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PRESSURE TEST ON A 0.04-SCALE MODEL OF
THE SATURN V LAUNCH VEHICLE AT
MACH NUMBERS FROM 1.80 THROUGH 3.00

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ARO, Inc.

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*Per A.F. Letter
dtg 26 April 72,
Signed by William
O. Cole*

FOREWORD

The work reported herein was done at the request of the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC), under System 921E.

The results of the test presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The test was conducted from March 16 through 21, 1967, under ARO Project No. PT1660, and the manuscript was submitted for publication on May 16, 1967.

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This technical report has been reviewed and is approved.

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Director of Test

ABSTRACT

In conjunction with an earlier transonic test, a 0.04-scale model of the Saturn V launch vehicle was tested at Mach numbers from 1.80 to 3.00 for Reynolds number based on model diameter varying from 1.59 to 2.77 million. Static pressure distributions and boundary-layer profiles were measured and are presented herein. Unsteady pressures were also measured, but these results are not presented.

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NOMENCLATURE

A	Model reference area, $\frac{\pi D^2}{4}$, 1.368 ft ²
C _p	Local pressure coefficient, $\frac{p - p_\infty}{q_\infty}$
D	Model reference diameter, 1.320 ft
L	Model length, 13.819 ft
M _L	Local Mach number as computed for each boundary-layer probe
M _∞	Free-stream Mach number
p	Local static pressure, psf
p _{t∞}	Free-stream total pressure, psf
p _∞	Free-stream static pressure, psf
q _∞	Free-stream dynamic pressure, psf
Re/ft	Reynolds number per foot, V_∞/ν_∞
V _∞	Free-stream velocity, ft/sec
x	Model station aft of LES rocket nose, ft (Fig. 3)
y	Vertical distance above model surface, in.
α	Angle of attack, deg
ν _∞	Free-stream kinematic viscosity, ft ² /sec
φ	Roll angle, deg
ψ	Angle of model orifice meridian (Fig. 3), deg

MODEL NOMENCLATURE

APU	Auxiliary propulsion unit
LM	Lunar module
LES	Launch escape system
S-IC	Saturn-IC (first stage)
S-II	Saturn-II (second stage)
S-IVB	Saturn-IVB (third stage)

SECTION I INTRODUCTION

A 0.04-scale model of the Saturn V launch vehicle, previously tested in the 16-ft Propulsion Wind Tunnel, Transonic (16T) (Ref. 1), was tested at supersonic speeds to determine the fluctuating pressure environment, static pressure distribution, and boundary-layer profiles over the model length. Protuberance effects on local static pressures were also determined.

Four model configurations were tested in the Propulsion Wind Tunnel, Supersonic (16S). The basic configurations were the model with all protuberances (configuration 1) and the model with all protuberances removed (configuration 2). Both configurations were tested at angles of attack from -4 to +4 deg and roll angles of 0 and 60 deg for Mach numbers from 1.80 through 3.00. In addition, configuration 1 was tested at angles of attack of -6 and +6 deg for selected Mach numbers. Two additional configurations consisting of two minor protuberance changes were also tested. These protuberance changes did not significantly affect the data presented in this report; consequently, these configurations are not distinguished from the basic configurations.

SECTION II APPARATUS

2.1 WIND TUNNEL

The Propulsion Wind Tunnel, Supersonic (16S) is a variable density tunnel which has a 16-ft-square test section. At present the Mach number range is from 1.7 to 3.1. A more thorough description of the tunnel may be found in Ref. 2, and calibration results are presented in Refs. 3 and 4.

A schematic of configuration 1 installed in the 16S test section is presented in Fig. 1.

2.2 TEST ARTICLE

A photograph of the model with all protuberances (configuration 1) as installed in the 16S test section is shown in Fig. 2. Both configurations were identical to those tested in 16T, and the configuration nomenclature and identification are the same.

Configuration 1 was the first of two basic configurations tested. This configuration was tested with all protuberances to determine their effect on the steady and fluctuating pressures in their vicinity. Configuration 2 had all the external protuberances removed and provided an aerodynamically clean model for a comparison. In this report, all external elements protruding beyond the radius of the model surface are considered to be protuberances. The Launch Escape System (LES) rocket and escape tower were common to both configurations. The details of both configurations are presented in Fig. 3.

Two additional configurations having minor protuberance modifications in the region of the unsteady pressure sensors (microphones) were tested. The modifications were found to have insignificant effects on the steady pressures presented in this report.

Five retractable boundary-layer rakes were used on both models and were extended individually by remote control. The rakes pivoted about axes within the model and were designed to present a flush model surface in the extended or retracted position. The rakes were located longitudinally along the 130-deg meridian of the model (Fig. 3). Details of the boundary-layer rakes showing their model stations and probe ordinates are presented in Fig. 4.

2.3 INSTRUMENTATION

2.3.1 Steady-State Measurements

Static pressures were measured at 320 orifices, 233 of which were located on the 180-deg meridian (top centerline). Fifty-three orifices located in the S-IVB flare region at meridian angles of 5.62, 19.50, 36.25, and 78.75 deg provided a means of determining the interstage interference as well as protuberance disturbances on local pressures. In the shroud-fin region, 34 additional orifices were located at meridian angles of 22.50, 33.75, and 43.00 deg, and were staggered along the shroud to determine local pressure levels in this area.

Boundary-layer data were obtained from 61 total pressure probes housed in five retractable rakes and a static reference pressure orifice located near each rake longitudinal station.

The 381 pressures from these sources were measured using ten 48-port pneumatic switches having self-contained, differential strain-gage pressure transducers.

2.3.2 Unsteady Measurements

A total of 140 flush-mounted microphones was used to measure the unsteady pressures on the model surface for all test conditions. Five other microphones were mounted inside the model to determine the influence of the model vibrations on the microphone outputs. The output signals from these microphones were conditioned by miniature charge amplifiers mounted within the model in close proximity to the microphones, and recorded on magnetic tape.

Ten accelerometers were also located inside the model to give an indication of the vibration level. The signals from these accelerometers were also recorded on magnetic tape.

Because of the need to monitor the temperature inside the model, the outputs from 12 thermocouples were recorded on strip charts. The temperature inside the model was controlled by means of a cooling nitrogen line exhausting inside the model. The nitrogen was expelled through the model base.

SECTION III TEST DESCRIPTION

3.1 TEST PROCEDURE

The configurations were tested at Mach numbers from 1.80 through 3.00 at total pressures from 1150 to 1550 psf. Plots correlating Reynolds number, total pressure, and dynamic pressure are presented in Fig. 5. At Mach number 1.80, a low stagnation pressure check (700 psf) was made to determine the magnitude of the Reynolds number effects on the static and fluctuating pressures. For all Mach numbers, angle of attack was varied from -4 to +4 deg at roll angles of 0 and 60 deg. In addition, configuration 1 was tested at -6 and +6 deg at selected Mach numbers.

For a given Mach number, the model was pitched through the angle-of-attack range, and dynamic and static data were recorded consecutively at each pitch angle. The model was then rolled, and data were again taken at the new roll angle. Boundary-layer data were also taken at each Mach number, but only with the model at zero roll and zero pitch angles.

3.2 PRECISION OF MEASUREMENTS

The uncertainties in setting and maintaining tunnel conditions are estimated to be as follow:

Mach Number	±0.005
Total Pressure	±5 psf
Total Temperature	±5°F
Angle of Attack	±0.1 deg
Roll Angle	±0.1 deg

The longitudinal variation of Mach number along the tunnel center-line has a maximum value of ±0.02.

SECTION IV RESULTS AND DISCUSSION

4.1 STATIC PRESSURES

Comparisons of the pressure distributions at zero angle of attack for the two basic configurations are shown in Fig. 6. The plots are discontinued at a model station of 8 cal since no appreciable change was experienced beyond this point. The effects of the protuberances were most noticeable for the lower Mach numbers.

A more thorough inspection of singular protuberance effects at $\alpha = 0$ is presented in Figs. 7 and 8. Pressure coefficients in the S-IVB flare region along meridian angles of 5.62, 36.25, and 78.75 deg are presented in Fig. 7. The orifices along meridian angle 5.62 deg are very close to the auxiliary propulsion unit (APU), and these pressures exhibit extensive variations for all Mach numbers on configuration 1. The orifices along meridian angles of 36.25 and 78.75 deg are between protuberances, and the pressure from these sources tend to converge to the values for the clean model with increasing Mach number. On configuration 1, several of the orifices on meridian angle 19.50 deg were covered by a protuberance; therefore, the pressure coefficients for this meridian are omitted. The effects of the aerodynamic shroud on the local pressures are shown in Fig. 8. Here the disturbance is more gradual, and the pressure coefficient levels decrease with Mach number.

4.2 BOUNDARY-LAYER MEASUREMENTS

The Mach number profiles obtained from rakes 1 through 5 are shown in Fig. 9. An unusual feature is shown by rake 5 where the boundary

layer on the smooth model is slightly thicker than on the model with protuberances. Rakes 3 and 4 exhibit occasional protuberance interference, and rake 2 shows a sudden reduction in the Mach number approximately one inch above the model surface. By observing the apparent shock location from Fig. 7 for the clean model, the shock line is seen to pass approximately between the sixth and seventh probes on rake 2, and can be assumed to cause the reaction as observed. Rake 1 appears to be in a region influenced by the separated flow because the LES with a developing laminar sublayer noticeable on the bottom probe.

The effect of the protuberances on the profiles seems to be without noticeable pattern, occasionally causing large variations as on rake 4 at Mach number of 2.00, but mostly producing small changes throughout the Mach number range.

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5. Henson, Victor R. "Static Aerodynamic Characteristics of the Apollo-Saturn V Vehicle." NASA TM X-53307, July 26, 1965.

**APPENDIX
ILLUSTRATIONS**

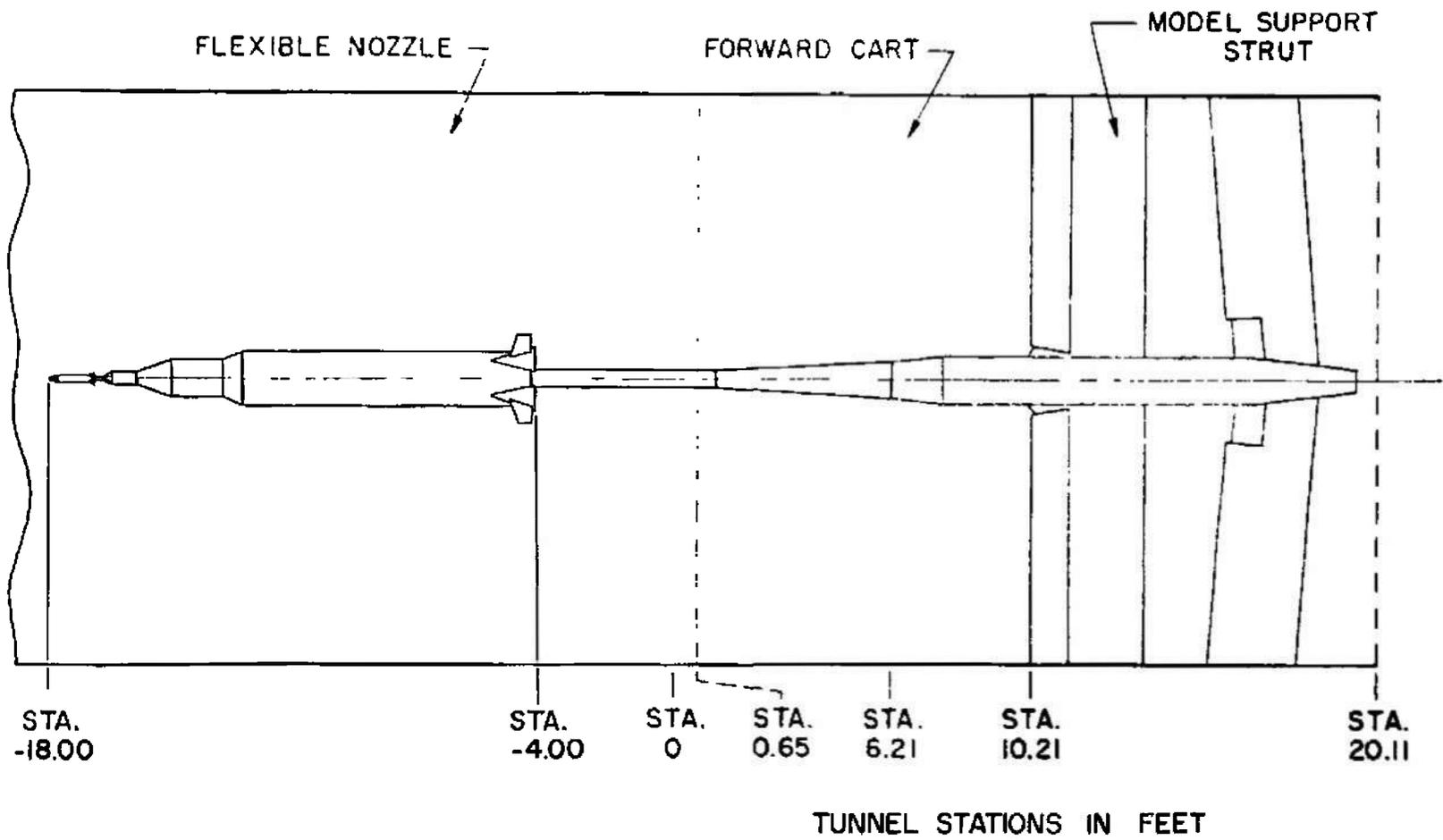


Fig. 1 Schematic of Configuration 1 in Tunnel 16S Test Section

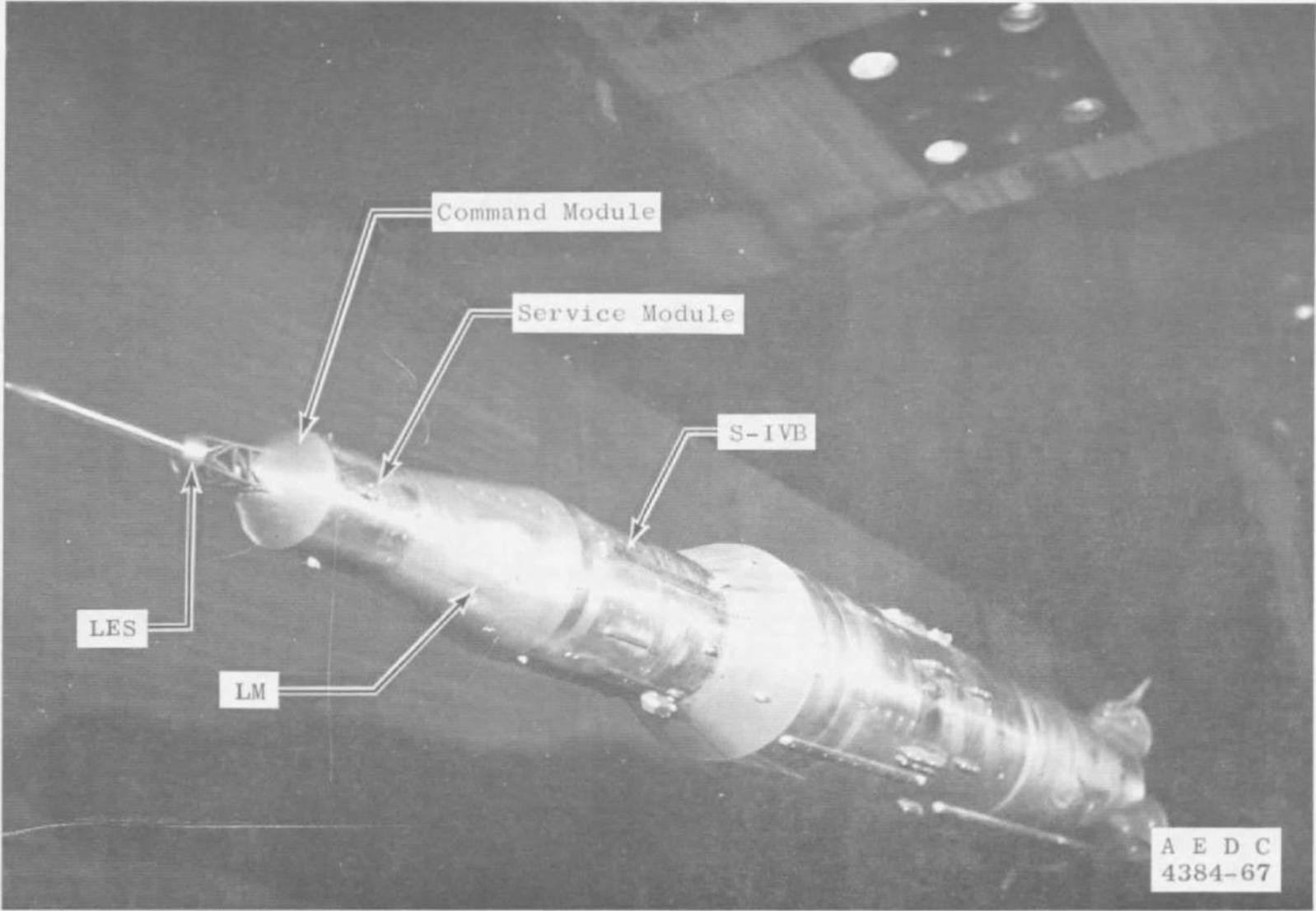


Fig. 2 Installation Photograph of Configuration 1 in Tunnel 16S Test Section

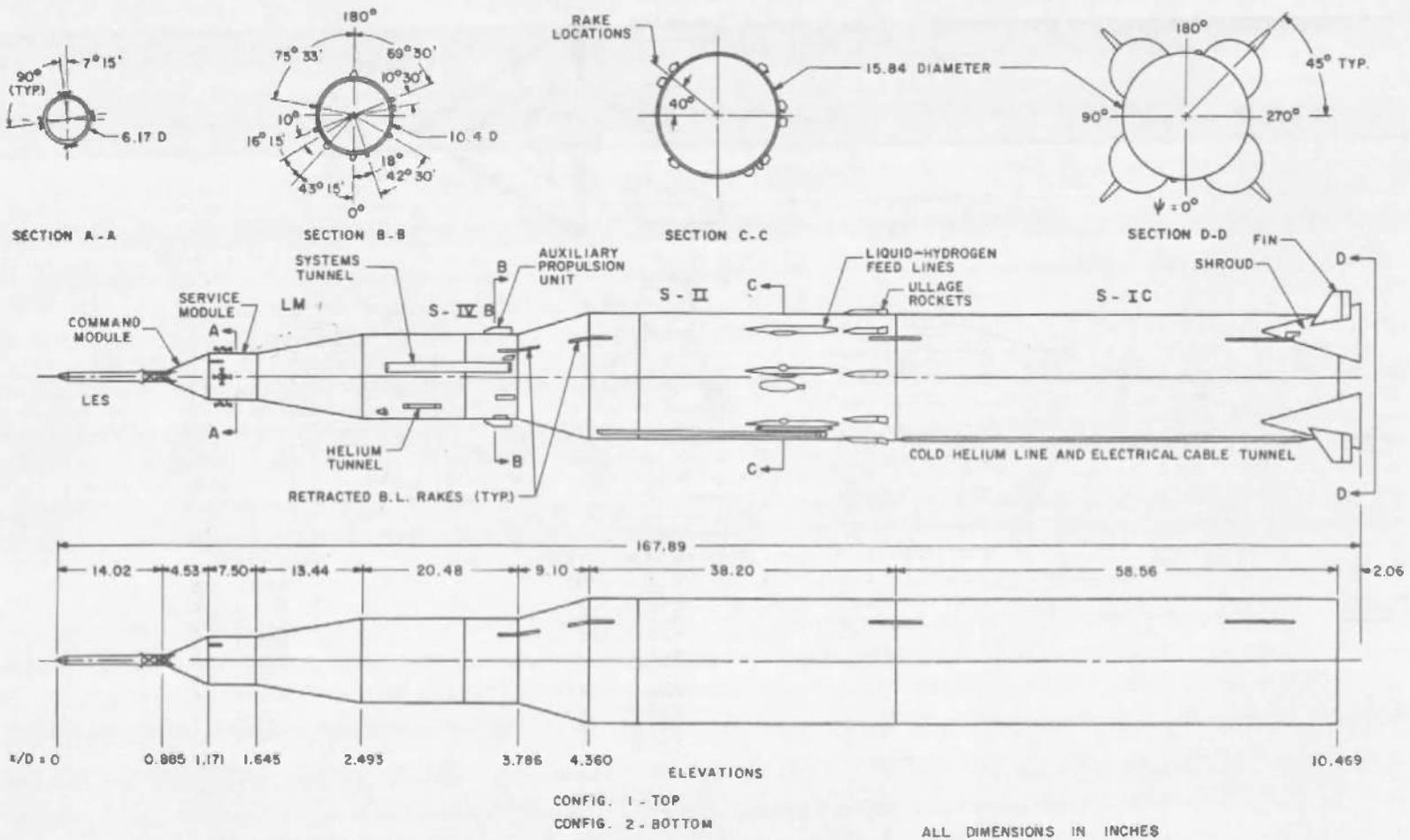
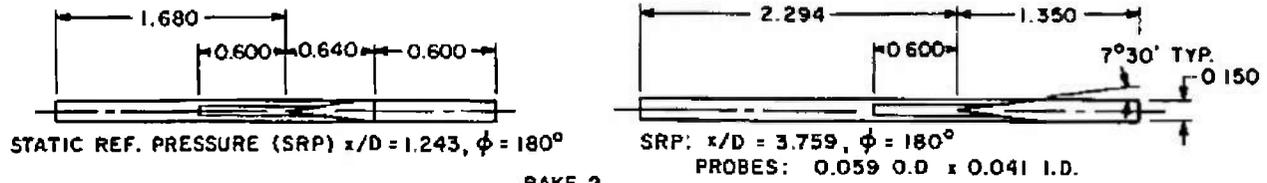


Fig. 3 Model Details

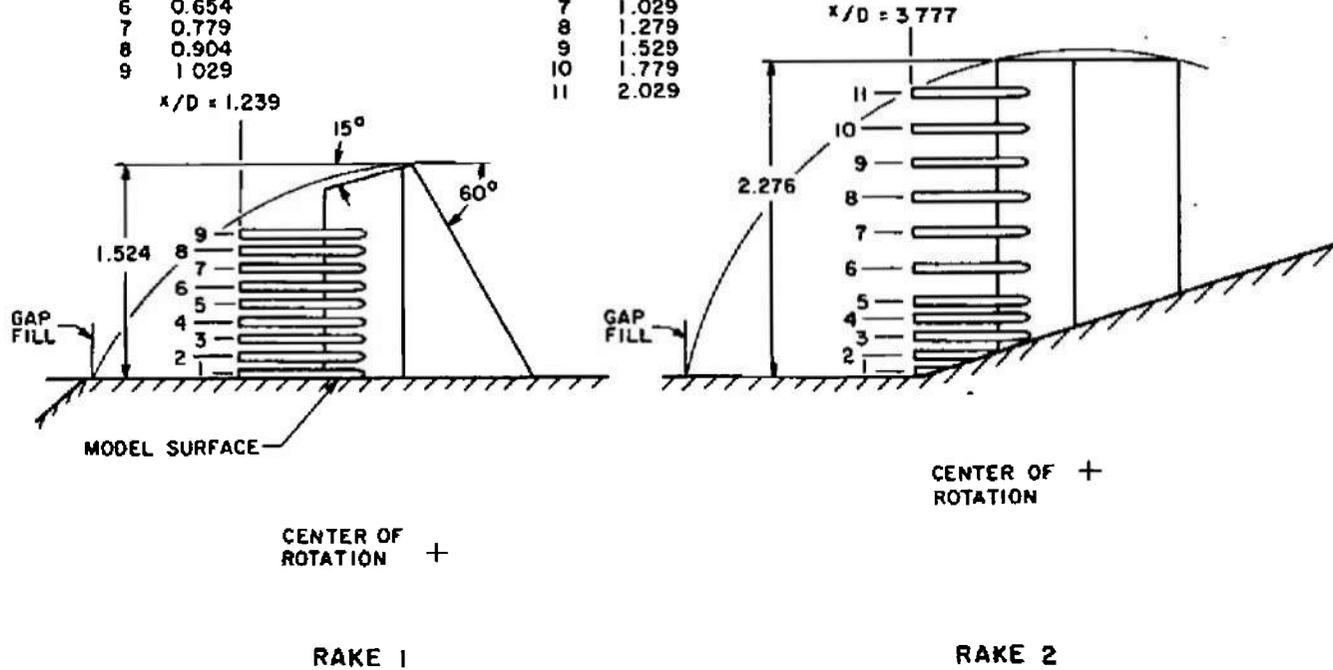


RAKE 1

PROBE	y
1	0.029
2	0.154
3	0.279
4	0.404
5	0.529
6	0.654
7	0.779
8	0.904
9	1.029

RAKE 2

PROBE	y
1	0.029
2	0.154
3	0.279
4	0.404
5	0.529
6	0.774
7	1.029
8	1.279
9	1.529
10	1.779
11	2.029

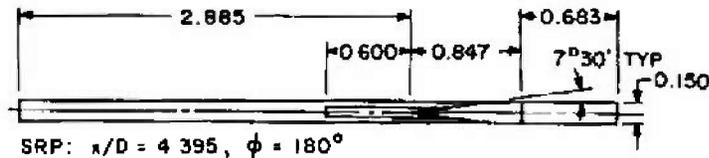


RAKE 1

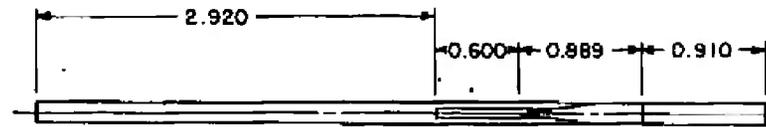
RAKE 2

ALL DIMENSIONS IN INCHES

a. Rakes 1 and 2
Fig. 4 Details of Boundary-Layer Rakes



SRP: $x/D = 4.395$, $\phi = 180^\circ$
 PROBES: 0.059 O.D. x 0.041 I.D.



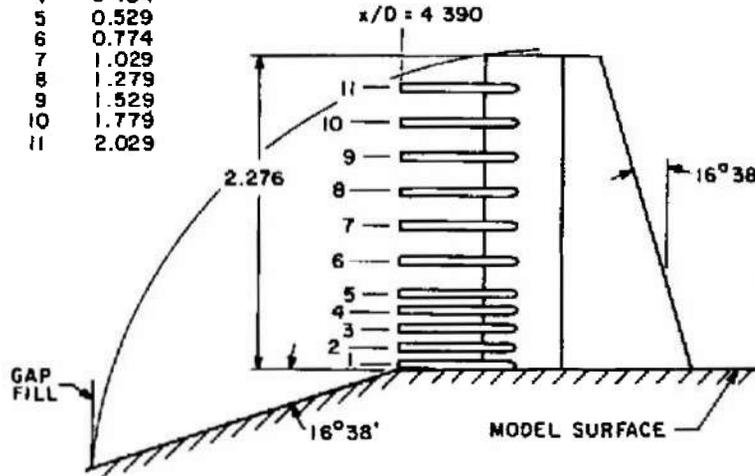
RAKE 4: $x/D = 6.820$ SRP: $x/D = 6.795$, $\phi = 180^\circ$
 RAKE 5: $x/D = 9.794$ SRP: $x/D = 9.801$, $\phi = 33.75^\circ$

RAKE 3

PROBE	y
1	0.029
2	0.154
3	0.279
4	0.404
5	0.529
6	0.774
7	1.029
8	1.279
9	1.529
10	1.779
11	2.029

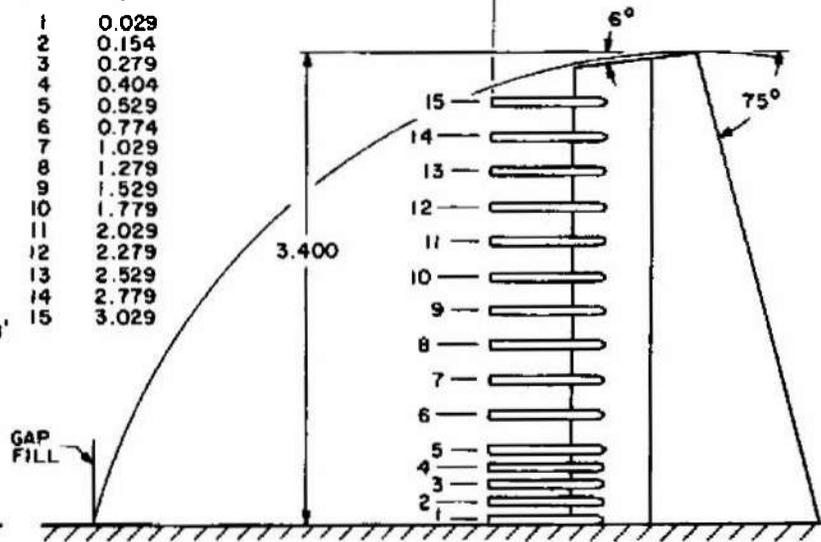
RAKES 4 & 5

PROBE	y
1	0.029
2	0.154
3	0.279
4	0.404
5	0.529
6	0.774
7	1.029
8	1.279
9	1.529
10	1.779
11	2.029
12	2.279
13	2.529
14	2.779
15	3.029



CENTER OF ROTATION +

RAKE 3

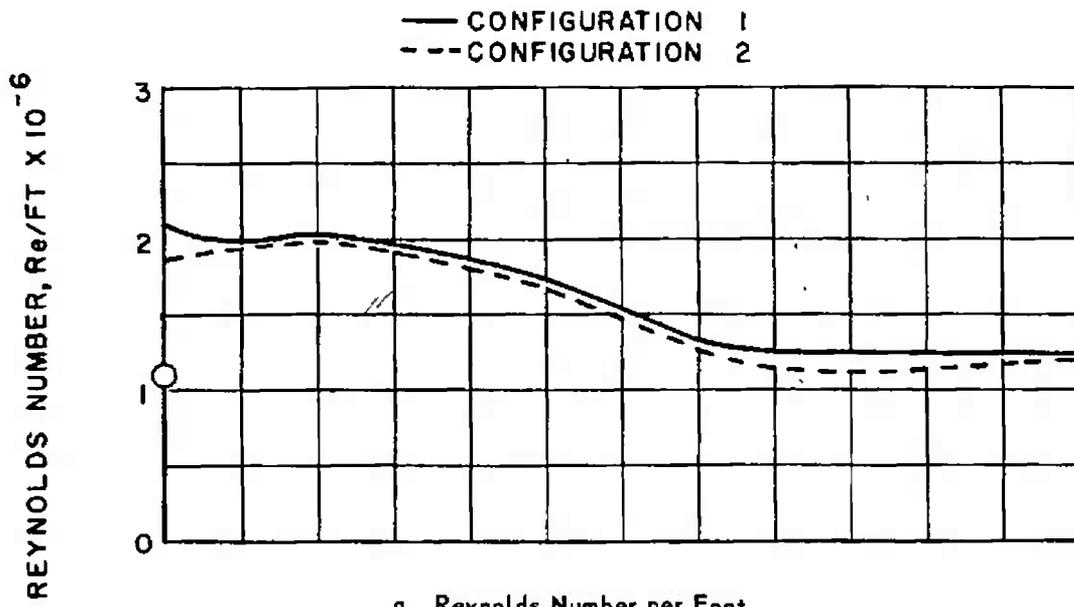


CENTER OF ROTATION +

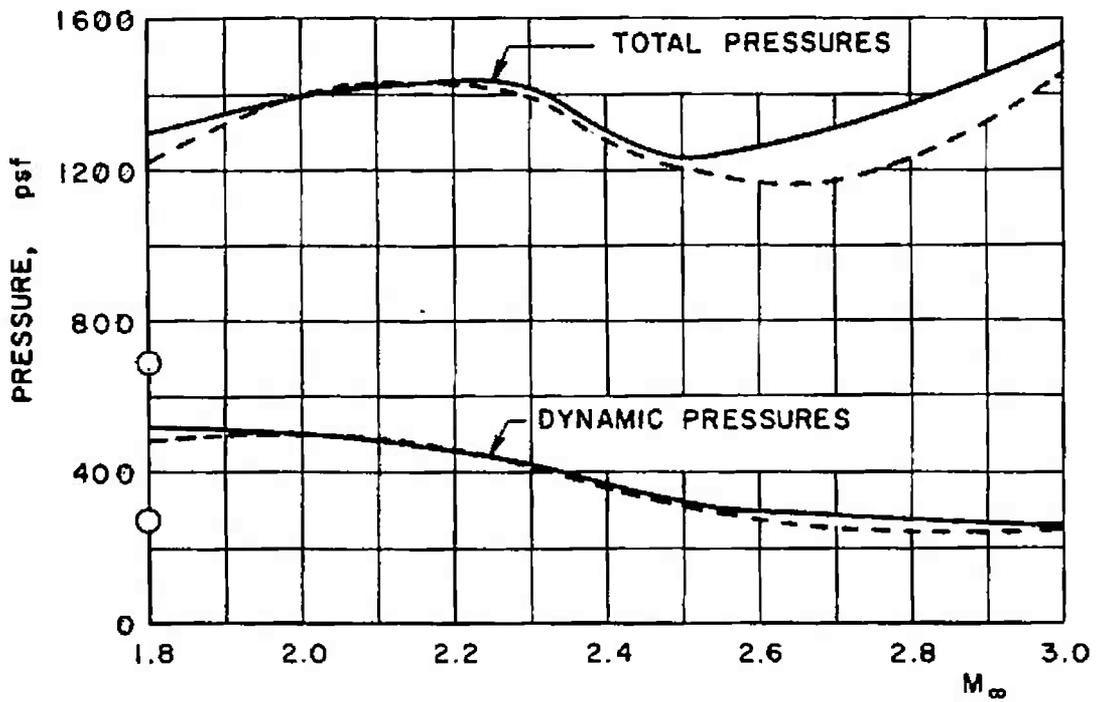
RAKES 4 & 5

ALL DIMENSIONS IN INCHES

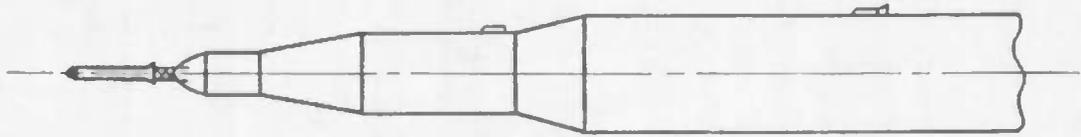
b. Rakes 3, 4, and 5
 Fig. 4 Concluded



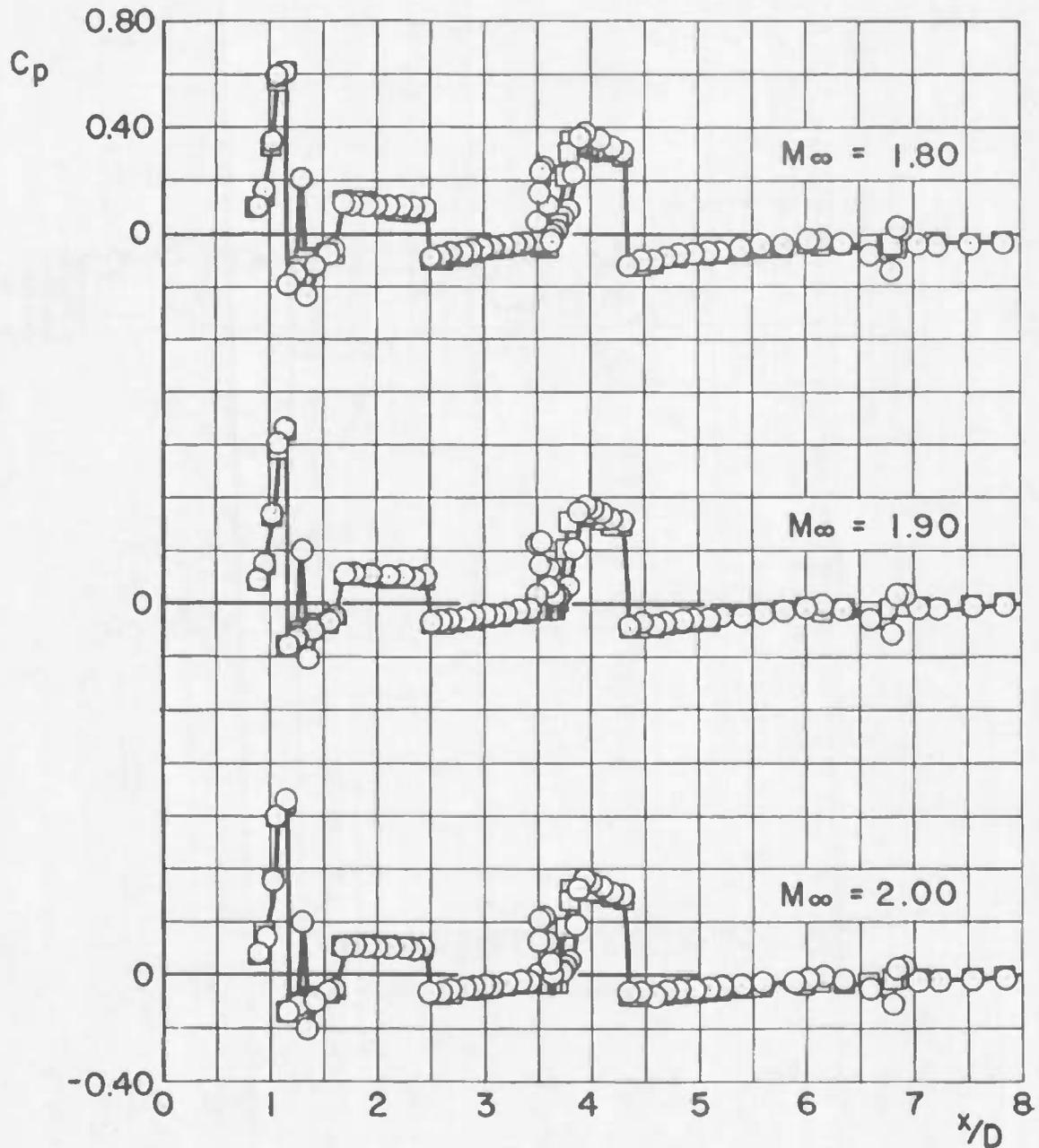
a. Reynolds Number per Foot



b. Total and Dynamic Pressures
 Fig. 5 Test Conditions

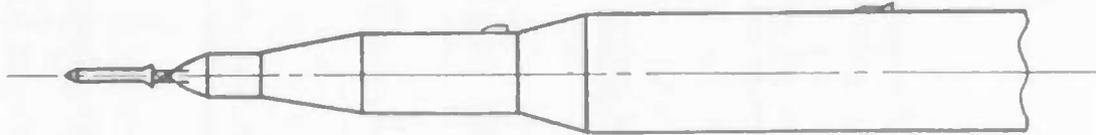


○ CONFIGURATION 1
 □ CONFIGURATION 2

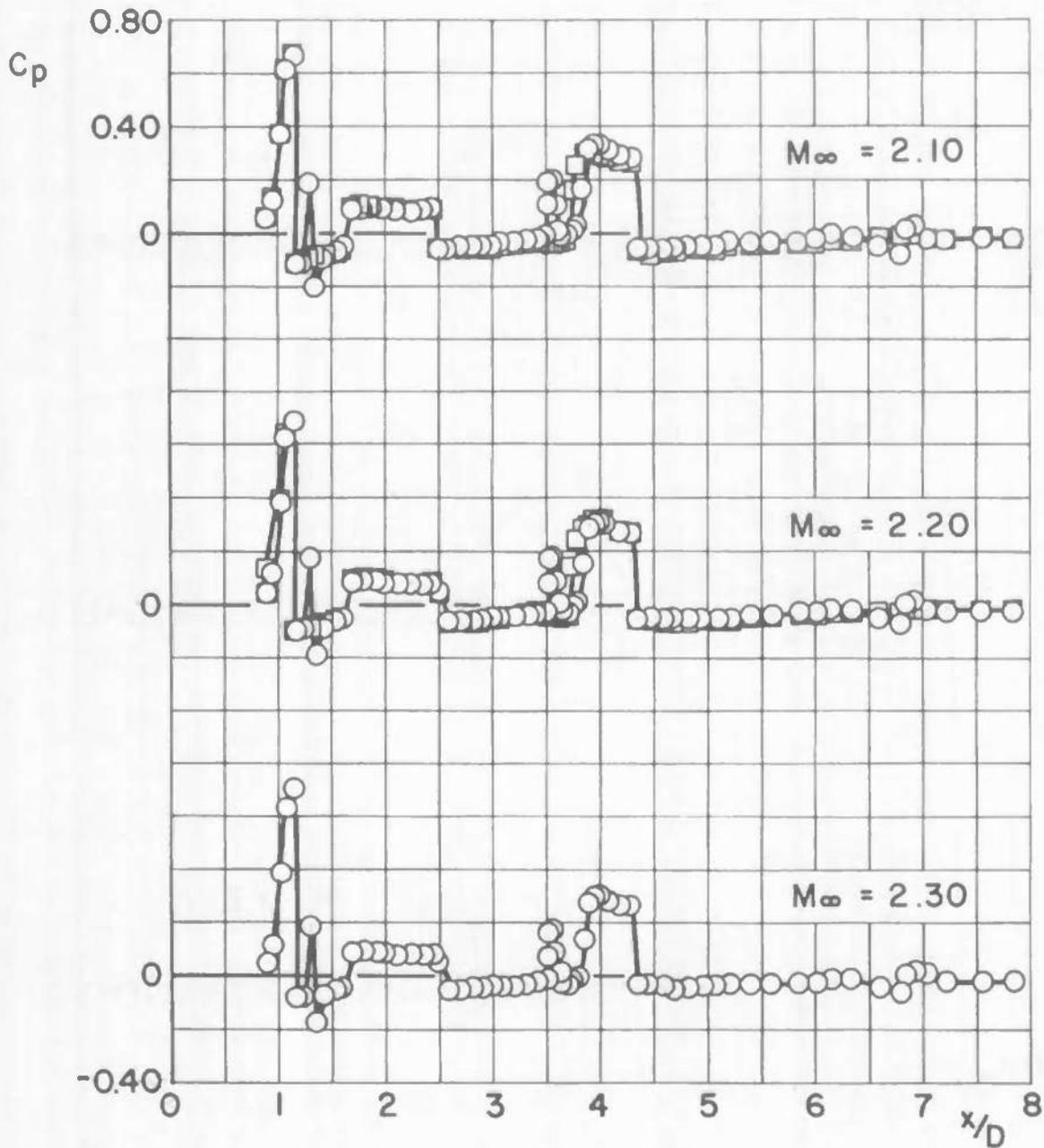


a. $M_\infty = 1.80$ through 2.00

Fig. 6 Pressure Coefficient Distribution along the Model 180-deg Meridian, $\alpha = 0$

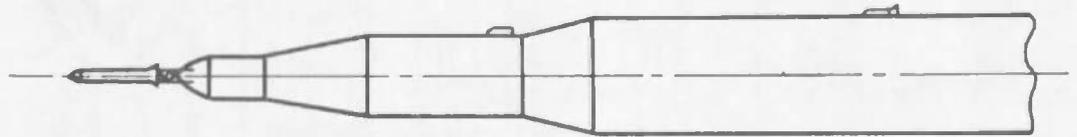


○ CONFIGURATION 1
 □ CONFIGURATION 2

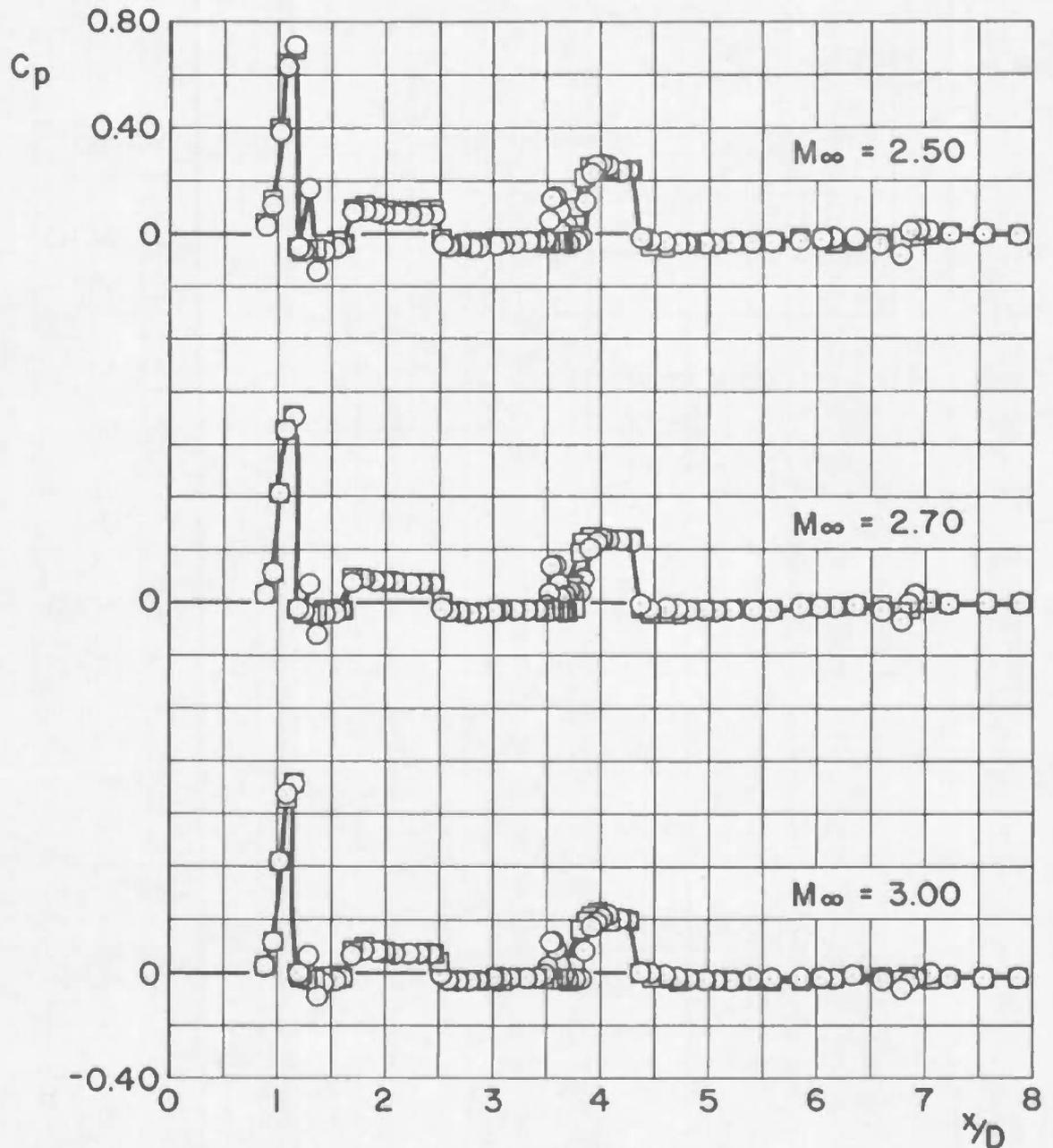


b. $M_\infty = 2.10$ through 2.30

Fig. 6 Continued

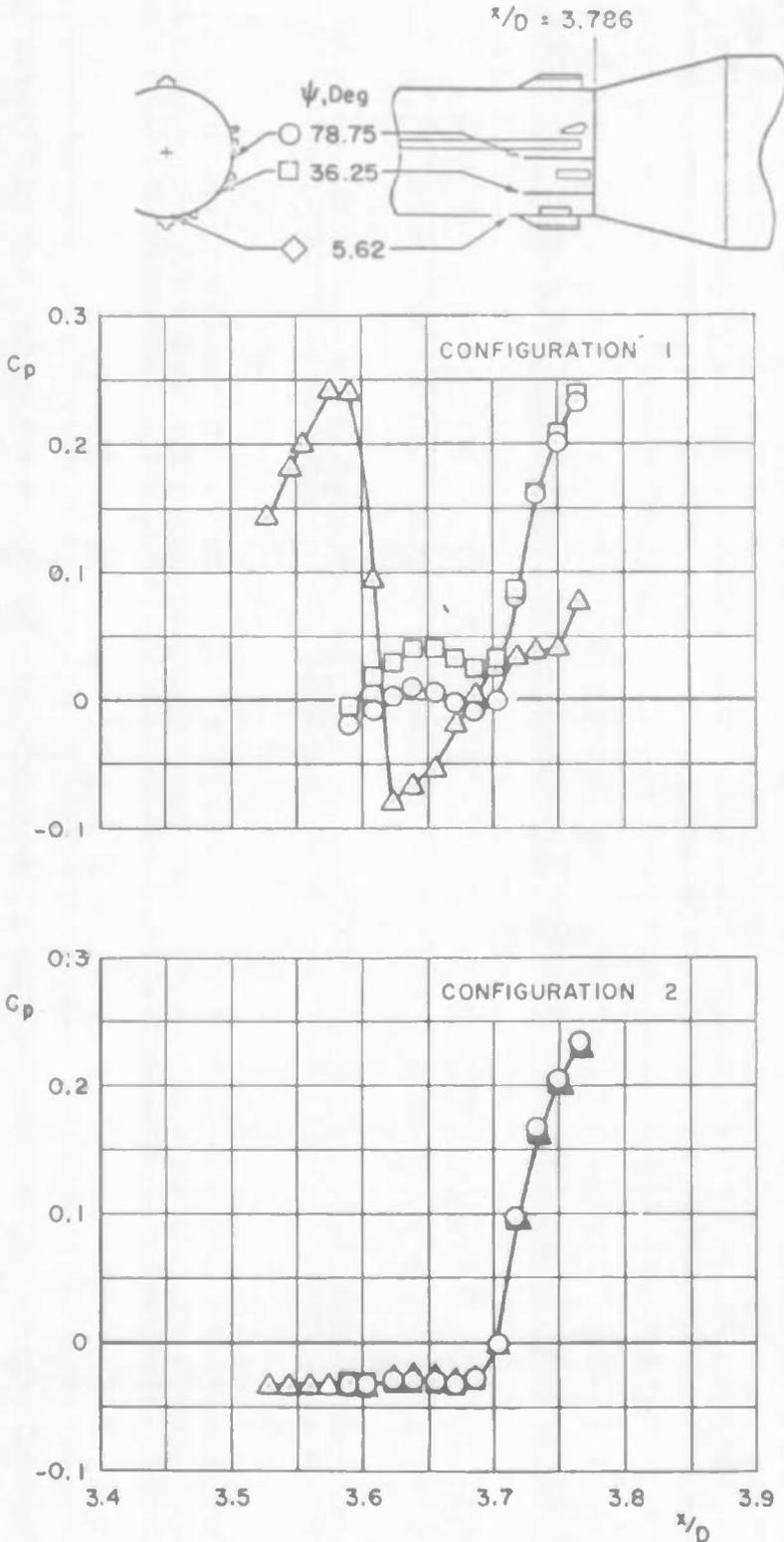


- CONFIGURATION 1
- CONFIGURATION 2



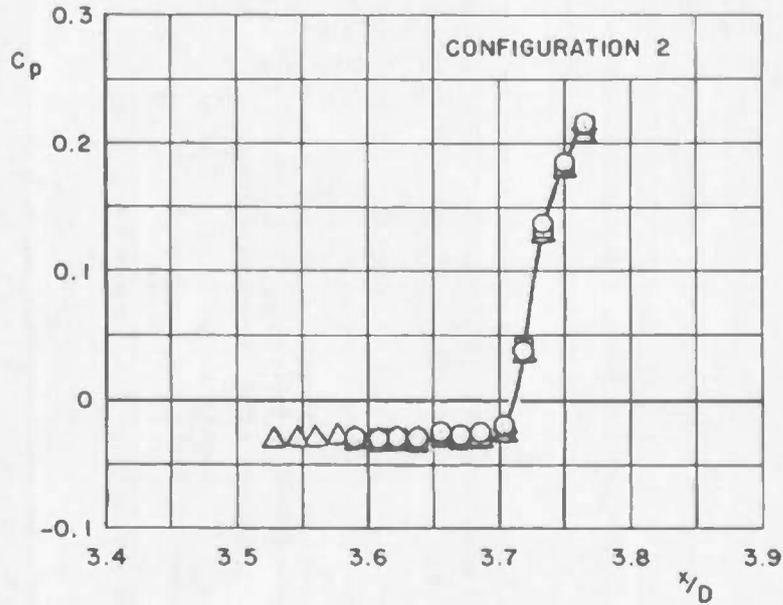
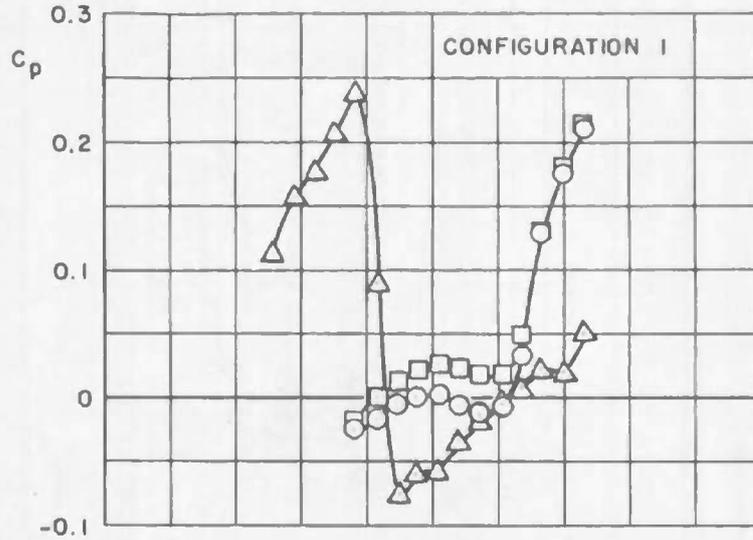
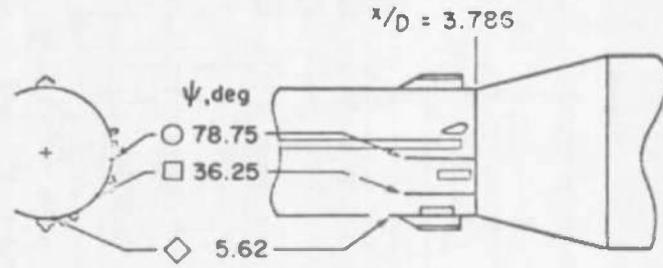
c. $M_\infty = 2.50$ through 3.00

Fig. 6 Concluded

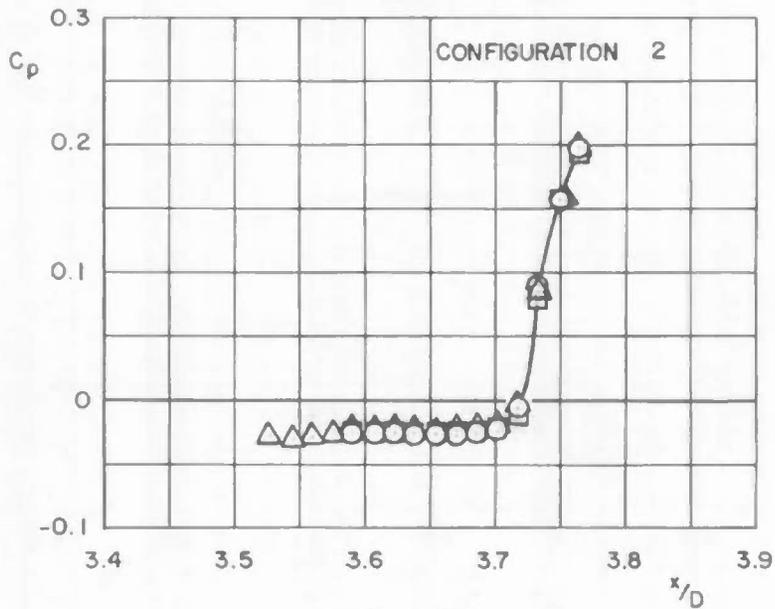
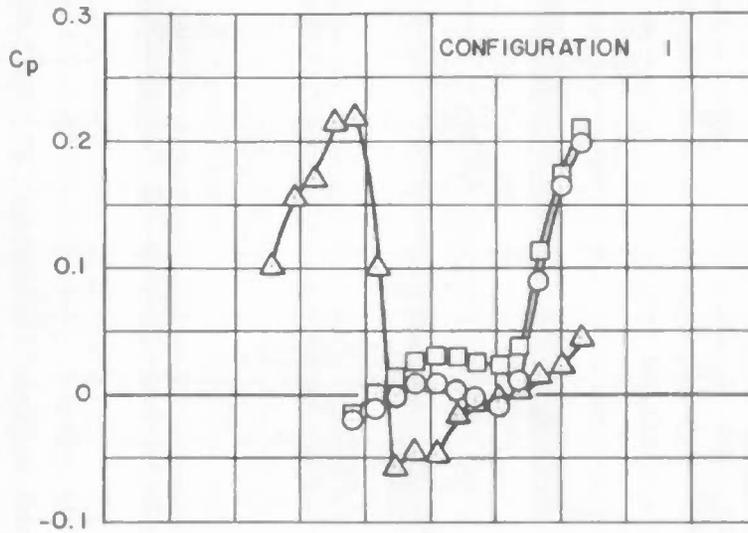
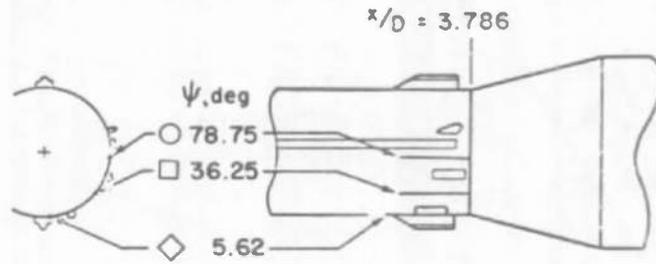


$\alpha = M_\infty = 1.80$

Fig. 7 Pressure Coefficient Distribution in the S-IVB Flare Region, Showing Protuberance and Interstage Effects, $\alpha = 0$

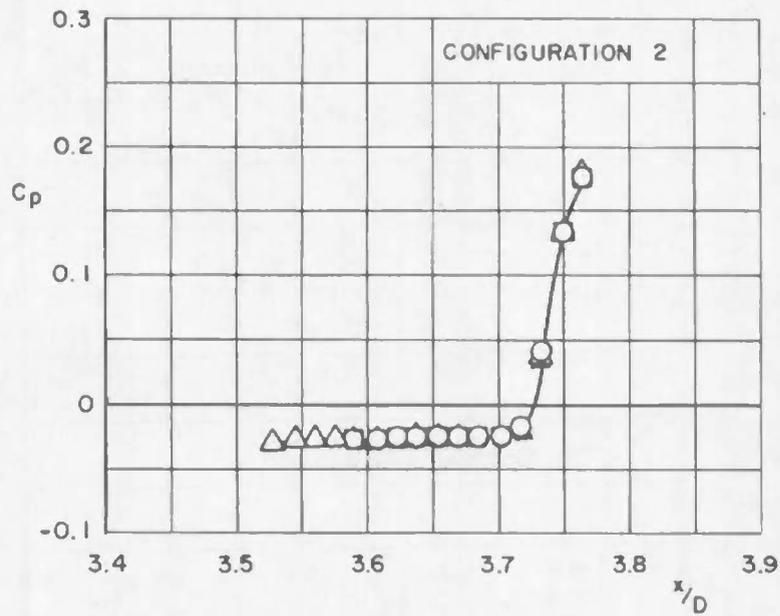
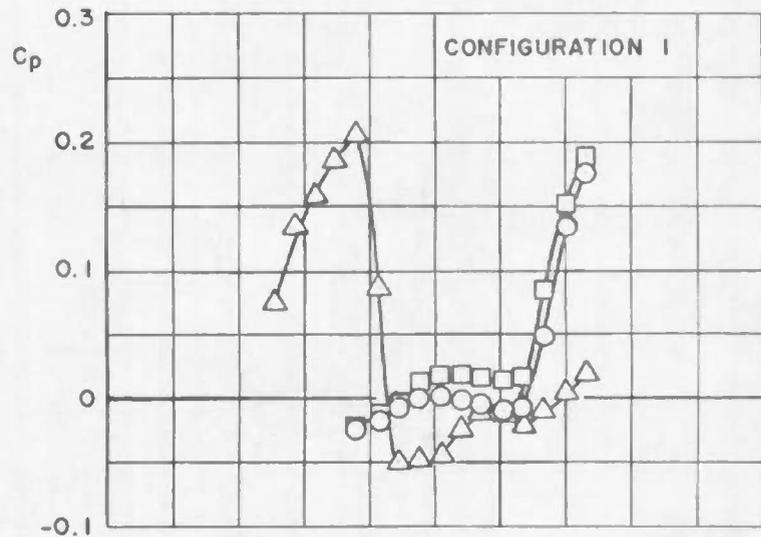
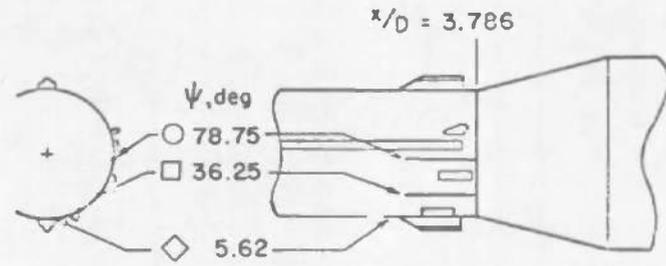


b. $M_{oc} = 1.90$
 Fig. 7 Continued



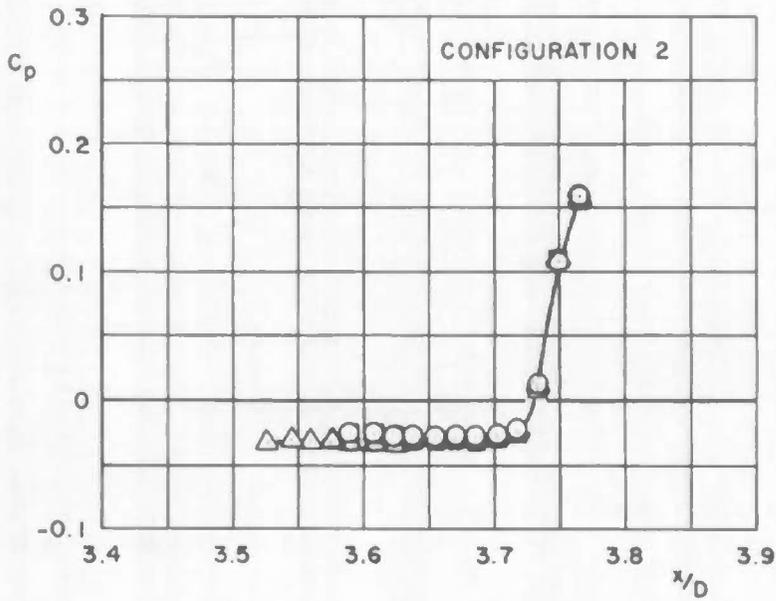
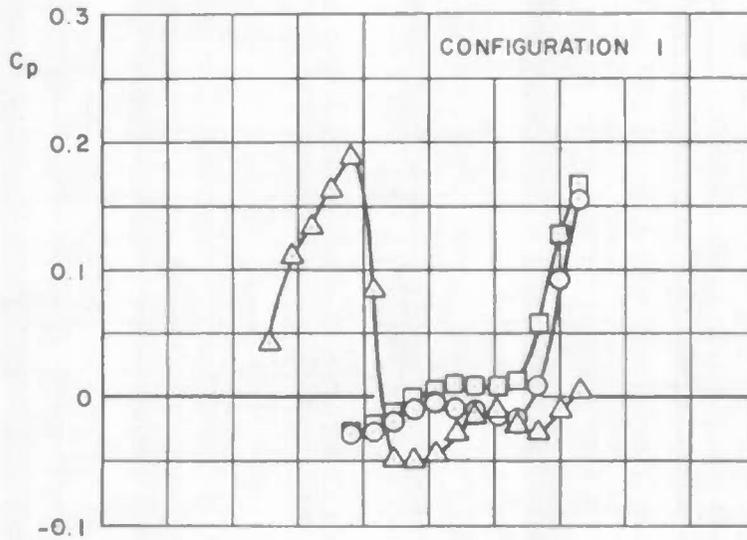
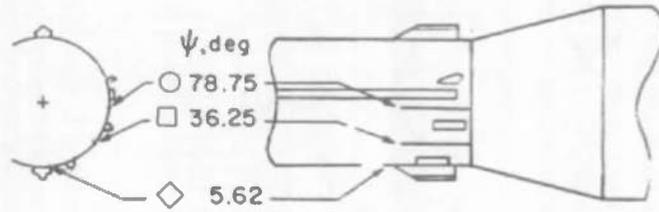
c. $M_\infty = 2.00$

Fig. 7 Continued



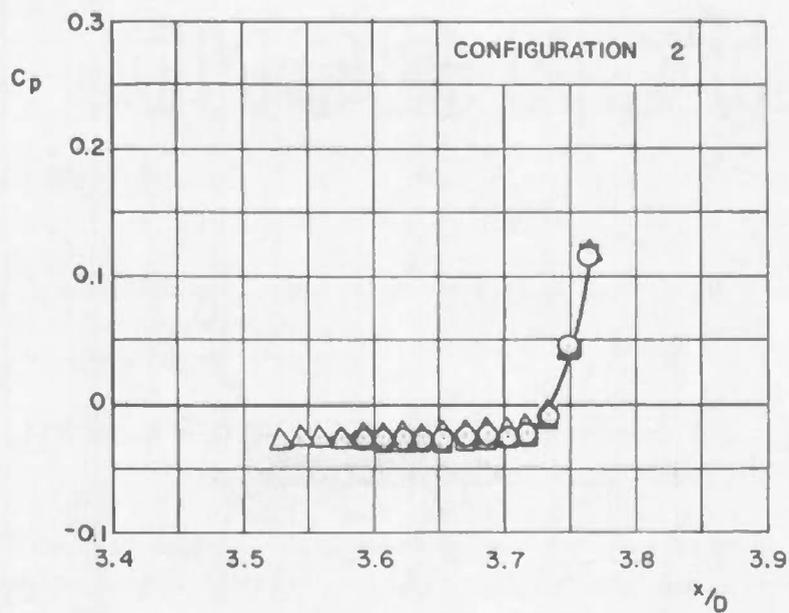
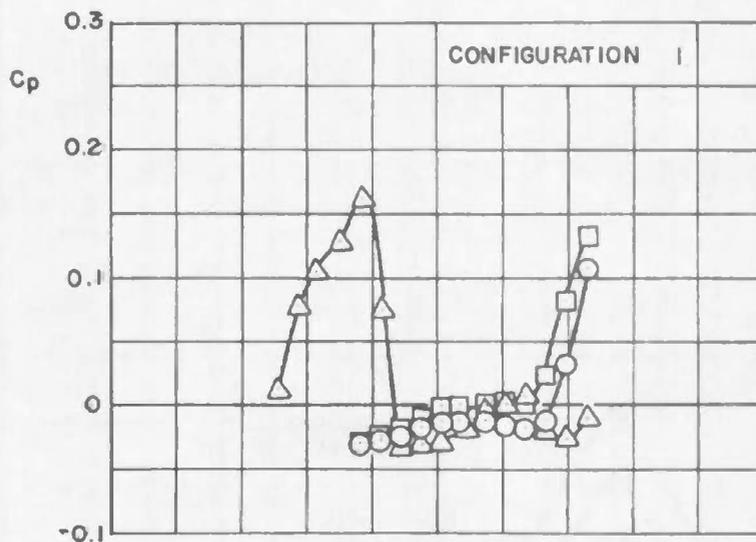
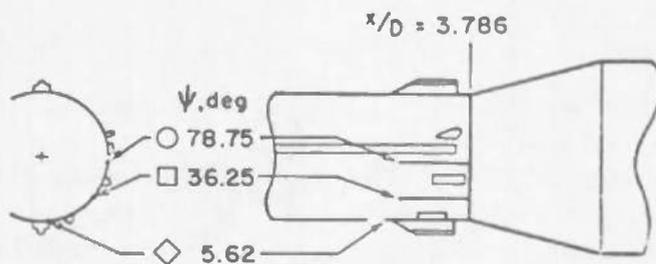
d. $M_\infty = 2.10$
 Fig. 7 Continued

$x/D = 3.786$

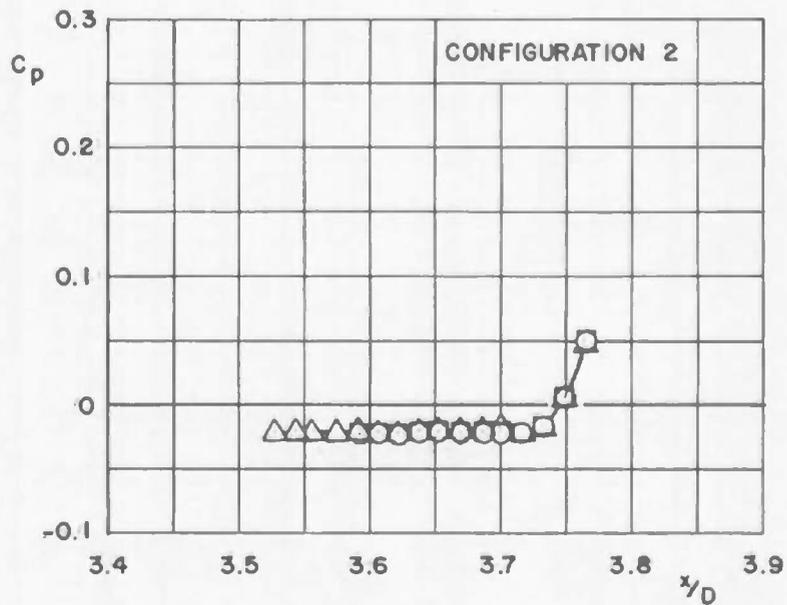
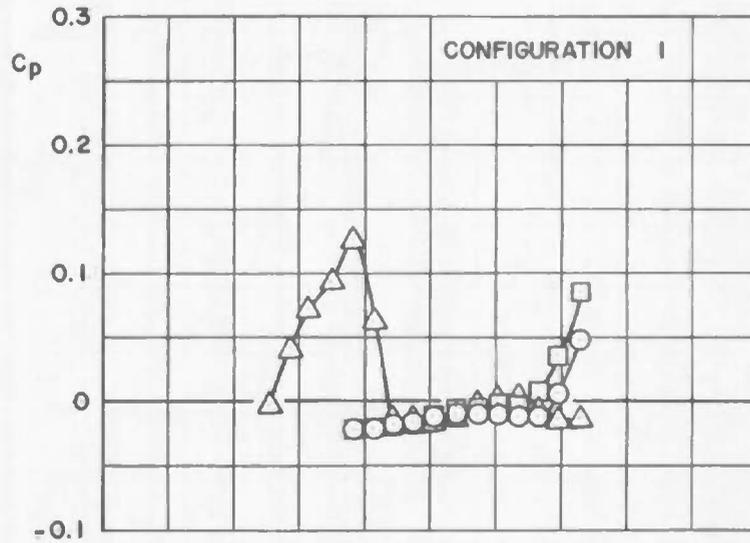
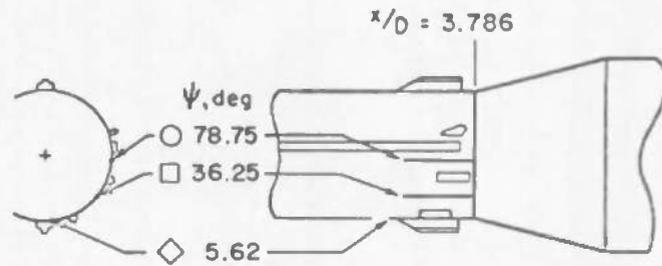


e. $M_\infty = 2.20$

Fig. 7 Continued



$f. M_\infty = 2.50$
 Fig. 7 Continued



h. $M_\infty = 3.00$
Fig. 7 Concluded

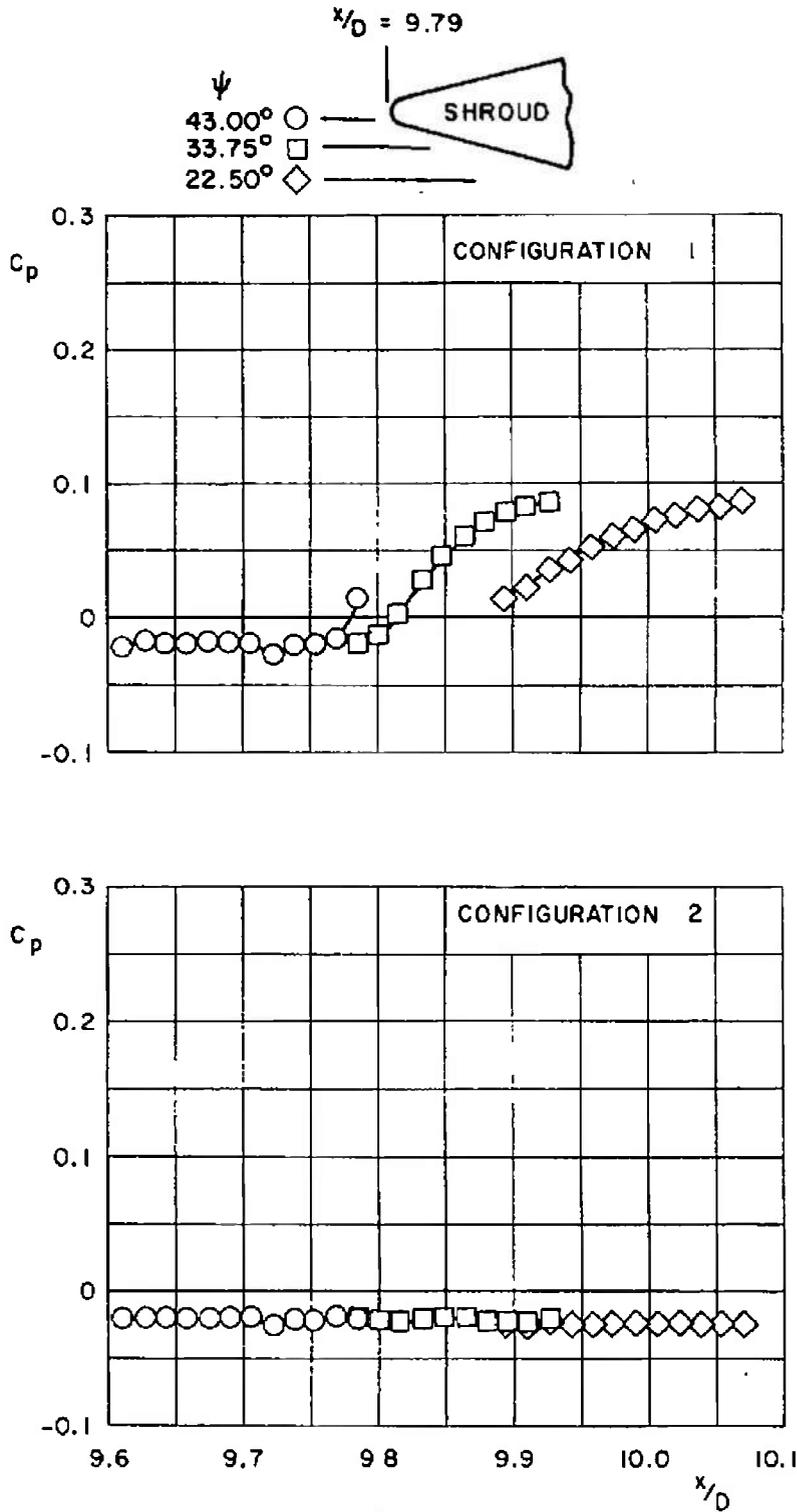
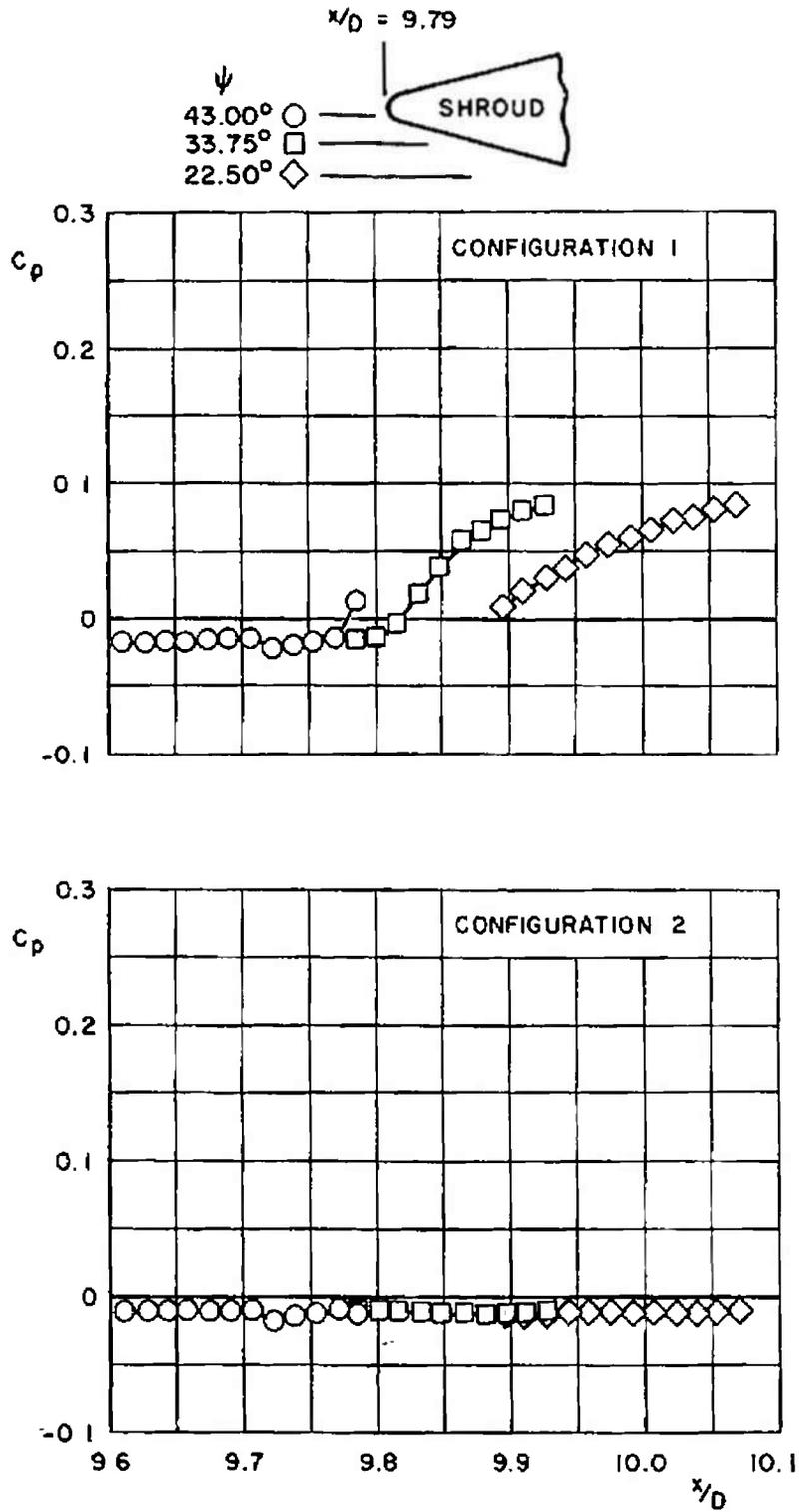
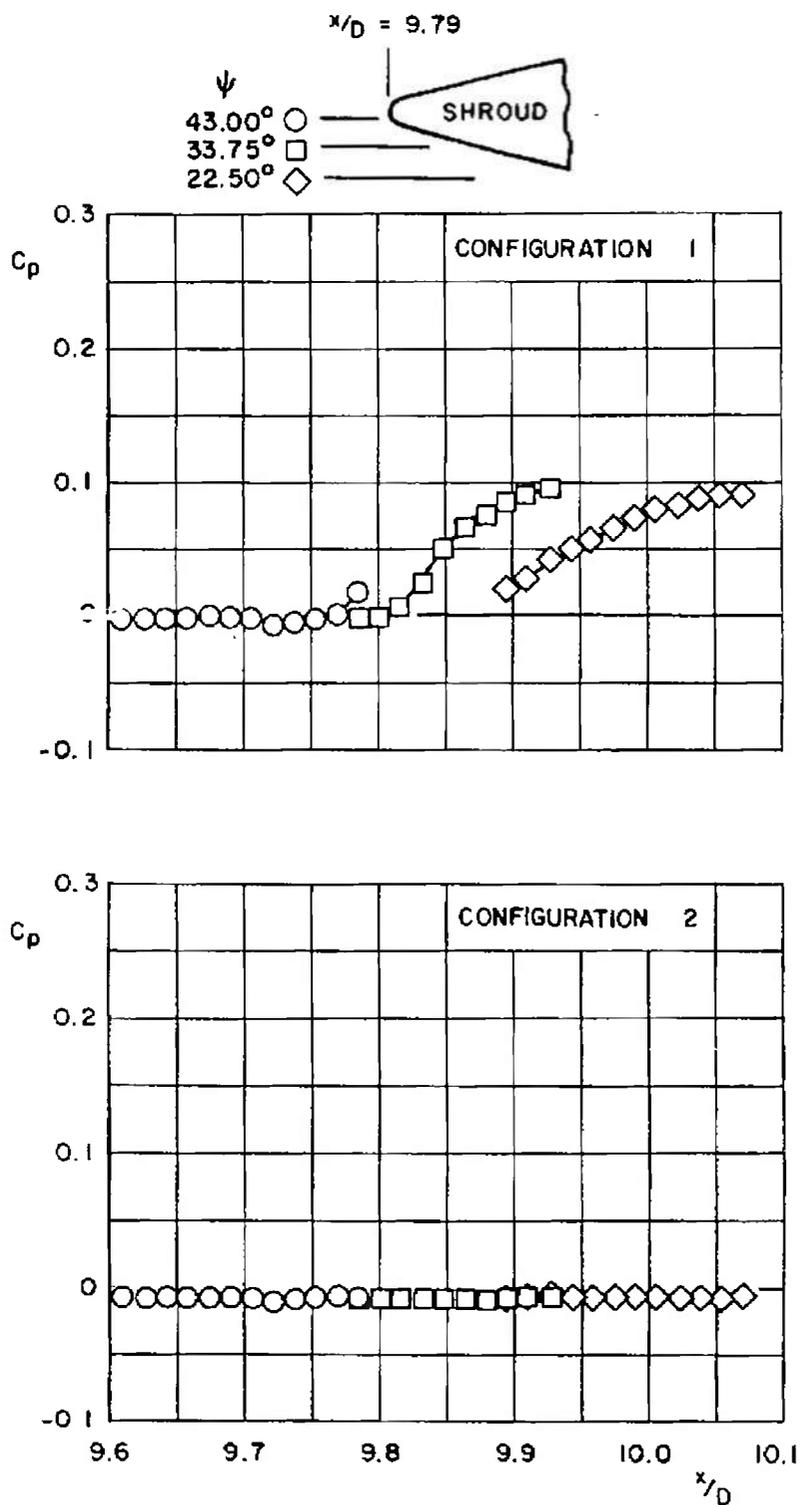


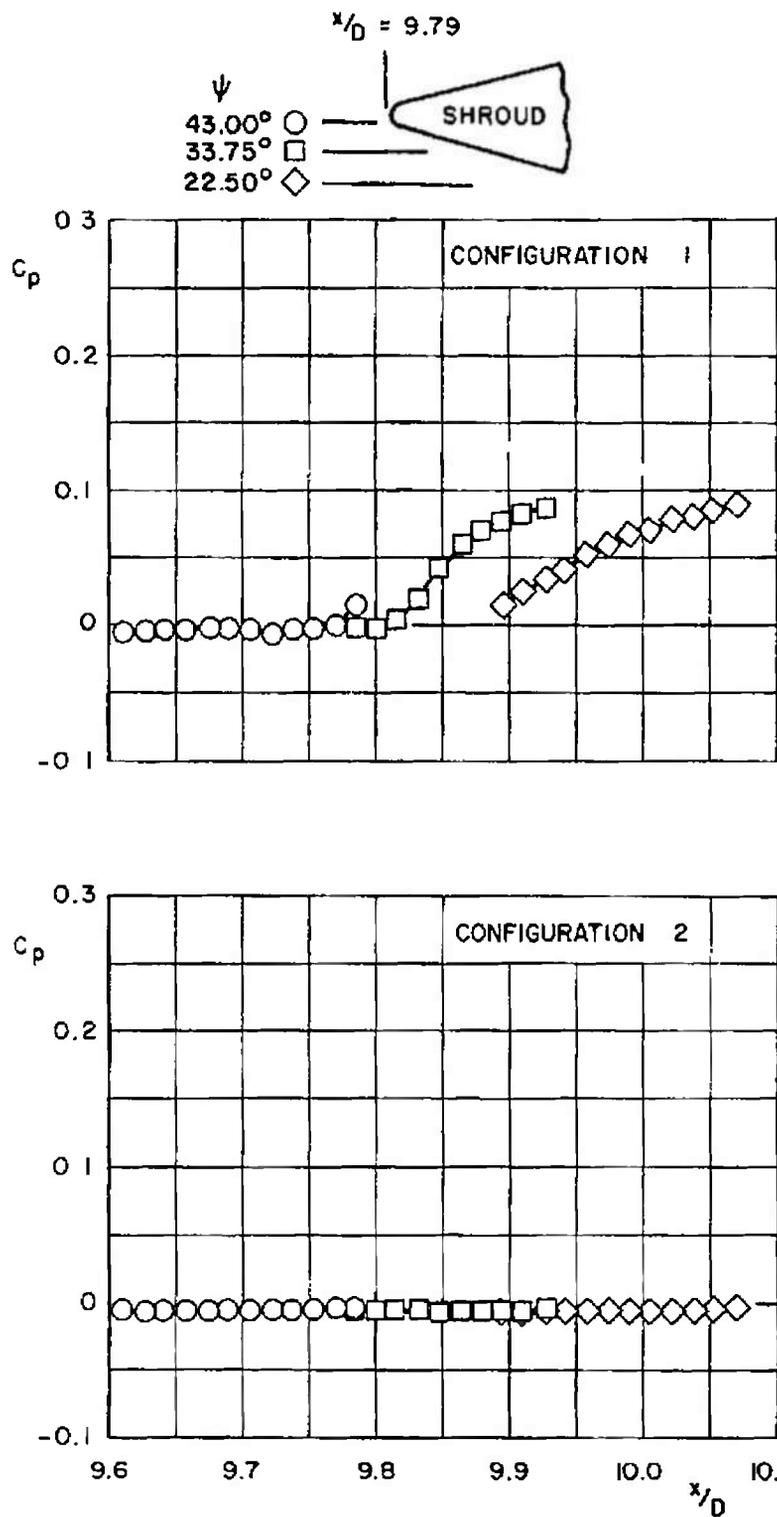
Fig. 8 Fin-Shroud Interference Effects on Local Pressure Coefficient Distribution, $\alpha = 0$



b. $M_\infty = 1.90$
Fig. 8 Continued

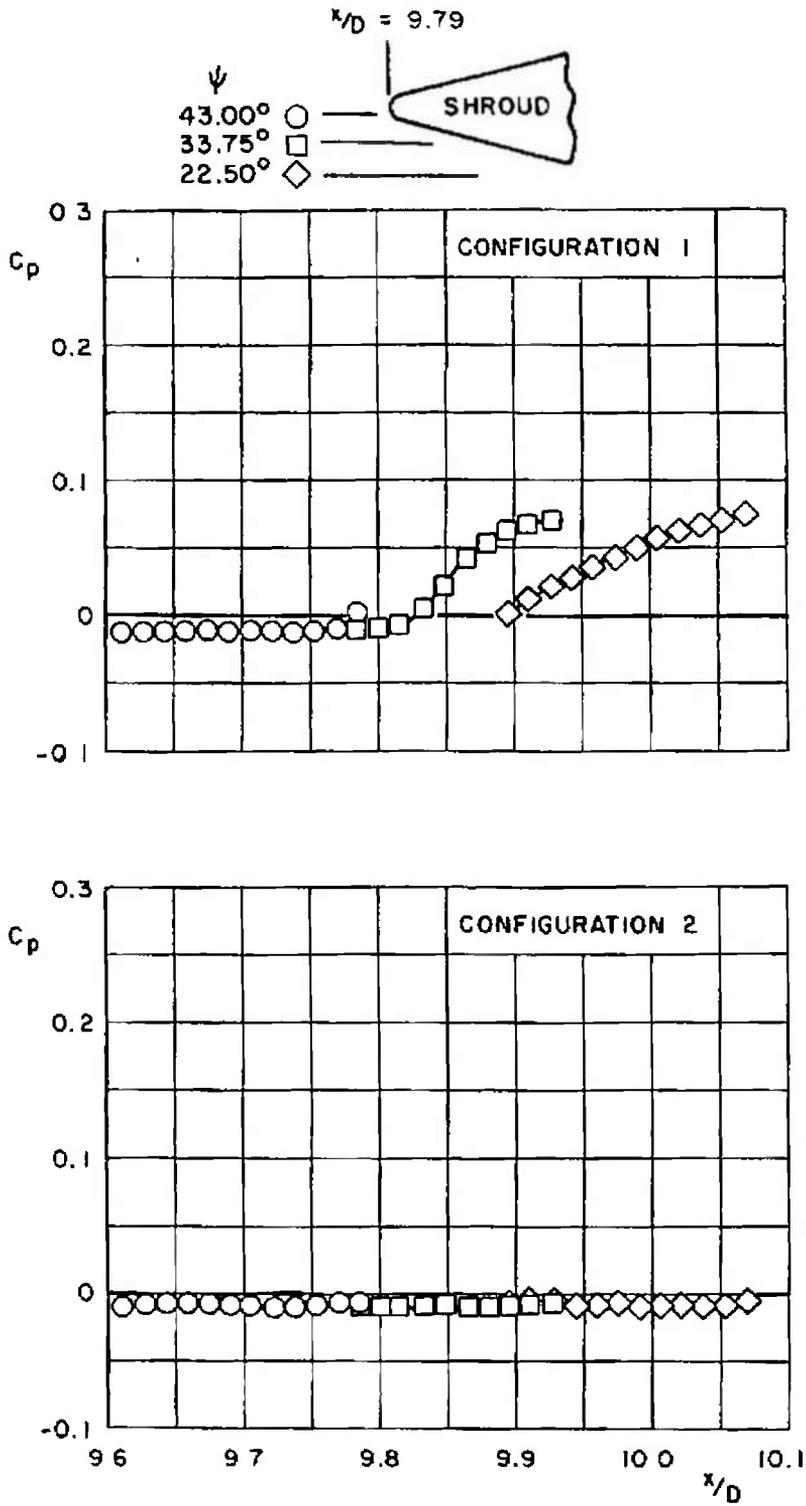


c. $M_\infty = 2.00$
 Fig. 8 Continued

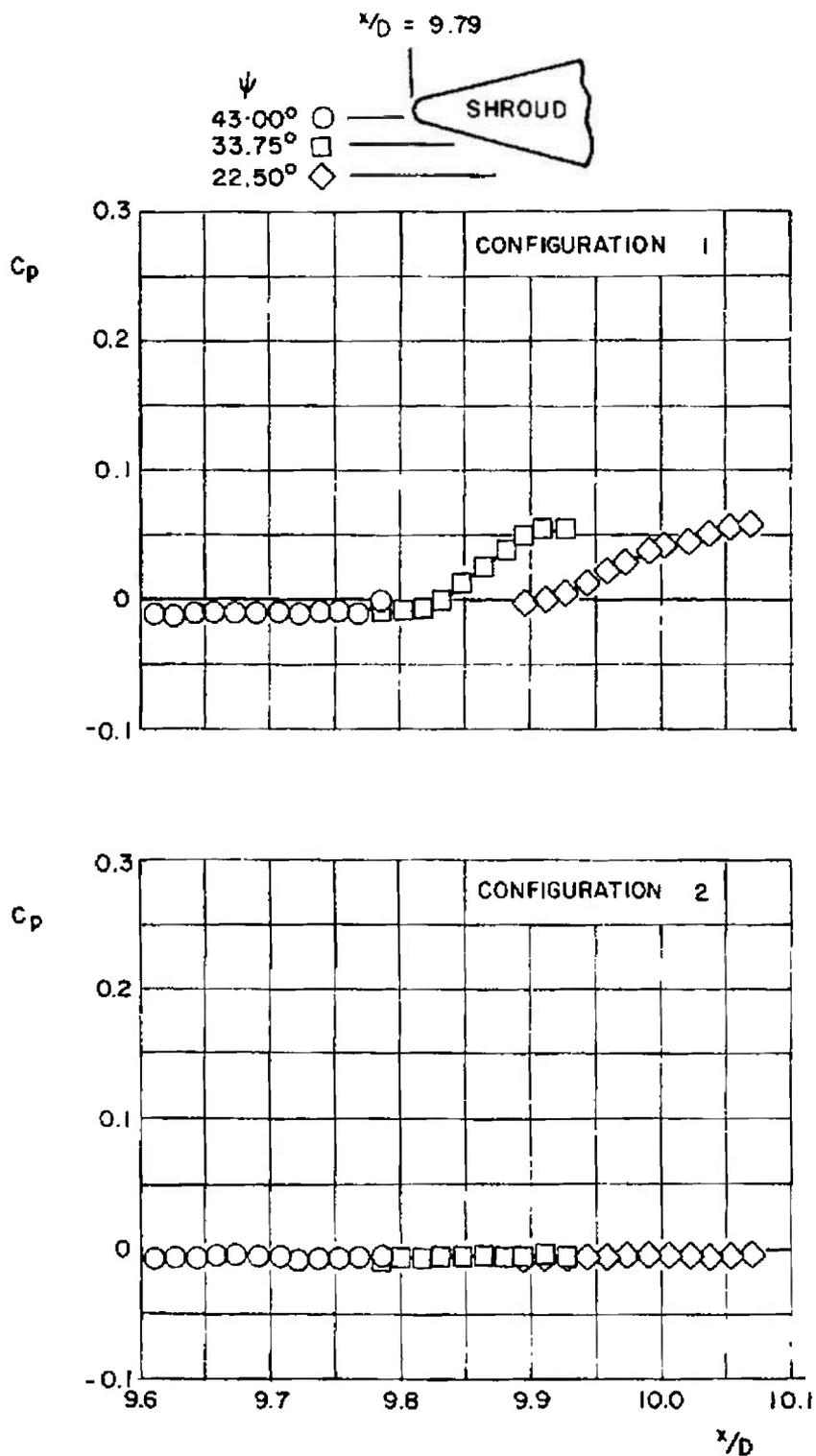


d. $M_\infty = 2.10$

Fig. 8 Continued

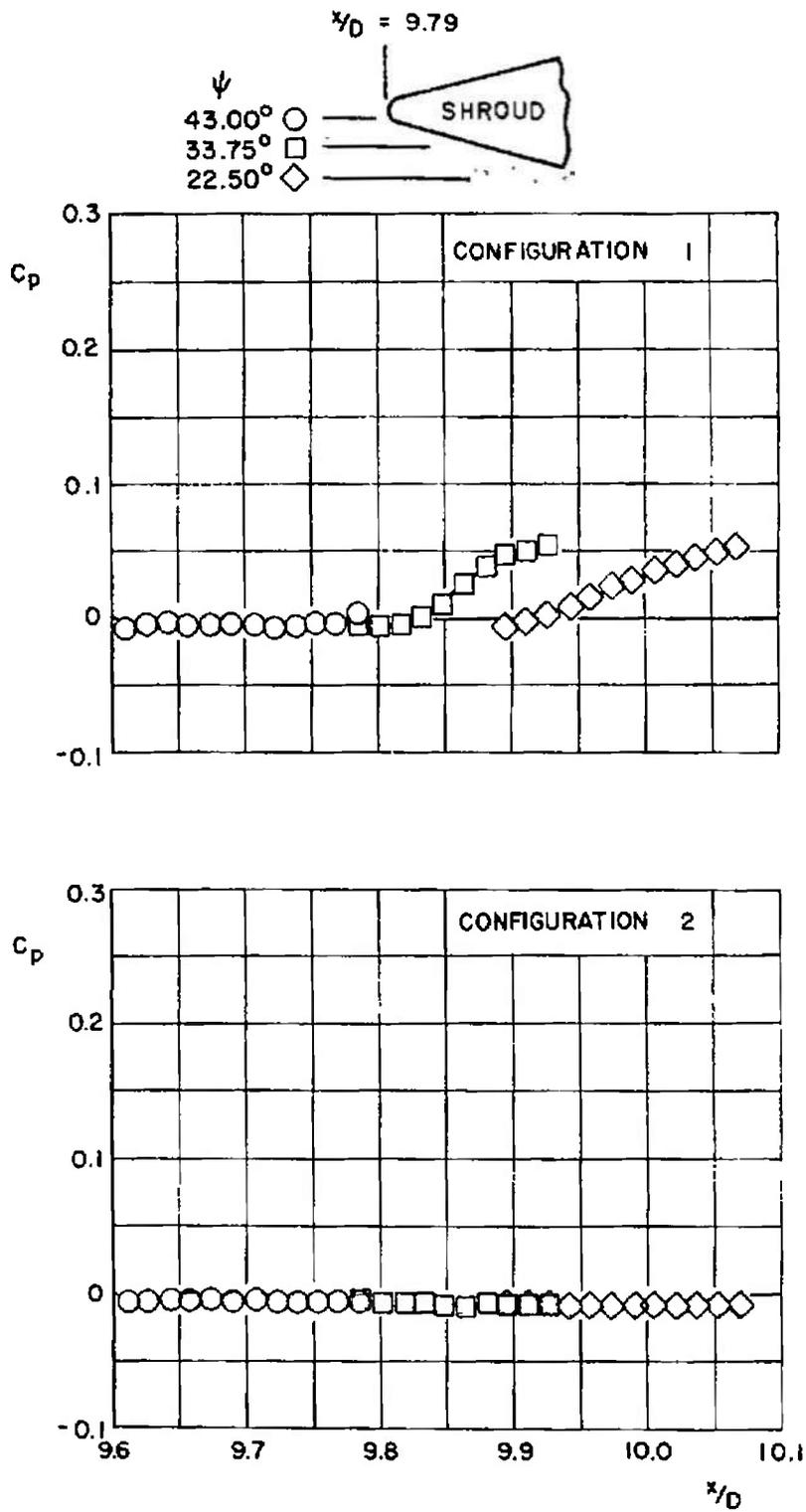


e. $M_{\infty} = 2.20$
 Fig. 8 Continued

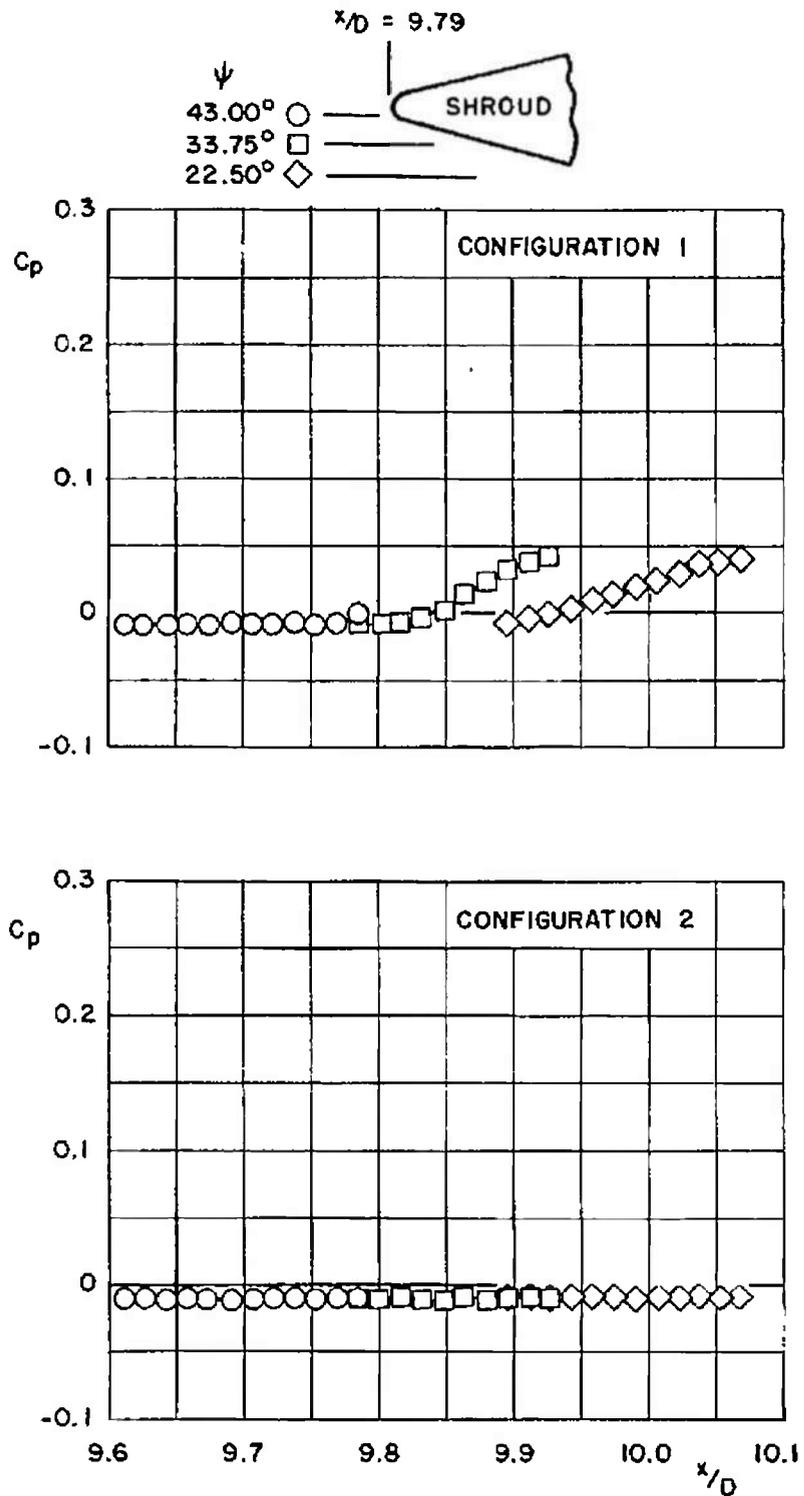


f. $M_\infty = 2.50$

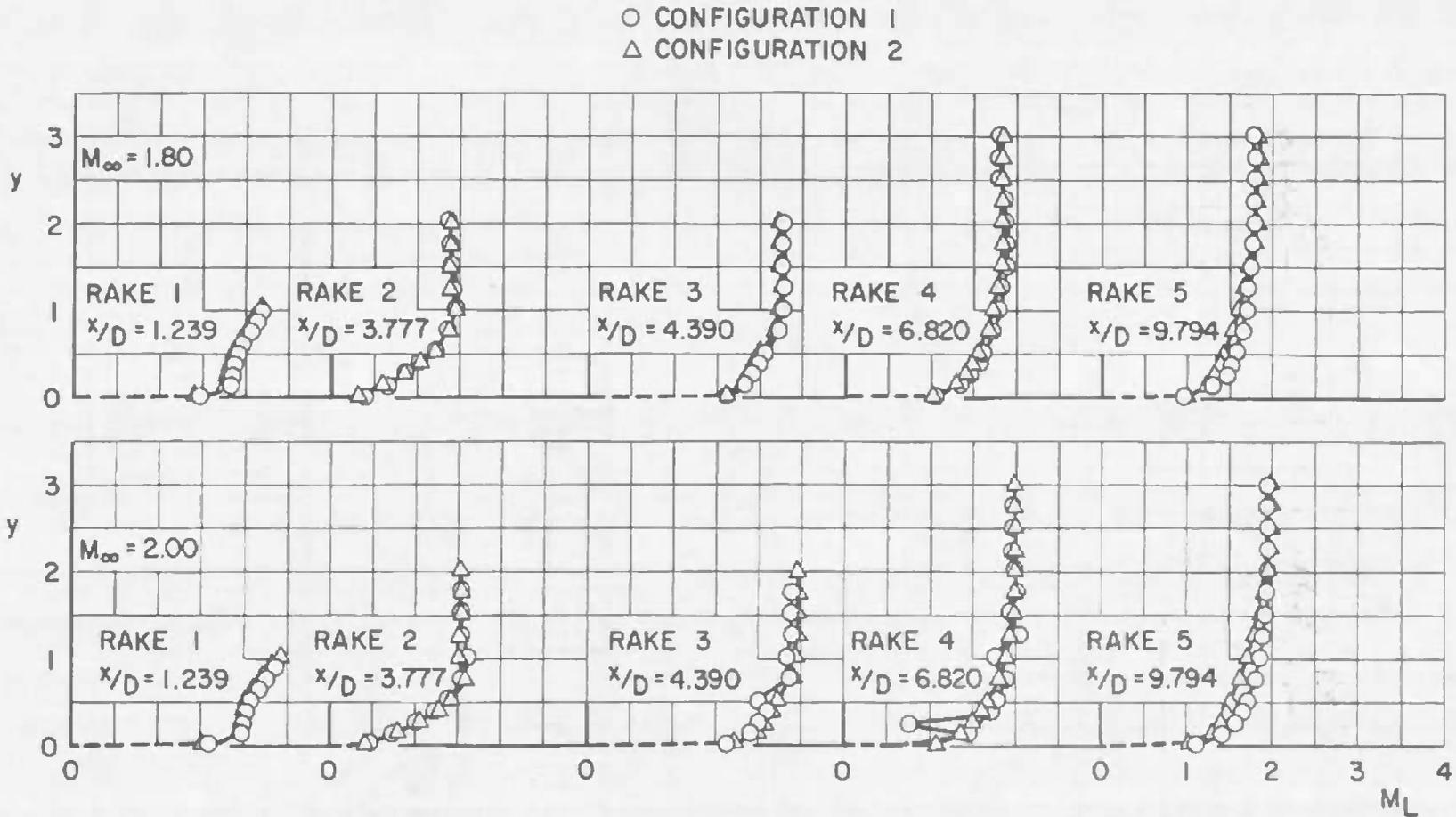
Fig. 8 Continued



g. $M_\infty = 2.70$
 Fig. 8 Continued



h. $M_\infty = 3.00$
 Fig. 8 Concluded

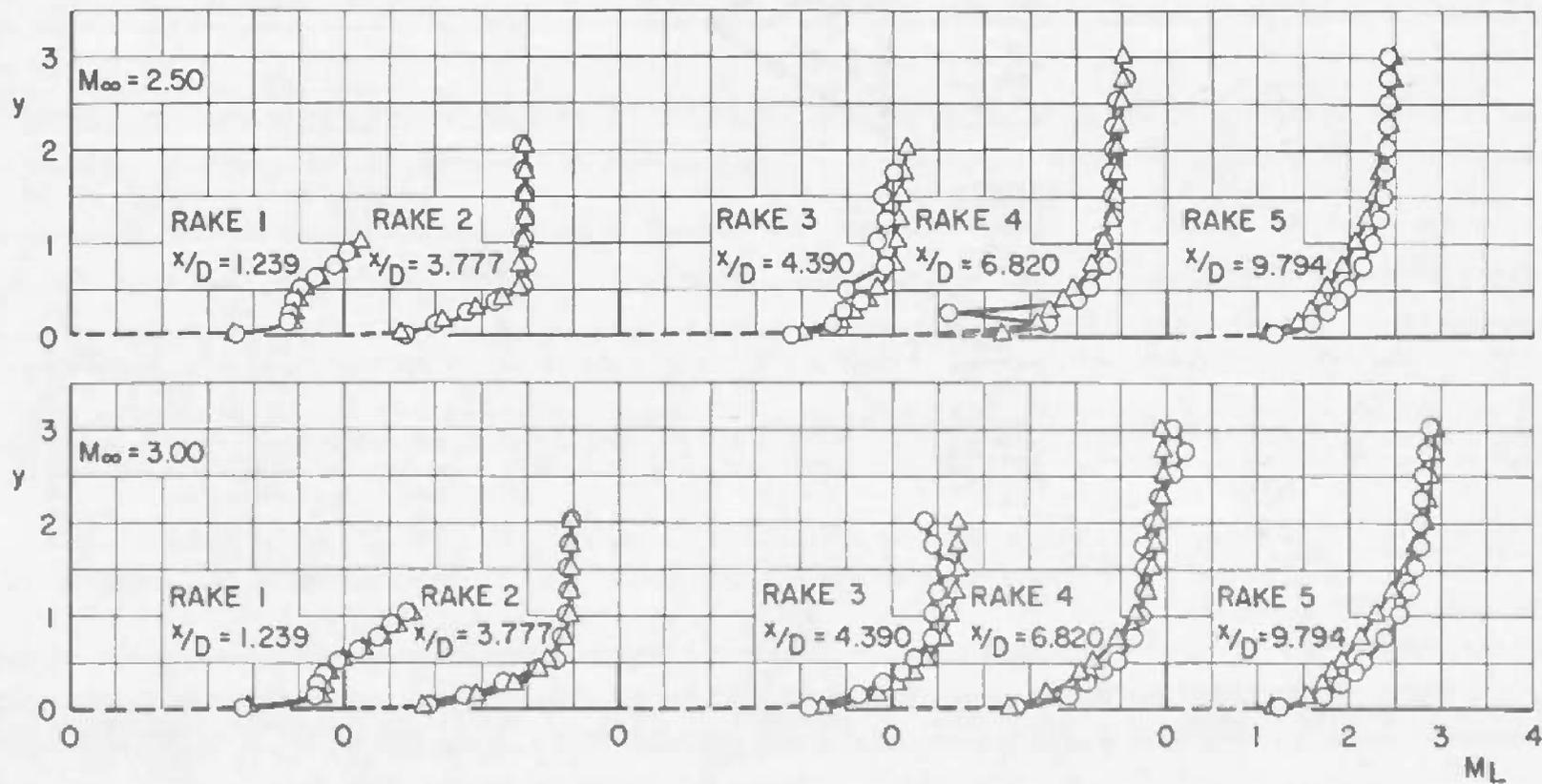


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a. $M_\infty = 1.80$ and 2.00

Fig. 9 Boundary-Layer Profiles for Configurations 1 and 2

○ CONFIGURATION 1
 △ CONFIGURATION 2



b. $M_\infty = 2.50$ and 3.00
 Fig. 9 Concluded

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13 ABSTRACT In conjunction with an earlier transonic test, a 0.04-scale model of the Saturn V launch vehicle was tested at Mach numbers from 1.80 to 3.00 for Reynolds number based on model diameter varying from 1.59 to 2.77 million. Static pressure distributions and boundary-layer profiles were measured and are presented herein. Unsteady pressures were also measured, but these results are not presented. (AFR 310-2 Statement 2)			

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