TESTING

This document has presented the development of a set of base pressure similarity parameters to be used for Space Shuttle development wind tunnel tests This section presents the procedure to be followed using these parameters in the development of the plume simulation wind tunnel tests (the procedure presented was taken in part from Ref 2-4)

The similarity parameters recommended are:

Single Nozzle Configuration

$$\left(\frac{\text{Momentum})_e}{\text{Momentum})_\infty} * \frac{\gamma_J M_J^2}{\gamma_\infty M_\infty^2}\right)_{\text{model}} = \left(\frac{\text{Momentum})_e}{\text{Momentum})_\infty} * \frac{\gamma_J M_J^2}{\gamma_J M_\infty^2}\right)_{\text{prototype}}$$

Triple Nozzle and Triple Body Configuration

$$\left(\frac{\text{Momentum})_e}{\text{Momentum})_\infty} * \frac{M_J \delta_J}{\gamma_J}\right)_{\text{model}} = \left(\frac{\text{Momentum})_e}{\text{Momentum})_\infty} * \frac{M_J \delta_J}{\gamma_J}\right)_{\text{prototype}}$$

Neither of these parameters allow an explicit determination of the base pressure (PB) and therefore, an implicit procedure was developed as follows Figure 6-1 shows a typical simulation plot The illustrated curve of possible prototype base pressure ratio as a function of simulation parameter can be computed knowing prototype engine characteristics by use of a nozzle flow analysis (i e , Ref 3-1 or 3-3) for a range of base pressures that might be expected This curve is established for a given trajectory at a set of M_∞, P_∞, and engine thrust level values Then a wind tunnel test is conducted at the trajectory M_∞ while measurements are obtained at varying PC levels (PC directly varies similarity parameter and correspondingly PB) The experimental PC levels are chosen to cause similarity parameter$)_{model}$ values to fall within the prototype range of interest In the data analysis stage the model PB/PINF vs similarity parameter$)_{model}$ is plotted on the same graph with the prototype possibility curve The intersection of these two curves is the condition which simultaneously satisfies both the prototype possibilities and the model actualities, and thus similarity parameter$)_{model}$ = similarity parameter$)_{prototype}$ for the given conditions.

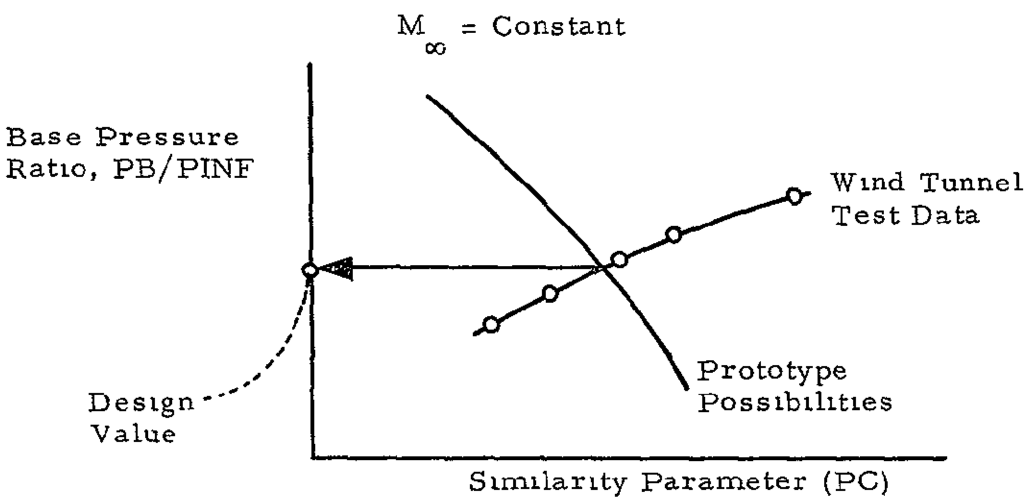

Fig 6-1 - Basic Simulation Procedure

7 CONCLUSIONS

Two base pressure similarity parameters have been recommended which will correlate base pressure on a single nozzle configuration, and a triple nozzle configuration (also applicable to a triple body configuration) The two recommended similarity parameters differ slightly for the single and triple nozzle configurations However, the similarity parameter for each configuration was found to be a strong function of nozzle exit and freestream momentum

The data base obtained during the various tests of the Plume Technology Program were for configurations and exhaust plumes (gaseous only and two phase) similar to the Space Shuttle vehicle The data base was limited and resulted in a range of values for the recommended similarity parameters for the single nozzle, triple nozzle and triple body configurations The similarity parameters may be applied to Space Shuttle design and development tests when the actual value of the similarity parameter lies within the bounds of the data base values Careful examination should be made of the similarity parameters for configurations other than tested in the Plume Technology test program or when the value of the similarity parameter falls beyond the limits of the data base

The experimental data base for gaseous only testing was quite extensive However, due to various problems that arose during testing, the useful two-phase data base was limited There is no data base utilizing two-phase flow for a triple body configuration However, based upon the good correlation achieved with the single nozzle data there is no reason to believe that the triple body data would not correlate as well, had a two-phase triple body data base existed

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1-2 Stephens, John T , "Scaling Parameters for the Simulation of Highly Expanded Rocket Exhaust Plumes and the Resultant Impingement Forces on an Immersed Body," LMSC-HREC D162424, Lockheed Missiles & Space Company, Huntsville, Ala., July 1970.

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Appendix A

METHOD FOR DETERMINING THE ABSOLUTE UNCERTAINTY OF A COMPUTED VALUE THAT IS A FUNCTION OF TWO MEASURED VALUES

Appendix A

To determine the absolute uncertainty of a computed value that is a function of two measured values, the following procedure is followed.

Let z = the computed value

and z = f(x, y) where x and y are the measured values

$$dz = \frac{\partial f}{\partial x} dx + \frac{\partial f}{\partial y} dy$$

for our case z = x/y

$$\frac{\partial f}{\partial x} = \frac{1}{y}, \quad \frac{\partial f}{\partial y} = \frac{-x}{y^2}$$

$$\therefore \quad dz = \frac{1}{y} dx - \frac{x}{y^2} dy$$

or

$$\left.\delta z = \frac{1}{y} \delta x - \frac{x}{y^2} \delta y \right\} \quad \text{absolute uncertainty}$$

the values of x and y are the measured values

The maximum value of δz is obtained by using the negative value of δy
Example calculation for our work

MA 10F   Nozzle 1   Run 505

Let: $x = PC$; $y = PW$

$\delta x = 18.75$ $\delta y = 227$

$$\delta z)_{\text{downstream tap}} = \left[\frac{1}{236\ 68}\right] * 18\ 75 + \left[\frac{1938}{236.68^2}\right] * .227$$

where:

δx and δy are obtained from Table 2-2.