

AD A 098264

LEVEL

12  
B.S.

DTIC  
ELECTED  
APR 28 1981  
C

DTIC FILE COPY

**DISTRIBUTION STATEMENT A**

Approved for public release;  
Distribution Unlimited

**NIELSEN ENGINEERING  
AND RESEARCH, INC.**

OFFICES: 510 CLYDE AVENUE / MOUNTAIN VIEW, CALIFORNIA 94043 / TELEPHONE (415) 988-9457

81 4 27 003

12  
COPY NO. 14

EXPERIMENTAL RESULTS ON VORTICITY  
SHEDDING AT THE EDGE OF A FLAT  
PLATE IN TWO-DIMENSIONAL FLOW

by

S. B. Spangler, R. G. Schwind,  
and K. Owen

NEAR TR 224  
September 1980

Technical Report  
For the period May, 1978 to March, 1980

Prepared under Contract No. N00014-78-C-0388

for

OFFICE OF NAVAL RESEARCH  
Arlington, Virginia 22217

by

NIELSEN ENGINEERING & RESEARCH, INC.  
510 Clyde Avenue, Mountain View, CA 94043  
Telephone (415) 968-9457

DTIC  
ELECTE  
APR 28 1981  
C

DISTRIBUTION STATEMENT A  
Approved for public release;  
Distribution Unlimited

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                | READ INSTRUCTIONS<br>BEFORE COMPLETING FORM |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|---------------------------------------------|
| 1. REPORT NUMBER                                                                                                                                                                                                                                                                                                                                                                                                                                          | 2. GOVT ACCESSION NO.                                          | 3. RECIPIENT'S CATALOG NUMBER               |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                           | AD-A098264                                                     |                                             |
| 4. TITLE (and Subtitle)                                                                                                                                                                                                                                                                                                                                                                                                                                   | 5. TYPE OF REPORT & PERIOD COVERED                             |                                             |
| EXPERIMENTAL RESULTS ON VORTICITY SHEDDING<br>AT THE EDGE OF A FLAT PLATE IN TWO-<br>DIMENSIONAL FLOW                                                                                                                                                                                                                                                                                                                                                     | Interim Technical Report<br>1 May 78 - 30 Mar 80               |                                             |
| 7. AUTHOR(s)                                                                                                                                                                                                                                                                                                                                                                                                                                              | 14. REPORT NUMBER                                              |                                             |
| S. B. Spangler & R. G. Schwind, and<br>K. Owen                                                                                                                                                                                                                                                                                                                                                                                                            | NEAR-TR-2247                                                   |                                             |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS                                                                                                                                                                                                                                                                                                                                                                                                               | 8. CONTRACT OR GRANT NUMBER(s)                                 |                                             |
| Nielsen Engineering & Research, Inc.<br>510 Clyde Avenue<br>Mountain View, CA 94043                                                                                                                                                                                                                                                                                                                                                                       | N00014-78-C-0388                                               |                                             |
| 11. CONTROLLING OFFICE NAME AND ADDRESS                                                                                                                                                                                                                                                                                                                                                                                                                   | 10. PROGRAM ELEMENT, PROJECT, TASK<br>AREA & WORK UNIT NUMBERS |                                             |
| Office of Naval Research<br>800 N. Quincy<br>Arlington, VA 22217                                                                                                                                                                                                                                                                                                                                                                                          | 62241N<br>RF 41-411-801<br>NR 212-253                          |                                             |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)                                                                                                                                                                                                                                                                                                                                                                               | 12. REPORT DATE                                                |                                             |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Sep 1980                                                       |                                             |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 13. NUMBER OF PAGES                                            |                                             |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 150                                                            |                                             |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 15. SECURITY CLASS. (of this report)                           |                                             |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Unclassified                                                   |                                             |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 15a. DECLASSIFICATION/DOWNGRADING<br>SCHEDULE                  |                                             |
| 16. DISTRIBUTION STATEMENT (of this Report)                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                |                                             |
| Approved for public release; distribution unlimited.                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                |                                             |
| 17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)                                                                                                                                                                                                                                                                                                                                                                |                                                                |                                             |
| 18. SUPPLEMENTARY NOTES                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                |                                             |
| 19. KEY WORDS (Continue on reverse side if necessary and identify by block number)                                                                                                                                                                                                                                                                                                                                                                        |                                                                |                                             |
| Vorticity<br>Vortex Shedding<br>Two-Dimensional Flow                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                |                                             |
| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)                                                                                                                                                                                                                                                                                                                                                                         |                                                                |                                             |
| A two-dimensional test was performed on a flat plate normal to a low subsonic flow to investigate the relationship between the vorticity shed at an edge and the vorticity appearing in the shear layer adjacent to the edge. Both a sharp and a rounded edge were provided on the plate. A splitter plate was used to create a steady wake flow behind the plate. The measurements made were velocities in the flow field, static pressures on the model |                                                                |                                             |

DD FORM 1 JAN 73 1473

Unclassified  
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

387783

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

Block 20 (Continued)

upstream and downstream surfaces, and surface flow visualization. A laser velocimeter was used to obtain the velocity measurements. Analysis of the data was performed to calculate circulation and vorticity transport rate in the flow adjacent to the edge and vorticity transport rate of the flow separating from the edge.

|                    |                                            |
|--------------------|--------------------------------------------|
| Accession For      |                                            |
| NTIS GRA&I         | <input checked="checked" type="checkbox"/> |
| DTIC TAB           | <input type="checkbox"/>                   |
| Unannounced        | <input type="checkbox"/>                   |
| Justification      |                                            |
| By                 |                                            |
| Distribution/      |                                            |
| Availability Codes |                                            |
| Dist               | Avail and/or<br>Special                    |
| A                  |                                            |

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

## PREFACE

This technical report covers the work performed under Contract N00014-78-C-0388 from May 1, 1978 through March 30, 1980. Significant cooperation was furnished by the Ames Research Center in conducting a test program in the 2- by 2-Foot Wind Tunnel. Specifically, we wish to express appreciation to Dr. Gary Chapman for his guidance and sponsorship of the test program and Mr. Earl Keener for the conduct of the test program, both of whom are members of the NASA staff.

Dr. Robert Whitehead and Mr. David Siegel, Office of Naval Research, were the Navy Scientific Officers.

This Document Contains  
Missing Page/s That Are  
Unavailable In The  
Original Document

OR ARE  
Blank pgs.  
that have  
Been Removed

**BEST  
AVAILABLE COPY**

## TABLE OF CONTENTS

| <u>Section</u>                     | <u>Page<br/>No.</u> |
|------------------------------------|---------------------|
| LIST OF TABLES                     | 5                   |
| LIST OF FIGURES                    | 6                   |
| 1. INTRODUCTION                    | 9                   |
| 2. DESCRIPTION OF EXPERIMENT       | 10                  |
| 2.1 Approach                       | 10                  |
| 2.2 Models                         | 11                  |
| 2.3 Laser Velocimeter              | 15                  |
| 2.4 Test Conditions                | 17                  |
| 3. EXPERIMENTAL DATA               | 18                  |
| 3.1 Pressures                      | 18                  |
| 3.2 Velocities                     | 23                  |
| 3.3 Flow Visualization             | 26                  |
| 4. METHODS OF ANALYSIS             | 30                  |
| 4.1 Contour Integration            | 30                  |
| 4.2 Vorticity                      | 31                  |
| 4.3 Thin Shear Layer Approximation | 34                  |
| 4.4 Boundary-Layer Vorticity       | 35                  |
| 5. RESULTS                         | 36                  |
| 5.1 Flow Fields                    | 36                  |
| 5.2 Vorticity                      | 39                  |
| 5.3 Vorticity Transport            | 43                  |
| 6. CONCLUDING REMARKS              | 47                  |
| REFERENCES                         | 51                  |

TABLE OF CONTENTS (Concluded)

| <u>Section</u>                                                 | <u>Page<br/>No.</u> |
|----------------------------------------------------------------|---------------------|
| APPENDIX A - STATISTICAL CONFIDENCE LEVELS IN VELOCITY<br>DATA | 52                  |
| TABLES I THROUGH V                                             | 55                  |
| FIGURES 1 THROUGH 29                                           | 81                  |
| LIST OF SYMBOLS                                                | 143                 |

## LIST OF TABLES

- I. Velocity Data for Sharp Edge Model,  $M = 0.25$ ,  $Re = .063 \times 10^6$
- II. Velocity Data for Sharp Edge Model,  $M = .25$ ,  $Re = .25 \times 10^6$
- III. Velocity Data for Sharp Edge Model,  $M = 0.5$ ,  $Re = .15 \times 10^6$
- IV. Velocity Data for Round Edge Model,  $M = .25$ ,  $Re = .25 \times 10^6$
- V. Velocity Data for Round Edge Model,  $M = 0.5$ ,  $Re = .15 \times 10^6$

## LIST OF FIGURES

1. Test apparatus.
2. Pressure tap locations - sharp-edged face.
3. Pressure tap locations - round-edged plate.
4. Pressure tap locations on support plate.
5. Pressure tap location on splitter plate.
6. Laser velocimeter installation, NASA/Ames 2- by 2-Foot TWT.
7. Variation of static pressure on the model face with distance from centerline.
8. Spanwise variation of magnitude of front and rear surfaces static pressure.
9. Streamwise variation of static pressure in separated region at  $z = 0$ .
10. Unsteady pressure traces.
11. Autocorrelation results for the sharp edge model at  $M = 0.25$ ,  $Re = 0.063 \times 10^6$ .
12. Power spectral density results for sharp edge model at  $M = 0.25$ ,  $Re = 0.063 \times 10^6$ .
13. Power spectral density results for front face transducer on round edge model at  $M = 0.25$ ,  $Re = 0.25 \times 10^6$ .
14. Power spectral density results for front face transducer on sharp edge model at  $M = 0.5$  and  $Re = 0.15 \times 10^6/\text{ft}$ .
15. Positions of velocity measurement.
16. Measured velocities in the vicinity of the sharp edge model at  $M = 0.25$ ,  $Re = 0.25 \times 10^6$ .
17. Measured velocities in the vicinity of the round edge model at  $M = 0.25$  and  $Re = 0.25 \times 10^6$ .
18. Velocity histograms through shear layer at  $x/(b/2) = 0.5$ .
19. Flow visualization on round edge model.
20. Spline fit to streamwise velocity component.

LIST OF FIGURES (Concluded)

21. Spline fit to vertical velocity component.
22. Vertical velocity derivative construction for sharp edge model,  $M = 0.25$ ,  $Re = 0.25 \times 10^6$ .
23. Velocity profile and recirculation region velocity vector data.
24. Contour integration results in free stream; sharp edge model at  $M = 0.25$ .
25. Contour integration results for circulation.
26. Construction of vorticity distribution for sharp edge model at  $M = 0.25$  for  $x/(b/2) = 1.0$ .
27. Comparison of contour integration and velocity derivative results for circulation.
28. Comparison of velocity derivative and thin shear layer approximation for total shear layer vorticity.
29. Comparison of velocity derivative and thin layer approximation results for vorticity transport rate.

EXPERIMENTAL RESULTS ON VORTICITY SHEDDING  
AT THE EDGE OF A FLAT PLATE IN  
TWO-DIMENSIONAL FLOW

by

S. B. Spangler, R. G. Schwind, and K. Owen

1. INTRODUCTION

Over the last several years, the requirement for good handling qualities of high-speed fighters at high angles of attack has led to the use of strakes, or leading-edge extensions. These have relatively sharp edges which produce flow separation and a leading-edge vortex system at high angles of attack. The vortex system interacts with the wing flow field to maintain lift to considerably higher angles of attack than for a wing without a strake.

The fluid mechanics of the leading-edge separating flow, the roll-up of the shear layer into a vortex, and the influence of the vortex on the flow about the strake and wing are poorly understood. In particular, strake design for a particular aircraft development program is an empirical process involving intuition and a great deal of wind tunnel testing.

The Office of Naval Research initiated a program at Nielsen Engineering & Research, Inc. (NEAR) to make a fundamental study of the fluid mechanics of flow over strakes. The overall objectives of the program are to develop a greater knowledge and understanding of the rate of shedding of vorticity at the edge and to develop methods for predicting the shedding rate. As a part of this program, experiments have been run at the Ames Research Center, NASA, on a two-dimensional model having both sharp and rounded edges. This report describes the test program and its results.

## 2. DESCRIPTION OF EXPERIMENT

This section contains a description of the test program, including the models, instrumentation, and flow conditions. An initial discussion on the general approach is given to show the rationale for the selection of the model configuration.

### 2.1 Approach

The flow over a three-dimensional strake/body configuration at moderate to high angles of attack is a steady flow exhibiting separation along the strake leading edges and roll-up of the vorticity in the shear layers into concentrated vortices above the leading edges. An essential feature of the problem is the viscous part: the boundary layer on the windward side of the strake that contains most of the vorticity leaving the edge and the lower speed viscous flow on the leeward side that also contains vorticity leaving the edge. A full consideration of the problem involves dealing with three-dimensional turbulent boundary layer growth on the windward side and the complicated three-dimensional separated flow on the leeward side dominated by the organized flow in the main leading-edge vortex.

Since prediction of shedding rate is an important aspect of the problem, it is desirable to start with a simple case in which the boundary-layer characteristics can be predicted with reasonable certainty, at least on the windward side, in order to provide some capability to compare measured and predicted shedding rates. The case selected is a two-dimensional experiment in which a model with a flat face facing upstream was placed across a wind tunnel test section. The flat face was selected over a more typical aircraft cross section of a cylinder with strakes because the windward side flow and boundary-layer development between the windward side stagnation line and the edge is more predictable than the cylinder/strake

combination, which would probably have flow separation in the corner formed by the intersection of the strake with the cylinder.

The model was supported at the ends on glass windows through which laser beams of a laser velocimeter (LV) could pass to measure velocities adjacent to the edges. Pressure measurements were made along the windward face and, to a lesser extent, on the leeward side, to define the pressure gradients under which the boundary layer develops. A splitter plate was used on the downstream side of the plate to obtain a steady flow in the shear layer and prevent the development of an unsteady wake vortex system that would otherwise develop behind the plate. Preliminary measurements were made in the NEAR Water/Wind Tunnel to select the splitter plate length.

The models were tested in the 2- by 2-Foot Transonic Wind Tunnel at Ames Research Center, NASA. This tunnel is not highly scheduled, is used primarily for research work, has an LV system, and has been used in similar kinds of tests on flow over two-dimensional shapes. The use of the tunnel was provided through the cooperation and interest of the technical staff of the Aerodynamics Division of Ames Research Center.

## 2.2 Models

Two models were tested. The configurations are shown in figure 1(a). The models consist of three pieces: a face piece, a support plate, and a splitter plate. The latter two pieces are common to both models. The two face pieces differ in edge radius, with one being sharp-edged and one rounded as shown. The rounded one was thicker, and thus it extended forward to  $x = -0.508$  cm [see fig. 1(a)]. The face pieces were fastened to the support piece with screws countersunk into the front of the face pieces, with the depression filled with wax and

smoothed. A 5 cm (2 inch) section at the center of the 61 cm (24 inch) span of the model was left without screws to provide a smooth surface at the center of the model where the velocity and pressure measurements were taken.

The support plate (used with both face pieces) was made with a cavity within which was laid the tubing connected to the pressure taps on the front and rear parts of the model. The tubing was led out the ends of the model through small holes in the center of the windows. The aft end of the support plate was dovetailed and fastened to the splitter plate with screws, countersunk and filled.

The splitter plate was made initially of a length such that the overall model length was 30.5 cm (12.5 inches) or 6 face widths. This length was selected based on information in the literature (ref. 1) indicating the length necessary to eliminate the unsteady wake behind a flat plate normal to the stream. It was also the maximum length permitted by the location of the wind tunnel sting which was used to support the trailing edge of the splitter plate.

Initial tests in the 2- by 2-Foot Tunnel showed high vibration levels characteristic of an unsteady wake. A 50.8 cm (20 inch) length of additional splitter plate was then added to the original splitter plate when an old short sting was located, so that trailing-edge support could still be achieved. Subsequent flow visualization tests indicated reattachment to occur about 3 cm aft of the original trailing edge. The step between the original and added splitter plates due to different thicknesses was blended with Devcon to provide a smooth transition between the two thicknesses of plate.

The model was supported at both ends of the support plate with pins that fitted into existing holes in the windows. A general arrangement of the test section is shown in figure 1(b)

and a close view of the window is shown in figure 1(c). The trailing edge was supported at its center with the short sting and sting support of the tunnel. In addition the outboard trailing edges of the splitter plate were fastened to the tunnel wall with angle brackets. With the longer splitter plate, the flexibility to change the attitude of the model slightly with the sting support to ensure orienting the face at zero angle of attack was lost. However, the face pressure with the final mounting arrangement showed essentially zero misalignment.

The locations of the pressure taps on the models are shown in figures 2-5. Figure 2 shows the locations on the face of the sharp-edge model. Most of the taps are concentrated at the center of the model, Row A [fig. 2(b)]. There are 13 taps over the half-width on which the velocity measurement were made, with the most outboard tap being .19 cm (.075 in.) from the sharp edge. It was not possible to place all the taps in a single row at the midspan station because of lack of space in the thin tip section, so the taps were staggered off the centerline as shown. Several taps were placed on the other half-width to examine the asymmetry of the pressures on the face. One tap (No. 18) was placed on the downstream side of the plate near the tip. A number of taps were placed at other stations along the span to assess the two-dimensionality of the flow, as shown.

Similar information is shown in figure 3 for the round-edge plate. In this case, taps were placed around the edge as well as on the top surface, with a spacing of 15 degrees around the edge.

Two pressure taps were placed in the support plate at the center station spanwise. The locations of these two stations are shown in figure 4.

Three pressure taps were placed on the splitter plate at midspan. The locations are shown in figure 5. These taps were placed on the side on which the velocity measurements were taken. The tubes for these three pressure taps were led aft along the opposite side of the plate back to the sting and out of the tunnel.

The tubing leaving the tunnel was connected into a standard scanivalve arrangement which is part of the data acquisition system for the facility. A one-second dwell time was used with the scanivalves in stepping through the ports. The length of tubing was such that all dynamic effects were damped out, and only steady state values were obtained. A series of 12.5 psi pressure transducers were used. The pressure data acquisition process includes a pressure check before and after a test series to identify leaky or blocked pressure taps. The pressure transducer output was digitized and processed in near-real-time and displayed in the control room.

Two Kulite high-frequency-response pressure transducers were used to assess the unsteadiness of the flow around the model. One was mounted on the front face of the model about 5 cm from the midspan station and about 1 cm from the center-line of the model. The second was mounted on the support plate about midway between the two static taps 32 and 33 shown on figure 4 but 5 cm from the midspan station.

The two transducers have a diameter of 2.3 mm (.090 inch) and were mounted from the rear of the surface such that the transducer surface was recessed approximately 3 mm (0.12 inch) from the exterior of the model surface. The hole size in the model at the transducers is approximately 1.8 mm (.070 inch). The transducers were statically calibrated in the 0 to 2 psi range. The output of the transducers was recorded on an FM four track tape recorder. The frequency response of the system is limited by the recording tape drive speed to about 5 KHz.

The coordinate system for the results presented in subsequent sections is shown in figure 1. The coordinates are centered on the midpoint of the sharp-edge front face, with x positive downstream and y positive up. For the round-edge face piece, the same physical location is used, but because of the greater thickness of the face piece, the front face is located at  $x = -0.508$  cm (-0.2 inch).

### 2.3 Laser Velocimeter

Velocity measurements were made with a laser velocimeter. Figure 6 is a schematic of the laser velocimeter system designed for the Ames 2- by 2-Foot Transonic Wind Tunnel. This fringe-mode velocimeter is a dual-color system utilizing the 4880 Angstrom and 5145 Angstrom lines of an argon-ion laser. One spectral line is used to measure the streamwise velocity component, the other to measure the vertical velocity component. Bragg-cell frequency shifting necessary for probing highly turbulent and separated flow regions is incorporated in both spectral lines. The frequency offsets also facilitate the direct measurement of the vertical velocity component (i.e.,  $\pm 45^\circ$  beam orientations to resolve the vertical velocity are unnecessary).

As seen in figure 6, most of the optical components are located outside the tunnel plenum chamber, where color separation, Bragg-cell frequency shifting, and the establishment of the four-beam matrix are accomplished. Only the transmitting optics, collecting lens, and photo detectors are mounted inside the plenum chamber. Two traversing systems are shown inside the plenum chamber. The one on the opposite side of the test section from the laser holds the collecting lens and photo detectors for forward-scatter light collection. The traversing system on the laser side of the test section supports the transmitting lenses. Mirrors fixed to this traversing system

permit three-dimensional scanning of the velocimeter's sensing volume; the optics outside the plenum chamber remain stationary. Both traversing systems are driven with computer-controlled stepper motors. The effective sensing volume is approximately ellipsoidal, 200  $\mu\text{m}$  in diameter and 3 mm long, with the long axis aligned in the cross stream direction.

Signal processing was accomplished with single-particle burst counters and the individual realizations from the two channels were simultaneously recorded. The mean velocities and turbulence intensities were calculated as follows:

$$\bar{u} = \sum_{i=1}^N u_i / N \quad (1)$$

$$\bar{v} = \sum_{i=1}^N v_i / N \quad (2)$$

$$\overline{u'^2} = \sum_{i=1}^N (u_i^2 / N) - \bar{u}^2 \quad (3)$$

$$\overline{v'^2} = \sum_{i=1}^N (v_i^2 / N) - \bar{v}^2 \quad (4)$$

Naturally occurring particles in the tunnel were used for light scattering. In this facility, lubrication oil within the drive system vaporizes and then condenses in the tunnel circuit to provide a generous supply of scattering centers. Previous measurements across a normal shock have shown that these particles are small enough in size (estimated to be 1  $\mu\text{m}$ ) to give very good response to a step change in velocity at sonic speeds. At each point in the flow, generally several hundred velocity realizations were used to calculate the flow properties given in Equations (1)-(4).

An analysis was performed to evaluate the confidence level on the velocity measurements. The approach is based on Gaussian probability statistics from reference 2 and is described briefly in Appendix A. Typical results are given for measurements made in the outer flow and shear layer. The curves of figure A-1 can be used with the calculated rms velocity values in Tables I-IV to estimate confidence levels for any of the measurements.

#### 2.4 Test Conditions

The 2- by 2-Foot Transonic Wind Tunnel is a variable density tunnel having a capability of 3 atmospheres of pressure and a continuously variable Mach number range from 0.2 to 1.4. The original test plan envisioned tests of both models at Mach numbers of .25 and .5 and at least two Reynolds numbers, one of which is the highest available value. The low Mach number was selected to provide as nearly an incompressible case as the tunnel would permit and the higher Mach number was selected to introduce some compressibility into the data.

A number of difficulties occurred, including the problem with the splitter plate noted previously, which limited the number of test conditions that could be run. In addition, a tunnel dynamic pressure limitation prevented operation at high combined Mach and Reynolds numbers. As a result, data were obtained under the following conditions.

| <u>Model</u> | <u>Reynolds No.</u> | <u>Mach No.</u> |
|--------------|---------------------|-----------------|
| sharp edge   | $.25 \times 10^6$   | .25             |
| sharp edge   | $.15 \times 10^6$   | .5              |
| round edge   | $.25 \times 10^6$   | .25             |
| round edge   | $.15 \times 10^6$   | .5              |

In addition, a small amount of velocity and pressure data was obtained for the sharp edge model at  $M = .25$  and  $Re = .063 \times 10^6$ .

### 3. EXPERIMENTAL DATA

This section presents the data obtained in the experiment. Included is information on pressures, velocities and flow visualization.

#### 3.1 Pressures

The pressure data consist of steady state measurements of a number of static pressure taps, with locations as shown in section 2.1, and two high-frequency-response Kulite transducer tape records.

Representative static pressure data for the front face are shown in figure 7 for the various combinations of models and flow conditions. In each case a pressure variation is shown for the upper (positive-y) half of the face containing the greatest number of taps, and the values at corresponding points on the lower (negative-y) half are also shown. For the sharp-edge model, data are also shown for a spanwise station 2.8 half-face-widths from the midspan, which show excellent agreement with the midspan data.

Figure 7(d) shows pressure data not only on the front face but also on the rounded edge and the two static taps on the support plate. In this case the abscissa is distance along the surface rather than along the y direction, with the two being identical out to  $.875 b/2$ . In the range of  $.875 b/2$  to  $1.2 b/2$ , the angular locations are also shown, as indicated in the sketch. The location of separation as deduced from the flow visualization photographs (section 3.3) is also marked at an angle of about 45 degrees.

The pressure data in figure 7 for negative  $y$  values generally agree well with the positive  $y$  pressures, which indicates that the front surface of the model was aligned reasonably well with the normal to the flow direction.

The results in figures 7(b), (c), and (d) show pressure coefficients near  $y=0$  with values greater than unity. An explanation could not be found. The results were repeatable and are felt to be due to some aspect of the tunnel pressure data acquisition and processing system.

Spanwise variations of the static pressures at three locations on the models are shown in figure 8. The three locations are the centerline of the front face, a line along the front face at  $y/(b/2) = .4$ , and the aftmost row of static taps on the support plate in the recirculation region. The data for the sharp edge model [figs. 8(a) and (b)] are similar in that the spanwise variations along the front face are very small and the variations in the separated region are significant. In the separated region (the lower curves) the pressure coefficients are negative and show the static pressure decreasing with distance away from the centerspan of the model, which would indicate a spanwise flow away from the centerspan towards the tips of the model.

The data for the round-edge model [fig. 8(c)] show somewhat more variation across the span on the front surface and a similar behavior on the rear surface.

The streamwise variation of static pressure on the support and splitter plates is shown in figure 9. Again the two sharp edge cases [figs. 9(a) and (b)] show similar results, with pressure recovery to nearly free-stream pressure within 16 half-face-widths distance aft of the face. The round-edge results [fig. 9(c)] show a more upstream recovery which does not agree with the flow visualization results (section 3.3). The data at  $x/(b/2) = 6.5$  are believed to be in error.

Static pressure data for the round edge model at  $M = 0.5$  were not obtained because of a problem with the data acquisition system during that part of the test.

Representative traces of the unsteady Kulite transducers are shown in figure 10 for each of the five cases for the transducer in the separated region on the support plate and for one case on the front surface. A band representing a fraction of the free-stream dynamic pressure is shown on all traces, as is a time scale. On the front surface (bottom trace), the amplitude of the pressure fluctuation is less than one-half percent of  $q$ .

In the separated region, the amplitude is the order of 10 percent of  $q$ .

These unsteady pressure data were processed on electronic signal analyzer equipment to obtain autocorrelation and power spectral density information. The data tape was replayed through a variable gain and then through 18 db/octave Butterworth filters which had high and low pass settings of 1 Hz and 20 kHz, respectively. The signals were then fed into a Saicor 42A, 400 line correlator where the auto and cross correlation functions, defined as

$$R_{xx} = \lim_{T \rightarrow \infty} \frac{1}{T} \int_0^T P_x(t) P_x(t + \tau) dt$$

and

$$R_{xy} = \lim_{T \rightarrow \infty} \frac{1}{T} \int_0^T P_x(t) P_y(t + \tau) dt$$

were determined, where  $\tau$  is the time delay. Spectra were obtained using a Honeywell SAI 52C, 400 line real time spectrum analyzer in the form

$$\psi_P^2 [f, f + \Delta f] = \lim_{T \rightarrow \infty} \frac{1}{T} \int_0^T P_X^2(t, f, \Delta f) dt$$

where  $\Delta f$  is the frequency range of each line. Some typical results are shown in figures 11-14.

Figure 11 shows autocorrelation coefficients as a function of time delay for the sharp-edge model at  $M = 0.25$ . For zero time delay the correlation coefficient by definition is unity, and it drops off with increasing time delay. For the transducer on the front face [fig. 11(a)] there is a distinct periodic content to the pressure fluctuation which occurs with a frequency of about 500 Hz and shows 10 cycles in the 20 millisecond sampling time. There may also be a periodic content with a frequency of about 60 Hz, but the sampling time was not sufficiently long to verify this. The transducer in the separated region on the support plate [fig. 11(b)] does not exhibit the 500 Hz content, but is more characteristic of a turbulent flow with a wide spectrum of frequencies. This difference in behavior between front and rear transducers was typical of all the cases examined.

The power spectral density results for the same test case are shown in figure 12. In this case both the front and rear transducers show a distinct energy content in the flow at about 500 Hz, with probably a harmonic at about 1000 Hz. The front transducer energy peak at 500 Hz is about the same as that of the low frequency energy, whereas the rear transducer energy peak at 500 Hz is about 12 db below the low frequency value, or about 1/16 the energy in the low frequency flow. The low energy level is probably responsible for lack of any noticeable frequency content in the autocorrelation.

Figure 13 shows the power spectral density results for the round edge model at the same Mach number. Again there is a peak

at about 500 Hz with a smaller peak at 1000 Hz. There is a small peak at about 5 kHz which is typical of the round edge model results, although the energy level at this frequency is very low. The peak at 9.5 kHz did not appear in most of the power density curves and is probably due to some source of spurious noise or signal in the tape.

Figure 14 shows power spectral density results for the sharp edge model at  $M = 0.5$ . There is a major source of energy at about 1000 Hz, with some harmonics at higher frequencies. Again, the 1000 Hz peak is typical of all of the  $M = 0.5$  results for both sharp- and round-edge models.

A Strouhal number was calculated for each of the two Mach numbers based on the two frequencies noted above, the free-stream velocity, and width of the front face of the model. The results are as follows:

$$\text{for } M = 0.25, St = \frac{fb}{V} = .299$$

$$\text{for } M = 0.5, St = .297$$

The results of the tests done by Fage and Johansen (ref. 3) for a sharp edge flat plate normal to the flow show a Strouhal number of 0.146 based on the frequency with which a vortex of one sign is transported in the wake behind the model. The Fage tests did not employ a splitter plate and the wake developed a definite periodicity, as in the wake behind a cylinder. If the Fage value is doubled to account for a complete cycle of shedding, the agreement with the Strouhal number based on the power spectrum frequencies is very good.

### 3.2 Velocities

All velocity measurements were made at the midspan station ( $z = 0$ ). The two components measured were the axial ( $u$ ) and the vertical ( $v$ ) velocity. The data acquisition rate varied considerably during the tests, depending on the density level in the tunnel and the power output of the drive system, both of which influenced the amount of oil leakage from the drive system which provided the seeding particles for the flow. The range of data rates (scattering particles crossing the measurement volume) were several counts per second to about 500 counts per second. For the data in the outer flow and shear layer, a sufficient sampling time was allowed to obtain several hundred counts at a given point. In the low velocity recirculation region, the data rates were much lower and as few as 50 counts were obtained in some cases. In general, the data acquisition rate was not sufficiently high to resolve any motion of the shear layer behind the model.

The data were acquired and processed by a HP 9830 computer, which calculated the average and rms values of the two velocity components. Both the raw data and the calculated values were recorded on floppy-disk magnetic storage which could be accessed for later processing. Also recorded in the computer were potentiometer outputs indicating the position of the measurement volume in model coordinates. The computer was also used to drive the optics to position the measurement volume through stepper motors. A position calibration was done before and after a series of LV measurements.

The positions of the velocity measurements for the models and flow conditions are shown in figure 15. Each dot represents a position at which LV measurements were obtained. In some cases, repeat measurements were made, which are indicated by two or three dots close together, side by side. The dashed

lines in these figures represent the approximate boundary of the shear layer, as deduced from the velocity measurements.

The tabular data for velocities are listed in Tables I through V. The listing consists of a point number, the two coordinates of the point, the average values of the two velocity components, and their rms values.

Some typical plots of variations of the velocity components with distance are shown in figures 16 and 17. Figure 16 shows  $u$  and  $v$  velocities for the sharp-edge model. The  $u$  profile in figure 16(a) is shown at  $x/(b/2) = 0.5$ , which is relatively close to the edge where the shear layer is rather thin. There is a small negative velocity in the recirculation region, a very steep gradient in the shear layer, and a small overshoot at the outer edge of the layer. Some repeat points are shown on the plot indicating small differences except at  $y/(b/2) = 1.4$ . If the shear layer is moving slightly, or if the LV measurement volume is not in exactly the same place, the differences in repeat data would be larger in the high gradient region than outside the shear layer.

The  $v$  curves are shown in figure 16(b): one close to the tip at  $y/(b/2) = 1.1$  where the shear layer is very thin and one further from the tip at  $y/(b/2) = 1.6$ . These curves should show zero values far upstream and downstream ( $x \rightarrow \pm\infty$ ) with high values only in the vicinity of the edge. The magnitudes and gradients near  $y = b/2$  are much greater than those further from the edge, although in both cases there is a large change in velocity through the outer edge of the shear layer.

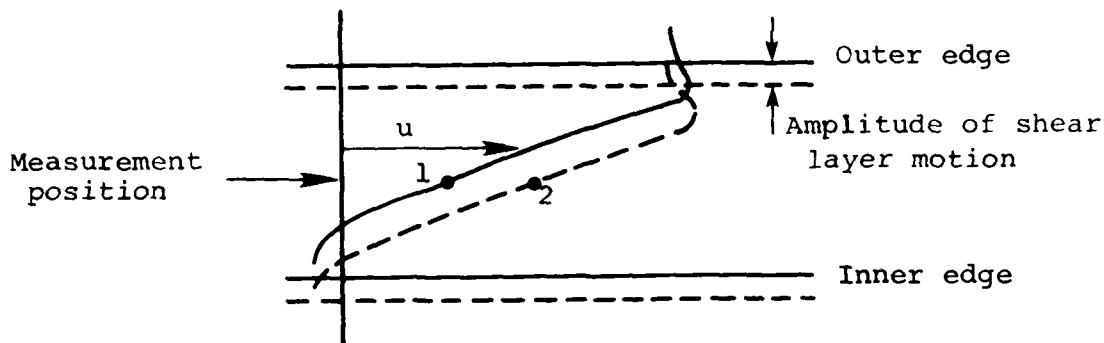
Some results for the round-edge model are shown in figure 17. Figure 17(a) shows three sets of  $u$  data: two very close to the edge and one well downstream of the edge. The data for  $x/(b/2) = -0.1$  are upstream of the shear layer and do not show the high gradients of the shear layer edge, whereas the

data for  $x/(b/2) = +0.1$  do show the steep gradient. The repeat data show reasonably good agreement. The vertical velocity variations shown in figure 17(b) indicate a sharp gradient near the edge as in the sharp edge model, but the gradients at  $y/(b/2) = 1.6$  are less severe than in the sharp-edge case.

Some examples of repeat data were shown in figures 16 and 17. The repeatability was generally quite good except in regions of high velocity gradient. In the experiment, a vertical scan of the LV system was made along constant  $x$  lines, and generally the repeat points were taken at a different time in the experiment. In processing and analyzing the velocity data, the sequence in which the velocity measurements were taken was taken into account in selecting the duplicate points to be deleted, and those points were retained which represent a systematic sweep in  $y$  at one time in the experiment. The points which were dropped are marked in the data presented in Tables I-V.

In order to get some insight into the unsteadiness of the shear layer, some histograms of the velocity measurements were examined. Some typical results are shown in figure 18. These are plots of the number of occurrences of a given velocity as the measurement volume sits at a given point in the flow, nondimensionalized by the number of occurrences of the most frequently observed velocity. Figure 18(a) shows  $u/V$  and  $v/V$  data for the sharp edge model at three vertical locations: one at the inner edge, one in the center, and one at the outer edge of the shear layer. Typically, the inner and outer edge data show relatively sharp peaks and narrow widths, whereas the center data show a broader curve.

If the shear layer were oscillating with some amplitude about a measurement point, as shown in the sketch below, the



histogram would tend to show two peaks with velocities at values 1 and 2. The top center curve of figure 18(a) tends to show this behavior, with peaks at .15 and .40. If one uses the appropriate mean velocity curve [similar to that of figure 16(a)] to calculate the amplitude of motion required to change the velocity at the measuring point from .15V to .40V, the resulting value is .38 mm (.015 inch), which is 1.5% of the model half-width.

The round edge model histogram data are shown in figure 18(b). Qualitatively, these show the same trends, except the second peak for the  $u$  velocity in the shear layer is much lower than the first peak. Probably the velocity fluctuations at a given point are due to a combination of small, shear-layer position variations and turbulence in the flow.

### 3.3 Flow Visualization

Surface flow visualization was performed on both the sharp edge and round edge models at the completion of the velocity data acquisition periods. A mixture of carbon black, oil, and kerosene was "painted" on the top and front surface of the models and the models were run about 15 minutes at the low

Mach number flow condition, at which time the oil pattern had dried. Photographs were then taken of the flow patterns on the surface. Qualitatively, the surface flow patterns on both the sharp and round edge models were very similar. Because of the short time available for the model change from the sharp to round edge configuration, more detailed photographs were obtained of the round edge configuration, and these are included with this report as figure 19.

An overall view of the top of the plate is shown in figure 19(a). The edge of the face piece is just in view at the top of the photograph and the flow direction is top to bottom. The straight horizontal line across the model near the face piece edge at the top of the photograph is the parting line between the support plate and splitter plate. The dark horizontal band near the center of the photograph is the devcon blending between the original splitter plate and the added, thicker plate. The tubing for the static pressure tap for the underside of the splitter plate is on the lower part of the photograph and the fitting for the trailing-edge sting support is seen at the bottom.

It is clear that the flow in the low speed recirculating region is not two dimensional. The white dashed ink line across the plate is the approximate reattachment line and the aft boundary of the recirculating region. The flow that leaves this line has an inboard component for both the forward moving recirculating flow and the aftward-moving attached flow.

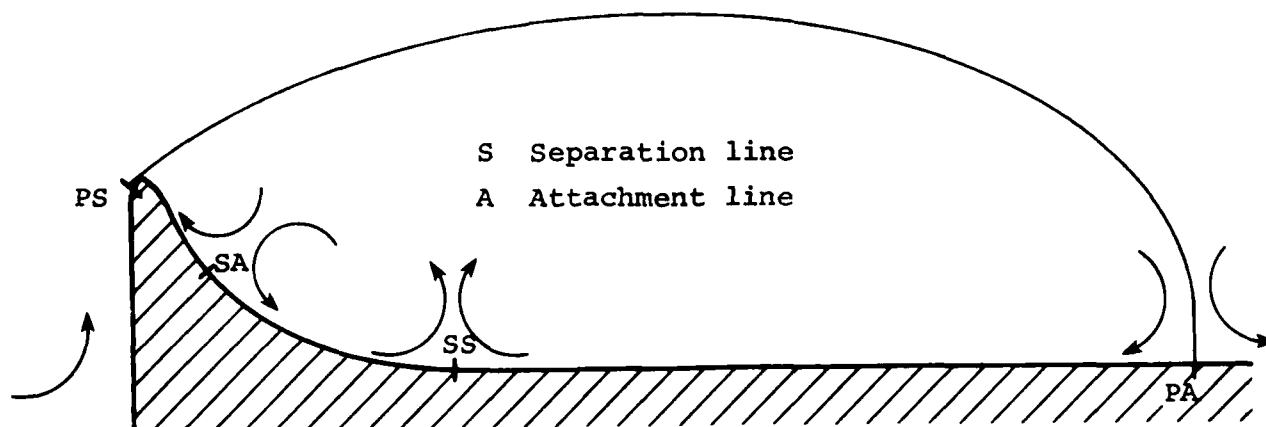
As the recirculating flow moves forward towards the front edge, it approaches a secondary separation line located approximately at the parting line between the splitter and support plates. The white ink arrow in the upper left corner indicates the location of this line.

The remaining major feature of the flow shown is a pair of vortices (the dark spots), one at each end (spanwise) of the plate close to the top of the photograph, at the ends of the secondary separation line. These were caused by the interaction of the flow over the model with the tunnel side-wall boundary layers passing over the windows. These vortices effectively acted as a sink for the recirculating flow.

Figure 19(b) shows a close up photograph of the secondary separation line at the center span of the model. This region is near the top center of figure 19(a). In figure 19(b), the edge of the face piece is along the left side of the photograph, and the free-stream flow direction is from left to right. The two straight vertical lines are the parting lines between the face piece, support plate, and splitter plate. The center span of the model ( $z = 0$ ) is very close to the horizontal dashed line near the center of the photograph. The forward moving recirculating flow moves from right to left and approaches a secondary separation line, shown by the white vertical dashed ink lines. At the center, spanwise, of the model, the flow stagnates and leaves an accumulation of carbon black. Away from the center, the surface flow turns rapidly to form a three-dimensional separation line (the vertical dashed ink lines).

This figure also shows a secondary reattachment line along the left side of the figure which coincides very closely with the parting line between the face piece and support plate. The curved white ink lines near the left edge of the photograph help show the surface flow directions in the secondary recirculation region.

The flow pattern at center span that is implied by these surface flows is shown in the sketch below. Primary separation (PS) occurs at the edge and forms a large recirculation region,



with primary reattachment (PA) well aft on the splitter plate. As the recirculating flow moves forward, it approaches a secondary separation line (SS). There is a corresponding secondary reattachment line (SA) just downstream of the edge and a secondary recirculation flow between SA and SS.

Figure 19(c) shows an enlarged view of the round edge of the face piece. The orientation is the same as in figure 19(b), with the free-stream flow direction from left to right. The left half of the photograph shows the surface flow pattern on the front surface of the face piece and indicates a two-dimensional flow approaching the edge. The flow visualization results for both the sharp and round edge models showed a two dimensional flow over the entire span of the model. The right half of the photograph (out of focus) shows the rear curved surface of the face piece and the parting line between the face piece and support plate. The primary separation line shows as a vertical line near the center of the photograph. In the lower center of the photograph are seen the static pressure taps near the edge [fig. 3(a)]. The white ink arrow points to the tap 45 degrees around the edge, which is closest to the separation line. This tap location is also shown on figure 7(d) as the location of separation. The spanwise length of edge in view in this photograph is about 6 cm (2.5 inches).

These results indicate that the attached flow on the front of the model is two dimensional, the flow in the recirculation region is largely three dimensional, and the surface flow at mid-span, which is where the velocity measurements were made, lies in a plane of symmetry normal to the span which divides the recirculating flow into two regions that have spanwise velocity components directed outward towards the two ends of the model.

#### 4. METHODS OF ANALYSIS

Several methods of analysis were used to evaluate the velocity data. These are discussed in this section.

##### 4.1 Contour Integration

The circulation around any closed contour in the flow can be calculated by the following expression

$$\frac{\Gamma}{bV} = \frac{1}{bV} \oint \vec{V}_s \cdot d\vec{s} \quad (11)$$

This calculation was made for a number of contours, mostly consisting of a streamwise length  $\Delta x/(b/2)$  of 0.1 and a height sufficient to cover the shear layer. Some calculations were also made in the flow upstream of the model to determine the circulation in the tunnel flow approaching the model.

In addition to the circulation, the net flow into the same contours was calculated according to the following expression

$$\frac{Q}{bV} = \frac{1}{bV} \oint \vec{V}_s \cdot \vec{n} ds \quad (12)$$

The purpose of making these net flow calculations was to assess the accuracy of the velocity data used in the contour integrations for circulation [Eq. (11)], since the net flow through a contour ought to be zero.

#### 4.2 Vorticity

The vorticity at a point in a two dimensional flow can be calculated as

$$\frac{\zeta(b/2)}{V} = \frac{\partial(v/V)}{\partial\left(\frac{x}{b/2}\right)} - \frac{\partial(u/V)}{\partial\left(\frac{y}{b/2}\right)} \quad (13)$$

In order to calculate the velocity derivatives, two approaches were used. In the first, the velocity data were spline-fitted to obtain an analytical expression that could be differentiated to get the derivatives required in Equation (13).

In general, this procedure worked well for the streamwise velocity component ( $u$ ), but in many cases the vertical velocity derivatives were not satisfactory. Typical examples are shown in figures 20 and 21. Figure 20(a) shows a computer-generated plot of the  $u$  variation with  $y$  and 20(b) shows the resulting derivative variation determined from the spline fit. The results show the steep gradient in velocity through the shear layer, the overshoot at the outer edge of the shear layer, and the large derivative values. The gradients in velocity are largest near the edge of the layer and decrease with increasing distance downstream along the shear layer.

Figure 21(a) shows the  $v$  variation with  $x$  and figure 21(b) shows the resulting derivatives, as evaluated from the spline fit. Typically the  $v$  component is small in the upstream flow, rises in the flow near the edge, reaches a peak at the outer edge of the shear layer and falls very rapidly through the

outer part of the shear layer to essentially zero at the inner edge of the shear layer. Generally, the  $v$  variations with  $x$  were not as smooth as the  $u$  variations with  $y$ , which are reflected in the derivative calculations, as shown in figure 21(b).

Various types of spline-fit codes were used with the velocity data, and the free parameters used to control the fit and the smoothing were varied to attempt to obtain a satisfactory analytical description of the velocity derivatives. This procedure proved successful generally only for the  $u$  derivatives, and the values used were the spline-fit results. For most of the  $v$  velocities, the plot and crossplot approach described below was used.

In order to obtain a smooth and systematic set of  $v$  component derivatives, the  $v$  velocity data were plotted by hand. Figure 22 shows some results of a sequence of plots to obtain values of the  $v$  derivative at  $x/(b/2) = 0.5$  for the sharp edge model. Generally, the spatial distribution of data [fig. 15(b)] favored initial plots of  $v/V$  versus  $y/(b/2)$ , as shown in figure 22(a). These were then used with the data to obtain smoothed plots of  $v/V$  versus  $x/(b/2)$  for constant values of  $y/(b/2)$  and to interpolate for intermediate  $y/(b/2)$  values where no data were available [fig. 22(b)]. In cases where no intermediate  $y$  data were obtained, linear interpolation was used. The slopes were obtained graphically to construct a curve of the  $v$  derivatives versus  $y/(b/2)$ , as shown in figure 22(c).

The results of these calculations are values of the vorticity at various  $y$  values through the shear layer at a series of axial stations downstream of the front face. These

values were then used in the following way. An "integrated value of vorticity" through the shear layer was obtained from the following expression

$$\frac{\gamma}{V} = \int_1^2 \left( \frac{\zeta(b/2)}{V} \right) d \frac{y}{b/2} \quad (14)$$

where the stations 1 and 2 are the inner and outer edges of the shear layer, respectively. The inner and outer edges were taken (approximately) as the points where  $\partial u / \partial y$  were zero. At the outer edge, the second zero slope point beyond the overshoot was used.

For purposes of comparison with the circulation values obtained from the contour integrations, and "average vorticity" was calculated from the velocity derivative data at the various axial stations considered, as follows.

$$\frac{\Gamma}{bV} = \frac{1}{2} \iint \frac{\zeta(b/2)}{V} d \left( \frac{y}{b/2} \right) d \left( \frac{x}{b/2} \right) \cong \frac{\Delta \left( \frac{x}{b/2} \right)}{2} \frac{\gamma}{V} \quad (15)$$

where  $\Delta \left( \frac{x}{b/2} \right)$  is typically 0.1, which is the spacing used in the data acquisition and the streamwise width of the strip used for the circulation contour integrations.

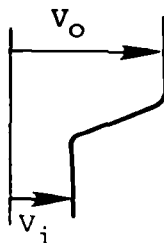
Finally, a streamwise rate of transport of vorticity over the height of the shear layer past a given axial station was calculated from the following expression

$$R = \int_1^2 \left( \frac{u}{V} \right) \frac{\zeta(b/2)}{V} d \left( \frac{y}{b/2} \right) \quad (16)$$

where again the stations 1 and 2 are the edges of the shear layer, as before.

#### 4.3 Thin Shear Layer Approximation

For a thin shear layer in parallel flow with a velocity profile shown in the sketch below, the vorticity can be



expressed in terms of the outer and inner velocities as

$$\frac{\gamma}{V} = \frac{V_o}{V} - \frac{V_i}{V} \quad (17)$$

and the rate of transport of vorticity as

$$R = \left[ \frac{V_o + V_i}{2V} \right] \frac{\gamma}{V} \quad (18)$$

As an approximate check on the vorticity calculations made with the velocity derivatives, "thin shear layer" quantities were calculated at various x stations using for the outer and inner velocities the vector sum of the u and v velocities at the outer and inner edges of the shear layer in Equation (17) and using that vorticity with the u components in the transport equation, Equation (18), to get the streamwise transport rate.

#### 4.4 Boundary-Layer Vorticity

A boundary layer is developed on the upstream surface of the model. As this boundary layer leaves the surface at the edge or at the separation point on the round edge model, its vorticity is convected into the shear layer. The rate of transport of this upstream surface vorticity is given by the following:

$$R = \int_0^1 \left( \frac{u}{v} \right) \frac{\partial u / V}{\partial y / \delta} d \left( \frac{y}{\delta} \right) = \frac{1}{2} \left( \frac{u_\delta}{V} \right)^2 \quad (19)$$

Further, the edge velocity  $u_\delta$  is related to the local static pressure. For incompressible flow, the relation is simply expressed as

$$C_P = 1 - \left( \frac{u_\delta}{V} \right)^2 \quad (20)$$

At a free-stream Mach number of .25, the compressibility correction is small and can be neglected. At  $M = .5$ , the correction on  $u_\delta$  is about 2 percent and may be included using the isentropic gas relations instead of Equation (20) to calculate  $u_\delta$  from the measured  $C_P$ .

For the sharp-edge model, the pressure tap closest to the edge is at  $y/(b/2) = .965$ . The pressure coefficient is changing rapidly, however [fig. 7(b)]. The static pressure was measured on the rear surface a short distance from the edge (see fig. 4), and it seems reasonable to expect that this rear surface pressure is very close to the rear surface pressure right at the edge, because of the low velocities in the recirculation region. For the sharp edge, there should be no pressure difference across the edge. Thus, the pressure used in

Equation (20) to calculate the shedding rate in Equation (19) is the rear surface pressure at tap number 18. For the round edge model, the location of separation at  $M = .25$  is known from the flow visualization, and the measured pressure at separation is used in Equations (19) and (20).

The average of several sets of pressures taken at each flow condition was used to calculate the shedding rate from Equations (19) and (20).

## 5. RESULTS

The results of the measurements and data analysis are described in this section, together with some discussion of the results. The presentation considers flow fields, vorticity, and vorticity transport.

### 5.1 Flow Fields

The flow fields are generally similar for both models and both Mach numbers. Plots of the velocity results are shown in figure 23. The velocities within the recirculation region are shown as vectors, with the tail of the vector at the measurement location, and the length and direction representing the magnitude and the direction of the measured velocity. The u component velocity data in the shear layer and outer flow are shown as profiles to illustrate the development of the shear layer. Some data, both in vector and profile form, are shown for the onset flow approaching the front surface. Note that the scale (upper left corners) is different by a factor of 5 between the velocity profile data in the shear layer and the vector data in the recirculation region, with the latter magnified because of the very low velocities there.

In order to gain some insight into flow ingestion into the shear layer, some analysis was made on the flow field data for the round edge model at  $M = 0.25$ . The data are those of figure 23(c). It is necessary to start at the wall on the downstream side of the model and analyze the flow, working toward the shear layer. First, it is known from the surface flow visualization that there is a secondary separation line at  $x/(b/2) = 2.1$  and a secondary reattachment line at  $x/(b/2) = 0.1$  (at the spanwise model center,  $z = 0$ ). These are marked S and A, respectively in figure 23(c). The location of the boundary of this secondary recirculation region cannot be determined precisely because the LV system could not acquire data close to the model. A "nominal" dashed line approximately parallel to the measured vectors is shown connecting S and A in figure 23(c). In a two-dimensional flow, the flow between this dashed line and the model is a recirculating flow which would not enter the main shear layer. From the carbon black flow visualization previously described, it is known that there is some flow spanwise out of this region. This spanwise flow must be balanced by ingestion from the fluid in the primary recirculation region across the dashed line.

The short dashed line well above the A-S line is the  $u = 0$  line in the shear layer. The flow between this line and some location within the secondary recirculation region is the forward moving recirculating flow, and that outside (above) the line is aft moving.

The recirculating flow rate moving forward between the wall and the  $u = 0$  line at  $x/(b/2) = 2$  was divided into four equal parts. In order to do this, the  $u$  velocity profile was extrapolated to zero at the wall. An attempt was then made at other  $x$  stations to integrate the flow starting at the wall and find the heights ( $y$  dimensions) encompassing the same four equal parts of the flow rate determined at  $x/(b/2) = 2.0$ . At the  $x/(b/2) = 2.55$  station, the heights marked A, B, C, and D were

determined. Again the  $u$ -velocity profile was extrapolated to zero at the wall. Thus, the four solid lines marked A, B, C, and D between  $x/(b/2)$  of 2.0 and 2.55 become streamlines of the recirculating flow.

Forward of the  $x/(b/2) = 2.0$  station, the same calculation process becomes dependent on the assumed boundary of the secondary recirculation region (the dashed line connecting S and A). The same procedure was used at  $x/(b/2) = 1.6$ , based on extrapolating the  $u$ -velocity profile to zero at the dashed line  $[y/(b/2) = 0.25]^*$ . The solid lines were then extended forward to  $x/(b/2) = 1.6$ , as shown. This result shows that the flow between streamlines C and D all enters the shear layer between  $x/(b/2)$  of 1.6 and 2.0, and the flow between the wall and C enters the inner part of the shear layer upstream of  $x/(b/2) = 1.6$ .

A similar calculation was made at  $x/(b/2) = 0.4$ , using the assumed location of the secondary recirculation boundary shown in figure 23(c)  $[y/(b/2) = 0.70]$ . The forward moving rate of flow between  $y/(b/2) = .70$  and the  $u = 0$  line is about 90 percent of the flow rate between the wall and streamline A at  $x/(b/2) = 2$ , which indicates that streamline A would intersect the  $u = 0$  line somewhat aft of  $x/(b/2) = 0.4$ .

Another calculation that can be made is to compute, for a given  $x$  station, the  $y$  coordinate in the shear layer at which the aft moving flow rate above the  $u = 0$  line equals the forward moving recirculating flow rate from the  $u = 0$  line down to the wall (or boundary of the secondary recirculation region). This calculation would indicate the relative proportion of the flow in the shear layer that is composed of ingested recirculation flow, as opposed to ingested free-stream flow. This was done for  $x/(b/2)$  values of 0.4, 1.6, 2, and 2.55, and

---

\*The  $u$  value goes to zero somewhat below this dashed line, but as an approximation, the dashed line location was used.

the results are shown by the long dashed line in figure 23(c) noted "dividing streamline." The position of this curve between .4 and 1.6 is faired from the four calculated points.

At  $x/(b/2) = 0.4$ , the "dividing streamline" occurs at the point in the shear layer at which  $u/V = 0.5$ , at which point about 15 percent of the shear layer flow is ingested from the recirculation region. At  $x/(b/2) = 2.0$ , the "dividing streamline" occurs at  $u/V = .8$ , at which point about 50 percent of the flow is ingested from the recirculation region.

These results are only approximate. The lack of velocity data near the wall limits one's ability to define the secondary recirculation region boundary precisely, and the measured velocities are very small and have relatively large fluctuating components (Tables I-IV). Nevertheless, the assumptions made appear reasonable and do give useful information on the ingestion aspects of the shear layer flow.

## 5.2 Vorticity

Some contour calculations for circulation in the flow upstream of the model were made for the sharp-edge model at  $M = 0.25$  to examine the character of the onset flow. The relationship used is Equation (11). The results are shown in figure 24, which show the contours as dashed lines. The calculated values near the center of the flow upstream of the model face show positive and negative values in adjacent contours. The velocities are relatively small and the continuity check performed on these contours in accordance with Equation (12) show very large flow imbalances (a net flux as high as 60 percent of the inflow), because of measurement uncertainties and spacing of the measurement locations. Consequently, these circulation values should only be viewed in a qualitative manner to indicate the vorticity content in this region of the flow.

The results at  $x = 0$  off the tip of the model are self consistent, and the continuity checks on these contours show net flows of the order of one percent of the inflow. The circulations in these contours are the order of 5 percent of the values in the contours through the shear layer, one of which is shown on the right side of the figure and are of the same sign. This vorticity in the upstream tunnel flow may result from an unused probe support structure in the plenum section of the tunnel. This structure sheds a wake which is about in the correct position for flow passing through the contours off the tip of the model. To our knowledge, no tunnel-empty flow surveys have been made in this tunnel to confirm or deny the presence of vorticity in the test section flow.

Contour integrations for circulation in the shear layer were made at a number of axial stations along the shear layer for all test cases. For the most part, the contours used covered an axial distance  $\Delta x/(b/2)$  of 0.1 and a lateral distance extending across the shear layer from the point (approximately) where  $\partial u/\partial y = 0$  on the inner side to the point beyond the overshoot where  $\partial u/\partial y = 0$  at the outer edge [see fig. 16(a) for a typical  $u$  profile]. One such contour is shown in figure 24. The value of the circulation is ascribed to the axial location of the midpoints (axially) of the contour. A summary of results for all cases is shown in figure 25.

There is a fair amount of scatter in all cases except the sharp-edge model at  $M = 0.5$ . A line has been drawn through these data to indicate the trend with axial distance.

Continuity checks using Equation (12) were made on all these contours to evaluate the circulation calculations. The contours for  $x/(b/2) < 0.3$  showed net flows through the contour as high as 30 percent of the inflow. In this region, the shear

layer is very thin and the grid spacing of the velocity data was not small enough to resolve the velocities well.

For the sharp-edge model at  $M = 0.25$ , the two adjacent contours centered at  $x/(b/2) = 0.85$  and  $0.95$  showed flow imbalances of +15 and -19 percent, respectively. The circulation values for these contours (fig. 25) are  $-.0855$  and  $-.063$ , respectively. This result would indicate some problems with the measured velocities at  $x/(b/2) = 0.9$ , which are used with both contours.

The continuity checks for all other contours indicated flow imbalances of only a few percent of the inflow. In particular, the flow imbalances for the sharp-edge  $M = 0.5$  case, which had the greatest consistency in circulation, were no different than the other cases.

The averages of the circulation values for each of the four cases are shown on the right side of figure 25. The values are very close and do not show any trend with respect to Mach number or edge radius.

Three data points are shown from the work of Fage and Johansen (ref. 3). Their model was a sharp-edge flat plate of about the same face width-to-length ratio as the present model, spanning a low speed tunnel, but had no splitter plate. The contours used by the authors were longer streamwise, so their circulation values were reduced by the axial length ratio to correspond to  $\Delta x/(b/2) = 0.1$ . The Fage data have the same level as the present data. No measurements were made further downstream by Fage, because of the unsteadiness associated with the periodic wake development.

Figure 26 shows some typical results for velocity and the construction of the velocity derivatives and vorticity at an axial station  $x/(b/2) = 1.0$  for the sharp edge model. The velocity data are shown in figures 26(a) and (b). In order to

obtain the  $v$ -velocity derivatives at various  $y$  values, it was necessary to plot  $v/V$  versus  $x/(b/2)$  at as many  $y$  stations as the data permit, as shown in figure 26(b), and interpolate on velocities to get derivative values at intermediate  $y$  values. Generally, the gradients in velocity are most severe near the model tip, and the greatest uncertainty in their determination occurs there. Also, the  $u$ -velocity profiles were more easily defined [fig. 26(a)] than the  $v$ -velocity profiles [fig. 26(b)]. As is shown in figure 26(c), the  $u$ -velocity derivatives are generally larger than the  $v$ -velocity derivatives, so the greater uncertainty in the  $v$  derivatives does not carry over directly into the vorticity calculation. The vorticity distribution is shown in figure 26(d). The (negative) vorticity is highest in the high  $u$ -gradient region, and there is a small region of positive vorticity in the overshoot region at the outer edge of the shear layer. The rate of transport of vorticity, figure 26(e), is generally similar to the vorticity distribution but more peaked.

Some additional results for circulation are shown in figure 27. In this case, a circulation is calculated from the velocity data using Equation (15) by first calculating velocity derivatives and vorticity at various  $y$  values through the shear layer for a given  $x$  value, and dividing by the area of the contour to obtain an "average vorticity" for comparison with the contour integrations. In the results shown in figure 27, the two values of contour integration circulation on either side of a given  $x$  station are averaged to obtain a single value of circulation for comparison with the velocity derivative value at that  $x$  station. In almost all cases, two sets of values agree within a few percent, with the velocity derivative values smaller than the contour integration values. Fage and Johansen (ref. 3) found nearly identical results with respect to agreement between the two sets of values for their experiment.

Some results for integrated vorticity are shown in figure 28. The results using the velocity derivative data were calculated using Equation (14), and the "thin shear layer" results were obtained using Equation (17). The two sets of results show the same trends with  $x$  distance, although the thin shear layer approximations are 10 to 15 percent lower than the velocity derivative results.

### 5.3 Vorticity Transport

Vorticity transport rate was calculated in three ways. First, the rate at which upstream boundary layer vorticity leaves the separation point at the edge of the model was calculated in accordance with the discussion of section 4.4. This shedding rate depends only on the static pressure at the point where the boundary-layer flow leaves the surface. For the three cases where pressure data are available, the pressure coefficients at separation are the following:

| <u>Edge Condition</u> | <u>M</u> | <u>C<sub>p</sub> (separation)</u> |
|-----------------------|----------|-----------------------------------|
| Sharp                 | 0.25     | -.60                              |
| Sharp                 | 0.5      | -.50                              |
| Rounded               | 0.25     | -.59                              |

In the low Mach number cases, the effect of compressibility is negligible and the incompressible relationship between pressure and boundary layer edge velocity was used [Eq. (20)]. At  $M = 0.5$ , there is some effect of compressibility, and the isentropic gas relations were used.

The second method used to calculate transport rate is Equation (16). This method makes use of the velocity derivatives to calculate vorticity and its transport rate at various axial stations along the shear layer.

The third method is the thin shear layer approximation described in section 4.3.

The results of these calculations are shown in figure 29. The thin shear layer results show the same trend with  $x$  as the velocity derivative results, but are consistently lower in value by 10 to 20 percent. These results are very similar to those of Fage and Johansen (ref. 3), who found differences of 8 to 15 percent between the two sets of results. The upstream surface boundary-layer shedding rate results are shown as straight lines indicating the level of shedding.

Nearest the model edge [ $0.2 < x/(b/2) < 0.4$ ] the transport rate based on velocity derivatives is approximately 80 percent of the edge shedding rate. The low value of 0.4 at  $x/(b/2) = 0.2$  for the sharp edge model at  $M = 0.5$  appears inconsistent with the data at larger  $x$  values and is probably due to the lack of accuracy in calculating the velocity gradients near the edge where the shear layer is very thin and the gradients high.

One possible reason for the result that the shear layer vorticity transport rate just downstream of the edge is only 80 percent of the calculated rate being shed from the upstream model surface at the separation point on the edge is that vorticity of an opposite sign is being transported into the shear layer from the flow along the rear surface of the model. This vorticity is generated at the wall in the forward moving recirculating flow. Some calculations were made for the round edge model at  $M = 0.25$  in the following way.

The flow field is that of figure 23(c). The velocity data at  $x/(b/2) = 0.4$  were used in Equation (16) to obtain a vorticity transport rate for the forward moving recirculation flow between the  $u = 0$  line at  $y/(b/2) = 1.28$  and the edge of the secondary recirculation region at  $y/(b/2) = 0.7$ . The  $u$ -velocity

were extrapolated to  $u = 0$  at  $y/(b/2) = 0.7$ . The resulting transport rate of the vorticity of positive sign forward through this  $x$  station is calculated to be  $R = 0.007$ , which is about 1 percent of the rate in the shear layer.

To this value must be added the (positive) vorticity which is produced at the wall between the secondary attachment line ["A" in fig. 23(c)] and the separation line for the forward moving flow, which is close to the line at the tip where the forward surface boundary layer separates. As a means of estimating this contribution, the velocity measurements nearest the surface were used as an indication of the velocities in the region just aft of the primary separation line. Figure 15(d) shows the locations of the following velocities.

| $x/(b/2)$ | $y/(b/2)$ | $u/V$ | $v/V$ | $\sqrt{u^2 + v^2}/V$ |
|-----------|-----------|-------|-------|----------------------|
| 0         | 1.025     | -.11  | .032  | .115                 |
| .1        | 0.95      | -.075 | .027  | .08                  |
| .2        | 0.8       | -.026 | -.001 | .026                 |

The surface pressure in this region is relatively uniform [fig. 7(d)]. If one assumes that a boundary layer on the rear surface separates with a local edge velocity  $u_\delta/V = .115$  and a shedding rate is calculated from Equation (19), the rear surface contribution is .007, which is also about one percent of the front surface rate, and the sum of these two effects is .014. Thus, these two rear surface contributions do not appear to be responsible for much of the 20 percent difference between the calculated front surface rate and the measured shear layer rate.

Another feature of interest in figure 29 is the increase in vorticity transport rate within the shear layer with increasing distance downstream of the edge. If the vorticity in the

shear layer were generated only at the edge, the transport rate would be uniform along the length of the shear layer. In fact, vorticity can enter the inner edge of the shear layer with the recirculation fluid ingested by the shear layer. If there is any vorticity in the onset flow, as was indicated by figure 24, this could also be ingested into the outer edge of the shear layer. Estimates were made of both the quantities, again for the case of the round edge model at  $M = 0.25$ .

For the outer flow, the vorticity transport rate,  $R$ , was calculated at  $x/(b/2) = -0.1$  over the height from  $y/(b/2) = 1.1$  to  $2.0$  using Equations (16) and (13). The  $v$ -derivative contributions were obtained from the velocities at  $x/(b/2) = 0, -0.1$ , and  $-0.2$ . The calculated transport rate was  $R = -.04$ . If this vorticity enters the outer edge of the shear layer, it could account for a portion of the (negative) increase shown in figure 29.

For the recirculating flow, the rate of transport of vorticity moving forward at  $x/(b/2) = 1.6$  between the  $u = 0$  line [ $y/(b/2) = 1.6$ ] and  $y/(b/2) = 0.2$  was calculated. This location was selected because of the velocity data available [fig. 15(d)]. The inner part of this region has positive vorticity which is part of the opposite-sense vorticity introduced from the recirculation region into the shear layer near the edge. The outer part of this region [in the approximate range from  $y/(b/2)$  of  $1.2$  to  $1.6$ ] has negative vorticity moving forward at a rate  $R \approx .02$  (positive because of negative  $u$  velocity). In accordance with the flow reconstruction of figure 23(c), the negative vorticity enters the inner part of the shear layer over the  $x/(b/2)$  range from about  $0.8$  to  $1.6$ , which would not account for all of the (negative) increase in  $R$  between  $x/(b/2)$  of  $0.4$  and  $0.8$  shown in figure 29.

## 6. CONCLUDING REMARKS

A two-dimensional test was performed on a flat plate at low subsonic speeds to investigate the relationship between the vorticity shed at an edge and the vorticity appearing in the flow field shear layer adjacent to the edge. The measurements made were velocities in the flow field, pressures on the model, and surface flow visualization. Two degrees of sharpness of the edge were tested.

The flow over the entire span of the front face was two dimensional. The resulting flow in the recirculation region on the model was not two dimensional. The velocity- and most of the pressure-measurements were taken at the center span of the model (center of the tunnel), which was shown by the flow visualization and pressures to be a plane of symmetry dividing two regions of flow having a spanwise component towards the ends of the model in the recirculating region. It is felt that the lack of two dimensionality in the recirculating flow behind the model had little influence on the results, because the measurement plane coincided with the plane of symmetry dividing the outboard flows towards the ends of the model and the measured velocities in the recirculation region are small ( $u/v < 0.1$  and  $v/u < 0.05$ ).

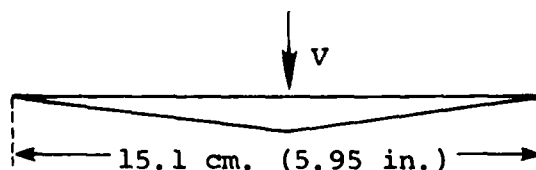
The flow appeared to be reasonably steady, particularly the flow outside the shear layer. The reattachment point of the recirculating flow was well forward of the splitter plate trailing edge. The histograms of the LV velocity data in the shear layer, and the spectral analysis of the surface pressures show indication of a small amount of energy in a frequency typical of a Strouhal shedding rate. However, the repeatability of the velocity measurements and the small magnitudes of these unsteady effects, within and outside of the shear layer,

indicate that the unsteady aspect of the flow should have little influence on the results.

The boundary layer on the model upstream surface is laminar. The only evidence to show any influence of Reynolds number on the shedding rate is the pressure data for the sharp-edge model at  $M = .25$ . The data show  $C_p = -0.52$  at  $Re = 0.063 \times 10^6$  and  $C_p = -0.6$  at  $Re = 0.25 \times 10^6$  at the static tap on the rear surface of the model closest to the edge [fig. 9(a)]. On the basis that this pressure is the value at the edge from which the upstream surface boundary-layer vorticity transport rate is computed, there is little change in the rate over this Reynolds number range.

The results of the experiment show that the vorticity transport rate measured in the shear layer close to the edge is about 80 percent of the predicted value in the upstream surface boundary layer at separation. The boundary-layer rate depends on  $u_\delta$ , which in turn depends on the local pressure at separation. For the rounded edge case, the latter is well established from the behavior of the pressure distribution [fig. 7(d)] and the surface flow visualization. There is some question, however, for the sharp-edge case, because the pressure at the edge could not be measured.

An effort was made to locate data at the edge of a flat plate normal to the flow. The only source found is the work of Fage and Johansen (ref. 4). The plate cross section is as shown below, and no splitter plate was used. Although no



tables are given of static pressure tap location, it appears that the front surface static pressure was measured to within .02 to .03  $b/2$  of the edge. The  $C_p$  values are -0.7 nearest the edge on the front surface and -1.38 (essentially uniform) on the rear surface, whereas the present experiment shows -0.6 on the rear surface near the edge. One would expect the  $C_p$  on the rear surface to be greater (less negative) for the present experiment than for the Fage test because a splitter plate is known to reduce the drag considerably.

Fage also measured the velocity in the plane of the front surface a short distance off the tip and found that it agreed within 5 percent with a predicted velocity using the rear surface static pressure and the assumption that the total head in the flow just off the tip is free-stream total head. Thus, even though the rear surface static pressure is different in the Fage test, the assumption in the present case of using the rear surface pressure near the tip for purposes of calculating  $u$  is supported by the results of reference 4, and any discrepancy between calculated-boundary-layer and measured-shear-layer vorticity rates should not be attributable to use of an incorrect pressure at separation.

Vorticity of an opposite sign to that shed from the front surface boundary layer is produced at the edge by the forward moving recirculating flow along the splitter plate and model rear surface. Calculations indicate that the transport rate of the recirculating flow approaching the secondary reattachment point is roughly 2 percent of the forward surface shedding rate, whereas there is a difference of 20 percent between the calculated forward surface rate and the measured rate in the shear layer adjacent to the edge. Thus, the rear surface contributions appear to account only for a part of the differences between the measured shear layer rate and the calculated forward surface shedding rate.

Vorticity also enters the shear layer along both the outer surface (due to vorticity in the onset tunnel flow) and the inner surface. Estimates of the quantities of these transport rates indicate values generally smaller than the changes in transport rate measured along the shear layer.

As a final comment, it does not appear possible to account for the difference between the calculated shedding rate of the front surface boundary layer at separation and the measured rate in the shear layer just downstream of the edge. The  $u_\delta$  method [Eq. (19)] of calculating shedding rate at separation is an old concept (for instance, ref. 5) and has been used extensively. In these experiments, however, no direct measurement of the vorticity flux at separation could be made, so no check is available on how accurately the  $u_\delta$  method predicts the shedding rate at a separation point.

As a practical matter, an approach has been adopted in engineering analysis methods (for instance, ref. 6) in which the shedding rate is calculated as

$$R = \Lambda \frac{1}{2} \left( \frac{u_\delta}{V} \right)^2$$

where  $\Lambda$  is an empirical factor which is assigned a value based on experimental observations. For a cylinder in crossflow, for example, the value is 0.5 to 0.6, based on the vorticity which appears in the wake vortices. The "missing" vorticity is attributed to the rear surface boundary-layer/shear-flow and other unknown factors.

In the present experiment, the value of  $\Lambda$  based on the measurements obtained is approximately 0.8. This value appears to hold for both the sharp edge and rounded edge cases tested.

#### REFERENCES

1. Apelt, C. J. and Wert, G. S.: The Effects of Wake Splitter Plates on Bluff-Body Flow in the Range  $10^4 < Re < 5 \times 10^4$ . JMF, Vol. 71, Pt. 1, 1975, pp. 145-160.
2. Lindgren, B. W. and McElrath, C. W.: Introduction to Probability and Statistics. MacMillan, New York, 1959.
3. Fage, A. and Johansen, F. C.: The Structure of Vortex Sheets. Philosophical Magazine S7, Vol. 5, No. 28, Feb. 1928.
4. Fage, A. and Johansen, F. C.: On the Flow of Air Behind an Inclined Flat Plate of Infinite Span. ARC R&M No. 1104, Feb. 1927.
5. Goldstein, S.: Modern Developments in Fluid Dynamics. Vol. I, Ch. II, Oxford University Press, 1938.
6. Fidler, J. E.: Approximate Method for Estimating Wake Vortex Strength. AIAA Journal, Vol. 12, No. 5, May 1977.

## APPENDIX A

### STATISTICAL CONFIDENCE LEVELS IN VELOCITY DATA

Using relationships based on Gaussian probability statistics, estimates can be made of the confidence level in the laser velocimeter data as functions of the number of samples of a given measurement and the rms error. The theory and relationships are obtained from reference 2.

For a given Doppler frequency measurement,  $f_D$ , the error may be expressed as

$$|\bar{f}_D - \beta_D| < \frac{K_f S_f}{\sqrt{N}} \quad (A-1)$$

where  $\beta_D$  is the true mean frequency,  $K_f$  is a multiplier related to the confidence level and the Gaussian probability distribution, and  $N$  is the number of measurements. The quantity  $S_f$  is the calculated variance,

$$S_f^2 = \frac{1}{N} \left[ \sum_{i=1}^N (f_i - \bar{f})^2 \right] \quad (A-2)$$

and  $\bar{f}$  is the calculated mean frequency

$$\bar{f}_D = \frac{1}{N} \left[ \sum_{i=1}^N f_D \right] \quad (A-3)$$

From Equation (A-1), the error increases as the variance increases and decreases with the number of samples. The confidence level can thus be expressed as

$$\frac{|\bar{f} - \beta_D|}{\bar{f}_D} < \frac{K_f S_f}{\bar{f}_D \sqrt{N}} \quad (A-4)$$

The relationship between the confidence level, the number of samples, the error in mean measurement, and the rms variation about the mean,  $\sigma$ , is shown in figure A-1.

In the outer flow and outer part of the shear layer, typically about 300 samples were taken at a given point and the rms level is the order of 8 percent of the mean velocity. For these values, figure A-1 shows that 50 percent of the measurements would be in error by less than four percent of the rms or .32 percent of the mean, and one percent would be in error by less than 15 percent of the rms or 1.2 percent of the mean.

For the measurements in the reverse flow region where the velocities are low ( $u \approx 10$  m/sec. and  $v \approx 1$  m/sec.), it was more difficult to obtain measurements because of fewer scattering particles. Typically, 50 samples were obtained, and the rms level was the order of 100 percent of the mean in  $u$  and 300 percent of the mean in  $v$ . For these values, figure A-1 shows that 50 percent of the  $u$  measurements would be in error by 10 percent of the mean and 50 percent of the  $v$  measurements would be in error by 30 percent of the mean.

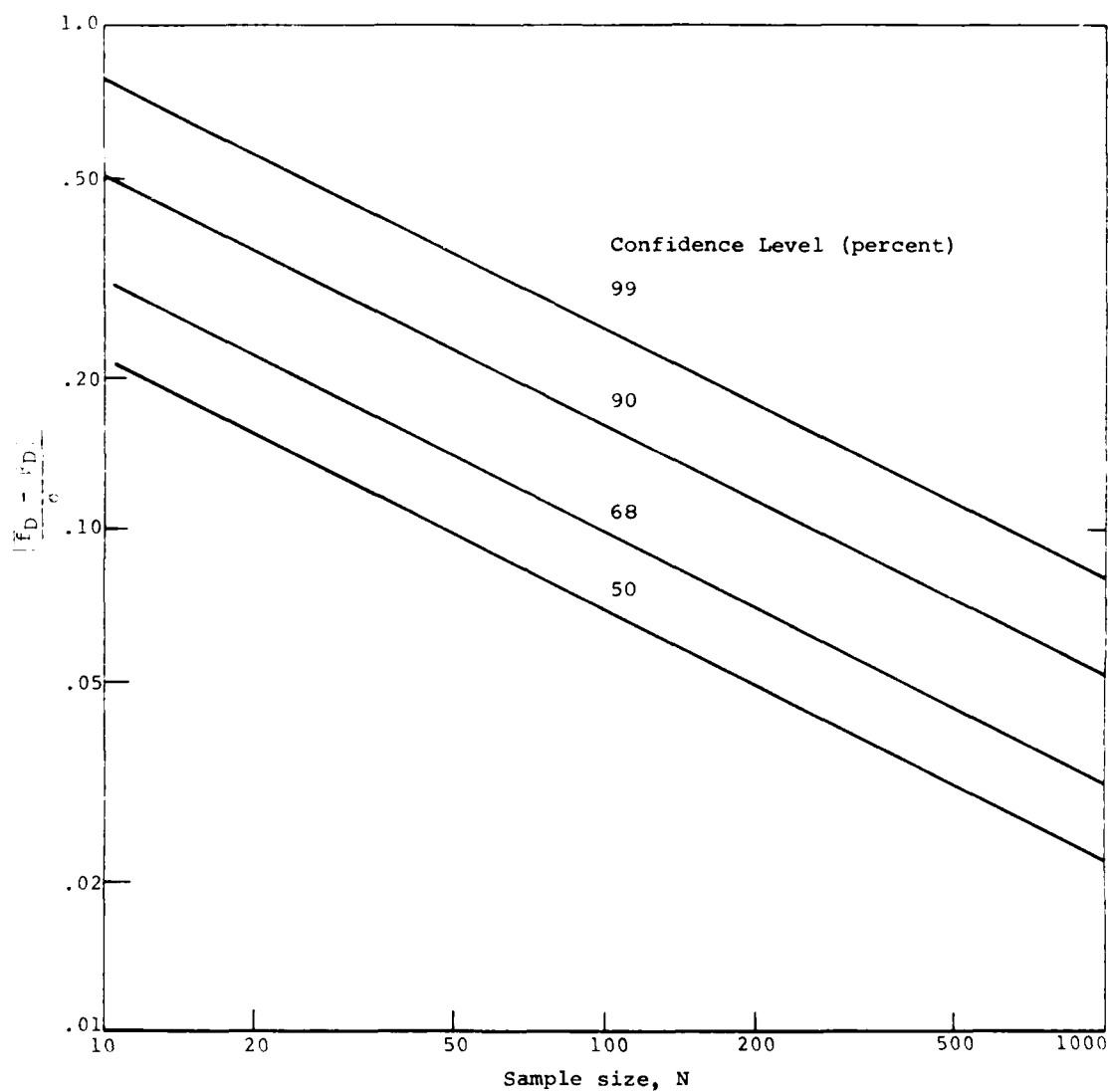


Figure A-1.- Variation of Mean Measurement Accuracy Parameter with Confidence Level and Sample Size.

TABLE I.- VELOCITY DATA FOR SHARP EDGE MODEL  
 $M = 0.25$ ,  $Re = .063 \times 10^6$

| Pt | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|----|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 1  | 0.0             | 1.50000         | 0.73403       | 0.09241        | 0.59030       | 0.10427        |
| 2  | 0.0             | 2.00000         | 0.84582       | 0.10768        | 0.45444       | 0.14420        |
| 3  | 0.0             | 2.50000         | 0.90207       | 0.09441        | 0.38105       | 0.07574        |
| 4  | 0.0             | 1.50000         | 0.71054       | 0.12388        | 0.57785       | 0.12341        |
| 5  | 0.50000         | 1.50000         | 0.95197       | 0.16522        | 0.60921       | 0.08701        |
| 6  | 0.50000         | 1.25000         | -0.12741      | 0.09699        | 0.01151       | 0.07186        |
| 7  | 0.50000         | 1.30000         | -0.11097      | 0.10357        | -0.00634      | 0.07973        |
| 8  | 0.50000         | 1.35000         | -0.04568      | 0.13492        | 0.04838       | 0.09089        |
| 9  | 0.50000         | 1.40000         | 0.14784       | 0.22346        | 0.17085       | 0.11531        |
| 10 | 0.50000         | 1.45000         | 0.45009       | 0.29662        | 0.37999       | 0.12835        |
| 11 | 0.50000         | 1.50000         | 0.91698       | 0.19962        | 0.58478       | 0.09007        |
| 12 | 0.50000         | 1.60000         | 0.98086       | 0.09758        | 0.61719       | 0.08337        |
| 13 | 0.50000         | 2.00000         | 0.95409       | 0.13304        | 0.48849       | 0.11367        |

TABLE II.- VELOCITY DATA FOR SHARP EDGE MODEL  
 $M = .25$ ,  $Re = .25 \times 10^6$

(\*indicates points dropped from analysis)

| Pt  | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|-----|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 14  | 0.50000         | 2.00000         | 0.95479       | 0.11731        | 0.42156       | 0.26609        |
| 15* | 0.50000         | 1.50000         | 0.97769       | 0.18953        | 0.62799       | 0.11273        |
| 16  | 0.50000         | 1.25000         | -0.09934      | 0.09829        | 0.01339       | 0.08067        |
| 17* | 0.50000         | 1.30000         | -0.09394      | 0.11085        | -0.00716      | 0.08607        |
| 18* | 0.50000         | 1.35000         | -0.08384      | 0.11766        | 0.03464       | 0.08631        |
| 19* | 0.50000         | 1.40000         | 0.06106       | 0.18941        | 0.11801       | 0.11743        |
| 20* | 0.50000         | 1.45000         | 0.47358       | 0.29039        | 0.41733       | 0.21278        |
| 21* | 0.50000         | 1.50000         | 0.98250       | 0.20996        | 0.65688       | 0.09969        |
| 22  | 1.00000         | 1.50000         | -0.10709      | 0.12118        | 0.03253       | 0.09876        |
| 23  | 1.00000         | 1.60000         | 0.10733       | 0.23062        | 0.10568       | 0.11860        |
| 24  | 1.00000         | 1.65000         | 0.36003       | 0.30660        | 0.19551       | 0.14772        |
| 25  | 1.00000         | 1.70000         | 0.69387       | 0.32151        | 0.33924       | 0.13798        |
| 26  | 1.00000         | 1.75000         | 1.02078       | 0.22487        | 0.46360       | 0.12788        |
| 27  | 1.00000         | 1.80000         | 1.09864       | 0.13938        | 0.48826       | 0.10063        |
| 28  | 1.00000         | 2.00000         | 1.05390       | 0.12647        | 0.46137       | 0.18894        |
| 29  | 1.00000         | 1.40000         | -0.14244      | 0.11590        | 0.01714       | 0.10204        |
| 30  | 2.00000         | 2.00000         | 0.63668       | 0.33760        | 0.14690       | 0.23156        |
| 31  | 2.00000         | 2.20000         | 1.12365       | 0.18835        | 0.12647       | 0.49331        |
| 32  | 2.00000         | 2.40000         | 1.15066       | 0.11837        | 0.27900       | 0.29779        |
| 33  | 2.00000         | 2.60000         | 1.13727       | 0.11484        | 0.32233       | 0.08384        |
| 34  | 2.00000         | 1.80000         | 0.04803       | 0.23544        | 0.03969       | 0.28605        |
| 35  | 2.00000         | 1.60000         | -0.14620      | 0.15383        | 0.01362       | 0.21548        |
| 36  | 2.00000         | 1.40000         | -0.16522      | 0.12341        | 0.02642       | 0.16674        |
| 37  | 2.00000         | 1.50000         | -0.15395      | 0.13845        | 0.01069       | 0.19469        |
| 38  | 2.00000         | 1.70000         | -0.09852      | 0.16217        | -0.00975      | 0.24389        |
| 39  | 2.00000         | 1.90000         | 0.29180       | 0.30249        | 0.03147       | 0.30272        |
| 40  | 2.00000         | 2.10000         | 0.96430       | 0.28899        | 0.24789       | 0.20056        |
| 41  | 2.00000         | 2.30000         | 1.15124       | 0.12776        | 0.20878       | 0.42954        |
| 42  | 2.00000         | 2.50000         | 1.13187       | 0.12001        | 0.25857       | 0.39455        |
| 43  | 2.00000         | 1.55000         | -0.13023      | 0.13269        | 0.02677       | 0.16945        |
| 44  | 2.00000         | 1.65000         | -0.11343      | 0.15477        | 0.02466       | 0.20045        |
| 45  | 2.00000         | 1.75000         | -0.02842      | 0.19434        | 0.04357       | 0.21923        |
| 46  | 2.00000         | 1.85000         | 0.15406       | 0.25587        | 0.05578       | 0.18624        |
| 47  | 2.00000         | 1.95000         | 0.46231       | 0.33736        | 0.11578       | 0.18729        |
| 48  | 2.00000         | 2.05000         | 0.81541       | 0.32186        | 0.19822       | 0.20115        |
| 49  | 2.00000         | 2.15000         | 1.06341       | 0.24025        | 0.24166       | 0.30860        |
| 50  | 2.00000         | 2.25000         | 1.15512       | 0.13751        | 0.22698       | 0.35557        |
| 51* | 0.60000         | 1.60000         | 1.01597       | 0.22346        | 0.33220       | 0.51268        |
| 52* | 0.60000         | 1.56000         | 0.96360       | 0.32727        | 0.52031       | 0.29756        |
| 53  | 0.0             | 1.50000         | 0.73309       | 0.07527        | 0.54568       | 0.06975        |
| 54  | 0.0             | 1.40000         | 0.69775       | 0.07351        | 0.60028       | 0.07762        |
| 55  | 0.0             | 1.30000         | 0.62248       | 0.08114        | 0.66299       | 0.07433        |
| 56  | 0.0             | 1.20000         | 0.51902       | 0.09394        | 0.72405       | 0.08596        |
| 57  | 0.0             | 1.10000         | 0.35897       | 0.12776        | 0.82421       | 0.09089        |

TABLE II.- Continued.

| Pt  | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|-----|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 58  | 0.0             | 1.05000         | 0.21959       | 0.11966        | 0.86343       | 0.14314        |
| 59  | 0.0             | 1.60000         | 0.76679       | 0.06975        | 0.51691       | 0.06787        |
| 60  | 0.0             | 1.70000         | 0.78065       | 0.07421        | 0.48121       | 0.06646        |
| 61  | 0.0             | 1.80000         | 0.80930       | 0.06752        | 0.45902       | 0.07245        |
| 62  | 0.0             | 2.00000         | 0.83866       | 0.06411        | 0.40442       | 0.17297        |
| 63  | 0.0             | 2.20000         | 0.87165       | 0.07022        | 0.38445       | 0.06188        |
| 64  | 0.0             | 2.40000         | 0.88938       | 0.07093        | 0.34594       | 0.06764        |
| 65  | 0.0             | 3.00000         | 0.93001       | 0.07292        | 0.28147       | 0.05953        |
| 66  | 0.0             | 3.50000         | 0.95092       | 0.06670        | 0.24272       | 0.06036        |
| 67  | 0.10000         | 3.50000         | 0.95996       | 0.07938        | 0.23908       | 0.06047        |
| 68  | 0.10000         | 3.00000         | 0.93906       | 0.08525        | 0.29509       | 0.06177        |
| 69  | 0.10000         | 2.40000         | 0.92520       | 0.07245        | 0.33772       | 0.06458        |
| 70  | 0.10000         | 2.20000         | 0.89232       | 0.07081        | 0.39138       | 0.06764        |
| 71  | 0.10000         | 2.00000         | 0.87553       | 0.06482        | 0.42473       | 0.07104        |
| 72  | 0.10000         | 1.80000         | 0.83725       | 0.08419        | 0.44657       | 0.21148        |
| 73  | 0.10000         | 1.70000         | 0.82821       | 0.07081        | 0.49378       | 0.19587        |
| 74  | 0.10000         | 1.60000         | 0.81799       | 0.07093        | 0.53722       | 0.07351        |
| 75  | 0.10000         | 1.50000         | 0.77701       | 0.07363        | 0.57151       | 0.08748        |
| 76  | 0.10000         | 1.40000         | 0.73192       | 0.07574        | 0.62670       | 0.08114        |
| 77  | 0.10000         | 1.30000         | 0.64596       | 0.11813        | 0.69692       | 0.08267        |
| 78  | 0.10000         | 1.20000         | 0.67027       | 0.07316        | 0.81517       | 0.08983        |
| 79  | 0.30000         | 1.10000         | -0.07832      | 0.08819        | -0.00869      | 0.07104        |
| 80  | 0.30000         | 1.30000         | 0.33842       | 0.18248        | 0.39302       | 0.14185        |
| 81  | 0.30000         | 1.20000         | -0.09324      | 0.09288        | 0.01080       | 0.06975        |
| 82* | 0.30000         | 1.30000         | 0.26397       | 0.24859        | 0.41334       | 0.14972        |
| 83  | 0.30000         | 1.35000         | 0.87330       | 0.11085        | 0.64913       | 0.09136        |
| 84  | 0.30000         | 1.40000         | 0.86167       | 0.07821        | 0.64209       | 0.08948        |
| 85  | 0.30000         | 1.45000         | 0.84605       | 0.09958        | 0.61660       | 0.08325        |
| 86  | 0.30000         | 1.50000         | 0.84934       | 0.08079        | 0.61073       | 0.08243        |
| 87  | 0.30000         | 1.60000         | 0.86872       | 0.07410        | 0.55836       | 0.08584        |
| 88  | 0.30000         | 1.80000         | 0.87835       | 0.08760        | 0.49472       | 0.08220        |
| 89  | 0.30000         | 2.00000         | 0.90395       | 0.06858        | 0.42543       | 0.17825        |
| 90  | 0.30000         | 2.50000         | 0.92414       | 0.08971        | 0.35216       | 0.06411        |
| 91  | 0.30000         | 3.00000         | 0.93906       | 0.06740        | 0.29239       | 0.06423        |
| 92  | 0.30000         | 3.50000         | 0.95233       | 0.07034        | 0.24612       | 0.06858        |
| 93  | 0.30000         | 1.32500         | 0.71101       | 0.22346        | 0.60287       | 0.10604        |
| 94  | 0.40000         | 1.10000         | -0.07421      | 0.09347        | 0.02525       | 0.08067        |
| 95  | 0.40000         | 1.30000         | -0.07586      | 0.15312        | 0.04263       | 0.08666        |
| 96  | 0.40000         | 1.40000         | 0.76233       | 0.23755        | 0.54368       | 0.09347        |
| 97  | 0.40000         | 1.35000         | 0.21512       | 0.25552        | 0.26679       | 0.12612        |
| 98  | 0.40000         | 1.37500         | 0.41181       | 0.23344        | 0.41815       | 0.13563        |
| 99  | 0.40000         | 1.42500         | 0.90676       | 0.14995        | 0.60698       | 0.14760        |
| 100 | 0.40000         | 1.45000         | 0.92954       | 0.09077        | 0.61696       | 0.08185        |
| 101 | 0.40000         | 1.50000         | 0.90442       | 0.07703        | 0.59054       | 0.08795        |
| 102 | 0.40000         | 1.55000         | 0.88387       | 0.07609        | 0.58232       | 0.08748        |

TABLE II.- Continued.

| Pt  | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|-----|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 103 | 0.40000         | 1.60000         | 0.89490       | 0.10016        | 0.57891       | 0.08725        |
| 104 | 0.40000         | 1.65000         | 0.90183       | 0.09394        | 0.55014       | 0.07562        |
| 105 | 0.40000         | 1.70000         | 0.91710       | 0.07785        | 0.53276       | 0.08314        |
| 106 | 0.40000         | 1.80000         | 0.91792       | 0.07245        | 0.47757       | 0.19375        |
| 107 | 0.40000         | 2.00000         | 0.92426       | 0.07457        | 0.44587       | 0.07186        |
| 108 | 0.40000         | 2.50000         | 0.93671       | 0.08372        | 0.35169       | 0.06177        |
| 109 | 0.40000         | 3.00000         | 0.95843       | 0.09394        | 0.30249       | 0.06106        |
| 110 | 0.40000         | 3.50000         | 0.97558       | 0.07915        | 0.25329       | 0.06517        |
| 111 | 0.50000         | 3.50000         | 0.99155       | 0.06811        | 0.26057       | 0.05953        |
| 112 | 0.50000         | 3.00000         | 0.97992       | 0.08419        | 0.31259       | 0.06282        |
| 113 | 0.50000         | 2.50000         | 0.97264       | 0.09899        | 0.36214       | 0.06623        |
| 114 | 0.50000         | 2.00000         | 0.95784       | 0.07116        | 0.43084       | 0.23978        |
| 115 | 0.50000         | 1.80000         | 0.95808       | 0.07468        | 0.50247       | 0.07774        |
| 116 | 0.50000         | 1.70000         | 0.95139       | 0.08995        | 0.54004       | 0.09535        |
| 117 | 0.50000         | 1.60000         | 0.94481       | 0.07574        | 0.56153       | 0.08619        |
| 118 | 0.50000         | 1.50000         | 0.97969       | 0.12024        | 0.56682       | 0.10310        |
| 119 | 0.50000         | 1.40000         | 0.18589       | 0.22839        | 0.20608       | 0.11743        |
| 120 | 0.50000         | 1.47500         | 0.90254       | 0.21031        | 0.54615       | 0.10744        |
| 121 | 0.50000         | 1.45000         | 0.71994       | 0.24624        | 0.45949       | 0.11731        |
| 122 | 0.50000         | 1.42500         | 0.40348       | 0.25364        | 0.34371       | 0.12224        |
| 123 | 0.50000         | 1.35000         | -0.06047      | 0.13434        | 0.06353       | 0.09570        |
| 124 | 0.50000         | 1.30000         | -0.11484      | 0.11942        | 0.01714       | 0.07961        |
| 125 | 0.50000         | 1.20000         | -0.09887      | 0.09711        | 0.00423       | 0.07515        |
| 126 | 0.50000         | 1.00000         | -0.08325      | 0.10510        | -0.00505      | 0.07950        |
| 127 | 0.50000         | 0.80000         | -0.06599      | 0.09793        | -0.02255      | 0.05026        |
| 128 | 0.60000         | 0.80000         | -0.06717      | 0.10251        | 0.00552       | 0.08807        |
| 129 | 0.60000         | 1.00000         | -0.08607      | 0.10427        | -0.00117      | 0.06717        |
| 130 | 0.60000         | 1.20000         | -0.11519      | 0.10874        | 0.00705       | 0.07257        |
| 131 | 0.60000         | 1.40000         | -0.03934      | 0.14890        | 0.04685       | 0.09136        |
| 132 | 0.60000         | 1.50000         | 0.65747       | 0.28124        | 0.41522       | 0.12318        |
| 133 | 0.60000         | 1.45000         | 0.24695       | 0.26667        | 0.17637       | 0.10803        |
| 134 | 0.60000         | 1.55000         | 0.99354       | 0.14655        | 0.53417       | 0.10615        |
| 135 | 0.60000         | 1.60000         | 0.98403       | 0.11649        | 0.54580       | 0.08549        |
| 136 | 0.60000         | 1.70000         | 0.97886       | 0.08995        | 0.53922       | 0.08842        |
| 137 | 0.60000         | 2.00000         | 0.97898       | 0.07961        | 0.45890       | 0.07797        |
| 138 | 0.60000         | 2.50000         | 0.98227       | 0.08901        | 0.37259       | 0.07515        |
| 139 | 0.60000         | 3.00000         | 0.96548       | 0.08126        | 0.32386       | 0.06834        |
| 140 | 0.60000         | 3.50000         | 0.96935       | 0.08419        | 0.27795       | 0.04897        |
| 141 | 0.80000         | 3.50000         | 0.98297       | 0.09535        | 0.26186       | 0.07550        |
| 142 | 0.80000         | 3.00000         | 0.98732       | 0.07961        | 0.31271       | 0.05636        |
| 143 | 0.80000         | 2.50000         | 0.98368       | 0.10122        | 0.36660       | 0.07691        |
| 144 | 0.80000         | 2.00000         | 0.99507       | 0.09488        | 0.49108       | 0.07504        |
| 145 | 0.80000         | 1.80000         | 1.00517       | 0.10639        | 0.51585       | 0.07621        |
| 146 | 0.80000         | 1.70000         | 1.02384       | 0.11531        | 0.50376       | 0.08960        |
| 147 | 0.80000         | 1.60000         | 0.72475       | 0.29251        | 0.44998       | 0.11132        |
| 148 | 0.80000         | 1.50000         | 0.06787       | 0.19904        | 0.10721       | 0.08513        |

TABLE II.- Continued.

| Pt  | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|-----|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 149 | 0.80000         | 1.55000         | 0.27771       | 0.28077        | 0.25376       | 0.11907        |
| 150 | 0.80000         | 1.40000         | -0.12435      | 0.11261        | 0.01750       | 0.09723        |
| 151 | 0.80000         | 1.20000         | -0.12295      | 0.11226        | 0.00423       | 0.08678        |
| 152 | 0.80000         | 1.00000         | -0.08819      | 0.10768        | -0.01538      | 0.09969        |
| 153 | 0.20000         | 1.20000         | 0.25740       | 0.24460        | 0.38727       | 0.26456        |
| 154 | 0.20000         | 1.10000         | -0.06611      | 0.08960        | 0.02208       | 0.06975        |
| 155 | 0.20000         | 1.15000         | -0.09288      | 0.08877        | -0.01444      | 0.13868        |
| 156 | 0.20000         | 1.17500         | -0.04004      | 0.26233        | 0.11285       | 0.14690        |
| 157 | 0.20000         | 1.19000         | 0.07327       | 0.30895        | 0.28018       | 0.17872        |
| 158 | 0.20000         | 1.22500         | 0.63011       | 0.20761        | 0.71571       | 0.11696        |
| 159 | 0.20000         | 1.25000         | 0.81447       | 0.09112        | 0.80002       | 0.09993        |
| 160 | 0.20000         | 1.27500         | 0.79685       | 0.06952        | 0.81505       | 0.07785        |
| 161 | 0.20000         | 1.30000         | 0.78311       | 0.07374        | 0.77877       | 0.10604        |
| 162 | 0.20000         | 1.40000         | 0.76409       | 0.11555        | 0.70150       | 0.10733        |
| 163 | 0.20000         | 1.50000         | 0.81505       | 0.07738        | 0.62835       | 0.08584        |
| 164 | 0.20000         | 1.60000         | 0.83537       | 0.07163        | 0.57856       | 0.06153        |
| 165 | 0.20000         | 1.80000         | 0.86743       | 0.06975        | 0.49648       | 0.05801        |
| 166 | 0.20000         | 2.00000         | 0.88997       | 0.06775        | 0.40899       | 0.32198        |
| 167 | 0.20000         | 2.50000         | 0.91827       | 0.08901        | 0.35357       | 0.06517        |
| 168 | 0.20000         | 3.00000         | 0.94868       | 0.06893        | 0.30449       | 0.06494        |
| 169 | 0.20000         | 3.50000         | 0.96736       | 0.06470        | 0.27713       | 0.04051        |
| 170 | 1.00000         | 1.30000         | -0.15782      | 0.10651        | -0.01867      | 0.07186        |
| 171 | 1.00000         | 1.55000         | 0.01867       | 0.19998        | 0.07574       | 0.06153        |
| 172 | 1.00000         | 1.77000         | 1.02219       | 0.13621        | 0.43037       | 0.10979        |
| 173 | 1.00000         | 1.85000         | 1.03370       | 0.10615        | 0.47863       | 0.08631        |
| 174 | 1.00000         | 1.90000         | 1.04756       | 0.09887        | 0.47687       | 0.06952        |
| 175 | 1.20000         | 3.50000         | 1.04122       | 0.07233        | 0.23016       | 0.06693        |
| 176 | 1.20000         | 3.50000         | 1.05296       | 0.05801        | 0.27266       | 0.05237        |
| 177 | 1.20000         | 3.00000         | 1.06623       | 0.08044        | 0.31635       | 0.05648        |
| 178 | 1.20000         | 2.50000         | 1.07691       | 0.06940        | 0.35404       | 0.06858        |
| 179 | 1.20000         | 2.00000         | 1.10756       | 0.07233        | 0.42449       | 0.07480        |
| 180 | 1.20000         | 1.80000         | 0.95115       | 0.24847        | 0.35404       | 0.10768        |
| 181 | 1.20000         | 1.70000         | 0.44375       | 0.33502        | 0.16733       | 0.12882        |
| 182 | 1.20000         | 1.75000         | 0.69457       | 0.30519        | 0.26867       | 0.12365        |
| 183 | 1.20000         | 1.65000         | 0.16721       | 0.26468        | 0.10803       | 0.12271        |
| 184 | 1.20000         | 1.60000         | 0.00458       | 0.19082        | 0.06083       | 0.09688        |
| 185 | 1.20000         | 1.50000         | -0.11238      | 0.13105        | 0.02971       | 0.07915        |
| 186 | 1.20000         | 1.30000         | -0.15312      | 0.10427        | 0.03053       | 0.07621        |
| 187 | 1.20000         | 1.10000         | -0.14549      | 0.12060        | 0.03957       | 0.08995        |
| 188 | 1.40000         | 1.10000         | -0.17039      | 0.12752        | 0.05942       | 0.09230        |
| 189 | 1.40000         | 1.30000         | -0.17931      | 0.13680        | 0.05143       | 0.08079        |
| 190 | 1.40000         | 1.50000         | -0.15148      | 0.11766        | 0.02771       | 0.08173        |
| 191 | 1.40000         | 1.70000         | 0.11989       | 0.24765        | 0.09558       | 0.10968        |
| 192 | 1.40000         | 1.80000         | 0.55085       | 0.33478        | 0.20784       | 0.13340        |

TABLE II.- Continued.

| Pt   | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|------|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 193  | 1.40000         | 1.90000         | 1.01409       | 0.22464        | 0.34500       | 0.11202        |
| 194  | 1.40000         | 1.85000         | 0.85932       | 0.28828        | 0.28957       | 0.13058        |
| 195  | 1.40000         | 1.82500         | 0.69187       | 0.31717        | 0.23192       | 0.12165        |
| 196  | 1.40000         | 1.75000         | 0.30390       | 0.29979        | 0.12506       | 0.13950        |
| 197  | 1.40000         | 2.00000         | 1.12013       | 0.10956        | 0.36543       | 0.24965        |
| 198  | 1.40000         | 2.20000         | 1.10909       | 0.08854        | 0.38387       | 0.07480        |
| 199  | 1.40000         | 2.40000         | 1.10028       | 0.06987        | 0.36355       | 0.06235        |
| 200  | 1.40000         | 2.60000         | 1.08948       | 0.07316        | 0.35615       | 0.06717        |
| 201  | 1.40000         | 3.00000         | 1.07891       | 0.07222        | 0.31000       | 0.06364        |
| 202  | 1.40000         | 3.50000         | 1.06728       | 0.06036        | 0.27090       | 0.05883        |
| 203  | 1.60000         | 3.50000         | 1.08960       | 0.05989        | 0.25446       | 0.06552        |
| 204  | 1.60000         | 3.00000         | 1.08572       | 0.07457        | 0.30049       | 0.06599        |
| 205  | 1.60000         | 2.50000         | 1.11496       | 0.07468        | 0.33490       | 0.07151        |
| 206  | 1.60000         | 2.00000         | 1.06223       | 0.20009        | 0.33807       | 0.12647        |
| 207  | 1.60000         | 1.80000         | 0.32057       | 0.29979        | 0.11273       | 0.14021        |
| 208  | 1.60000         | 1.85000         | 0.45808       | 0.31313        | 0.16064       | 0.15289        |
| 209  | 1.60000         | 1.90000         | 0.75000       | 0.29603        | 0.19939       | 0.14173        |
| 210  | 1.60000         | 1.75000         | 0.15183       | 0.25176        | 0.12717       | 0.11120        |
| 211  | 1.60000         | 1.70000         | 0.00998       | 0.18671        | 0.06423       | 0.10721        |
| 212  | 1.60000         | 1.60000         | -0.12036      | 0.14749        | 0.04908       | 0.11766        |
| 213  | 1.60000         | 1.40000         | -0.16874      | 0.13621        | 0.03992       | 0.08079        |
| 214  | 1.60000         | 1.20000         | -0.18013      | 0.11989        | 0.04568       | 0.10474        |
| 215  | 1.60000         | 1.00000         | -0.14866      | 0.13727        | 0.02090       | 0.09512        |
| 216  | -0.10000        | 1.10000         | 0.46219       | 0.10885        | 0.91522       | 0.09253        |
| 217  | -0.20000        | 1.10000         | 0.36332       | 0.34147        | 0.57985       | 0.21689        |
| 218  | 0.30000         | 1.25000         | -0.06494      | 0.13704        | 0.01585       | 0.08701        |
| 219  | 0.30000         | 1.27500         | -0.04216      | 0.15712        | 0.04721       | 0.09112        |
| 220  | 0.30000         | 1.37500         | 0.89338       | 0.16287        | 0.72922       | 0.08913        |
| 221  | 0.20000         | 1.30000         | 0.82715       | 0.12189        | 0.81106       | 0.08372        |
| 222  | 0.25000         | 1.30000         | 0.74096       | 0.30308        | 0.74284       | 0.14079        |
| 223  | 0.35000         | 1.30000         | -0.00341      | 0.15559        | 0.06271       | 0.08807        |
| 224  | 0.20000         | 1.40000         | 0.76667       | 0.13281        | 0.75200       | 0.07961        |
| 225  | 0.45000         | 1.40000         | 0.24401       | 0.23356        | 0.21712       | 0.25611        |
| 226  | 0.55000         | 1.40000         | -0.01198      | 0.19246        | 0.04803       | 0.09418        |
| 227  | 0.70000         | 1.50000         | 0.13657       | 0.26761        | 0.11872       | 0.11390        |
| 228  | 1.00000         | 1.30000         | -0.14667      | 0.20467        | 0.03546       | 0.08408        |
| 229* | 1.00000         | 1.55000         | -0.02466      | 0.18483        | 0.06717       | 0.12036        |
| 230* | 1.00000         | 1.77000         | 0.98262       | 0.21829        | 0.43941       | 0.11508        |
| 231* | 1.00000         | 1.90000         | 1.01949       | 0.15218        | 0.45209       | 0.08126        |
| 232  | 0.25000         | 1.02000         | -0.04216      | 0.15524        | -0.00552      | 0.08255        |
| 233  | 0.30000         | 1.04000         | -0.05437      | 0.13257        | -0.00305      | 0.08807        |
| 234* | 0.40000         | 1.10000         | -0.08173      | 0.13081        | 0.05155       | 0.06952        |
| 235* | 0.50000         | 1.16000         | -0.11942      | 0.14021        | 0.03088       | 0.08185        |
| 236  | 0.70000         | 0.87000         | -0.08091      | 0.14385        | -0.00740      | 0.13375        |
| 237  | 0.80000         | 0.98000         | -0.11907      | 0.12647        | 0.00540       | 0.09324        |
| 238  | 0.90000         | 1.09000         | -0.13070      | 0.13962        | 0.00399       | 0.13116        |

TABLE II.- Continued.

| Pt   | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|------|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 239  | 0.60000         | 0.76000         | -0.05073      | 0.12306        | -0.01515      | 0.09300        |
| 240  | 1.00000         | 0.57000         | -0.02031      | 0.13269        | 0.00986       | 0.08490        |
| 241  | 1.05000         | 0.71000         | -0.11132      | 0.13175        | -0.00059      | 0.09159        |
| 242  | 1.10000         | 0.85000         | -0.12224      | 0.14667        | 0.00986       | 0.10052        |
| 243  | 1.15000         | 0.99000         | -0.14079      | 0.17720        | 0.01139       | 0.11003        |
| 244  | 1.20000         | 1.14000         | -0.14443      | 0.14526        | 0.02607       | 0.14396        |
| 245  | -0.10000        | 1.20000         | 0.32515       | 0.39044        | 0.70291       | 0.07457        |
| 246  | -0.10000        | 1.30000         | 0.57233       | 0.12482        | 0.64056       | 0.07574        |
| 247  | -0.10000        | 1.40000         | 0.64760       | 0.11437        | 0.61837       | 0.06705        |
| 248  | -0.10000        | 1.50000         | 0.70056       | 0.11003        | 0.58877       | 0.05801        |
| 249  | -0.10000        | 1.60000         | 0.74061       | 0.09253        | 0.56271       | 0.07762        |
| 250  | -0.10000        | 1.70000         | 0.76750       | 0.10263        | 0.52865       | 0.06047        |
| 251  | -0.10000        | 1.80000         | 0.78605       | 0.10193        | 0.47816       | 0.19763        |
| 252  | 0.90000         | 1.30000         | -0.15806      | 0.13081        | 0.01797       | 0.07386        |
| 253  | 0.90000         | 1.40000         | -0.12788      | 0.13269        | 0.04075       | 0.08032        |
| 254  | 0.90000         | 1.50000         | -0.10698      | 0.11837        | 0.01773       | 0.09265        |
| 255  | 0.90000         | 1.60000         | 0.15582       | 0.24624        | 0.09899       | 0.12388        |
| 256  | 0.90000         | 1.70000         | 0.82915       | 0.30507        | 0.37189       | 0.16498        |
| 257  | 0.90000         | 1.80000         | 1.05578       | 0.13657        | 0.47816       | 0.15359        |
| 258  | 0.90000         | 1.90000         | 1.05625       | 0.15160        | 0.46712       | 0.11343        |
| 259  | 1.10000         | 1.90000         | 1.08584       | 0.13093        | 0.43906       | 0.11073        |
| 260  | 1.10000         | 1.80000         | 0.94446       | 0.25247        | 0.37553       | 0.11543        |
| 261  | 1.10000         | 1.70000         | 0.36062       | 0.29368        | 0.18847       | 0.13657        |
| 262  | 1.10000         | 1.60000         | -0.01820      | 0.19446        | 0.06435       | 0.10416        |
| 263  | 1.10000         | 1.50000         | -0.13809      | 0.14537        | 0.03018       | 0.08431        |
| 264  | 1.10000         | 1.40000         | -0.12447      | 0.11672        | 0.02595       | 0.06952        |
| 265  | 1.10000         | 1.30000         | -0.12365      | 0.15089        | 0.04251       | 0.10110        |
| 266  | 1.90000         | 1.60000         | -0.11790      | 0.15841        | 0.02630       | 0.09030        |
| 267  | 1.90000         | 1.70000         | -0.08654      | 0.17215        | 0.04345       | 0.11473        |
| 268  | 1.90000         | 1.80000         | 0.05554       | 0.24636        | 0.04591       | 0.13821        |
| 269  | 1.90000         | 1.90000         | 0.32797       | 0.31822        | 0.08114       | 0.16956        |
| 270  | 1.90000         | 2.00000         | 0.64549       | 0.33396        | 0.17884       | 0.13387        |
| 271  | 1.90000         | 2.10000         | 0.99683       | 0.25270        | 0.27125       | 0.12447        |
| 272  | 1.90000         | 2.20000         | 1.14526       | 0.14162        | 0.32386       | 0.11343        |
| 273  | 1.90000         | 2.30000         | 1.13316       | 0.11144        | 0.34359       | 0.08243        |
| 274  | 1.80000         | 2.30000         | 1.11719       | 0.19000        | 0.33807       | 0.17156        |
| 275  | 1.80000         | 2.20000         | 1.12224       | 0.11496        | 0.34007       | 0.13046        |
| 276  | 1.80000         | 2.10000         | 1.05355       | 0.18330        | 0.30801       | 0.17614        |
| 277  | 1.80000         | 2.00000         | 0.79944       | 0.30965        | 0.22299       | 0.15101        |
| 278  | 1.80000         | 1.90000         | 0.39338       | 0.33995        | 0.12271       | 0.14843        |
| 279  | 1.80000         | 1.80000         | 0.08795       | 0.26644        | 0.06552       | 0.12165        |
| 280  | 1.80000         | 1.70000         | -0.10251      | 0.20244        | 0.05225       | 0.11649        |
| 281  | 1.80000         | 1.60000         | -0.10627      | 0.16381        | 0.04004       | 0.09652        |
| 282  | 1.00000         | 1.20000         | -0.14667      | 0.15453        | 0.01339       | 0.08443        |
| 283* | 0.0             | 1.50000         | 0.78593       | 0.09382        | 0.61519       | 0.08572        |
| 284* | 0.0             | 2.00000         | 0.88692       | 0.08173        | 0.44927       | 0.06318        |

TABLE II.- Continued.

| Pt   | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|------|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 285* | 0.0             | 1.80000         | 0.84429       | 0.13070        | 0.49706       | 0.07809        |
| 286* | 0.0             | 1.70000         | 0.81235       | 0.21595        | 0.52149       | 0.12705        |
| 287* | 0.0             | 1.60000         | 0.77607       | 0.21923        | 0.54122       | 0.16733        |
| 288* | 0.0             | 1.50000         | 0.64209       | 0.39854        | 0.45702       | 0.40207        |
| 289* | 0.0             | 1.40000         | 0.51667       | 0.51339        | 0.49648       | 0.36555        |
| 290* | 0.0             | 1.30000         | 0.07715       | 0.72287        | 0.06141       | 0.57222        |
| 291* | 0.50000         | 1.15700         | -0.09230      | 0.10392        | 0.01080       | 0.09840        |
| 292* | 0.40000         | 1.10000         | -0.08466      | 0.10662        | 0.01292       | 0.09758        |
| 293  | 0.30000         | 1.04000         | -0.06940      | 0.09382        | -0.00270      | 0.10568        |
| 294  | 0.25000         | 1.02000         | -0.05895      | 0.10216        | 0.00705       | 0.09547        |
| 295  | 0.90000         | 1.10000         | -0.12811      | 0.11332        | 0.00364       | 0.09042        |
| 296  | 0.80000         | 0.98200         | -0.12694      | 0.11919        | 0.01186       | 0.08596        |
| 297  | 0.70000         | 0.87000         | -0.08314      | 0.11578        | -0.00540      | 0.08889        |
| 298  | 0.60000         | 0.75600         | -0.05096      | 0.10110        | -0.01057      | 0.08091        |
| 299  | 0.50000         | 0.64000         | -0.00845      | 0.10733        | -0.02360      | 0.08666        |
| 300  | 0.70000         | 0.50000         | 0.01832       | 0.10510        | -0.01562      | 0.08690        |
| 301  | 0.80000         | 0.70000         | -0.04861      | 0.11813        | -0.00810      | 0.08654        |
| 302  | 0.95000         | 0.90000         | -0.10897      | 0.12729        | 0.02090       | 0.08924        |
| 303  | 1.20000         | 1.13600         | -0.14667      | 0.13351        | 0.02724       | 0.08842        |
| 304  | 1.15000         | 0.99300         | -0.14068      | 0.14584        | 0.02395       | 0.07961        |
| 305  | 1.10000         | 0.85000         | -0.12729      | 0.12412        | 0.02959       | 0.08854        |
| 306  | 1.05000         | 0.70700         | -0.10322      | 0.13903        | 0.01773       | 0.09993        |
| 307  | 1.01000         | 0.61800         | -0.08008      | 0.13046        | 0.00388       | 0.08748        |
| 308  | 1.00000         | 0.56500         | -0.05636      | 0.12823        | -0.01597      | 0.09018        |
| 309  | 0.95000         | 0.40000         | -0.04122      | 0.29556        | 0.06318       | 0.37271        |
| 310  | 1.20000         | 0.50000         | -0.03581      | 0.13950        | 0.00963       | 0.08924        |
| 311  | 1.40000         | 0.50000         | -0.07633      | 0.12999        | 0.03523       | 0.09629        |
| 312  | 1.60000         | 0.50000         | -0.08396      | 0.13809        | 0.03581       | 0.08995        |
| 313  | 2.00000         | 0.50000         | -0.11813      | 0.14162        | 0.03699       | 0.08502        |
| 314  | 1.80000         | 0.50000         | -0.10498      | 0.14549        | 0.04497       | 0.08701        |
| 315  | 2.00000         | 0.40000         | -0.08055      | 0.14667        | 0.03828       | 0.08149        |
| 316  | 2.00000         | 0.30000         | -0.06881      | 0.14138        | 0.03687       | 0.48697        |
| 317  | 2.00000         | 0.60000         | -0.12565      | 0.14890        | 0.03264       | 0.09253        |
| 318  | 2.00000         | 0.70000         | -0.12612      | 0.15876        | 0.04650       | 0.09347        |
| 319  | 2.00000         | 0.80000         | -0.16076      | 0.13821        | 0.05155       | 0.09206        |
| 320  | 2.00000         | 1.00000         | -0.18647      | 0.13727        | 0.04721       | 0.10157        |
| 321  | 2.00000         | 1.20000         | -0.18037      | 0.14302        | 0.05695       | 0.09324        |
| 322  | 2.00000         | 1.30000         | -0.16968      | 0.16616        | 0.05108       | 0.09523        |
| 323  | 0.30000         | 0.80000         | -0.02208      | 0.10651        | -0.01233      | 0.07222        |
| 324  | 0.60000         | 1.00000         | -0.08549      | 0.11907        | 0.00975       | 0.08490        |
| 325  | 1.40000         | 0.80000         | -0.14537      | 0.14537        | 0.04544       | 0.09805        |
| 326  | 1.40000         | 1.10000         | -0.16534      | 0.13175        | 0.02924       | 0.08596        |
| 327  | 1.60000         | 1.10000         | -0.15418      | 0.14302        | 0.02184       | 0.08325        |
| 328  | 1.60000         | 0.80000         | -0.14819      | 0.15019        | 0.02689       | 0.09359        |
| 329  | 1.80000         | 0.80000         | -0.15066      | 0.14995        | 0.05613       | 0.10709        |
| 330  | 1.80000         | 1.10000         | -0.16252      | 0.14831        | 0.04744       | 0.09065        |

TABLE II.- Continued.

| Pt  | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|-----|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 331 | -0.30000        | 1.30000         | 0.58936       | 0.12259        | 0.51996       | 0.16498        |
| 332 | -0.30000        | 1.10000         | 0.43037       | 0.22158        | 0.51667       | 0.23520        |
| 333 | -0.30000        | .90000          | 0.35686       | 0.22957        | 0.48744       | 0.25188        |
| 334 | -0.40000        | 0.80000         | 0.18812       | 0.44105        | 0.34758       | 0.25975        |
| 335 | -0.40000        | 0.60000         | 0.20937       | 0.28758        | 0.27266       | 0.29779        |
| 336 | -0.40000        | 0.40000         | 0.16193       | 0.31188        | 0.15839       | 0.30824        |
| 337 | -0.40000        | 0.20000         | -0.06799      | 0.53605        | 0.12341       | 0.19551        |
| 338 | -0.40000        | 0.0             | -0.06705      | 0.51691        | 0.03793       | 0.25470        |
| 339 | -0.40000        | -0.20000        | -0.05308      | 0.51092        | 0.09981       | 0.42449        |
| 340 | -0.40000        | -0.40000        | -0.00423      | 0.48051        | -0.15500      | 0.06717        |
| 341 | -0.60000        | -0.40000        | 0.26163       | 0.35345        | -0.09429      | 0.21477        |
| 342 | -0.60000        | -0.20000        | 0.33619       | 0.12142        | -0.00012      | 0.27337        |
| 343 | -0.60000        | 0.0             | 0.30437       | 0.11473        | 0.02971       | 0.23133        |
| 344 | -0.60000        | 0.20000         | 0.30719       | 0.15442        | 0.14514       | 0.34277        |
| 345 | -0.60000        | 0.40000         | 0.33055       | 0.13551        | 0.17027       | 0.24824        |
| 346 | -0.60000        | 0.60000         | 0.37142       | 0.10698        | 0.24084       | 0.15171        |
| 347 | -0.60000        | 0.80000         | 0.41839       | 0.08725        | 0.29885       | 0.15054        |
| 348 | -0.60000        | 1.00000         | 0.49096       | 0.07703        | 0.35157       | 0.09429        |
| 349 | -0.60000        | 1.20000         | 0.56552       | 0.05589        | 0.38715       | 0.18729        |
| 350 | -0.60000        | 1.40000         | 0.65524       | 0.06505        | 0.39596       | 0.16851        |
| 351 | -0.60000        | 1.60000         | 0.72123       | 0.06224        | 0.40395       | 0.08255        |
| 352 | -0.60000        | 1.80000         | 0.71360       | 0.07046        | 0.39021       | 0.17649        |
| 353 | -0.60000        | 2.00000         | 0.80672       | 0.09570        | 0.36543       | 0.11743        |
| 354 | -1.00000        | 2.00000         | 0.80061       | 0.07410        | 0.29380       | 0.16240        |
| 355 | -1.00000        | 1.50000         | 0.69481       | 0.10791        | 0.29756       | 0.07868        |
| 356 | -1.00000        | 1.00000         | 0.56470       | 0.12083        | 0.24542       | 0.10592        |
| 357 | -1.00000        | 0.80000         | 0.50611       | 0.22722        | 0.21653       | 0.09406        |
| 358 | -1.00000        | 0.60000         | 0.36449       | 0.35733        | 0.17532       | 0.10110        |
| 359 | -1.00000        | 0.40000         | 0.23462       | 0.52184        | 0.13269       | 0.24977        |
| 360 | -1.00000        | 0.20000         | 0.43988       | 0.23192        | 0.09101       | 0.30167        |
| 361 | -1.00000        | 0.0             | 0.46818       | 0.10698        | 0.02924       | 0.20949        |
| 362 | -1.00000        | -0.20000        | 0.47757       | 0.11519        | -0.02161      | 0.19798        |
| 363 | -1.00000        | -0.40000        | 0.45291       | 0.24295        | -0.04920      | 0.31341        |
| 364 | -1.00000        | -0.60000        | 0.44634       | 0.33384        | -0.04380      | 0.40254        |
| 365 | -2.00000        | -0.60000        | 0.71442       | 0.09512        | -0.06470      | 0.06294        |
| 366 | -2.00000        | -0.40000        | 0.71395       | 0.06376        | -0.05002      | 0.06952        |
| 367 | -2.00000        | -0.20000        | 0.70021       | 0.08713        | -0.01902      | 0.06881        |
| 368 | -2.00000        | 0.0             | 0.70197       | 0.06975        | -0.01116      | 0.07950        |
| 369 | -2.00000        | 0.20000         | 0.70409       | 0.06846        | 0.03311       | 0.06928        |
| 370 | -2.00000        | 0.40000         | 0.70103       | 0.09641        | 0.05026       | 0.08455        |
| 371 | -2.00000        | 0.60000         | 0.70362       | 0.08302        | 0.07457       | 0.09312        |
| 372 | -2.00000        | 0.80000         | 0.71841       | 0.08419        | 0.10193       | 0.08008        |

TABLE II.- Concluded.

| Pt  | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|-----|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 373 | -2.00000        | 1.00000         | 0.74378       | 0.07410        | 0.12588       | 0.07586        |
| 374 | -2.00000        | 1.20000         | 0.74871       | 0.07363        | 0.13727       | 0.06928        |
| 375 | -2.00000        | 1.40000         | 0.76198       | 0.07139        | 0.15571       | 0.07057        |
| 376 | -2.00000        | 1.60000         | 0.78452       | 0.08960        | 0.16428       | 0.07363        |
| 377 | -2.00000        | 2.00000         | 0.83055       | 0.07163        | 0.18906       | 0.08666        |
| 378 | -2.00000        | 2.50000         | 0.87459       | 0.06764        | 0.17755       | 0.08091        |
| 379 | -1.80000        | 0.0             | 0.66040       | 0.10322        | 0.00481       | 0.07492        |
| 380 | -1.60000        | 0.0             | -0.63492      | 0.72863        | -0.00153      | 0.09558        |
| 381 | -1.20000        | 0.0             | -0.14267      | 0.56999        | 0.01292       | 0.19129        |
| 382 | -0.80000        | 0.0             | 0.39432       | 0.18471        | 0.01080       | 0.20632        |
| 383 | -0.60000        | 0.0             | 0.21383       | 0.38856        | 0.01785       | 0.12318        |

TABLE III.- VELOCITY DATA FOR SHARP EDGE MODEL  
 $M = 0.5$ ,  $Re = .15 \cdot 10^6$

(\*indicates points dropped from analysis)

| Pt   | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|------|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 384  | 0.20000         | 1.00000         | -0.07122      | 0.05893        | 0.00346       | 0.06101        |
| 385  | 0.20000         | 1.10000         | -0.08639      | 0.06627        | 0.00101       | 0.05624        |
| 386  | 0.20000         | 1.15000         | -0.08776      | 0.07290        | -0.00179      | 0.05409        |
| 387  | 0.20000         | 1.17500         | -0.05015      | 0.10233        | 0.05576       | 0.07445        |
| 388  | 0.20000         | 1.20000         | 0.08657       | 0.16263        | 0.26955       | 0.13773        |
| 389  | 0.20000         | 1.22500         | 0.36913       | 0.20549        | 0.60549       | 0.13618        |
| 390  | 0.20000         | 1.25000         | 0.65881       | 0.16131        | 0.80227       | 0.11493        |
| 391  | 0.20000         | 1.27500         | 0.77307       | 0.11701        | 0.88997       | 0.09015        |
| 392  | 0.20000         | 1.30000         | 0.85469       | 0.05200        | 0.88961       | 0.07606        |
| 393  | 0.20000         | 1.35000         | 0.80776       | 0.05725        | 0.87642       | 0.06896        |
| 394  | 0.20000         | 1.40000         | 0.74597       | 0.10036        | 0.82609       | 0.07701        |
| 395  | 0.20000         | 1.50000         | 0.82734       | 0.08543        | 0.69743       | 0.05779        |
| 396  | 0.20000         | 1.60000         | 0.80561       | 0.22699        | 0.62418       | 0.13893        |
| 397  | 0.20000         | 1.70000         | 0.88287       | 0.07964        | 0.58406       | 0.10973        |
| 398  | 0.20000         | 1.80000         | 0.88364       | 0.08931        | 0.56406       | 0.07469        |
| 399  | 2.00000         | 2.40000         | 1.23397       | 0.06293        | 0.36227       | 0.05678        |
| 400  | 2.00000         | 2.30000         | 1.23940       | 0.07594        | 0.36173       | 0.05851        |
| 401  | 2.00000         | 2.20000         | 1.21552       | 0.14036        | 0.34454       | 0.05860        |
| 402  | 2.00000         | 2.10000         | 1.08955       | 0.25773        | 0.31373       | 0.08436        |
| 403  | 2.00000         | 2.00000         | 0.70466       | 0.32824        | 0.28125       | 0.11570        |
| 404  | 2.00000         | 1.90000         | 0.37576       | 0.32472        | 0.15773       | 0.13303        |
| 405  | 2.00000         | 1.92500         | 0.43887       | 0.32860        | 0.19379       | 0.13212        |
| 406  | 2.00000         | 1.95000         | 0.52281       | 0.33504        | 0.21439       | 0.12173        |
| 407  | 2.00000         | 1.85000         | 0.20131       | 0.29015        | 0.11612       | 0.11779        |
| 408  | 2.00000         | 1.80000         | 0.10304       | 0.26800        | 0.08436       | 0.13707        |
| 409  | 2.00000         | 1.75000         | -0.00197      | 0.23027        | 0.06257       | 0.11875        |
| 410  | 2.00000         | 1.70000         | -0.06436      | 0.19528        | 0.04919       | 0.12776        |
| 411  | 2.00000         | 1.60000         | -0.15475      | 0.14907        | 0.05152       | 0.09558        |
| 412  | 2.00000         | 1.50000         | -0.17958      | 0.13815        | 0.04054       | 0.11015        |
| 413  | 2.00000         | 1.40000         | -0.18901      | 0.14000        | 0.05582       | 0.09397        |
| 414  | 2.00000         | 1.30000         | -0.19845      | 0.14048        | 0.03803       | 0.08627        |
| 415  | 2.00000         | 1.20000         | -0.20866      | 0.13319        | 0.04961       | 0.08633        |
| 416  | 2.00000         | 1.00000         | -0.19821      | 0.14967        | 0.05940       | 0.08949        |
| 417  | 2.00000         | 0.80000         | -0.18764      | 0.14293        | 0.05069       | 0.08591        |
| 418  | 2.00000         | 0.70000         | -0.17606      | 0.14012        | 0.05087       | 0.07946        |
| 419  | 2.00000         | 0.60000         | -0.13946      | 0.14215        | 0.05582       | 0.08030        |
| 420  | 2.00000         | 0.50000         | -0.12358      | 0.13660        | 0.04185       | 0.07737        |
| 421* | 2.00000         | 0.40000         | -0.09242      | 0.14436        | 0.00764       | 0.14167        |
| 422  | 2.00000         | 0.40000         | -0.07152      | 0.14173        | 0.05248       | 0.24890        |
| 423  | 1.90000         | 1.40000         | -0.18460      | 0.12621        | 0.04722       | 0.07934        |
| 424  | 1.90000         | 1.50000         | -0.18710      | 0.13182        | 0.06113       | 0.09964        |
| 425  | 1.90000         | 1.60000         | -0.15093      | 0.16155        | 0.04878       | 0.09504        |

TABLE III.- Continued.

| Pt   | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|------|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 426  | 1.90000         | 1.70000         | -0.04012      | 0.18245        | 0.05057       | 0.11206        |
| 427  | 1.90000         | 1.80000         | 0.18788       | 0.28304        | 0.12836       | 0.10609        |
| 428  | 1.90000         | 1.90000         | 0.49003       | 0.33528        | 0.18525       | 0.12018        |
| 429  | 1.90000         | 2.00000         | 0.78919       | 0.36000        | 0.33242       | 0.10716        |
| 430  | 1.90000         | 2.10000         | 1.14913       | 0.21916        | 0.32096       | 0.05296        |
| 431  | 1.90000         | 2.20000         | 1.26525       | 0.06776        | 0.29642       | 0.19361        |
| 432  | 1.20000         | 1.13600         | -0.16919      | 0.14346        | 0.00663       | 0.07033        |
| 433  | 1.20000         | 1.20000         | -0.19672      | 0.10925        | 0.04758       | 0.06543        |
| 434  | 1.20000         | 1.30000         | -0.17564      | 0.13463        | 0.03493       | 0.06597        |
| 435  | 1.20000         | 1.40000         | -0.19140      | 0.11964        | 0.01421       | 0.06018        |
| 436  | 1.20000         | 1.50000         | -0.14776      | 0.12448        | 0.01558       | 0.07403        |
| 437  | 1.20000         | 1.60000         | 0.00764       | 0.20645        | 0.04597       | 0.09003        |
| 438  | 1.20000         | 1.70000         | 0.37785       | 0.29487        | 0.20866       | 0.11487        |
| 439  | 1.20000         | 1.65000         | 0.15606       | 0.25015        | 0.11564       | 0.09373        |
| 440  | 1.20000         | 1.75000         | 0.69851       | 0.30746        | 0.32328       | 0.11976        |
| 441  | 1.20000         | 1.80000         | 0.89696       | 0.29182        | 0.41164       | 0.10764        |
| 442  | 1.20000         | 2.00000         | 1.20746       | 0.06275        | 0.34537       | 0.23612        |
| 443* | 2.00000         | 2.05000         | 0.77636       | 0.36782        | 0.33576       | 0.12213        |
| 444* | 2.00000         | 2.15000         | 1.19600       | 0.10728        | 0.16478       | 0.25158        |
| 445* | 2.00000         | 2.05000         | 0.80358       | 0.30791        | 0.22478       | 0.20340        |
| 446  | 0.0             | 1.50000         | 0.68498       | 0.05542        | 0.57479       | 0.05101        |
| 447  | 0.0             | 1.80000         | 0.79482       | 0.04017        | 0.47872       | 0.04070        |
| 448  | 0.0             | 1.70000         | 0.76724       | 0.04255        | 0.50989       | 0.04380        |
| 449  | 0.0             | 1.60000         | 0.73528       | 0.04535        | 0.53665       | 0.04487        |
| 450  | 0.0             | 1.40000         | 0.62479       | 0.04672        | 0.60751       | 0.04797        |
| 451  | 0.0             | 1.30000         | 0.52670       | 0.04869        | 0.66824       | 0.05423        |
| 452  | 0.0             | 1.20000         | 0.42652       | 0.07271        | 0.74184       | 0.07706        |
| 453  | 0.0             | 1.10000         | 0.21400       | 0.07223        | 0.81567       | 0.09815        |
| 454  | 0.0             | 1.05000         | 0.02729       | 0.21633        | 0.73391       | 0.11526        |
| 455  | 0.10000         | 1.05000         | -0.05912      | 0.05447        | 0.02342       | 0.04964        |
| 456  | 0.10000         | 1.10000         | -0.06448      | 0.06097        | 0.04708       | 0.06508        |
| 457  | 0.10000         | 1.20000         | 0.57986       | 0.23856        | 0.83617       | 0.26031        |
| 458  | 0.10000         | 1.30000         | 0.59625       | 0.10703        | 0.77616       | 0.05364        |
| 459  | 0.10000         | 1.15000         | 0.30095       | 0.19607        | 0.38951       | 0.30554        |
| 460* | 0.10000         | 1.20000         | 0.65334       | 0.06645        | 0.94225       | 0.07759        |
| 461  | 0.10000         | 1.40000         | 0.64726       | 0.09410        | 0.66502       | 0.09297        |
| 462  | 0.10000         | 1.50000         | 0.74178       | 0.06913        | 0.61824       | 0.05119        |
| 463  | 0.10000         | 1.60000         | 0.77980       | 0.05852        | 0.57515       | 0.04660        |
| 464  | 0.10000         | 1.70000         | 0.81305       | 0.05513        | 0.53456       | 0.04309        |
| 465  | 0.10000         | 1.80000         | 0.83004       | 0.05441        | 0.50387       | 0.04052        |
| 466* | 0.20000         | 1.80000         | 0.86841       | 0.05906        | 0.51853       | 0.04261        |
| 467* | 0.20000         | 1.70000         | 0.82962       | 0.11603        | 0.54762       | 0.06281        |
| 468* | 0.20000         | 1.60000         | 0.83045       | 0.06764        | 0.59595       | 0.04952        |
| 469* | 0.20000         | 1.50000         | 0.76931       | 0.07324        | 0.65572       | 0.04696        |
| 470* | 0.20000         | 1.40000         | 0.72741       | 0.08701        | 0.75864       | 0.05226        |

TABLE III.- Continued.

| Pt   | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|------|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 471* | 0.20000         | 1.30000         | 0.86311       | 0.06907        | 0.82110       | 0.04684        |
| 472* | 0.20000         | 1.20000         | 0.02271       | 0.14154        | 0.17300       | 0.08772        |
| 473* | 0.20000         | 1.25000         | 0.45346       | 0.19869        | 0.56251       | 0.10250        |
| 474* | 0.20000         | 1.27500         | 0.60423       | 0.12133        | 0.71293       | 0.25834        |
| 475* | 0.20000         | 1.22500         | 0.22181       | 0.19392        | 0.34023       | 0.12288        |
| 476* | 0.20000         | 1.10000         | -0.07586      | 0.05930        | -0.00232      | 0.05715        |
| 477  | 0.25000         | 1.01500         | -0.06311      | 0.05834        | -0.01663      | 0.06943        |
| 478  | 0.30000         | 1.10000         | -0.08486      | 0.06907        | -0.00435      | 0.06103        |
| 479  | 0.30000         | 1.20000         | -0.10048      | 0.07187        | -0.00757      | 0.05221        |
| 480  | 0.30000         | 1.30000         | 0.16281       | 0.18272        | 0.26836       | 0.10578        |
| 481  | 0.30000         | 1.25000         | -0.06436      | 0.08534        | 0.02199       | 0.05012        |
| 482  | 0.30000         | 1.35000         | 0.64607       | 0.14964        | 0.69559       | 0.09482        |
| 483  | 0.30000         | 1.32500         | 0.45375       | 0.20369        | 0.52908       | 0.12354        |
| 484  | 0.30000         | 1.37500         | 0.82980       | 0.09333        | 0.76097       | 0.05727        |
| 485  | 0.30000         | 1.40000         | 0.97640       | 0.05203        | 0.74791       | 0.05340        |
| 486  | 0.30000         | 1.50000         | 0.83397       | 0.06430        | 0.72497       | 0.05560        |
| 487  | 0.30000         | 1.60000         | 0.86031       | 0.07521        | 0.62932       | 0.03850        |
| 488  | 0.30000         | 1.70000         | 0.89607       | 0.06818        | 0.58749       | 0.04231        |
| 489  | 0.30000         | 1.80000         | 0.90942       | 0.06454        | 0.54392       | 0.04225        |
| 490  | 0.40000         | 1.80000         | 0.93892       | 0.08933        | 0.55661       | 0.04273        |
| 491  | 0.40000         | 1.70000         | 0.93319       | 0.07277        | 0.60870       | 0.04362        |
| 492  | 0.40000         | 0.60000         | 0.90614       | 0.06669        | 0.67569       | 0.05209        |
| 493  | 0.40000         | 1.50000         | 0.99172       | 0.04756        | 0.70542       | 0.04452        |
| 494  | 0.40000         | 1.40000         | 0.52980       | 0.19785        | 0.54064       | 0.08474        |
| 495  | 0.40000         | 1.45000         | 0.94958       | 0.12104        | 0.68105       | 0.08731        |
| 496  | 0.40000         | 1.42500         | 0.69893       | 0.24762        | 0.67318       | 0.10006        |
| 497  | 0.40000         | 1.37500         | 0.33915       | 0.24476        | 0.38570       | 0.11198        |
| 498  | 0.40000         | 1.35000         | 0.13611       | 0.19136        | 0.19541       | 0.07688        |
| 499  | 0.40000         | 1.30000         | -0.08856      | 0.08999        | 0.00328       | 0.05602        |
| 500  | 0.40000         | 1.20000         | -0.09672      | 0.08135        | -0.01162      | 0.05113        |
| 501  | 0.40000         | 1.10000         | -0.09934      | 0.08147        | -0.00656      | 0.05763        |
| 502  | 0.40000         | 1.00000         | -0.06871      | 0.07902        | -0.00793      | 0.05662        |
| 503  | 0.50000         | 1.00000         | -0.07962      | 0.08409        | -0.01383      | 0.04923        |
| 504  | 0.50000         | 1.10000         | -0.09917      | 0.07849        | -0.01263      | 0.05662        |
| 505  | 0.50000         | 1.20000         | -0.09487      | 0.08802        | -0.00697      | 0.05578        |
| 506  | 0.50000         | 1.30000         | -0.12157      | 0.08671        | 0.00072       | 0.05846        |
| 507  | 0.50000         | 1.40000         | 0.09678       | 0.18021        | 0.15977       | 0.07908        |
| 508  | 0.50000         | 1.50000         | 0.87223       | 0.20375        | 0.64505       | 0.07652        |
| 509  | 0.50000         | 1.60000         | 0.99774       | 0.04636        | 0.64893       | 0.04803        |
| 510  | 0.50000         | 1.42500         | 0.33015       | 0.21472        | 0.31156       | 0.07974        |
| 511  | 0.50000         | 1.45000         | 0.50125       | 0.21824        | 0.43701       | 0.08886        |
| 512  | 0.50000         | 1.47500         | 0.72390       | 0.24547        | 0.53892       | 0.10524        |
| 513  | 0.50000         | 1.55000         | 1.06067       | 0.05292        | 0.62265       | 0.03611        |
| 514  | 0.50000         | 1.70000         | 0.95560       | 0.07342        | 0.62980       | 0.05048        |
| 515  | 0.50000         | 1.80000         | 0.98689       | 0.06788        | 0.56663       | 0.04452        |

TABLE III.- Continued.

| Pt   | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|------|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 516  | 0.50000         | 2.00000         | 0.99231       | 0.06889        | 0.50334       | 0.04511        |
| 517  | 0.60000         | 1.80000         | 0.98851       | 0.08123        | 0.57950       | 0.05060        |
| 518  | 0.60000         | 1.70000         | 1.02020       | 0.05083        | 0.60828       | 0.05280        |
| 519  | 0.60000         | 1.60000         | 1.08903       | 0.05393        | 0.59452       | 0.03564        |
| 520  | 0.60000         | 1.55000         | 0.84309       | 0.13844        | 0.58611       | 0.08170        |
| 521  | 0.60000         | 1.50000         | 0.47426       | 0.24934        | 0.38099       | 0.10453        |
| 522  | 0.60000         | 1.45000         | 0.12187       | 0.21257        | 0.14374       | 0.08874        |
| 523  | 0.60000         | 1.52500         | 0.65453       | 0.23057        | 0.49410       | 0.09249        |
| 524  | 0.60000         | 1.47500         | 0.32807       | 0.22700        | 0.26990       | 0.07294        |
| 525  | 0.60000         | 1.40000         | -0.05936      | 0.11734        | 0.01168       | 0.05536        |
| 526  | 0.60000         | 1.30000         | -0.14148      | 0.10089        | -0.01037      | 0.04589        |
| 527  | 0.60000         | 1.20000         | -0.12986      | 0.08492        | 0.01466       | 0.06818        |
| 528  | 0.60000         | 1.10000         | -0.11091      | 0.08921        | -0.02044      | 0.07551        |
| 529  | 0.90000         | 1.10000         | -0.16031      | 0.09672        | -0.01520      | 0.06967        |
| 530  | 0.90000         | 1.20000         | -0.14696      | 0.10703        | 0.00054       | 0.05238        |
| 531  | 0.90000         | 1.30000         | -0.16365      | 0.09928        | 0.01150       | 0.05703        |
| 532  | 0.90000         | 1.40000         | -0.16901      | 0.09547        | 0.00781       | 0.05191        |
| 533  | 0.90000         | 1.50000         | -0.08540      | 0.13105        | 0.02205       | 0.07163        |
| 534  | 0.90000         | 1.60000         | 0.27843       | 0.26031        | 0.18099       | 0.08737        |
| 535  | 0.90000         | 1.50000         | -0.07175      | 0.14017        | 0.02223       | 0.06985        |
| 536  | 0.90000         | 1.55000         | 0.03826       | 0.18600        | 0.07408       | 0.07723        |
| 537  | 0.90000         | 1.65000         | 0.60346       | 0.26335        | 0.34410       | 0.10215        |
| 538  | 0.90000         | 1.62500         | 0.45113       | 0.26853        | 0.27199       | 0.09601        |
| 539  | 0.90000         | 1.67500         | 0.72163       | 0.24821        | 0.44398       | 0.08897        |
| 540  | 0.90000         | 1.70000         | 0.90060       | 0.23021        | 0.50393       | 0.09285        |
| 541  | 0.90000         | 1.80000         | 1.13218       | 0.04875        | 0.54464       | 0.03737        |
| 542  | 0.90000         | 1.90000         | 1.10840       | 0.04791        | 0.55268       | 0.04273        |
| 543  | 0.90000         | 2.00000         | 1.08093       | 0.06824        | 0.53957       | 0.05054        |
| 544  | 1.00000         | 2.00000         | 1.11466       | 0.05298        | 0.52819       | 0.04636        |
| 545  | 1.00000         | 1.90000         | 1.14070       | 0.04958        | 0.52938       | 0.04541        |
| 546  | 1.00000         | 1.80000         | 1.15876       | 0.07229        | 0.54833       | 0.06001        |
| 547  | 1.00000         | 1.70000         | 0.64207       | 0.30036        | 0.36996       | 0.07574        |
| 548  | 1.00000         | 1.60000         | 0.10530       | 0.21621        | 0.10942       | 0.06871        |
| 549  | 1.00000         | 1.75000         | 0.90173       | 0.22539        | 0.44779       | 0.07247        |
| 550  | 1.00000         | 1.65000         | 0.35840       | 0.27092        | 0.21466       | 0.08141        |
| 551  | 1.00000         | 1.50000         | -0.13862      | 0.11395        | 0.02586       | 0.06913        |
| 552  | 1.00000         | 1.40000         | -0.15608      | 0.09952        | 0.00441       | 0.06359        |
| 553* | 1.00000         | 1.30000         | -0.17139      | 0.10441        | -0.00733      | 0.05238        |
| 554  | 1.00000         | 1.20000         | -0.16347      | 0.10942        | 0.02962       | 0.08254        |
| 555  | 1.00000         | 1.10000         | -0.13838      | 0.11251        | 0.01561       | 0.06317        |
| 556  | 1.10000         | 1.10000         | -0.16591      | 0.12294        | 0.00632       | 0.07539        |
| 557  | 1.10000         | 1.20000         | -0.15590      | 0.13159        | -0.00656      | 0.08719        |
| 558  | 1.10000         | 1.30000         | -0.16770      | 0.11895        | 0.01412       | 0.07229        |
| 559  | 1.10000         | 1.40000         | -0.16377      | 0.11180        | 0.02312       | 0.06764        |
| 560  | 1.10000         | 1.50000         | -0.15894      | 0.11359        | 0.01681       | 0.05882        |
| 561  | 1.10000         | 1.60000         | -0.02777      | 0.15375        | 0.03880       | 0.09064        |

TABLE III.- Concluded.

| Pt   | $\frac{x}{b/2}$ | $\frac{u}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|------|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 562  | 1.10000         | 1.70000         | 0.34297       | 0.26853        | 0.19172       | 0.08969        |
| 563  | 1.10000         | 1.65000         | 0.12473       | 0.24207        | 0.08576       | 0.08796        |
| 564  | 1.10000         | 1.75000         | 0.60197       | 0.27521        | 0.34994       | 0.08576        |
| 565  | 1.10000         | 1.80000         | 0.94416       | 0.26818        | 0.46400       | 0.07223        |
| 566  | 1.10000         | 1.85000         | 1.16210       | 0.10465        | 0.52938       | 0.05471        |
| 567  | 1.10000         | 1.90000         | 1.17741       | 0.05375        | 0.50846       | 0.04565        |
| 568  | 1.10000         | 2.00000         | 1.16323       | 0.04660        | 0.51925       | 0.04976        |
| 569  | 1.10000         | 2.10000         | 1.13498       | 0.05590        | 0.52986       | 0.04166        |
| 570  | 1.10000         | 2.20000         | 1.13796       | 0.04899        | 0.48653       | 0.04762        |
| 571  | 0.30000         | 1.04300         | -0.05763      | 0.06728        | 0.02068       | 0.05471        |
| 572  | 0.50000         | 1.15700         | -0.11079      | 0.08665        | -0.01156      | 0.05417        |
| 573  | 0.80000         | 0.98200         | -0.12670      | 0.11901        | -0.04750      | 0.06246        |
| 574  | 0.70000         | 0.87000         | -0.09476      | 0.11329        | -0.00167      | 0.09333        |
| 575  | 0.60000         | 0.75600         | -0.02998      | 0.08784        | -0.00799      | 0.09184        |
| 576* | 1.20000         | 1.13600         | -0.16740      | 0.11502        | 0.04708       | 0.07342        |
| 577  | 1.15000         | 0.99300         | -0.15173      | 0.11663        | -0.00703      | 0.07330        |
| 578  | 1.10000         | 0.85000         | -0.11955      | 0.12521        | 0.01162       | 0.09422        |
| 579  | 1.05000         | 0.70700         | -0.08206      | 0.11955        | -0.02247      | 0.07628        |
| 580  | 1.01000         | 0.61800         | -0.04881      | 0.10667        | -0.02092      | 0.07580        |
| 581  | 1.00000         | 0.56500         | -0.01645      | 0.12098        | -0.05131      | 0.10638        |
| 582  | 0.98000         | 0.50000         | 0.02878       | 0.10173        | -0.01818      | 0.05787        |
| 583  | 1.20000         | 0.50000         | 0.00471       | 0.12139        | -0.08838      | 0.05310        |
| 584  | 1.40000         | 0.50000         | -0.03647      | 0.11758        | 0.03850       | 0.08868        |
| 585  | 1.60000         | 0.50000         | -0.06645      | 0.13880        | 0.03605       | 0.05167        |
| 586  | 1.80000         | 0.50000         | -0.06275      | 0.13820        | 0.01907       | 0.08826        |
| 587* | 2.00000         | 0.50000         | -0.09720      | 0.12628        | 0.02068       | 0.03713        |
| 588* | 2.00000         | 0.80000         | -0.18814      | 0.12700        | 0.05656       | 0.05435        |
| 589  | 2.00000         | 1.10000         | -0.20703      | 0.10679        | 0.07086       | 0.05012        |
| 590  | 1.80000         | 1.10000         | -0.19362      | 0.13981        | 0.01871       | 0.04184        |
| 591  | 1.80000         | 0.80000         | -0.16901      | 0.13558        | 0.02884       | 0.06180        |
| 592  | 1.60000         | 0.80000         | -0.17116      | 0.11669        | 0.06532       | 0.10936        |
| 593  | 1.60000         | 1.10000         | -0.18707      | 0.15197        | 0.03331       | 0.08212        |
| 594  | 1.40000         | 1.10000         | -0.15793      | 0.13075        | 0.03820       | 0.06055        |
| 595  | 1.40000         | 0.80000         | -0.15185      | 0.12765        | 0.03355       | 0.09368        |
| 596  | 0.80000         | 0.70000         | -0.05012      | 0.10083        | -0.02908      | 0.06132        |
| 597  | 0.95000         | 0.90000         | -0.10101      | 0.11204        | -0.04136      | 0.08862        |
| 598  | 0.40000         | 0.80000         | -0.10602      | 0.08582        | -0.03111      | 0.07604        |
| 599  | 0.40000         | 0.80000         | -0.02098      | 0.07306        | -0.03641      | 0.10447        |
| 600  | -0.50000        | 1.00000         | 0.45483       | 0.05143        | 0.08570       | 0.24839        |
| 601  | -0.50000        | 1.20000         | 0.52402       | 0.03123        | 0.32437       | 0.05727        |
| 602  | -0.50000        | 1.40000         | 0.60423       | 0.03153        | 0.37944       | 0.08147        |
| 603  | -0.50000        | 1.60000         | 0.67723       | 0.03337        | 0.35650       | 0.04899        |
| 604  | -0.50000        | 2.00000         | 0.78886       | 0.03528        | 0.36144       | 0.06406        |
| 605  | -0.10000        | 2.00000         | 0.84595       | 0.04231        | 0.37128       | 0.14315        |
| 606  | -0.10000        | 1.80000         | 0.78415       | 0.04052        | 0.48319       | 0.05602        |
| 607  | -0.10000        | 1.60000         | 0.70584       | 0.04219        | 0.38486       | 0.13147        |
| 608  | -0.10000        | 1.40000         | 0.58516       | 0.04541        | 0.12128       | 0.25495        |

TABLE IV.- VELOCITY DATA FOR ROUND EDGE MODEL  
 $M = .25$ ,  $Re = .25 \times 10^6$

(\*indicates points dropped from analysis)

| Pt   | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|------|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 609* | -0.20000        | 1.50000         | 0.79641       | 0.14136        | 0.54216       | 0.08172        |
| 610  | -0.20000        | 2.00000         | 0.90470       | 0.09223        | 0.41344       | 0.14820        |
| 611  | -0.20000        | 1.80000         | 0.88002       | 0.08963        | 0.45879       | 0.07121        |
| 612  | -0.20000        | 1.70000         | 0.89655       | 0.08160        | 0.48370       | 0.08101        |
| 613  | -0.20000        | 1.60000         | 0.83656       | 0.10109        | 0.51464       | 0.06967        |
| 614  | -0.20000        | 1.40000         | 0.77161       | 0.10900        | 0.58526       | 0.07900        |
| 615  | -0.20000        | 1.30000         | 0.70666       | 0.17100        | 0.62459       | 0.08314        |
| 616  | -0.20000        | 1.20000         | 0.63699       | 0.12600        | 0.67336       | 0.07074        |
| 617* | -0.10000        | 1.20000         | 0.66675       | 0.18812        | 0.75508       | 0.06601        |
| 618  | -0.10000        | 1.25000         | 0.71977       | 0.10097        | 0.72024       | 0.06743        |
| 619  | -0.10000        | 1.30000         | 0.76299       | 0.08184        | 0.65753       | 0.07003        |
| 620* | -0.10000        | 1.30000         | 0.76075       | 0.08148        | 0.66308       | 0.06826        |
| 621  | -0.10000        | 1.40000         | 0.80231       | 0.07652        | 0.61313       | 0.06590        |
| 622  | -0.10000        | 1.50000         | 0.83396       | 0.07251        | 0.55716       | 0.08207        |
| 623  | -0.10000        | 1.60000         | 0.85569       | 0.06743        | 0.52728       | 0.06944        |
| 624  | -0.10000        | 1.70000         | 0.87541       | 0.06247        | 0.49114       | 0.06294        |
| 625  | -0.10000        | 1.80000         | 0.89254       | 0.06519        | 0.46800       | 0.05940        |
| 626  | -0.10000        | 2.00000         | 0.91863       | 0.06294        | 0.40966       | 0.12577        |
| 627  | 0.0             | 2.00000         | 0.94284       | 0.10687        | 0.42773       | 0.06306        |
| 628  | 0.0             | 1.80000         | 0.92194       | 0.07806        | 0.48512       | 0.06448        |
| 629  | 0.0             | 1.70000         | 0.90931       | 0.06637        | 0.51323       | 0.06365        |
| 630  | 0.0             | 1.60000         | 0.89549       | 0.06814        | 0.55113       | 0.05964        |
| 631  | 0.0             | 1.50000         | 0.87624       | 0.07204        | 0.58243       | 0.05952        |
| 632  | 0.0             | 1.40000         | 0.85439       | 0.07676        | 0.63840       | 0.06637        |
| 633  | 0.0             | 1.30000         | 0.78602       | 0.10735        | 0.72237       | 0.06448        |
| 634  | 0.0             | 1.25000         | 0.76405       | 0.11254        | 0.77893       | 0.07546        |
| 635  | 0.0             | 1.20000         | 0.81613       | 0.07333        | 0.81944       | 0.07570        |
| 636  | 0.0             | 1.15000         | 0.86738       | 0.06554        | 0.83184       | 0.06424        |
| 637  | 0.10000         | 1.15000         | 0.07192       | 0.16970        | 0.15942       | 0.10723        |
| 638  | 0.10000         | 1.20000         | 0.74244       | 0.24740        | 0.60227       | 0.10191        |
| 639  | 0.10000         | 1.30000         | 0.90364       | 0.06802        | 0.74693       | 0.07381        |
| 640  | 0.10000         | 1.17500         | 0.38179       | 0.23016        | 0.48878       | 0.11325        |
| 641  | 0.10000         | 1.40000         | 0.88309       | 0.09884        | 0.67796       | 0.06542        |
| 642  | 0.10000         | 1.50000         | 0.91675       | 0.10109        | 0.61290       | 0.05538        |
| 643  | 0.10000         | 1.60000         | 0.93481       | 0.07180        | 0.56519       | 0.06802        |
| 644  | 0.10000         | 1.70000         | 0.94580       | 0.06684        | 0.52811       | 0.06743        |
| 645  | 0.10000         | 1.80000         | 0.95914       | 0.08066        | 0.50390       | 0.07310        |
| 646  | 0.20000         | 1.80000         | 0.98299       | 0.08928        | 0.50709       | 0.06353        |
| 647  | 0.20000         | 1.70000         | 0.98170       | 0.09188        | 0.53826       | 0.06719        |
| 648  | 0.20000         | 1.60000         | 0.97520       | 0.10711        | 0.57806       | 0.06117        |
| 649  | 0.20000         | 1.50000         | 0.95607       | 0.08030        | 0.61762       | 0.06412        |

TABLE IV.- Continued.

| Pt   | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|------|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 650  | 0.20000         | 1.40000         | 0.95477       | 0.07841        | 0.69249       | 0.07333        |
| 651  | 0.20000         | 1.30000         | 1.01630       | 0.10274        | 0.65612       | 0.08278        |
| 652  | 0.20000         | 1.20000         | 0.02197       | 0.15624        | 0.11195       | 0.07381        |
| 653  | 0.20000         | 1.25000         | 0.47095       | 0.24740        | 0.75472       | 0.12470        |
| 654* | 0.20000         | 1.25000         | 0.40624       | 0.23902        | 0.37600       | 0.16308        |
| 655  | 0.20000         | 1.27500         | 0.79334       | 0.24055        | 0.53779       | 0.31660        |
| 656  | 0.20000         | 1.10000         | -0.08892      | 0.08668        | 0.03236       | 0.07558        |
| 657  | 0.10000         | 1.05000         | -0.09967      | 0.07558        | 0.00803       | 0.07286        |
| 658  | 0.10000         | 1.10000         | -0.10900      | 0.07853        | 0.02846       | 0.07983        |
| 659  | 0.0             | 1.10000         | 0.14561       | 0.22662        | 0.00945       | 0.55550        |
| 660  | -0.05000        | 1.10000         | 0.79570       | 0.07865        | 0.01878       | 0.37931        |
| 661  | -0.10000        | 1.10000         | 0.60286       | 0.13923        | 0.23040       | 0.52610        |
| 662  | -0.15000        | 1.10000         | 0.54263       | 0.13510        | 0.24067       | 0.55621        |
| 663  | -0.20000        | 1.10000         | 0.52586       | 0.09436        | 0.00756       | 0.27114        |
| 664  | -0.20000        | 1.15000         | 0.57050       | 0.09684        | 0.34223       | 0.57204        |
| 665  | -0.15000        | 1.15000         | 0.59258       | 0.11266        | 0.54263       | 0.59447        |
| 666  | -0.10000        | 1.15000         | 0.65092       | 0.11868        | 0.28590       | 0.50661        |
| 667  | -0.05000        | 1.15000         | 0.72166       | 0.11384        | 0.30231       | 0.65683        |
| 668* | 0.0             | 1.15000         | 0.86644       | 0.07794        | 0.81767       | 0.10038        |
| 669  | 0.18000         | 0.97000         | -0.05834      | 0.07711        | 0.05102       | 0.16958        |
| 670  | 0.25000         | 1.01500         | -0.07747      | 0.08503        | -0.00650      | 0.07688        |
| 671  | 0.30000         | 1.04300         | -0.09223      | 0.08975        | 0.00791       | 0.06920        |
| 672  | 0.30000         | 1.10000         | -0.11101      | 0.10487        | 0.03000       | 0.08680        |
| 673  | 0.30000         | 1.20000         | -0.11101      | 0.08396        | 0.00579       | 0.06873        |
| 674  | 0.30000         | 1.30000         | 0.38026       | 0.24705        | 0.30940       | 0.10250        |
| 675  | 0.30000         | 1.40000         | 1.04889       | 0.07156        | 0.65600       | 0.07239        |
| 676  | 0.30000         | 1.35000         | 1.05031       | 0.12411        | 0.61632       | 0.08739        |
| 677  | 0.30000         | 1.32500         | 0.79299       | 0.26464        | 0.55125       | 0.11160        |
| 678  | 0.30000         | 1.25000         | 0.01122       | 0.16533        | 0.08668       | 0.10050        |
| 679  | 0.30000         | 1.27500         | 0.12530       | 0.18682        | 0.15139       | 0.10345        |
| 680  | 0.30000         | 1.31000         | 0.46032       | 0.25697        | 0.38321       | 0.22048        |
| 681  | 0.30000         | 1.50000         | 1.00331       | 0.08373        | 0.63769       | 0.07133        |
| 682  | 0.30000         | 1.60000         | 1.01370       | 0.11278        | 0.58007       | 0.06861        |
| 683  | 0.30000         | 1.70000         | 1.01913       | 0.08314        | 0.57062       | 0.07097        |
| 684  | 0.30000         | 1.80000         | 1.02409       | 0.11762        | 0.51760       | 0.08231        |
| 685  | 0.30000         | 2.00000         | 1.01889       | 0.12104        | 0.44202       | 0.08928        |
| 686  | 0.40000         | 2.00000         | 1.04889       | 0.10569        | 0.44934       | 0.14301        |
| 687  | 0.40000         | 1.80000         | 1.04051       | 0.09046        | 0.52220       | 0.07121        |
| 688  | 0.40000         | 1.70000         | 1.03791       | 0.15316        | 0.54440       | 0.06991        |
| 689* | 0.40000         | 1.70000         | 1.04405       | 0.09967        | 0.54535       | 0.06696        |
| 690* | 0.40000         | 1.60000         | 1.00685       | 0.09152        | 0.55090       | 0.09660        |
| 691* | 0.40000         | 1.70000         | 1.04936       | 0.07806        | 0.51075       | 0.10061        |
| 692  | 0.40000         | 1.60000         | 1.05042       | 0.08928        | 0.54074       | 0.12990        |
| 693  | 0.40000         | 1.50000         | 1.07003       | 0.08833        | 0.57452       | 0.06601        |
| 694  | 0.40000         | 1.40000         | 0.93470       | 0.26783        | 0.50945       | 0.18375        |

TABLE IV.- Continued.

| Pt  | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|-----|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 695 | 0.40000         | 1.35000         | 0.36774       | 0.25012        | 0.26760       | 0.10522        |
| 696 | 0.40000         | 1.30000         | 0.02515       | 0.16863        | 0.09223       | 0.08987        |
| 697 | 0.40000         | 1.32500         | 0.14820       | 0.22603        | 0.15328       | 0.09648        |
| 698 | 0.40000         | 1.37500         | 0.52374       | 0.27350        | 0.37081       | 0.15517        |
| 699 | 0.40000         | 1.20000         | -0.11349      | 0.10014        | 0.01618       | 0.06755        |
| 700 | 0.40000         | 1.10000         | -0.11845      | 0.08680        | 0.01382       | 0.06838        |
| 701 | 0.40000         | 1.00000         | -0.10853      | 0.09471        | -0.00154      | 0.08184        |
| 702 | 0.40000         | 0.90000         | -0.07487      | 0.09211        | 0.00496       | 0.07794        |
| 703 | 0.40000         | 0.80000         | -0.04771      | 0.08857        | 0.00059       | 0.07357        |
| 704 | 0.50000         | 1.00000         | -0.07877      | 0.10239        | 0.00744       | 0.07735        |
| 705 | 0.50000         | 1.10000         | -0.11632      | 0.11195        | 0.02409       | 0.07487        |
| 706 | 0.50000         | 1.20000         | -0.12128      | 0.10711        | 0.00945       | 0.07475        |
| 707 | 0.50000         | 1.30000         | -0.07404      | 0.10900        | 0.03637       | 0.08503        |
| 708 | 0.50000         | 1.40000         | 0.33940       | 0.26500        | 0.25626       | 0.11431        |
| 709 | 0.50000         | 1.50000         | 1.10805       | 0.11313        | 0.54901       | 0.07912        |
| 710 | 0.50000         | 1.45000         | 0.90777       | 0.27055        | 0.47012       | 0.09447        |
| 711 | 0.50000         | 1.42500         | 0.59849       | 0.30739        | 0.38911       | 0.10274        |
| 712 | 0.50000         | 1.60000         | 1.09589       | 0.06932        | 0.53082       | 0.06613        |
| 713 | 0.50000         | 1.70000         | 1.07747       | 0.08042        | 0.52445       | 0.06684        |
| 714 | 0.50000         | 1.80000         | 1.08302       | 0.07239        | 0.48772       | 0.05574        |
| 715 | 0.50000         | 2.00000         | 1.07936       | 0.06259        | 0.45146       | 0.05975        |
| 716 | 0.60000         | 2.00000         | 1.09991       | 0.06778        | 0.43552       | 0.05786        |
| 717 | 0.60000         | 1.80000         | 1.10723       | 0.06908        | 0.49043       | 0.05940        |
| 718 | 0.60000         | 1.70000         | 1.12329       | 0.07274        | 0.50201       | 0.06306        |
| 719 | 0.60000         | 1.60000         | 1.13533       | 0.07239        | 0.51937       | 0.06188        |
| 720 | 0.60000         | 1.50000         | 0.97095       | 0.26606        | 0.45158       | 0.09943        |
| 721 | 0.60000         | 1.45000         | 0.46906       | 0.30043        | 0.28885       | 0.11762        |
| 722 | 0.60000         | 1.47500         | 0.70489       | 0.32676        | 0.35923       | 0.11993        |
| 723 | 0.60000         | 1.42500         | 0.25413       | 0.26783        | 0.19792       | 0.10923        |
| 724 | 0.60000         | 1.40000         | 0.14041       | 0.23465        | 0.12766       | 0.11443        |
| 725 | 0.60000         | 1.30000         | -0.12093      | 0.11963        | 0.02870       | 0.09176        |
| 726 | 0.60000         | 1.20000         | -0.11833      | 0.10569        | 0.01145       | 0.07109        |
| 727 | 0.60000         | 1.10000         | -0.11585      | 0.10711        | 0.00803       | 0.06755        |
| 728 | 0.60000         | 1.00000         | -0.11750      | 0.11797        | 0.01488       | 0.09412        |
| 729 | 0.60000         | 0.75600         | -0.07168      | 0.11691        | -0.00354      | 0.17974        |
| 730 | 0.70000         | 0.87000         | -0.06708      | 0.13096        | 0.01063       | 0.08514        |
| 731 | 0.80000         | 0.98200         | -0.11502      | 0.11974        | 0.01016       | 0.10168        |
| 732 | 0.80000         | 0.60000         | -0.04263      | 0.13722        | -0.01016      | 0.10239        |
| 733 | 0.90000         | 0.86000         | -0.10191      | 0.12825        | 0.02374       | 0.08538        |
| 734 | 0.90000         | 1.00000         | -0.13061      | 0.14147        | 0.02633       | 0.09152        |
| 735 | 0.90000         | 1.10000         | -0.15328      | 0.11514        | 0.04452       | 0.08857        |
| 736 | 0.90000         | 1.20000         | -0.14667      | 0.13262        | 0.01358       | 0.07605        |
| 737 | 0.90000         | 1.30000         | -0.16852      | 0.15340        | 0.04665       | 0.09034        |
| 738 | 0.90000         | 1.40000         | -0.11845      | 0.13805        | 0.01653       | 0.10616        |
| 739 | 0.90000         | 1.50000         | 0.12305       | 0.25366        | 0.10687       | 0.14313        |
| 740 | 0.90000         | 1.52500         | 0.16639       | 0.25520        | 0.11242       | 0.12907        |

TABLE IV.- Continued.

| Pt   | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|------|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 741  | 0.90000         | 1.55000         | 0.30940       | 0.31282        | 0.19532       | 0.14277        |
| 742  | 0.90000         | 1.57500         | 0.44296       | 0.30491        | 0.22095       | 0.13888        |
| 743  | 0.90000         | 1.60000         | 0.63250       | 0.34247        | 0.29393       | 0.09790        |
| 744  | 0.90000         | 1.65000         | 1.03649       | 0.25378        | 0.37565       | 0.10321        |
| 745  | 0.90000         | 1.70000         | 1.17478       | 0.13214        | 0.44367       | 0.10002        |
| 746  | 1.63000         | 1.62500         | 0.90352       | 0.33951        | 0.36124       | 0.11951        |
| 747  | 0.90000         | 1.80000         | 1.15376       | 0.12423        | 0.43989       | 0.12104        |
| 748  | 0.90000         | 1.90000         | 1.14702       | 0.18340        | 0.43363       | 0.08432        |
| 749  | 0.90000         | 2.00000         | 1.14608       | 0.13840        | 0.42159       | 0.06897        |
| 750  | 1.00000         | 2.00000         | 1.14891       | 0.16356        | 0.38439       | 0.28047        |
| 751  | 1.00000         | 1.90000         | 1.18009       | 0.08810        | 0.41875       | 0.09376        |
| 752  | 1.00000         | 1.80000         | 1.16226       | 0.16096        | 0.41120       | 0.06944        |
| 753  | 1.00000         | 1.70000         | 1.10416       | 0.23725        | 0.40198       | 0.10250        |
| 754  | 1.00000         | 1.60000         | 0.42147       | 0.33751        | 0.19910       | 0.13037        |
| 755  | 1.00000         | 1.50000         | 0.05031       | 0.21847        | 0.06897       | 0.11101        |
| 756  | 1.00000         | 1.65000         | 0.81885       | 0.33999        | 0.29263       | 0.13273        |
| 757  | 1.00000         | 1.55000         | 0.18292       | 0.26275        | 0.14608       | 0.13144        |
| 758  | 1.00000         | 1.40000         | -0.12045      | 0.14643        | 0.02740       | 0.10841        |
| 759  | 1.00000         | 1.30000         | -0.12907      | 0.13462        | 0.02657       | 0.09235        |
| 760  | 1.00000         | 1.20000         | -0.16757      | 0.10593        | 0.06046       | 0.17737        |
| 761  | 1.00000         | 1.10000         | -0.17336      | 0.12459        | 0.02681       | 0.11290        |
| 762  | 1.00000         | 0.56500         | -0.03991      | 0.29535        | 0.01417       | 0.09837        |
| 763  | 1.01000         | 0.61800         | -0.11030      | 0.13935        | -0.01630      | 0.09672        |
| 764  | 1.05000         | 0.70700         | -0.07440      | 0.15057        | 0.00213       | 0.14159        |
| 765  | 1.10000         | 0.85000         | -0.13167      | 0.14714        | 0.02126       | 0.08077        |
| 766  | 1.15000         | 0.99300         | -0.13262      | 0.13982        | 0.01252       | 0.09943        |
| 767  | 1.20000         | 1.13600         | -0.17796      | 0.13699        | 0.02893       | 0.08739        |
| 768  | 1.20000         | 1.20000         | -0.19568      | 0.12435        | 0.04003       | 0.09530        |
| 769  | 1.20000         | 1.30000         | -0.15163      | 0.14195        | 0.05231       | 0.06554        |
| 770  | 1.20000         | 1.40000         | -0.13085      | 0.13262        | 0.03531       | 0.08385        |
| 771  | 1.20000         | 1.50000         | -0.06436      | 0.17100        | 0.04322       | 0.10156        |
| 772* | -0.20000        | 1.50000         | 0.82322       | 0.13651        | 0.54239       | 0.07971        |
| 773* | -0.20000        | 1.50000         | 0.78708       | 0.13557        | 0.51641       | 0.07853        |
| 774  | -0.20000        | 1.50000         | 0.78909       | 0.13793        | 0.52940       | 0.08054        |
| 775. | 0.10000         | 1.25000         | 0.92985       | 0.13510        | 0.72485       | 0.07511        |
| 776* | 0.10000         | 1.15000         | 0.09506       | 0.20241        | 0.19025       | 0.12175        |
| 777  | 0.20000         | 1.15000         | -0.08514      | 0.14195        | 0.00933       | 0.07794        |
| 778  | 0.20000         | 1.35000         | 0.94910       | 0.16521        | 0.65612       | 0.07723        |
| 779  | 0.40000         | 1.45000         | 1.04960       | 0.14336        | 0.57310       | 0.07829        |
| 780  | 0.40000         | 1.25000         | -0.08066      | 0.13604        | 0.01205       | 0.06448        |
| 781  | 0.60000         | 1.35000         | -0.03673      | 0.18139        | 0.04027       | 0.08739        |
| 782  | 0.60000         | 1.55000         | 1.09471       | 0.14419        | 0.50520       | 0.08184        |
| 783  | 0.90000         | 1.45000         | 0.03070       | 0.19627        | 0.06802       | 0.11939        |
| 784  | 0.90000         | 1.75000         | 1.10664       | 0.19450        | 0.43847       | 0.08290        |
| 785  | 1.00000         | 1.75000         | 1.12884       | 0.15340        | 0.41580       | 0.09695        |
| 786  | 1.00000         | 1.45000         | -0.03059      | 0.19839        | 0.02563       | 0.09471        |
| 787  | 1.20000         | 1.60000         | 0.27480       | 0.28496        | 0.12140       | 0.13675        |

TABLE IV.- Continued.

| Pt  | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|-----|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 788 | 1.20000         | 1.70000         | 0.80515       | 0.33089        | 0.26559       | 0.13344        |
| 789 | 1.20000         | 1.65000         | 0.54086       | 0.34211        | 0.18387       | 0.13876        |
| 790 | 1.20000         | 1.75000         | 1.05692       | 0.24563        | 0.33810       | 0.11880        |
| 791 | 1.20000         | 1.80000         | 1.12671       | 0.18529        | 0.37104       | 0.09105        |
| 792 | 1.20000         | 1.85000         | 1.13640       | 0.21127        | 0.39159       | 0.11963        |
| 793 | 1.20000         | 1.90000         | 1.14324       | 0.16474        | 0.40057       | 0.08113        |
| 794 | 1.20000         | 2.00000         | 1.14242       | 0.15683        | 0.39183       | 0.08278        |
| 795 | 1.10000         | 2.00000         | 1.12293       | 0.19095        | 0.40187       | 0.07286        |
| 796 | 1.10000         | 1.90000         | 1.15210       | 0.11490        | 0.42265       | 0.07239        |
| 797 | 1.10000         | 1.80000         | 1.14702       | 0.16273        | 0.42324       | 0.08243        |
| 798 | 1.10000         | 1.75000         | 1.12683       | 0.17596        | 0.39738       | 0.10522        |
| 799 | 1.10000         | 1.70000         | 0.99339       | 0.29086        | 0.33987       | 0.26559        |
| 800 | 1.10000         | 1.65000         | 0.70099       | 0.36597        | 0.27267       | 0.14419        |
| 801 | 1.10000         | 1.60000         | 0.39513       | 0.30125        | 0.20324       | 0.13191        |
| 802 | 1.10000         | 1.55000         | 0.16143       | 0.27350        | 0.11620       | 0.13415        |
| 803 | 1.10000         | 1.50000         | -0.01299      | 0.20583        | 0.04192       | 0.10770        |
| 804 | 1.10000         | 1.40000         | -0.13474      | 0.17135        | 0.03177       | 0.09991        |
| 805 | 1.10000         | 1.30000         | -0.16249      | 0.13120        | 0.03023       | 0.08869        |
| 806 | 1.10000         | 1.20000         | -0.17052      | 0.12589        | 0.04051       | 0.09613        |
| 807 | 1.10000         | 1.10000         | -0.16285      | 0.13108        | 0.03035       | 0.08940        |
| 808 | 1.20000         | 0.50000         | -0.08786      | 0.21221        | 0.02598       | 0.09176        |
| 809 | 1.40000         | 0.50000         | -0.08361      | 0.13829        | 0.02681       | 0.09069        |
| 810 | 1.60000         | 0.50000         | -0.11384      | 0.14336        | 0.03271       | 0.08727        |
| 811 | 1.80000         | 0.50000         | -0.13581      | 0.15246        | 0.03484       | 0.07617        |
| 812 | 2.00000         | 0.50000         | -0.13026      | 0.16745        | 0.04027       | 0.07971        |
| 813 | 2.20000         | 0.50000         | -0.16521      | 0.15706        | 0.03342       | 0.09223        |
| 814 | 2.40000         | 0.50000         | -0.18847      | 0.17419        | 0.04145       | 0.07912        |
| 815 | 2.55000         | 0.50000         | -0.21871      | 0.15163        | 0.02988       | 0.09400        |
| 816 | 2.55000         | 0.40000         | -0.16615      | 0.16899        | 0.04381       | 0.07759        |
| 817 | 2.55000         | 0.60000         | -0.18883      | 0.17442        | 0.01464       | 0.09376        |
| 818 | 2.55000         | 0.70000         | -0.16781      | 0.15990        | 0.05090       | 0.07511        |
| 819 | 2.55000         | 0.80000         | -0.21693      | 0.20820        | 0.05668       | 0.09400        |
| 820 | 2.55000         | 1.00000         | -0.17985      | 0.18080        | 0.04771       | 0.10333        |
| 821 | 2.55000         | 1.20000         | -0.19851      | 0.19273        | 0.06212       | 0.10534        |
| 822 | 2.55000         | 1.40000         | -0.17749      | 0.18009        | 0.05810       | 0.11467        |
| 823 | 2.55000         | 1.60000         | -0.10912      | 0.22426        | 0.06873       | 0.14124        |
| 824 | 2.55000         | 1.80000         | 0.13805       | 0.28625        | 0.10581       | 0.16651        |
| 825 | 2.55000         | 1.90000         | 0.40990       | 0.35983        | 0.10227       | 0.18103        |
| 826 | 2.55000         | 2.00000         | 0.65494       | 0.36372        | 0.12789       | 0.16651        |
| 827 | 2.55000         | 2.10000         | 0.96871       | 0.30243        | 0.16167       | 0.13321        |
| 828 | 2.55000         | 2.20000         | 1.13167       | 0.22721        | 0.21044       | 0.13640        |
| 829 | 2.55000         | 2.30000         | 1.19650       | 0.17560        | 0.24020       | 0.11538        |
| 830 | 2.55000         | 2.40000         | 1.21020       | 0.15801        | 0.27208       | 0.09046        |
| 831 | 2.00000         | 2.40000         | 1.18706       | 0.11148        | 0.29948       | 0.06342        |
| 832 | 2.00000         | 2.20000         | 1.20135       | 0.11986        | 0.30704       | 0.09495        |
| 833 | 2.00000         | 2.00000         | 1.07298       | 0.25803        | 0.25106       | 0.12081        |

TABLE IV.- Continued.

| Pt    | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|-------|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 834   | 2.00000         | 1.90000         | 0.75661       | 0.34306        | 0.17820       | 0.13829        |
| 835   | 2.00000         | 1.80000         | 0.36538       | 0.34754        | 0.11502       | 0.17289        |
| 836   | 2.00000         | 1.70000         | 0.12258       | 0.29039        | 0.06944       | 0.18446        |
| 837   | 2.00000         | 1.95000         | 0.88368       | 0.35026        | 0.20737       | 0.13569        |
| 838   | 2.00000         | 1.85000         | 0.53094       | 0.38769        | 0.14372       | 0.15293        |
| 839   | 2.00000         | 1.75000         | 0.23229       | 0.31790        | 0.10298       | 0.17430        |
| 840   | 2.00000         | 1.60000         | -0.05810      | 0.20076        | 0.05078       | 0.14372        |
| 841   | 2.00000         | 1.50000         | -0.13309      | 0.18800        | 0.06070       | 0.09778        |
| 842   | 2.00000         | 1.40000         | -0.14750      | 0.24315        | 0.05857       | 0.17938        |
| 843   | 2.00000         | 1.30000         | -0.17938      | 0.21316        | 0.05043       | 0.12010        |
| 844   | 2.00000         | 1.20000         | -0.19591      | 0.20158        | 0.03602       | 0.14348        |
| 845   | 2.00000         | 1.10000         | -0.18788      | 0.18304        | 0.05739       | 0.13510        |
| 846   | 2.00000         | 1.00000         | -0.20642      | 0.18706        | 0.03519       | 0.12624        |
| 847   | 2.00000         | 0.90000         | -0.19166      | 0.25378        | 0.02220       | 0.14006        |
| 848   | 2.00000         | 0.80000         | -0.18718      | 0.19391        | 0.04936       | 0.12530        |
| 849   | 2.00000         | 0.70000         | -0.15966      | 0.20383        | 0.00791       | 0.13569        |
| 850   | 2.00000         | 0.60000         | -0.15104      | 0.21717        | 0.03779       | 0.12506        |
| 851*  | 2.00000         | 0.50000         | -0.15128      | 0.23559        | 0.02881       | 0.10699        |
| 852   | 2.40000         | 0.80000         | -0.20796      | 0.21575        | 0.03165       | 0.12872        |
| 853   | 2.40000         | 1.10000         | -0.20725      | 0.20394        | 0.08597       | 0.17064        |
| 854   | 1.80000         | 1.10000         | -0.18529      | 0.17974        | 0.04936       | 0.12258        |
| 855   | 1.80000         | 0.80000         | -0.15635      | 0.19190        | 0.05716       | 0.11183        |
| 1001  | 1.90000         | 2.40000         | 1.11656       | 0.29854        | 0.28897       | 0.14206        |
| 1002  | 1.90000         | 2.20000         | 1.12872       | 0.34825        | 0.29476       | 0.23051        |
| 1003  | 1.90000         | 2.00000         | 1.07806       | 0.27645        | 0.27858       | 0.14620        |
| 1004  | 1.90000         | 1.90000         | 0.81330       | 0.36290        | 0.19391       | 0.15257        |
| 1005  | 1.90000         | 1.80000         | 0.40919       | 0.37778        | 0.14632       | 0.18044        |
| 1006  | 1.90000         | 1.85000         | 0.60794       | 0.37045        | 0.14053       | 0.20513        |
| 1007* | 1.90000         | 1.95000         | 0.86101       | 0.40919        | 0.20973       | 0.14726        |
| 1008  | 1.90000         | 1.75000         | 0.26453       | 0.36112        | 0.08869       | 0.21079        |
| 1009  | 1.90000         | 1.95000         | 0.98359       | 0.32652        | 0.20572       | 0.16120        |
| 1010  | 1.90000         | 1.70000         | 0.12246       | 0.31212        | 0.07782       | 0.21422        |
| 1011  | 1.90000         | 1.65000         | 0.04535       | 0.25555        | 0.02811       | 0.18139        |
| 1012  | 1.90000         | 1.60000         | -0.03932      | 0.26724        | 0.06330       | 0.16710        |
| 1013  | 1.90000         | 1.50000         | -0.12978      | 0.21823        | 0.04924       | 0.12093        |
| 1014  | 1.90000         | 1.40000         | -0.13368      | 0.18269        | 0.05338       | 0.11195        |
| 1015  | 1.60000         | 0.60000         | -0.12825      | 0.26453        | 0.05302       | 0.09943        |
| 1016  | 1.60000         | 0.70000         | -0.14950      | 0.22048        | 0.04606       | 0.15092        |
| 1017  | 1.60000         | 0.80000         | -0.11514      | 0.18387        | 0.03224       | 0.17017        |
| 1018  | 1.60000         | 0.90000         | -0.12116      | 0.17241        | 0.05102       | 0.12057        |
| 1019  | 1.60000         | 1.00000         | -0.14206      | 0.18470        | 0.02362       | 0.14112        |
| 1020  | 1.60000         | 1.10000         | -0.17383      | 0.19957        | 0.03200       | 0.13746        |
| 1021  | 1.60000         | 1.20000         | -0.18481      | 0.20949        | 0.07097       | 0.08963        |
| 1022  | 1.60000         | 1.30000         | -0.17702      | 0.16828        | 0.03283       | 0.14714        |
| 1023  | 1.60000         | 1.40000         | -0.14183      | 0.20406        | 0.05680       | 0.22130        |
| 1024  | 1.60000         | 1.50000         | -0.13037      | 0.23181        | 0.05125       | 0.11691        |

TABLE IV.- Continued.

| Pt    | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{\bar{v}}$ | $\frac{u'}{\bar{v}}$ | $\frac{v}{\bar{v}}$ | $\frac{v'}{\bar{v}}$ |
|-------|-----------------|-----------------|---------------------|----------------------|---------------------|----------------------|
| 1025  | 1.60000         | 1.60000         | 0.00142             | 0.25366              | 0.03188             | 0.14868              |
| 1026  | 1.60000         | 1.70000         | 0.25213             | 0.34695              | 0.10675             | 0.25709              |
| 1027  | 1.60000         | 1.80000         | 0.66875             | 0.42501              | 0.19544             | 0.17962              |
| 1028  | 1.60000         | 1.90000         | 1.00579             | 0.44202              | 0.30834             | 0.19662              |
| 1029  | 1.60000         | 2.00000         | 1.09589             | 0.38167              | 0.30279             | 0.31590              |
| 1030  | 1.60000         | 2.10000         | 1.04724             | 0.45642              | 0.29523             | 0.30338              |
| 1031  | 1.60000         | 2.20000         | 1.04735             | 0.48843              | 0.33644             | 0.20442              |
| 1032  | 1.60000         | 1.85000         | 0.91993             | 0.41911              | 0.17537             | 0.30668              |
| 1033  | 1.60000         | 1.75000         | 0.45087             | 0.37093              | 0.13781             | 0.13439              |
| 1034  | 1.40000         | 1.10000         | -0.20335            | 0.29547              | 0.03909             | 0.22874              |
| 1035  | 1.40000         | 0.80000         | -0.19119            | 0.31684              | 0.02385             | 0.18245              |
| 1036  | -0.70000        | 0.0             | 0.32050             | 0.12612              | 0.10038             | 0.43859              |
| 1037  | -0.70000        | -0.10000        | 0.26157             | 0.29358              | -0.02067            | 0.32700              |
| 1038  | -0.70000        | -0.20000        | 0.28980             | 0.25342              | -0.05775            | 0.34861              |
| 1039  | -0.70000        | 0.10000         | 0.26075             | 0.23855              | 0.06330             | 0.44580              |
| 1040  | -0.70000        | 0.20000         | 0.24315             | 0.31412              | 0.10298             | 0.40116              |
| 1041  | -0.70000        | 0.40000         | 0.17855             | 0.42903              | 0.16852             | 0.38805              |
| 1042  | -0.70000        | 0.60000         | 0.38699             | 0.11408              | 0.16403             | 0.29700              |
| 1043  | -0.70000        | 0.80000         | 0.41190             | 0.18375              | 0.23441             | 0.31944              |
| 1044  | -0.70000        | 0.90000         | 0.48205             | 0.11963              | 0.29110             | 0.33632              |
| 1045  | -0.70000        | 1.00000         | 0.50638             | 0.16108              | 0.33880             | 0.34341              |
| 1046  | -0.70000        | 1.10000         | 0.56129             | 0.16120              | 0.34365             | 0.27397              |
| 1047  | -0.70000        | 1.20000         | 0.58880             | 0.23536              | 0.28696             | 0.30302              |
| 1048  | -0.70000        | 1.40000         | 0.69119             | 0.09991              | 0.36549             | 0.20111              |
| 1049  | -0.70000        | 1.60000         | 0.69780             | 0.31318              | 0.32546             | 0.27043              |
| 1050  | -0.60000        | 1.10000         | 0.49717             | 0.25968              | 0.38462             | 0.34719              |
| 1051  | -0.60000        | 0.94000         | 0.45276             | 0.17997              | 0.34459             | 0.23713              |
| 1052  | -0.60000        | 0.80000         | 0.29830             | 0.27468              | 0.19367             | 0.32629              |
| 1053  | -0.60000        | 0.60000         | 0.34695             | 0.10994              | 0.19898             | 0.25272              |
| 1054  | -0.50000        | 1.10000         | 0.54251             | 0.11939              | 0.42855             | 0.29924              |
| 1055  | -0.40000        | 1.10000         | 0.50272             | 0.17277              | 0.48051             | 0.24374              |
| 1056  | -0.30000        | 1.10000         | 0.46032             | 0.14844              | 0.50118             | 0.31519              |
| 1057* | -0.25000        | 1.10000         | -0.37837            | 0.64384              | 0.52563             | 0.24410              |
| 1058  | -0.50000        | 0.94000         | 0.37707             | 0.32664              | 0.44296             | 0.07924              |
| 1059  | -0.40000        | 0.94000         | -0.12541            | 0.64325              | 0.52858             | 0.08467              |
| 1060* | -0.20000        | 1.50000         | 0.78519             | 0.12140              | 0.53224             | 0.06011              |
| 1061  | -0.25000        | 1.10000         | 0.51547             | 0.06826              | 0.35935             | 0.45784              |
| 1062* | -0.25000        | 1.10000         | 0.51464             | 0.07050              | 0.33137             | 0.49669              |
| 1063* | -0.50000        | 1.10000         | 0.34034             | 0.05857              | 0.40706             | 0.24622              |
| 1064  | -0.50000        | 0.60000         | 0.25272             | 0.05668              | 0.32641             | 0.11793              |
| 1065  | -0.40000        | 0.60000         | -0.50815            | 0.58066              | 0.34707             | 0.20501              |
| 1066  | -0.40000        | 0.80000         | -0.45194            | 0.50295              | 0.46682             | 0.20123              |
| 1067* | -0.10000        | 1.10000         | 0.68517             | 0.08160              | 0.37671             | 0.51905              |
| 1068  | -0.10000        | 1.12500         | 0.66202             | 0.10321              | 0.57546             | 0.43540              |
| 1069* | -0.10000        | 1.15000         | 0.67962             | 0.10628              | 0.77244             | 0.06849              |
| 1070  | -0.10000        | 1.17500         | 0.68163             | 0.11490              | 0.76724             | 0.06956              |

TABLE IV.- Concluded.

| Pt    | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{v}$ | $\frac{u'}{v}$ | $\frac{v}{v}$ | $\frac{v'}{v}$ |
|-------|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 1071  | -0.10000        | 1.20000         | 0.70205       | 0.08219        | 0.73252       | 0.06838        |
| 1072* | -0.30000        | 1.10000         | 0.47426       | 0.27586        | 0.62459       | 0.07581        |
| 1073  | -0.30000        | 0.94000         | -0.24598      | 0.29157        | 0.63155       | 0.09471        |
| 1074  | -0.35000        | 0.94000         | -1.17123      | 0.62931        | 0.60522       | 0.08196        |
| 1075  | -0.35000        | 0.80000         | -1.07015      | 0.73323        | 0.55066       | 0.08951        |
| 1076  | -0.30000        | 0.80000         | -0.94131      | 0.79180        | 0.60380       | 0.07263        |
| 1077  | -0.28000        | 0.80000         | -1.07286      | 0.78543        | 0.65411       | 0.05220        |
| 1078  | -0.25000        | 0.94000         | -1.02409      | 0.80905        | 0.29169       | 0.42052        |
| 1079  | -0.10000        | 1.07500         | 0.62518       | 0.35522        | 0.02338       | 0.42241        |
| 1080  | -0.10000        | 1.05000         | 0.70631       | 0.15435        | 0.21351       | 0.62907        |
| 1081  | -0.10000        | 1.02500         | 0.75685       | 0.07097        | 0.11538       | 0.60002        |
| 1082  | 0.0             | 1.02500         | -0.11065      | 0.11538        | 0.03212       | 0.09058        |
| 1083  | 0.10000         | 1.02500         | -0.08644      | 0.09849        | 0.02362       | 0.17419        |
| 1084  | 0.10000         | 1.00000         | -0.07877      | 0.08514        | 0.02208       | 0.18080        |
| 1085  | 0.10000         | 0.97500         | -0.06129      | 0.11042        | 0.01216       | 0.09872        |
| 1086  | 0.10000         | 0.95000         | -0.07475      | 0.11207        | 0.02681       | 0.15978        |
| 1087  | 0.15000         | 0.95000         | -0.06885      | 0.12683        | 0.01240       | 0.09719        |
| 1088  | 0.20000         | 0.95000         | -0.08231      | 0.12140        | 0.04818       | 0.15340        |
| 1089  | 0.20000         | 0.90000         | -0.05255      | 0.10829        | 0.01287       | 0.10605        |
| 1090  | 0.20000         | 0.85000         | -0.04251      | 0.15057        | 0.00047       | 0.10782        |
| 1091  | 0.20000         | 0.80000         | -0.01641      | 0.08455        | -0.00508      | 0.11148        |
| 1092  | 0.25000         | 0.80000         | -0.02622      | 0.07688        | -0.00071      | 0.11538        |
| 1093  | 0.30000         | 0.80000         | -0.05220      | 0.08467        | 0.01807       | 0.10652        |

TABLE V.- VELOCITY DATA FOR ROUND EDGE MODEL  
 $M = 0.5$ ,  $Re = .15 \cdot 10^6$

(\*indicates points dropped from analysis)

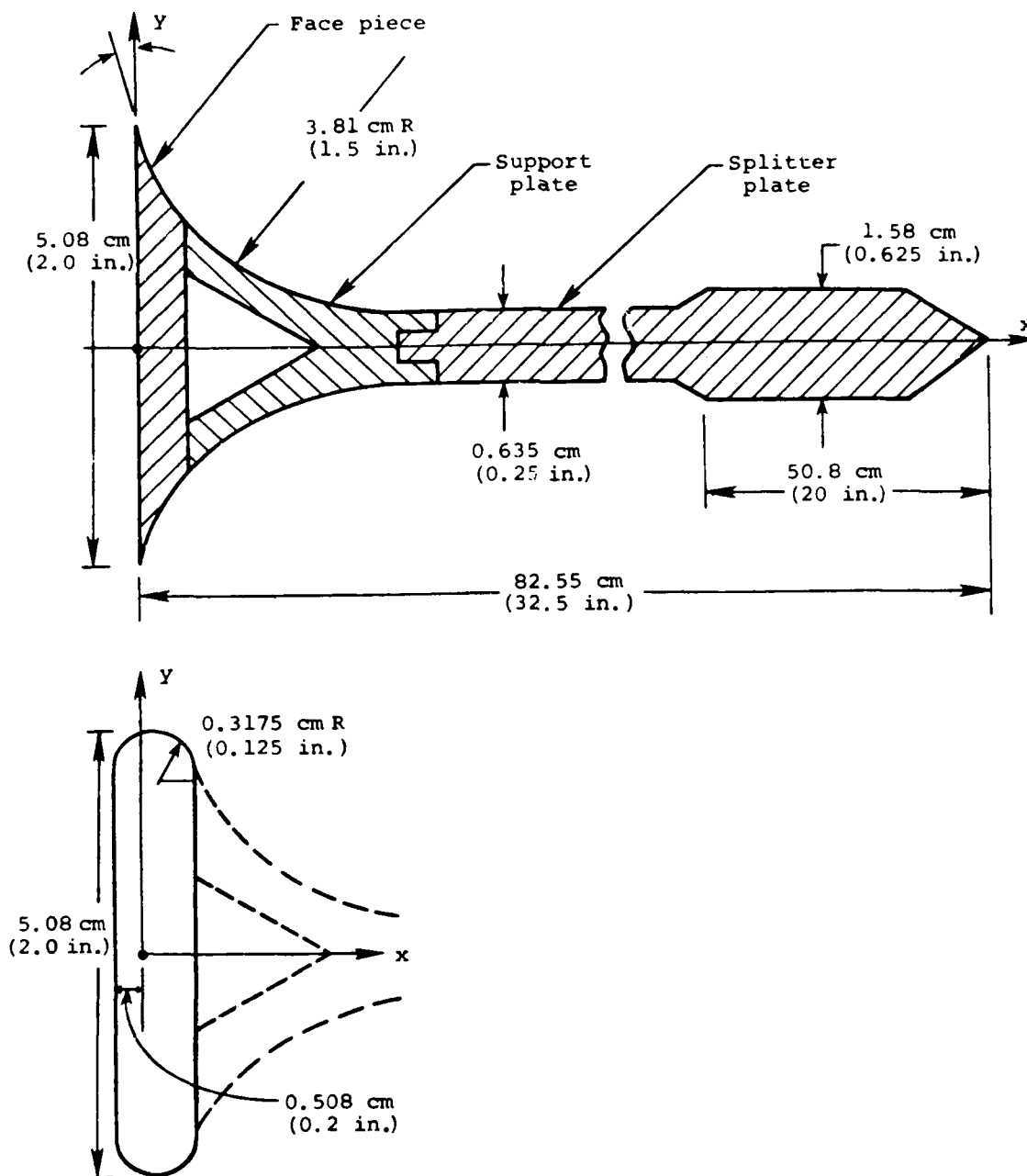
| Pt    | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|-------|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 1094  | -0.20000        | 1.50000         | 0.78678       | 0.06268        | 0.49396       | 0.05096        |
| 1095  | -0.20000        | 1.40000         | 0.74827       | 0.06764        | 0.53451       | 0.05048        |
| 1096  | -0.20000        | 1.30000         | 0.69492       | 0.07428        | 0.57476       | 0.05574        |
| 1097  | 0.60000         | 1.00000         | -0.11956      | 0.10305        | 0.00060       | 0.06094        |
| 1098  | 0.60000         | 1.10000         | -0.13313      | 0.10006        | 0.00233       | 0.06023        |
| 1099  | 0.60000         | 1.20000         | -0.13152      | 0.09085        | 0.00377       | 0.05371        |
| 1100  | 0.60000         | 0.75600         | -0.07506      | 0.09551        | -0.01011      | 0.06914        |
| 1101  | 0.60000         | 1.30000         | -0.08738      | 0.12033        | 0.01232       | 0.05748        |
| 1102  | 0.60000         | 1.40000         | 0.30676       | 0.23331        | 0.17075       | 0.08092        |
| 1103  | 0.60000         | 1.50000         | 0.99037       | 0.21884        | 0.45544       | 0.06585        |
| 1104  | 0.60000         | 1.60000         | 1.11794       | 0.04109        | 0.47667       | 0.04121        |
| 1105  | 0.60000         | 1.70000         | 1.10245       | 0.05102        | 0.47279       | 0.04701        |
| 1106  | 0.60000         | 1.80000         | 1.07667       | 0.06639        | 0.44001       | 0.04468        |
| 1107  | 0.60000         | 1.90000         | 1.08074       | 0.06358        | 0.41394       | 0.04043        |
| 1108  | 0.60000         | 1.35000         | 0.02865       | 0.18636        | 0.06142       | 0.09677        |
| 1109  | 0.60000         | 1.45000         | 0.58935       | 0.24982        | 0.30012       | 0.08822        |
| 1110  | 0.60000         | 1.37500         | 0.15646       | 0.22069        | 0.10383       | 0.07548        |
| 1111  | 0.60000         | 1.42500         | 0.42321       | 0.24593        | 0.21740       | 0.10849        |
| 1112  | 0.60000         | 1.47500         | 0.72536       | 0.24719        | 0.38547       | 0.08074        |
| 1113  | 0.60000         | 1.49000         | 0.83684       | 0.22249        | 0.43433       | 0.07452        |
| 1114  | -0.20000        | 1.50000         | 0.77177       | 0.05293        | 0.50694       | 0.04217        |
| 1115  | -0.20000        | 1.40000         | 0.73074       | 0.06328        | 0.55054       | 0.04743        |
| 1116  | -0.20000        | 1.30000         | 0.66208       | 0.11376        | 0.57392       | 0.05221        |
| 1117  | -0.20000        | 1.20000         | 0.53301       | 0.09522        | 0.58399       | 0.07835        |
| 1118* | -0.20000        | 1.10000         | 0.43236       | 0.04635        | -0.13959      | 0.35843        |
| 1119  | -0.20000        | 1.05000         | -0.05825      | 0.35341        | 0.06764       | 0.25574        |
| 1120  | -0.20000        | 1.07500         | 0.39892       | 0.05126        | 0.12536       | 0.27578        |
| 1121  | -0.20000        | 1.06000         | 0.37787       | 0.04707        | 0.15891       | 0.27022        |
| 1122  | -0.10000        | 1.05000         | 0.58379       | 0.15825        | 0.14408       | 0.22650        |
| 1123* | -0.10000        | 1.10000         | 0.61178       | 0.06495        | -1.69246      | 0.44528        |
| 1124* | -0.10000        | 1.15000         | 0.49073       | 0.09408        | -1.91088      | 0.42961        |
| 1125  | -0.10000        | 1.20000         | 0.57987       | 0.06962        | 0.71645       | 0.04199        |
| 1126  | -0.10000        | 1.30000         | 0.64234       | 0.04097        | 0.60335       | 0.15090        |
| 1127  | -0.10000        | 1.40000         | 0.72793       | 0.04785        | 0.58110       | 0.04880        |
| 1128  | -0.10000        | 1.50000         | 0.75167       | 0.03606        | 0.53517       | 0.03337        |
| 1129  | -0.10000        | 1.60000         | 0.76687       | 0.03230        | 0.50197       | 0.05987        |
| 1130  | -0.10000        | 1.70000         | 0.80048       | 0.02949        | 0.47159       | 0.03577        |
| 1131  | -0.10000        | 1.80000         | 0.81633       | 0.02949        | 0.45012       | 0.03750        |
| 1132  | 0.0             | 1.80000         | 0.83415       | 0.01980        | 0.45203       | 0.04432        |
| 1133  | 0.0             | 1.70000         | 4.19438       | 0.00084        | -2.92638      | 0.07781        |
| 1134  | 0.0             | 1.70000         | 0.89868       | 0.04611        | 0.48840       | 0.04850        |

TABLE V.- Continued.

| Pt    | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|-------|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 1135  | 0.0             | 1.60000         | 0.88170       | 0.05030        | 0.52859       | 0.04850        |
| 1136  | 0.0             | 1.50000         | 0.86238       | 0.05598        | 0.56782       | 0.04605        |
| 1137  | 0.0             | 1.40000         | 0.83313       | 0.06256        | 0.62165       | 0.06124        |
| 1138  | 0.0             | 1.30000         | 0.72291       | 0.08493        | 0.69151       | 0.06633        |
| 1139  | 0.0             | 1.20000         | 0.80138       | 0.05281        | 0.78852       | 0.06693        |
| 1140  | 0.0             | 1.80000         | 0.91238       | 0.04163        | 0.46555       | 0.04360        |
| 1141  | 0.0             | 2.00000         | 0.93385       | 0.04097        | 0.41812       | 0.03947        |
| 1142  | -0.10000        | 2.00000         | 0.90879       | 0.03756        | 0.40849       | 0.04342        |
| 1143  | -0.10000        | 1.80000         | 0.88134       | 0.04103        | 0.45496       | 0.04294        |
| 1144  | -0.10000        | 1.60000         | 0.84450       | 0.04516        | 0.50072       | 0.07913        |
| 1145  | -0.10000        | 1.40000         | 0.77679       | 0.05449        | 0.58929       | 0.05897        |
| 1146  | -0.10000        | 1.30000         | 0.71639       | 0.06364        | 0.65263       | 0.05173        |
| 1147  | -0.10000        | 1.20000         | 0.55341       | 0.15239        | 0.62500       | 0.26878        |
| 1148  | -0.10000        | 1.10000         | 0.56435       | 0.07751        | 0.14797       | 0.21896        |
| 1149  | -0.20000        | 1.10000         | 0.42410       | 0.04946        | 0.14151       | 0.28636        |
| 1150  | -0.20000        | 1.20000         | 0.56489       | 0.05467        | 0.64713       | 0.06669        |
| 1151  | -0.20000        | 1.30000         | 0.66609       | 0.05036        | 0.60927       | 0.04252        |
| 1152  | -0.20000        | 1.40000         | 0.71591       | 0.05006        | 0.55389       | 0.05616        |
| 1153  | -0.20000        | 1.50000         | 0.76519       | 0.04300        | 0.52608       | 0.04055        |
| 1154  | -0.20000        | 1.60000         | 0.79976       | 0.04749        | 0.49330       | 0.04862        |
| 1155  | -0.20000        | 1.80000         | 0.85293       | 0.03750        | 0.44222       | 0.04157        |
| 1156  | -0.20000        | 2.00000         | 0.88415       | 0.03600        | 0.40383       | 0.03349        |
| 1157  | 0.10000         | 2.00000         | 0.95772       | 0.04043        | 0.43050       | 0.03517        |
| 1158  | 0.10000         | 1.80000         | 0.94300       | 0.04157        | 0.47398       | 0.03553        |
| 1159  | 0.10000         | 1.60000         | 0.92195       | 0.05000        | 0.54850       | 0.03816        |
| 1160  | 0.10000         | 1.50000         | 0.89791       | 0.05951        | 0.59623       | 0.03977        |
| 1161  | 0.10000         | 1.40000         | 0.81394       | 0.09653        | 0.65520       | 0.04557        |
| 1162  | 0.10000         | 1.30000         | 0.88146       | 0.03194        | 0.73457       | 0.03882        |
| 1163  | 0.10000         | 1.20000         | 0.67476       | 0.01884        | 0.53977       | 0.12536        |
| 1164  | 0.10000         | 1.10000         | -0.10425      | 0.06047        | 0.01675       | 0.06394        |
| 1165* | 0.10000         | 1.00000         | 0.96609       | 0.88032        | 0.04007       | 0.05251        |
| 1166  | 0.10000         | 1.15000         | -0.01657      | 0.14294        | 0.09504       | 0.06077        |
| 1167  | 0.10000         | 1.17500         | 0.22201       | 0.15981        | 0.25054       | 0.08266        |
| 1168  | 0.10000         | 1.25000         | 0.80072       | 0.09563        | 0.65484       | 0.14839        |
| 1169  | 0.20000         | 1.25000         | 0.28810       | 0.21980        | 0.34504       | 0.09545        |
| 1170  | 0.20000         | 1.30000         | 0.81549       | 0.14874        | 0.61208       | 0.09450        |
| 1171  | 0.20000         | 1.40000         | 0.92566       | 0.05837        | 0.65467       | 0.04516        |
| 1172  | 0.20000         | 1.35000         | 0.98122       | 0.03146        | 0.65060       | 0.04324        |
| 1173  | 0.20000         | 1.27500         | 0.73164       | 0.16561        | 0.55903       | 0.09426        |
| 1174  | 0.20000         | 1.50000         | 0.90604       | 0.09246        | 0.60658       | 0.04862        |
| 1175  | 0.40000         | 1.50000         | 1.04127       | 0.03642        | 0.56537       | 0.04019        |
| 1176  | 0.40000         | 1.40000         | 0.75084       | 0.19211        | 0.52243       | 0.06930        |
| 1177  | 0.40000         | 1.30000         | 0.11094       | 0.20598        | 0.11465       | 0.07333        |
| 1178  | 0.40000         | 1.35000         | 0.43164       | 0.21932        | 0.28355       | 0.07877        |
| 1179  | 0.40000         | 1.45000         | 1.07488       | 0.08457        | 0.56848       | 0.05096        |
| 1180  | 0.40000         | 1.25000         | -0.10556      | 0.09384        | 0.00353       | 0.06693        |

TABLE V.- Concluded.

| Pt   | $\frac{x}{b/2}$ | $\frac{y}{b/2}$ | $\frac{u}{V}$ | $\frac{u'}{V}$ | $\frac{v}{V}$ | $\frac{v'}{V}$ |
|------|-----------------|-----------------|---------------|----------------|---------------|----------------|
| 1181 | 0.40000         | 1.20000         | -0.10598      | 0.08666        | -0.00233      | 0.05700        |
| 1182 | 0.40000         | 1.10000         | -0.11663      | 0.07201        | -0.00042      | 0.05622        |
| 1183 | -0.70000        | 1.10000         | 0.53080       | 0.03104        | 0.36806       | 0.04354        |
| 1184 | -0.60000        | 1.10000         | 0.52010       | 0.03164        | 0.40957       | 0.04342        |
| 1185 | -0.50000        | 1.10000         | 0.50150       | 0.03696        | 0.44844       | 0.08331        |
| 1186 | -0.40000        | 1.10000         | 0.48266       | 0.04031        | 0.48134       | 0.14635        |
| 1187 | -0.30000        | 1.10000         | 0.43529       | 0.04599        | 0.37231       | 0.28600        |
| 1188 | -0.40000        | 0.94000         | 0.36938       | 0.03062        | 0.48499       | 0.09001        |
| 1189 | -0.50000        | 0.94000         | 0.40377       | 0.03266        | 0.41770       | 0.06603        |
| 1190 | -0.60000        | 0.94000         | 0.43834       | 0.03307        | 0.37237       | 0.04372        |
| 1191 | -0.70000        | 0.94000         | 0.46328       | 0.03020        | 0.33720       | 0.04109        |
| 1192 | -0.70000        | 0.80000         | 0.40927       | 0.03122        | 0.30801       | 0.03056        |
| 1193 | -0.60000        | 0.80000         | 0.36998       | 0.03708        | 0.35341       | 0.03248        |
| 1194 | -0.50000        | 0.80000         | 0.32249       | 0.03272        | 0.36782       | 0.08349        |
| 1195 | -0.40000        | 0.80000         | 0.25239       | 0.03092        | 0.17410       | 0.26059        |
| 1196 | -0.40000        | 0.60000         | 0.17261       | 0.04240        | 0.15144       | 0.30090        |
| 1197 | -0.50000        | 0.60000         | 0.24743       | 0.03834        | 0.29504       | 0.04480        |
| 1198 | -0.60000        | 0.60000         | 0.30353       | 0.03343        | 0.26238       | 0.03559        |
| 1199 | -0.70000        | 0.60000         | 0.35562       | 0.03224        | 0.22476       | 0.13977        |
| 1200 | 1.00000         | 0.60000         | -0.09432      | 0.11693        | -0.00472      | 0.06555        |
| 1201 | 1.00000         | 0.80000         | -0.11316      | 0.12279        | 0.02984       | 0.06292        |
| 1202 | 1.00000         | 1.00000         | -0.13600      | 0.12099        | 0.03260       | 0.06310        |
| 1203 | 1.00000         | 1.20000         | -0.22482      | 0.10843        | 0.00108       | 0.07249        |
| 1204 | 1.00000         | 1.40000         | -0.14856      | 0.09312        | -0.00825      | 0.06746        |
| 1205 | 1.00000         | 1.60000         | 0.49856       | 0.23170        | 0.22327       | 0.09438        |
| 1206 | 1.00000         | 1.80000         | 1.16005       | 0.04821        | 0.41477       | 0.04740        |
| 1207 | 1.00000         | 1.50000         | 0.08876       | 0.17051        | 0.08612       | 0.07787        |
| 1208 | 1.00000         | 1.47500         | -0.00263      | 0.19169        | 0.04677       | 0.08403        |
| 1209 | 1.00000         | 1.70000         | 1.05149       | 0.20395        | 0.38774       | 0.06172        |
| 1210 | 1.00000         | 1.90000         | 1.15006       | 0.04498        | 0.41286       | 0.04557        |
| 1211 | 0.60000         | 1.55000         | 1.06142       | 0.10395        | 0.50197       | 0.04868        |



(a) Model configurations.  
Figure 1.- Test apparatus.

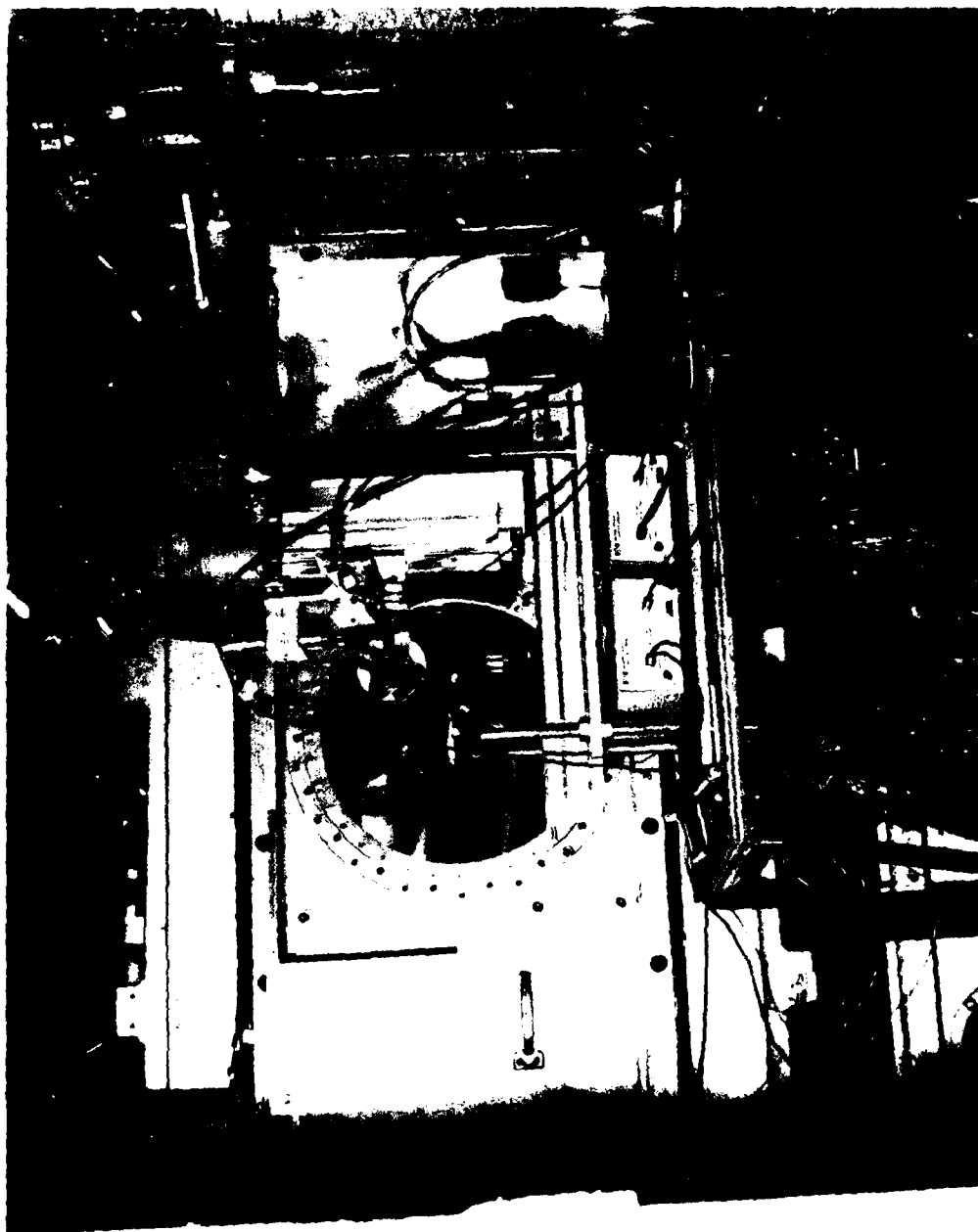
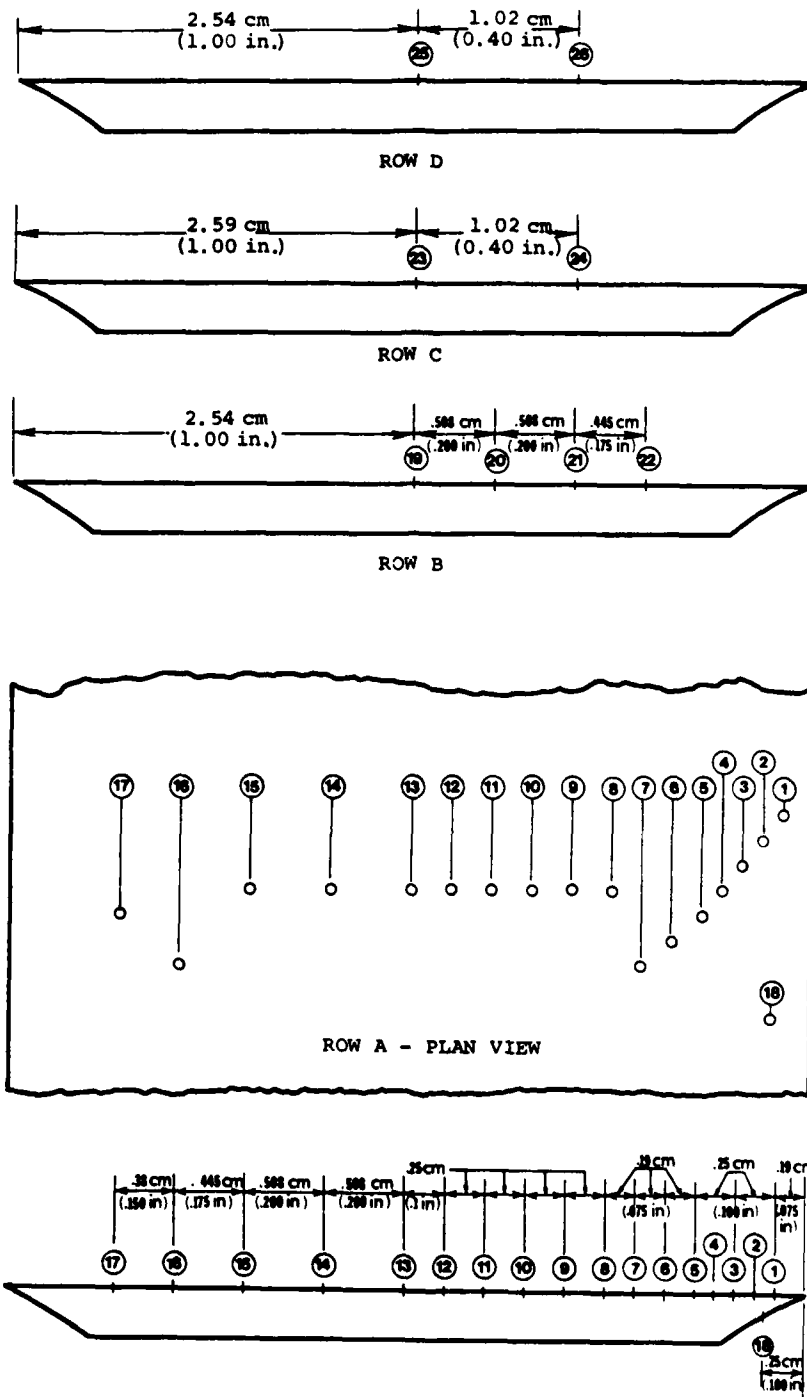


Fig. 1. General arrangement of the pump and engine.



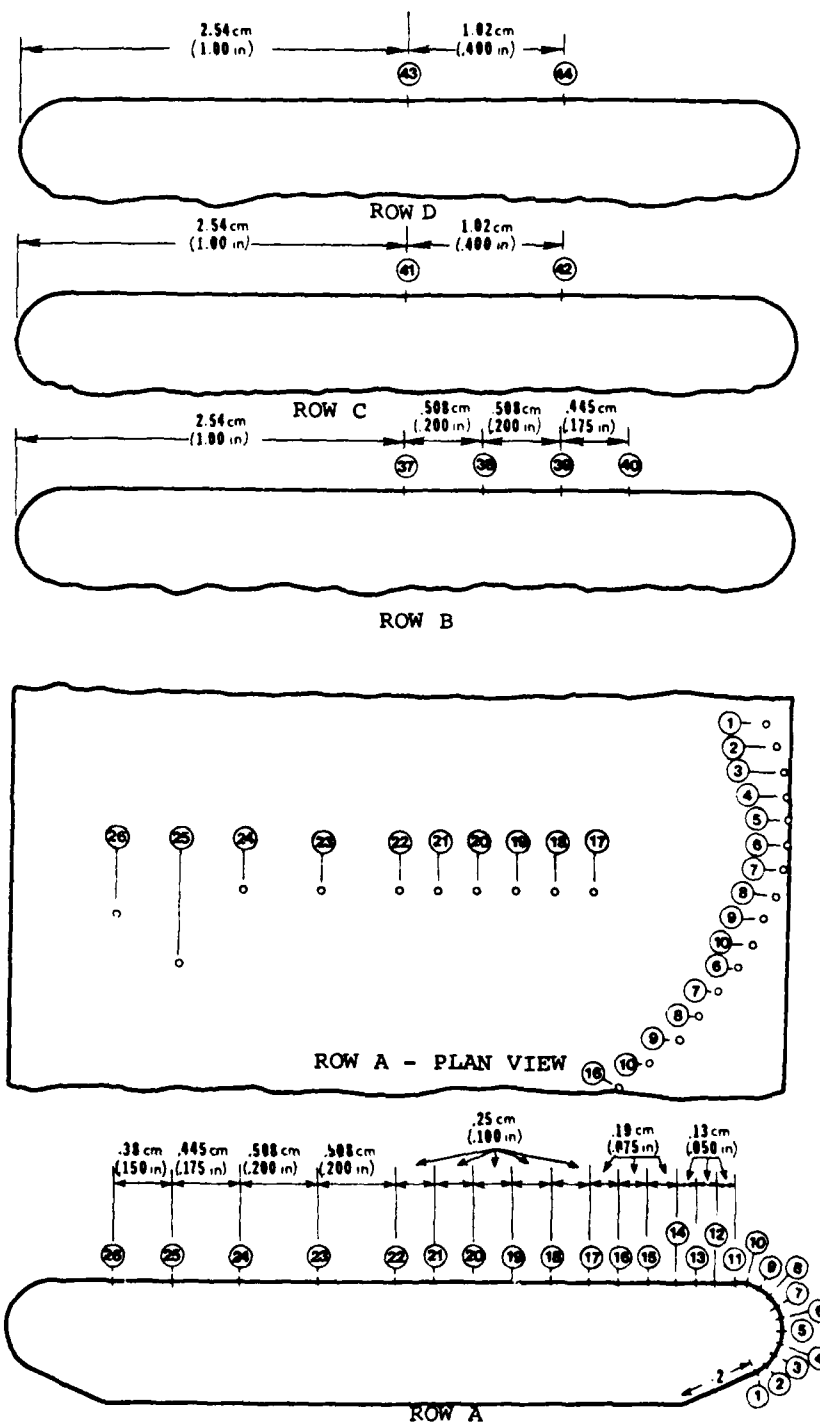
(c) Close view of model and window.  
Figure 1.- Continued.



(a) Tap locations.

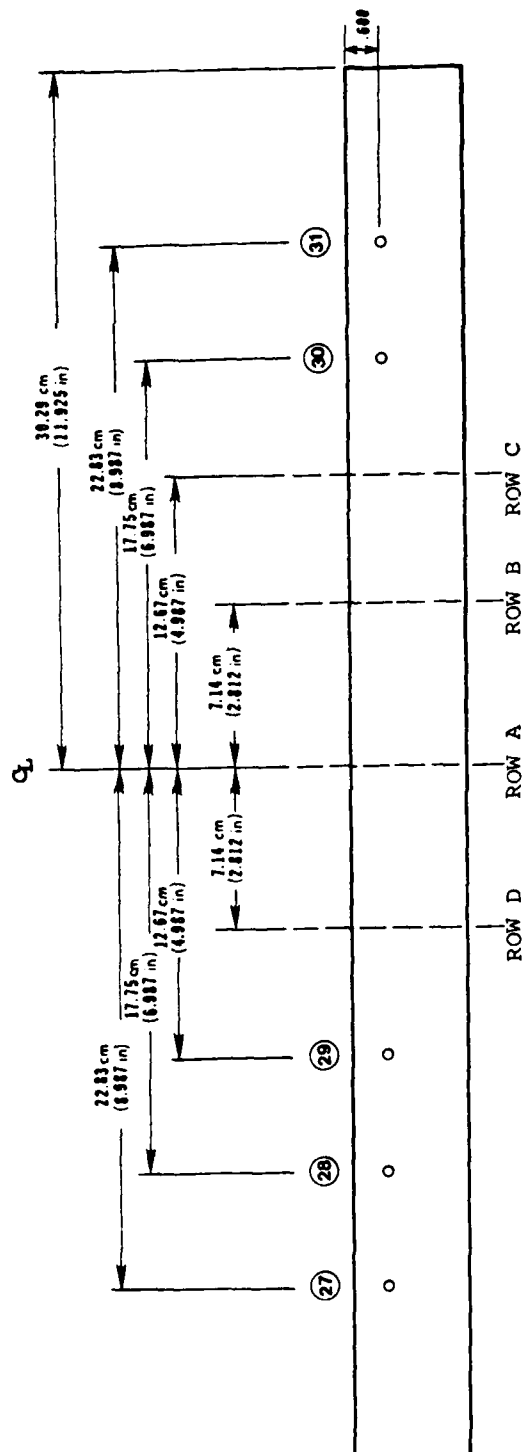
Figure 2.- Pressure tap locations - sharp-edged face.





(a) Tap locations

Figure 3.- Pressure tap locations - round-edged plate.



(b) Row locations

Figure 3.- Concluded.

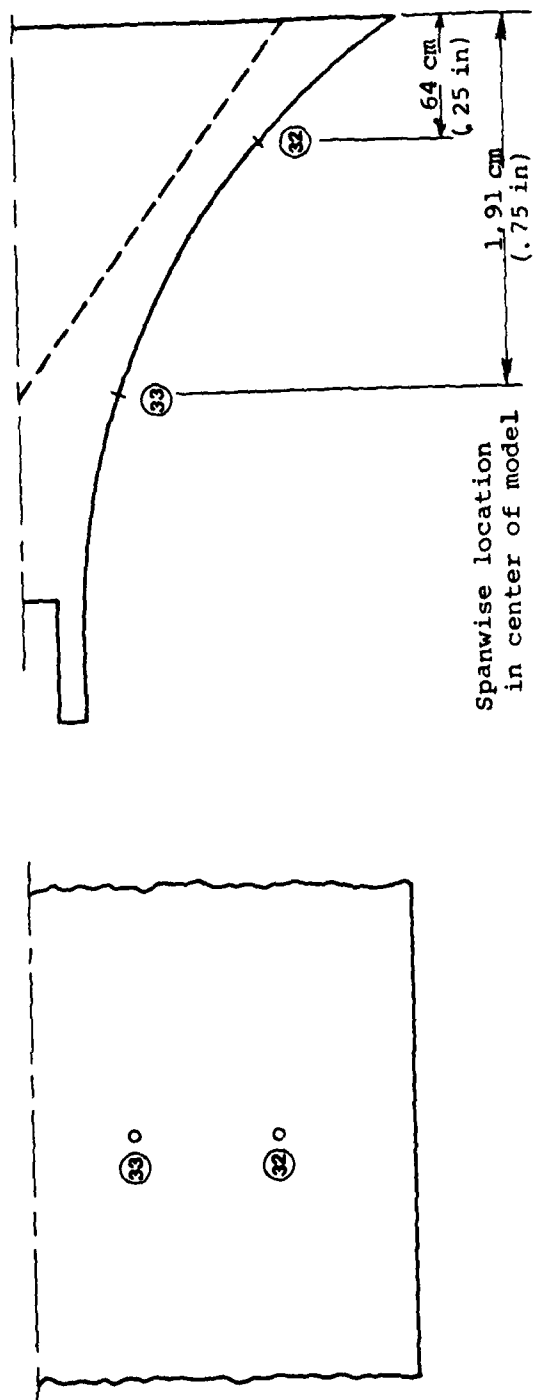


Figure 4.- Pressure tap locations on support plate.

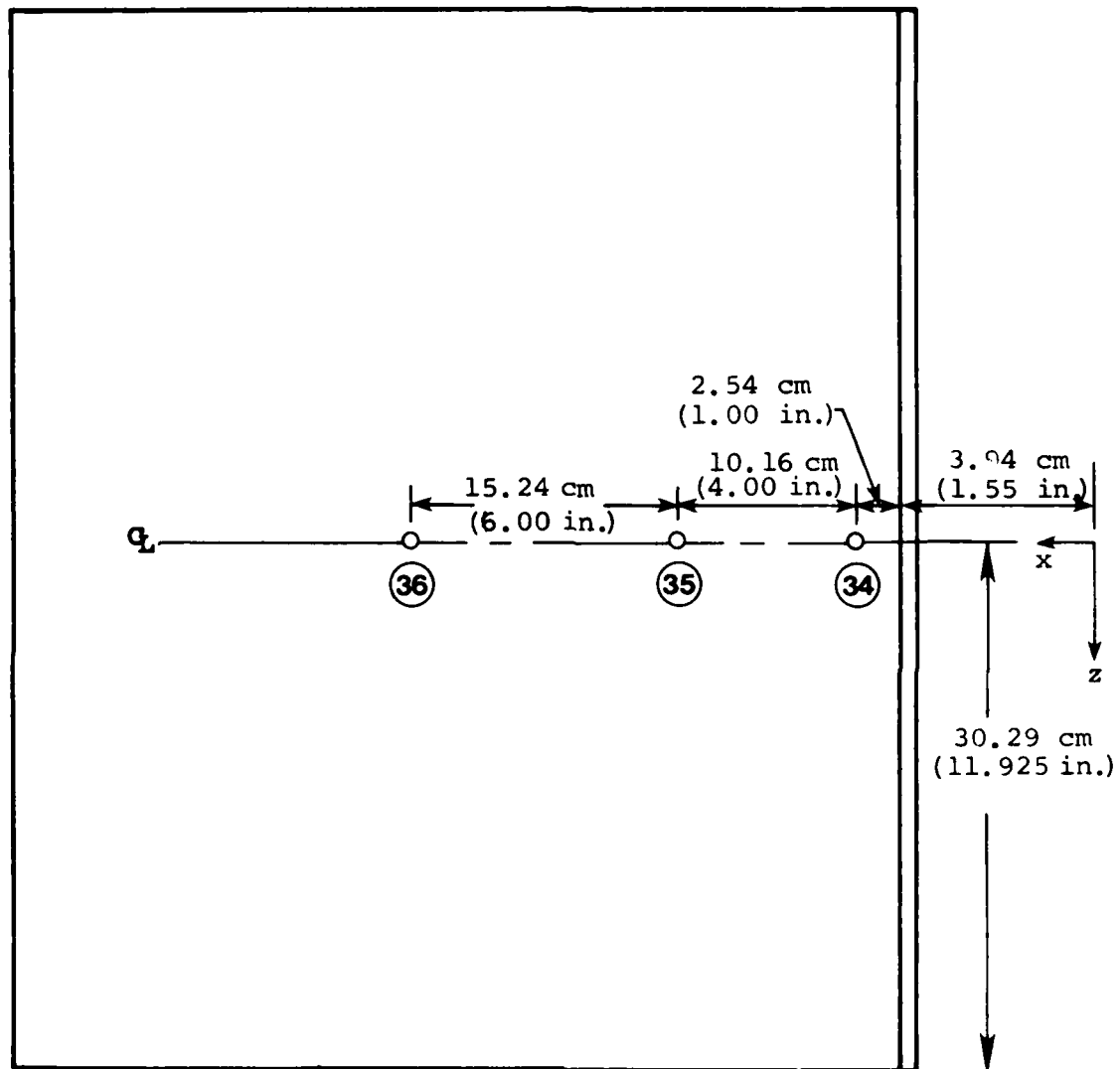


Figure 5.- Pressure tap location on splitter plate.

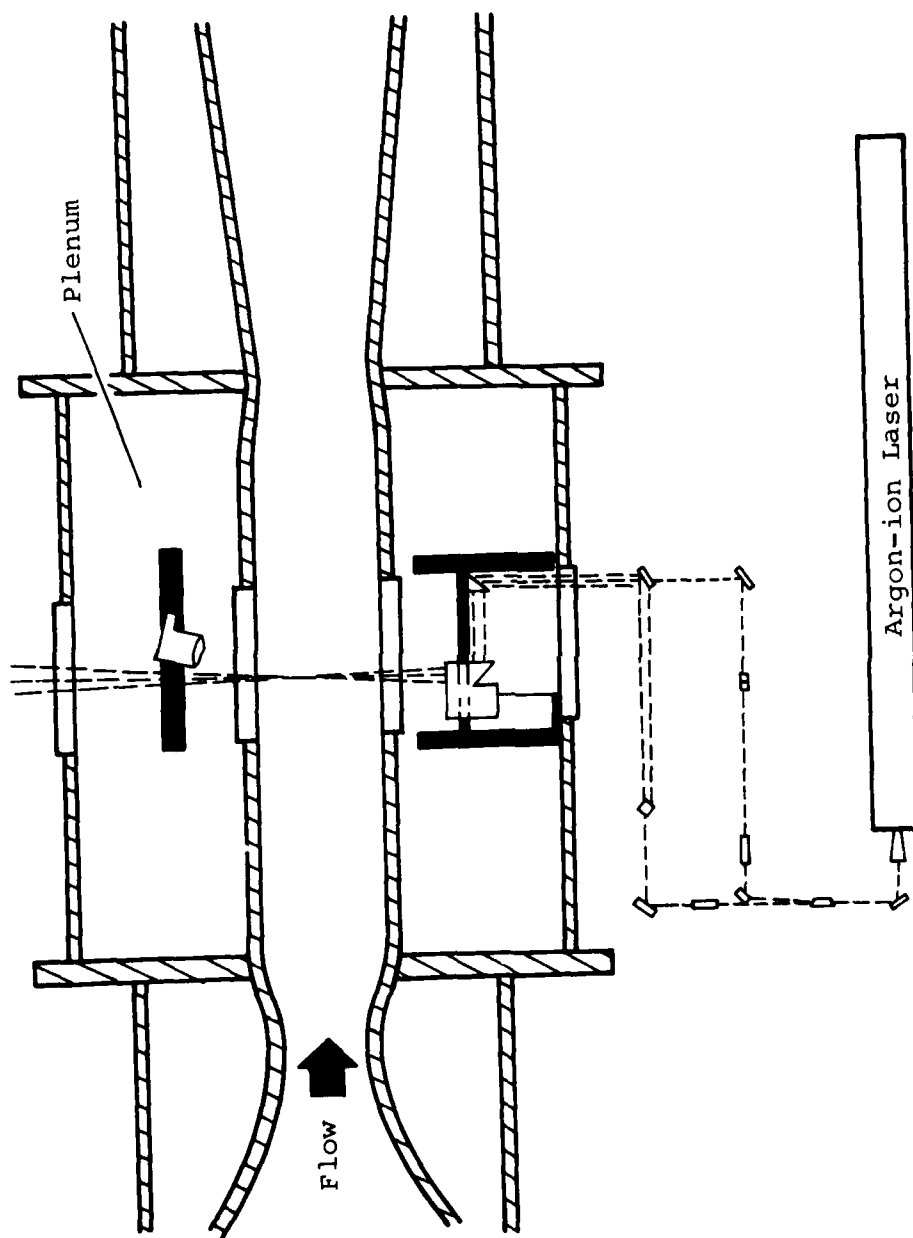
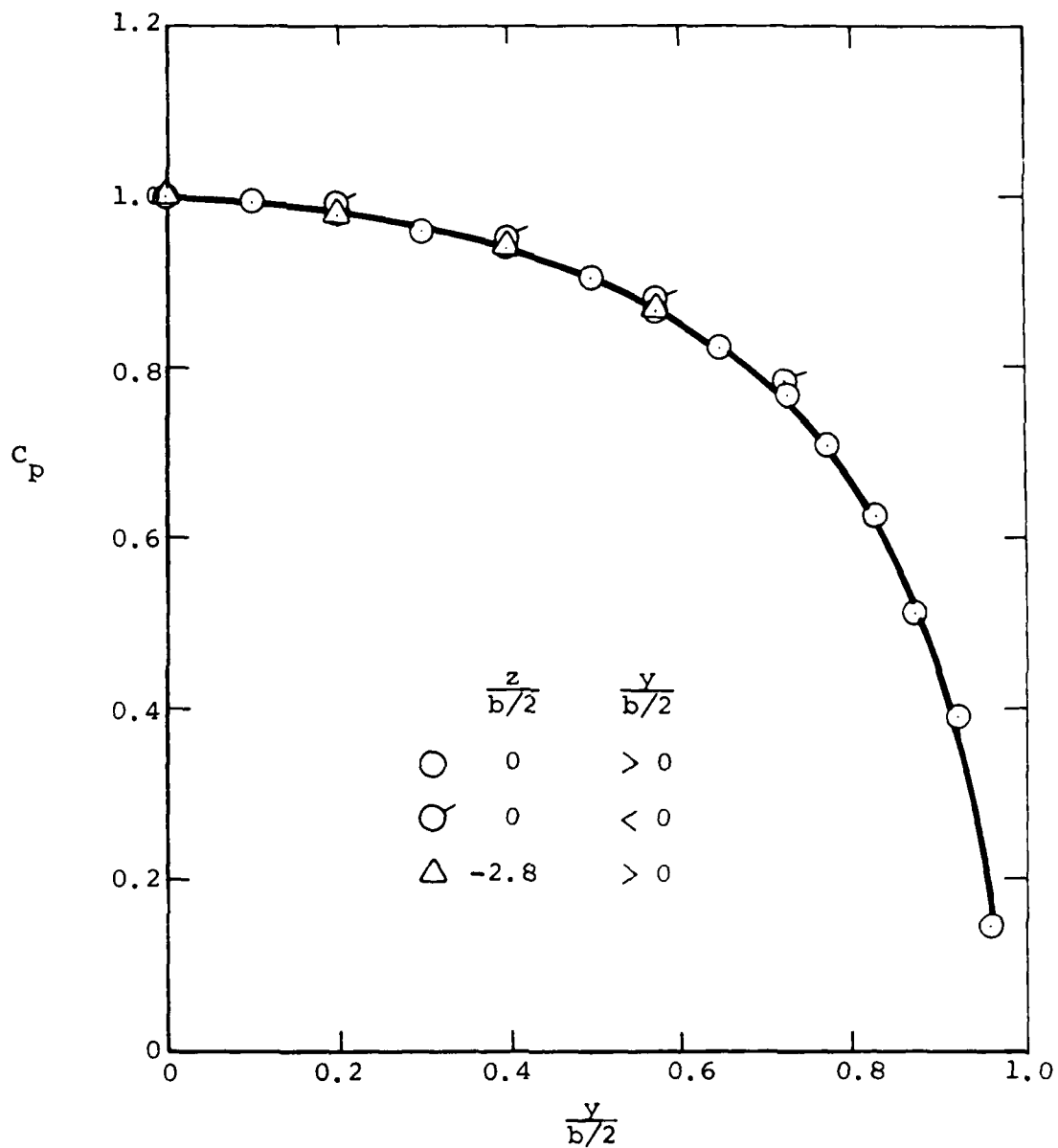
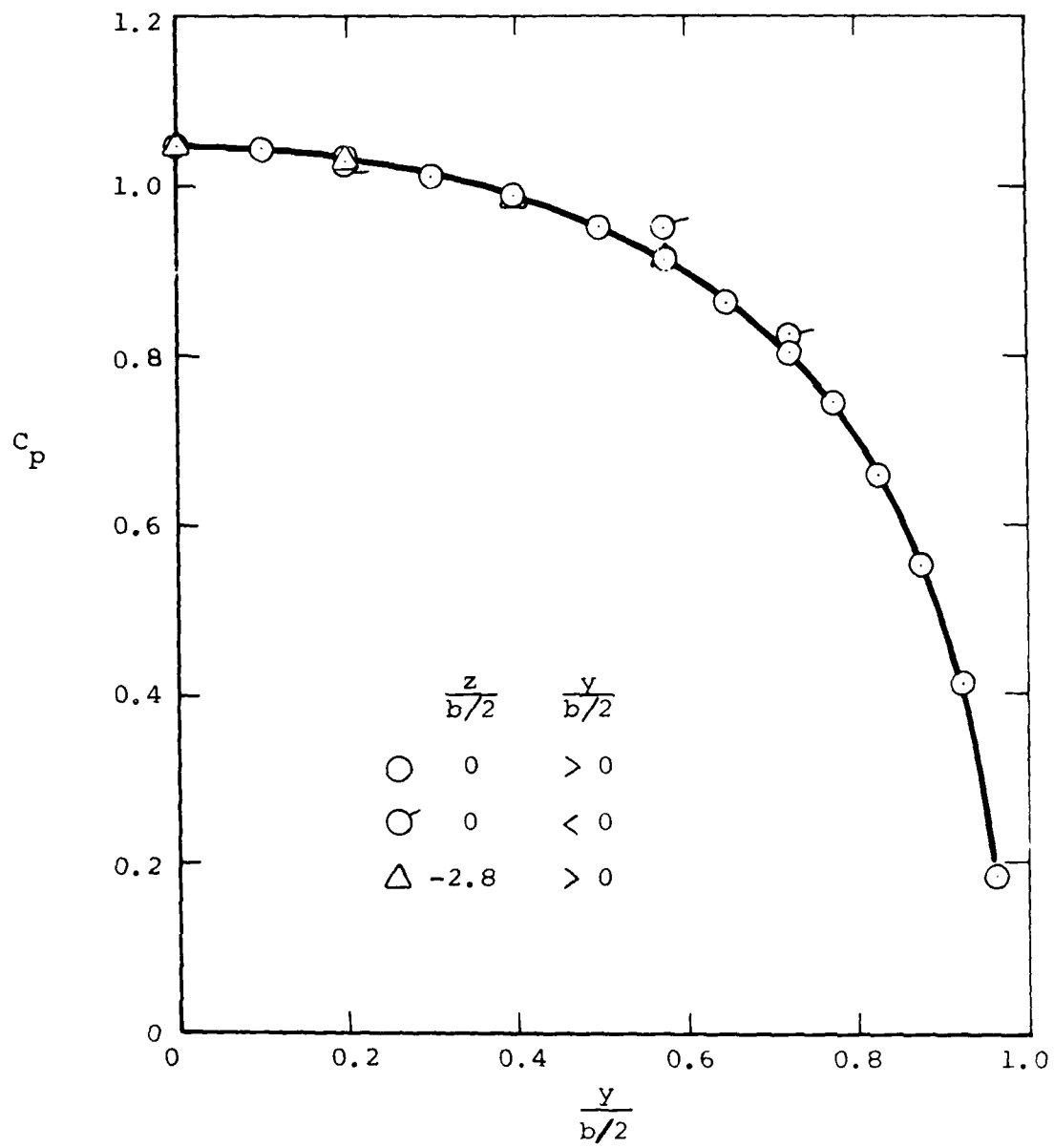


Figure 6.- Laser velocimeter installation  
NASA/Ames 2- by 2-foot TWT.



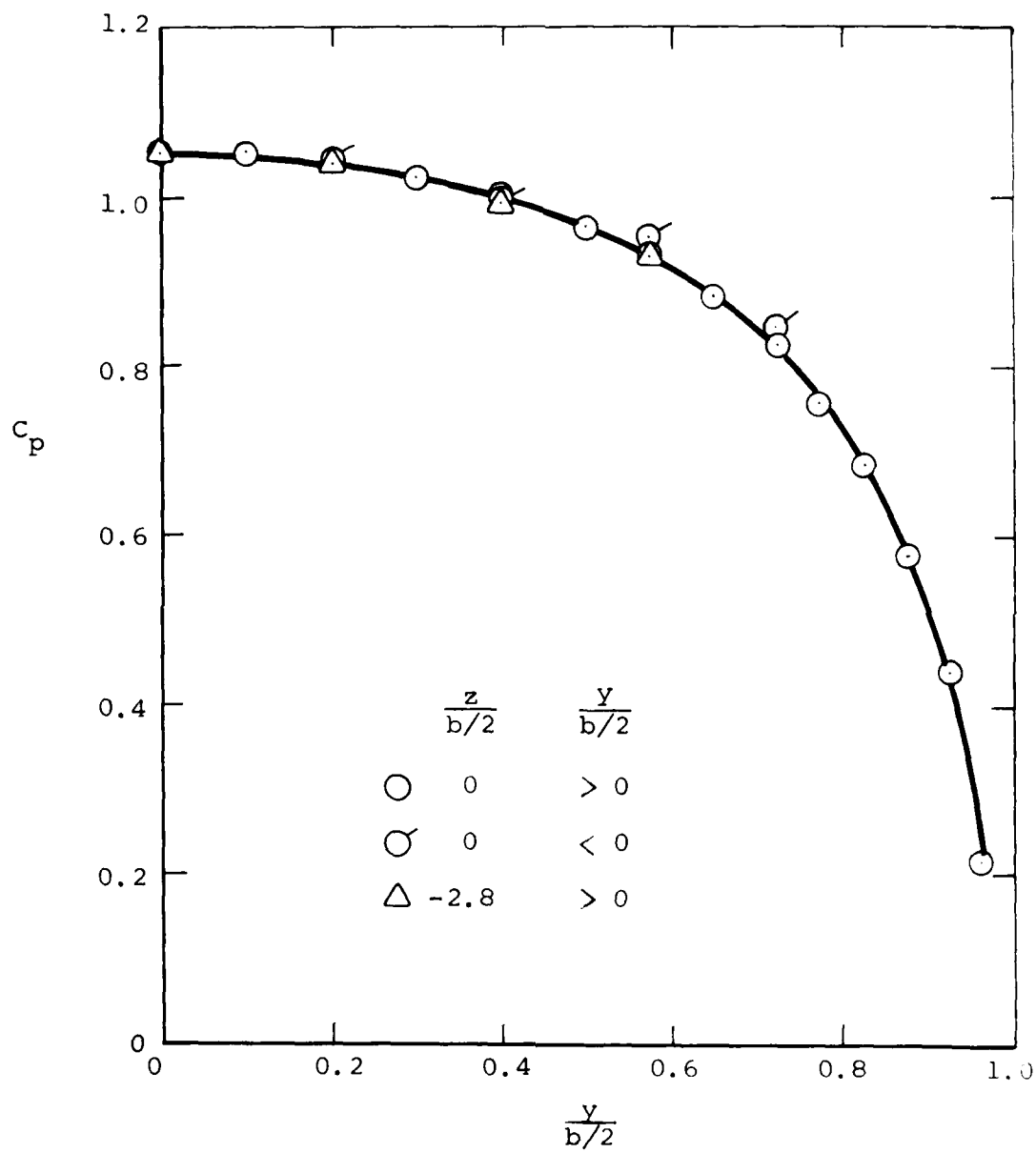
(a) Sharp edge model,  $M = 0.25$ ,  $Re = 0.063 \times 10^6$

Figure 7.- Variation of static pressure on the model face with distance from centerline.



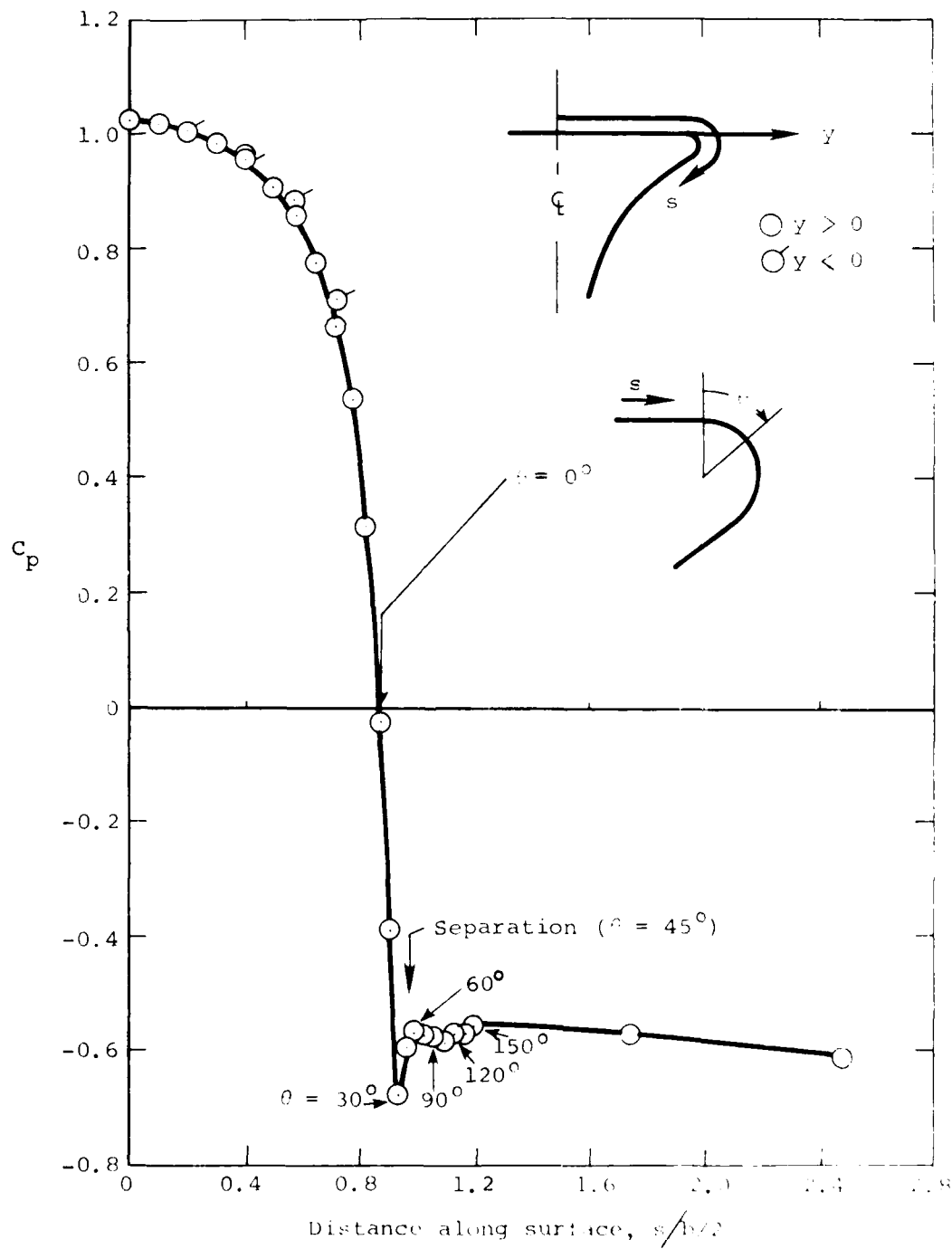
(b) Sharp edge model,  $M = 0.25$ ,  $Re = 0.25 \times 10^6$

Figure 7.- Continued.



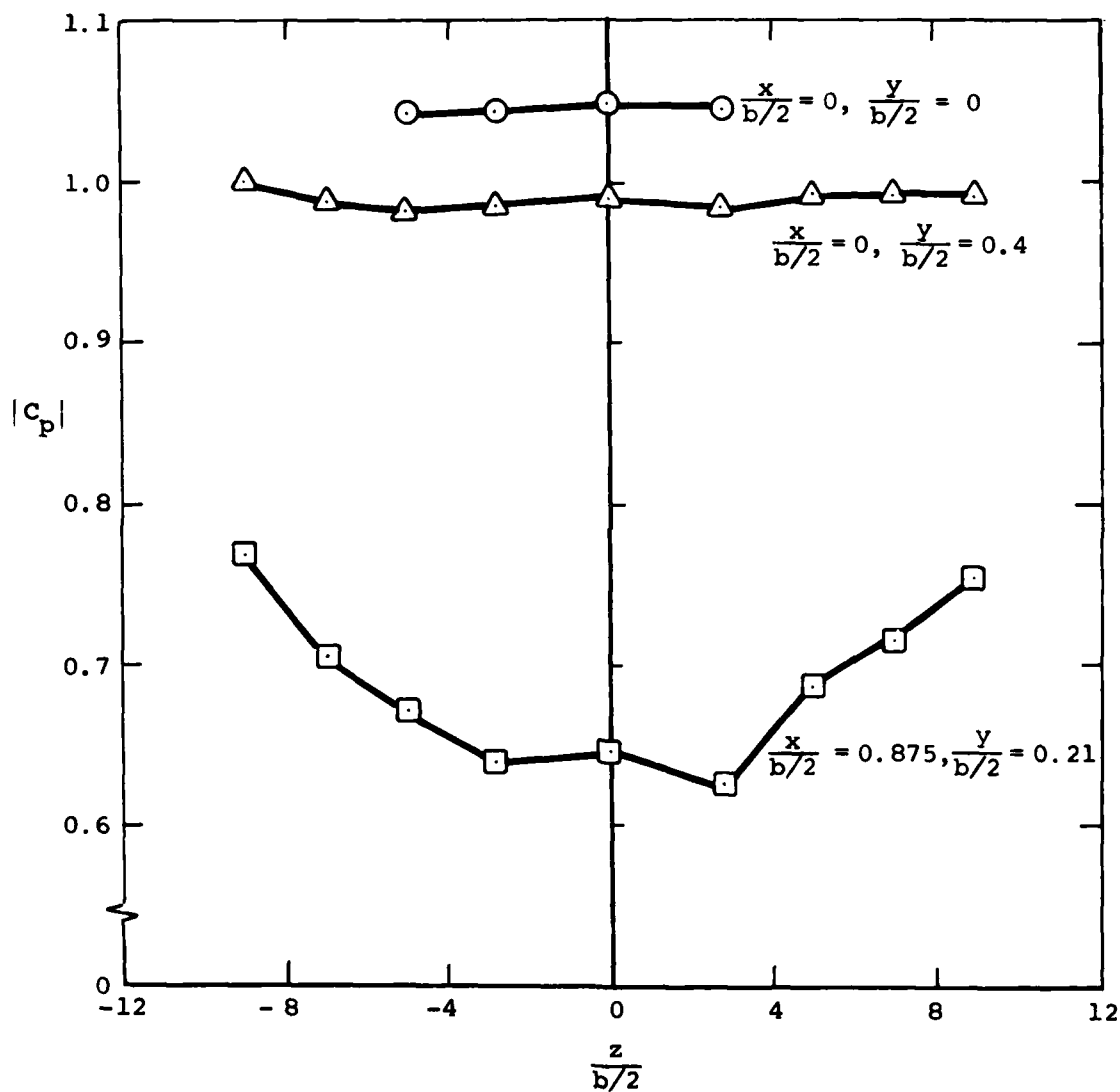
(c) Sharp edge model,  $M = 0.5$ ,  $Re = 0.15 \times 10^6$

Figure 7.- Continued.



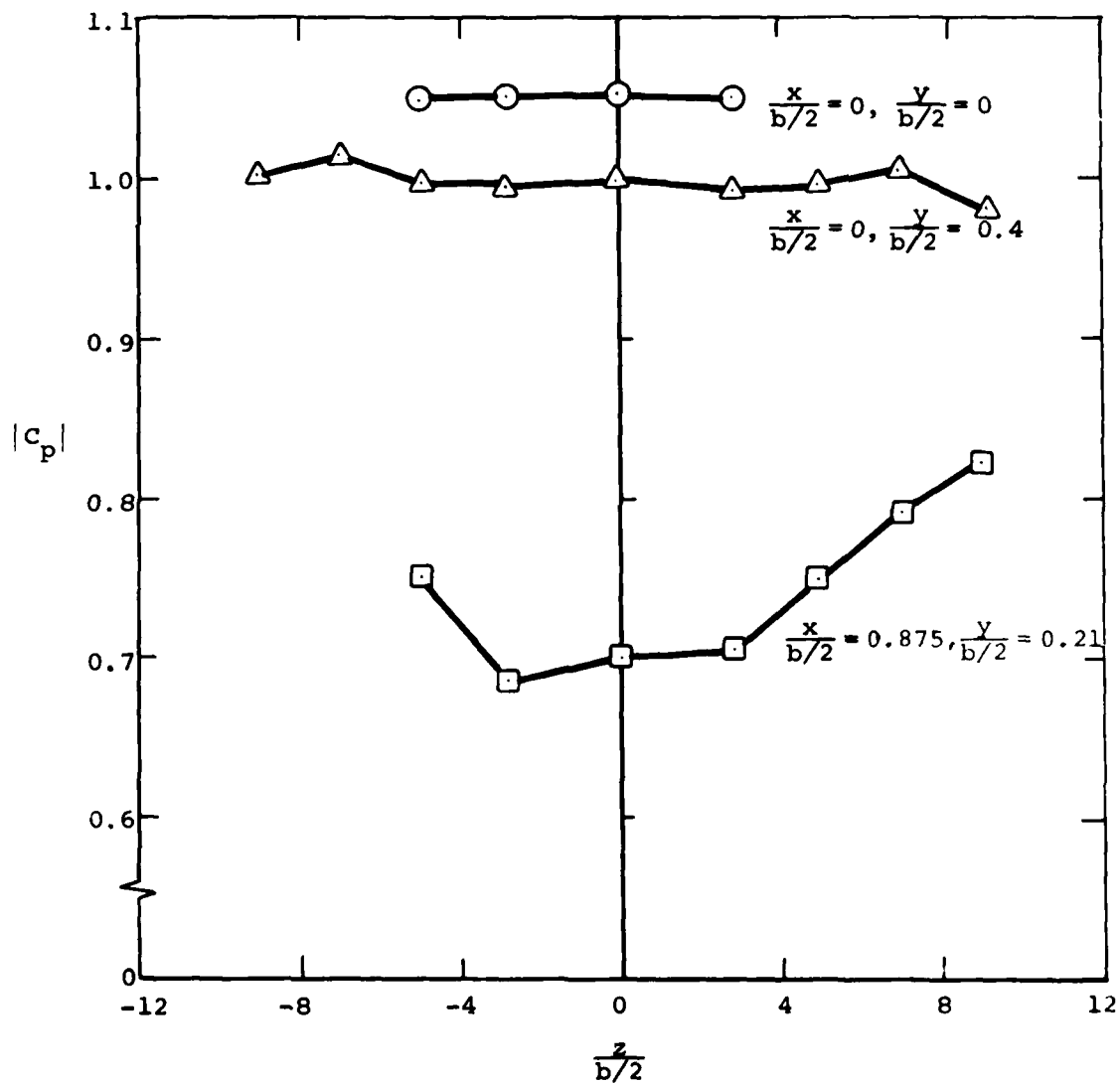
(d) Round edge model,  $M = 0.25$ ,  $Re = 0.25 \times 10^6$

Figure 7.- Concluded.



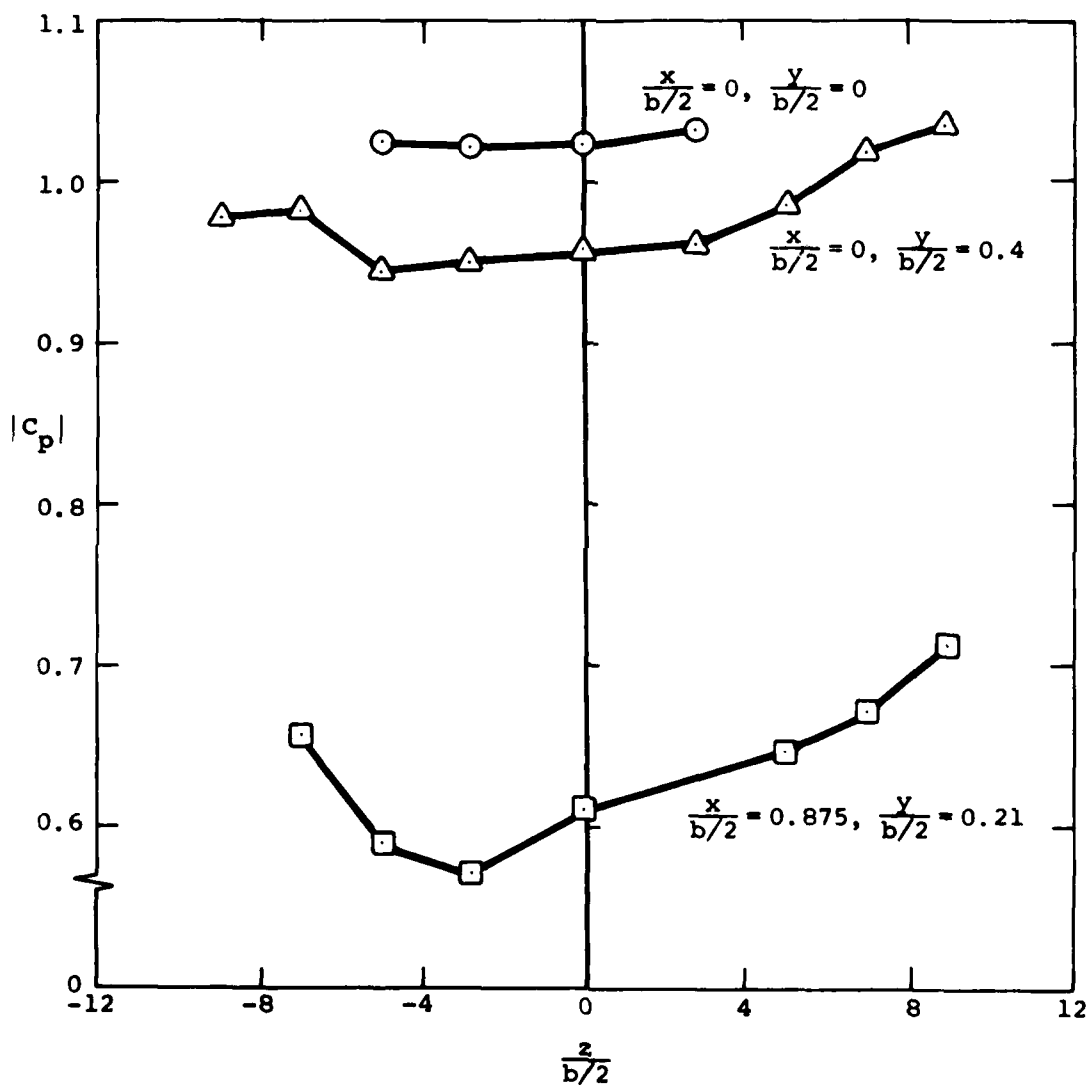
(a) Sharp edge model,  $M = 0.25$ ,  $Re = 0.25 \times 10^6$

Figure 8.- Spanwise variation of magnitude of front and rear surfaces static pressure.



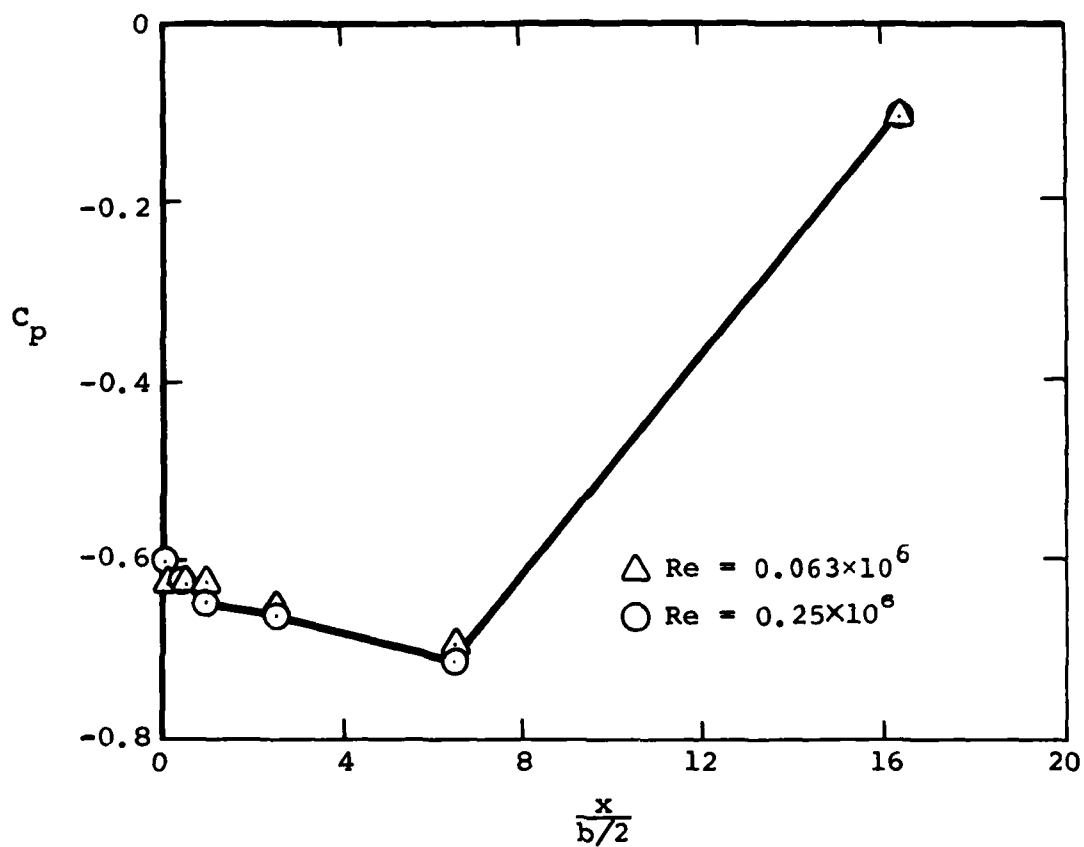
(b) Sharp edge model,  $M=0.5$ ,  $Re = 0.15 \times 10^6$

Figure 8.- Continued.



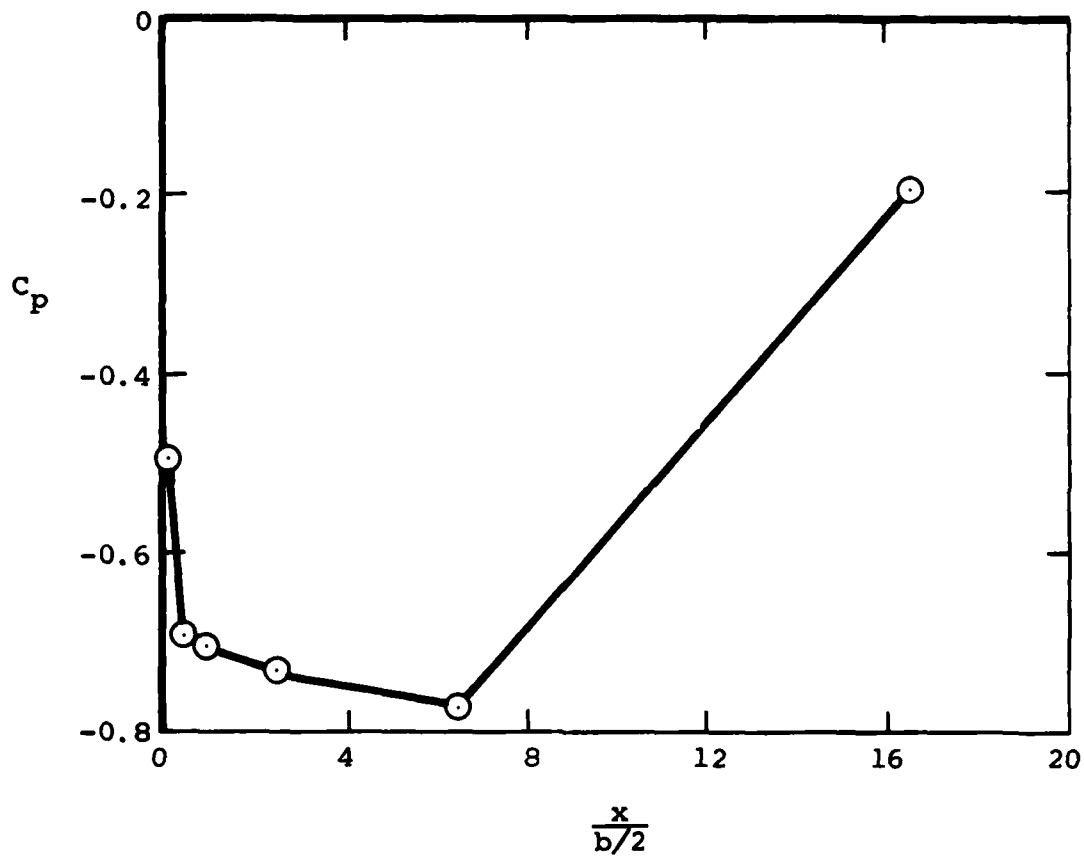
(c) Round edge model,  $M = 0.25$ ,  $Re = 0.25 \times 10^6$

Figure 8.- Concluded.



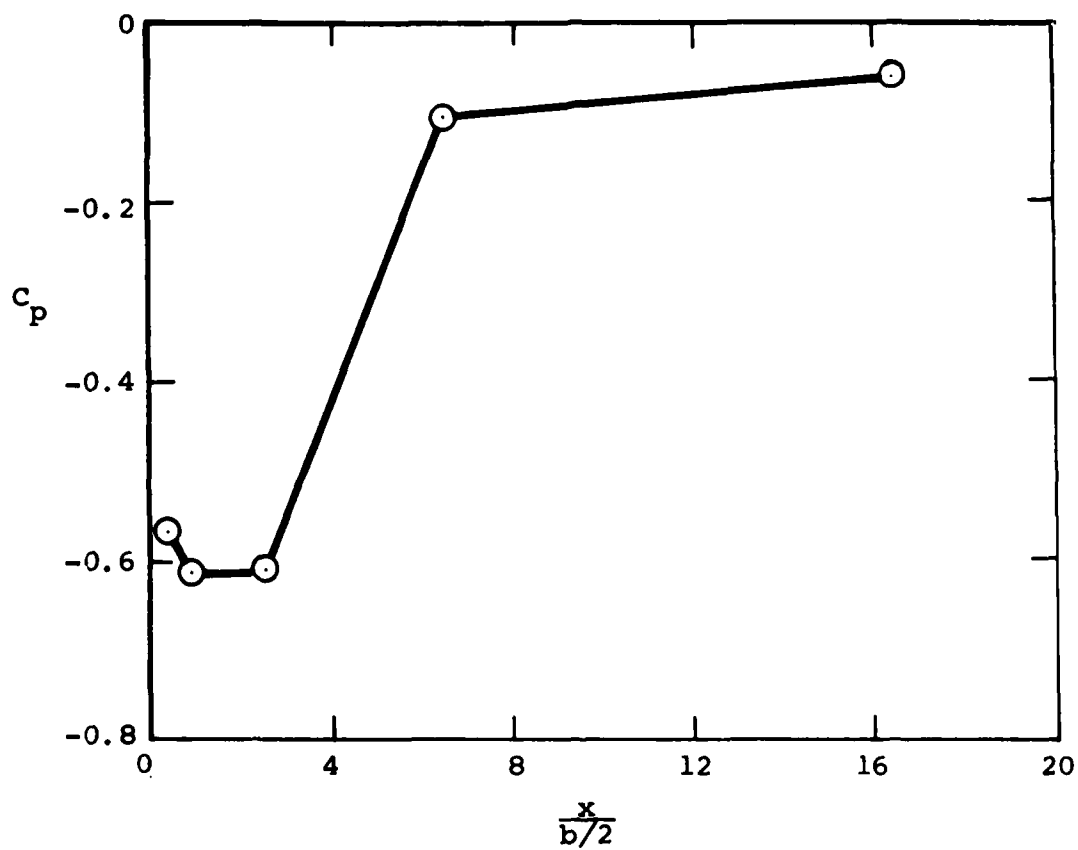
(a) Sharp edge model,  $M = 0.25$

Figure 9.- Streamwise variation of static pressure in separated region at  $z = 0$ .



(b) Sharp edge model,  $M = 0.5$ ,  $Re = 0.15 \times 10^6$

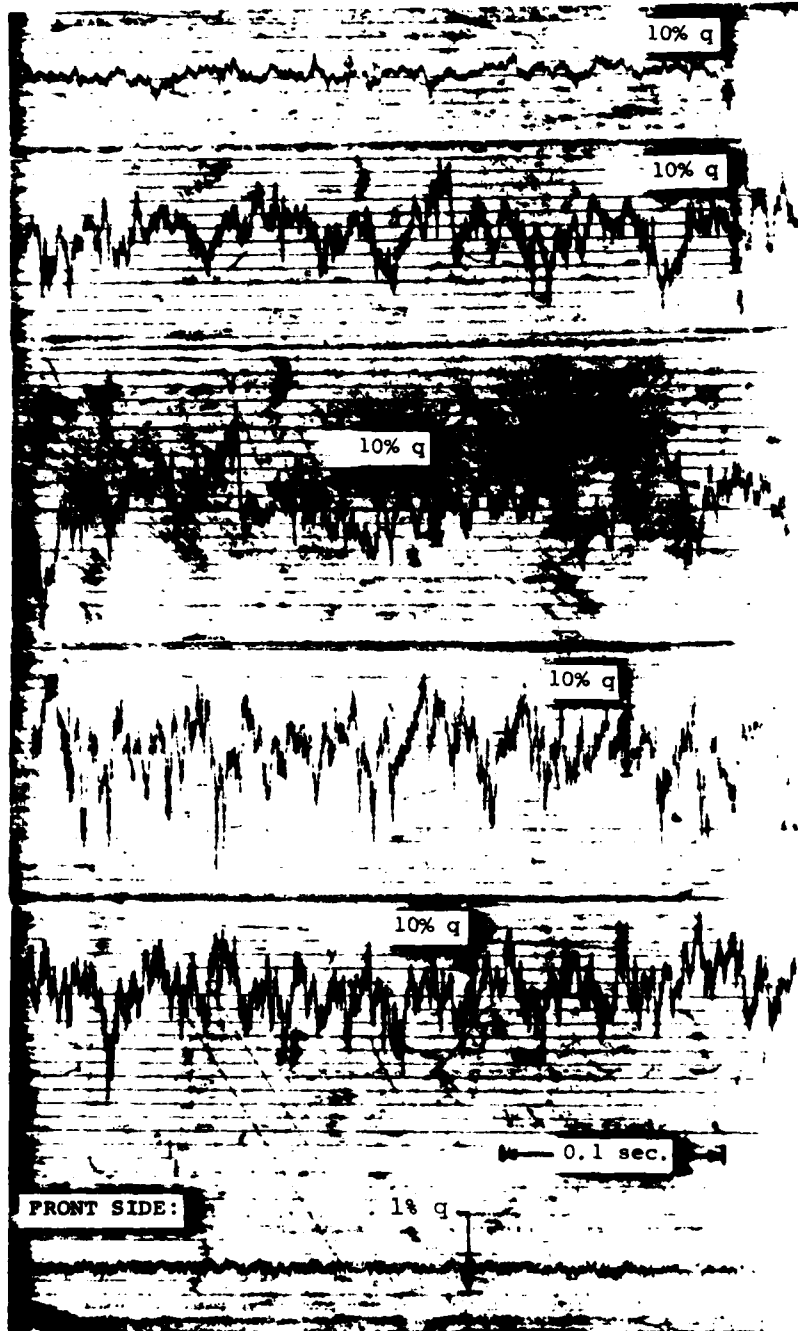
Figure 9.- Continued.



(c) Round edge model,  $M = 0.25$ ,  $Re = 0.25 \times 10^6$

Figure 9.- Concluded.

REAR SIDE ( $x = 0.375$ ,  $y = 0.50$ ):



Model M Re $\times 10^{-6}$

Sharp 0.25 0.063

Sharp 0.25 0.25

Rnd 0.25 0.25

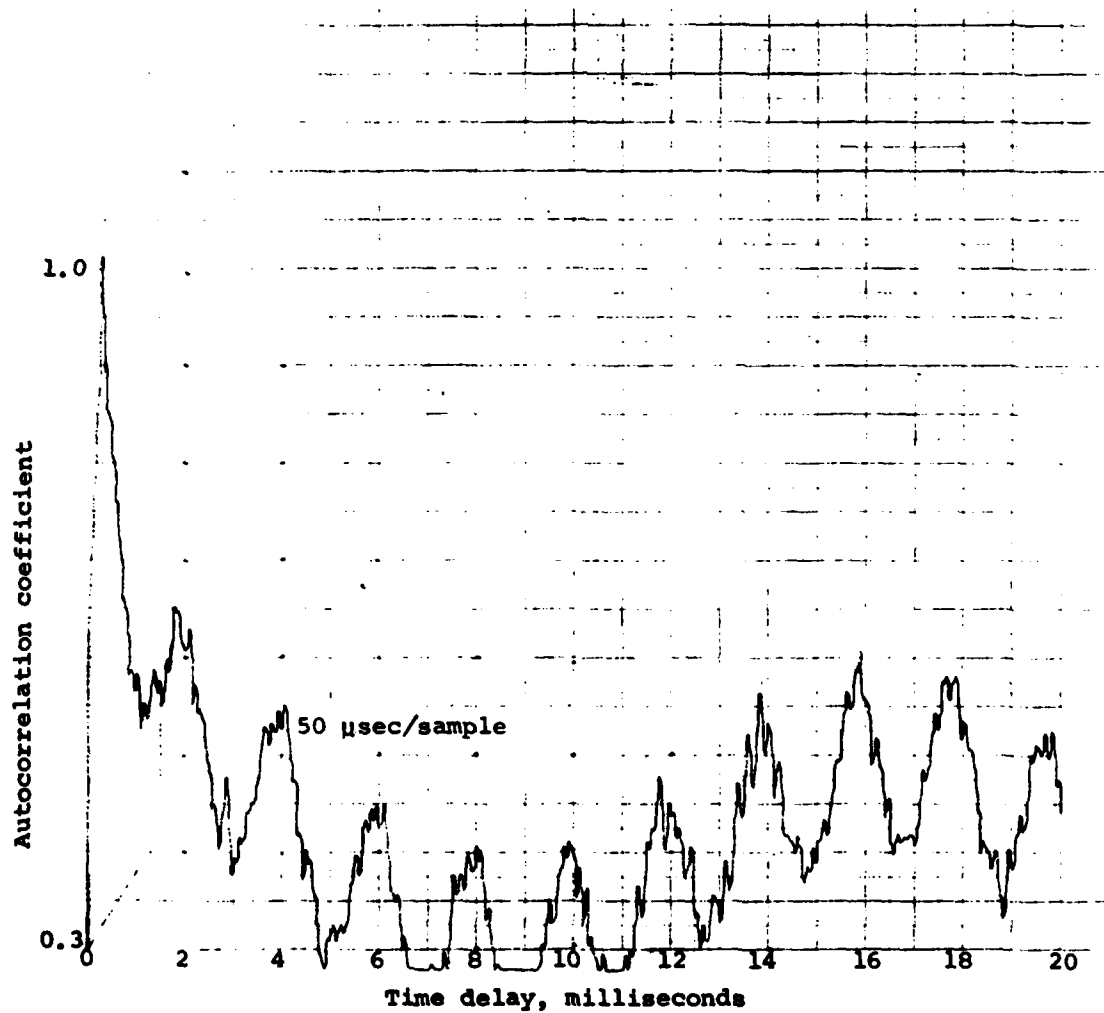
Rnd 0.50 0.15

Sharp 0.50 0.15

Sharp 0.50 0.15

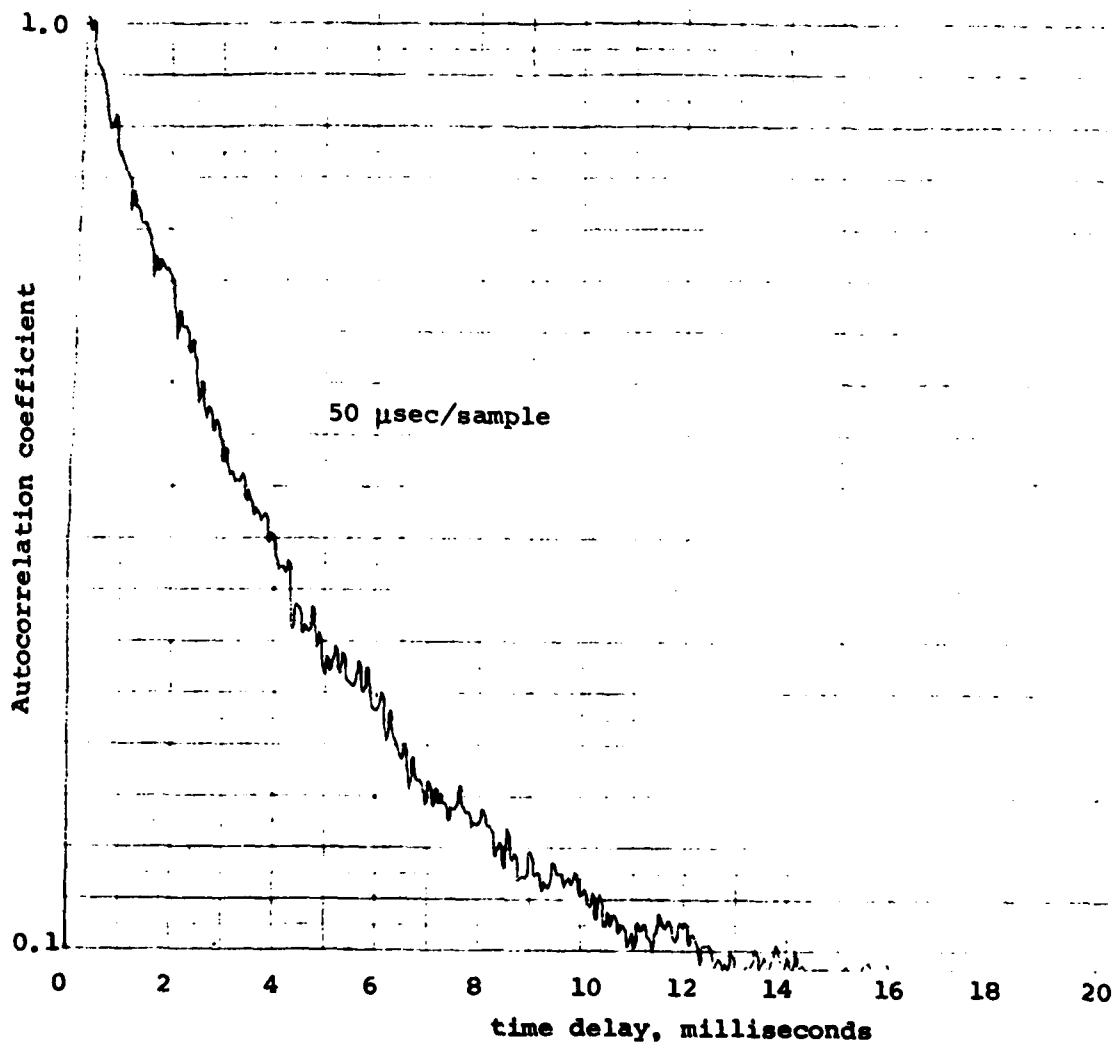
Sharp 0.50 0.15

Figure 10.- Unsteady pressure traces.



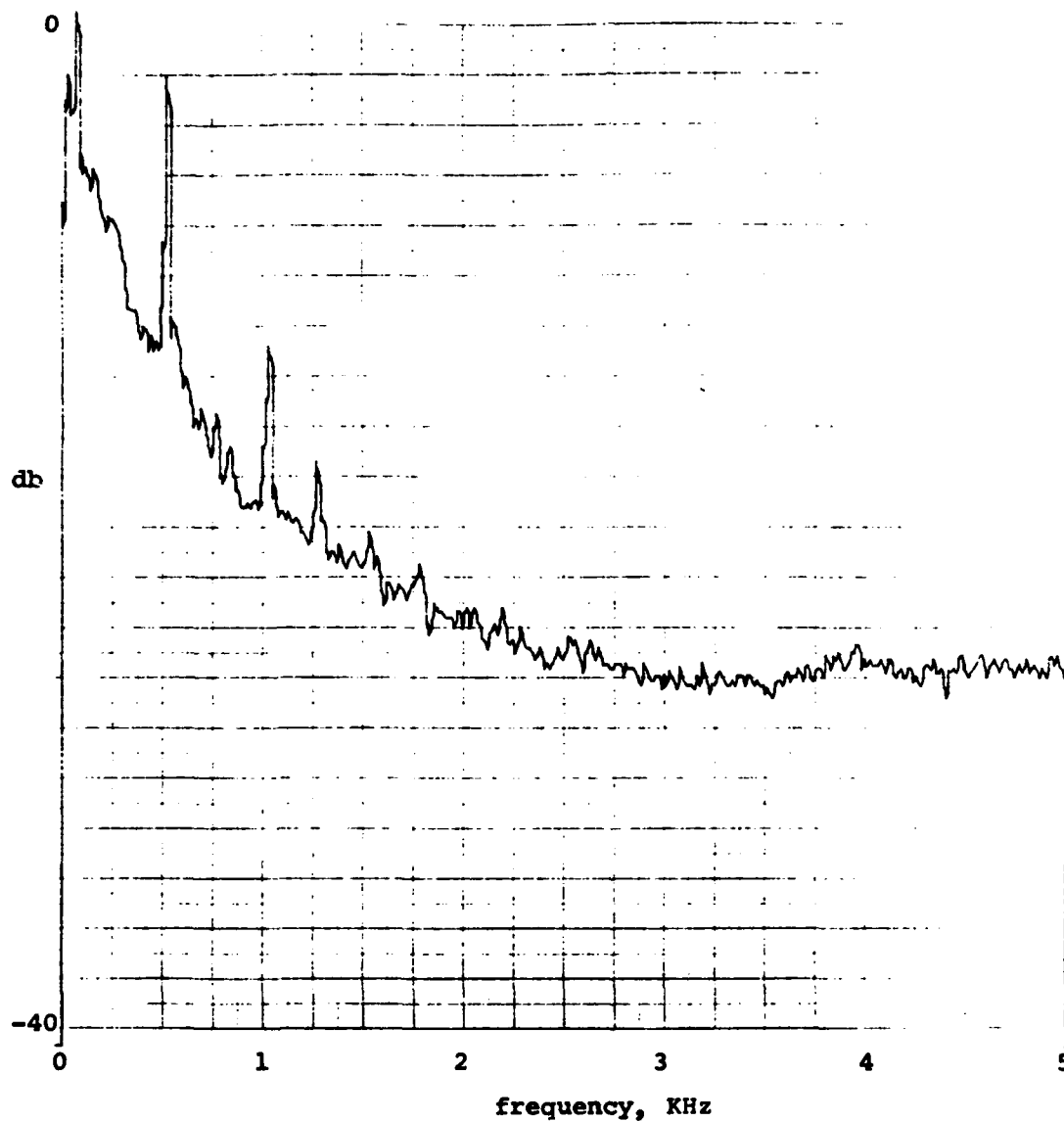
(a) Front face transducer.

Figure 11.- Autocorrelation results for the sharp edge model  
at  $M = 0.25$ ,  $Re = 0.063 \times 10^6$ .



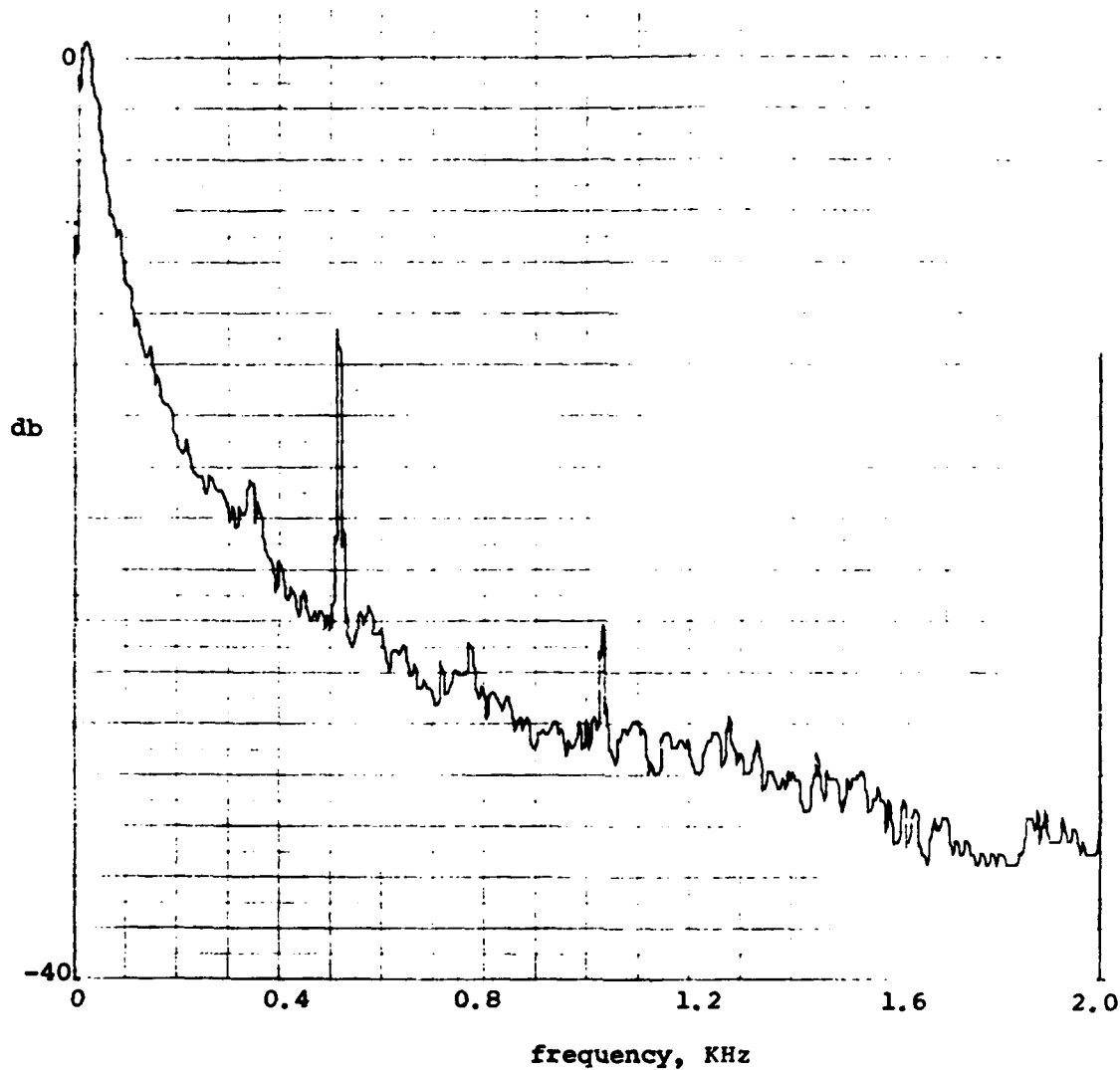
(b) Support plate transducer

Figure 11.- Concluded.



(a) Front face transducer.

Figure 12.- Power spectral density results for sharp edge model  
at  $M = 0.25$ ,  $Re = 0.063 \times 10^6$ .



(b) Support plate transducer.  
Figure 12.- Concluded.

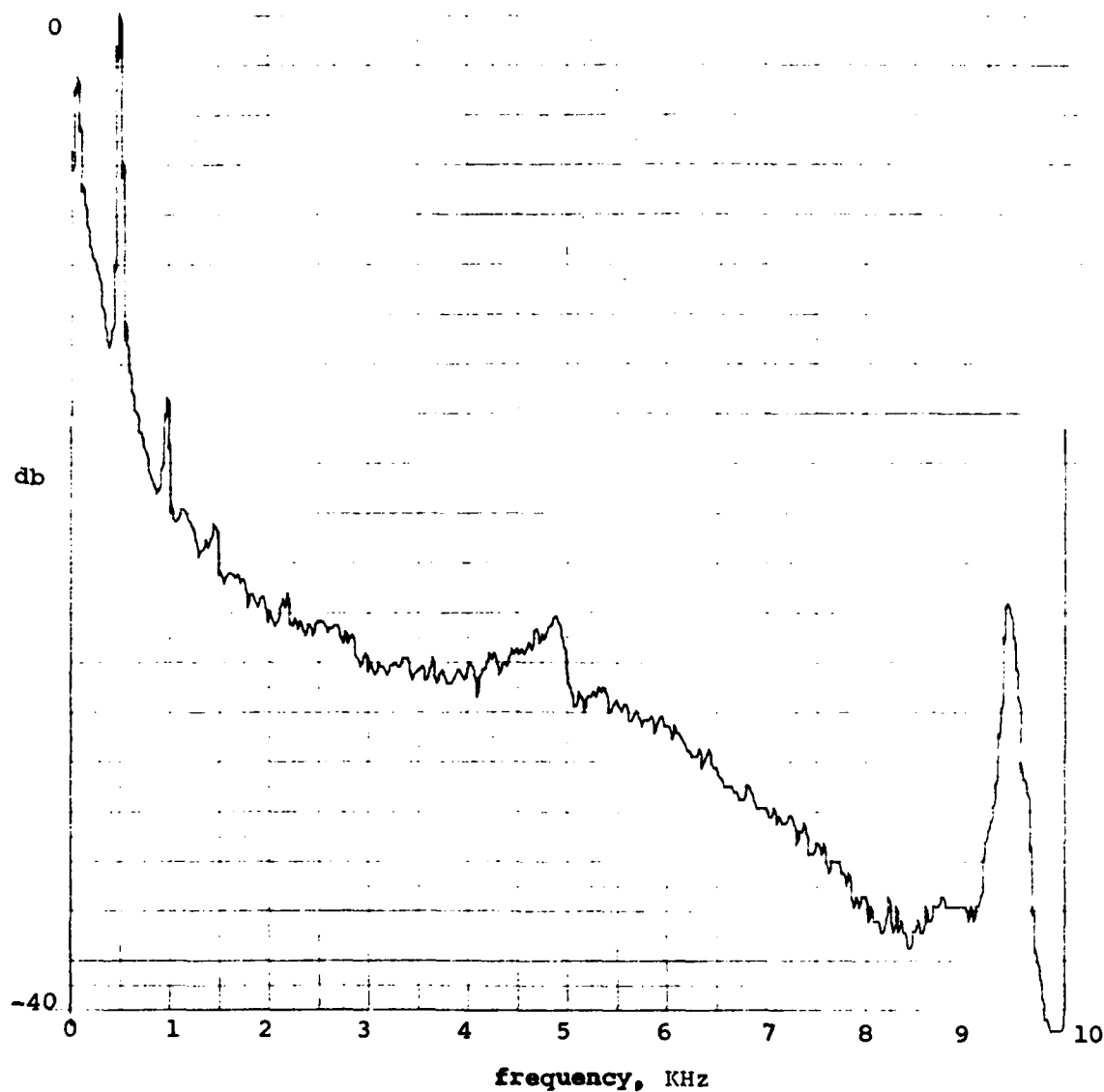


Figure 13.- Power spectral density results for front face transducer on round edge model at  $M = 0.25$ ,  $Re = 0.25 \times 10^6$ .

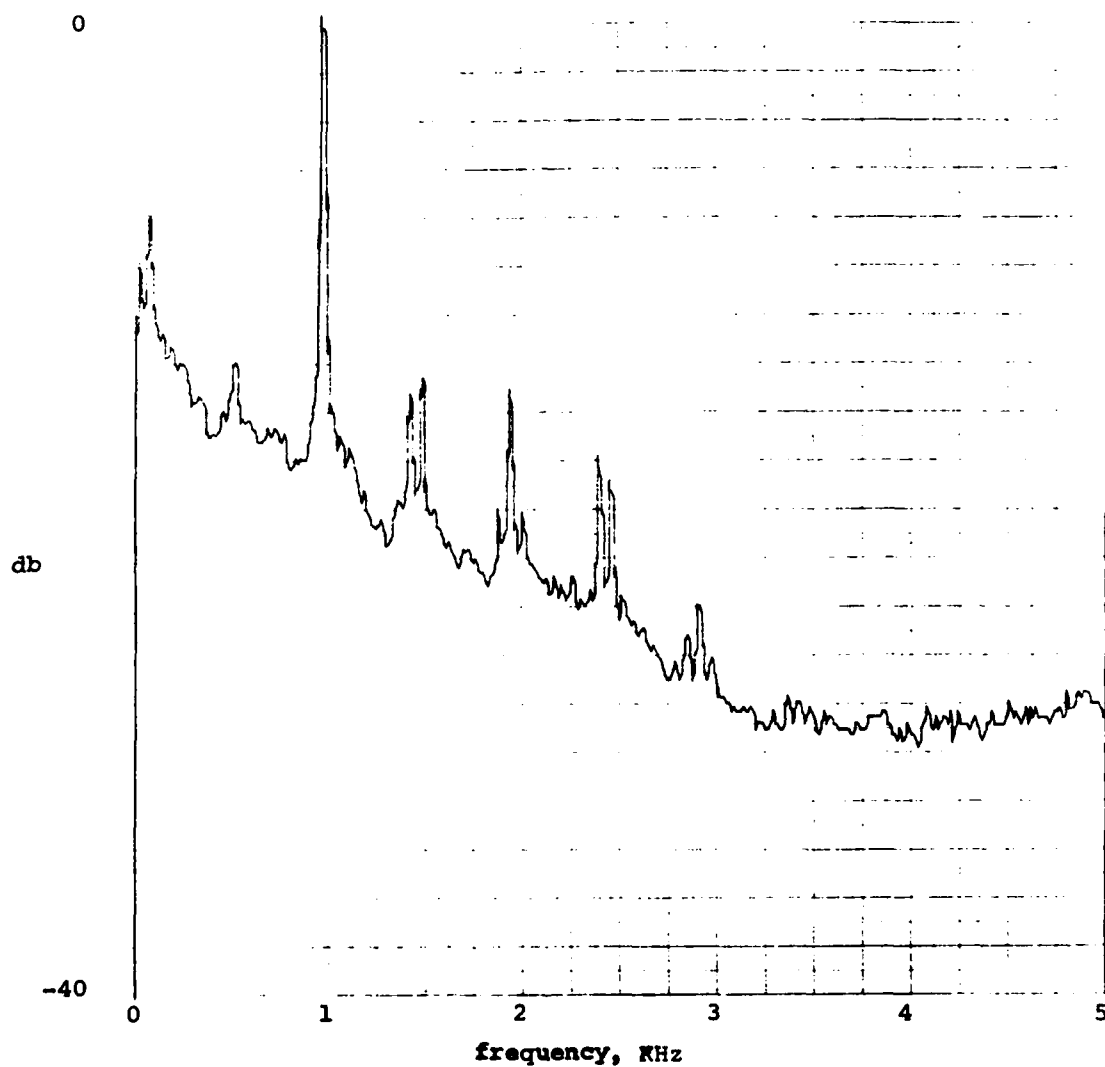
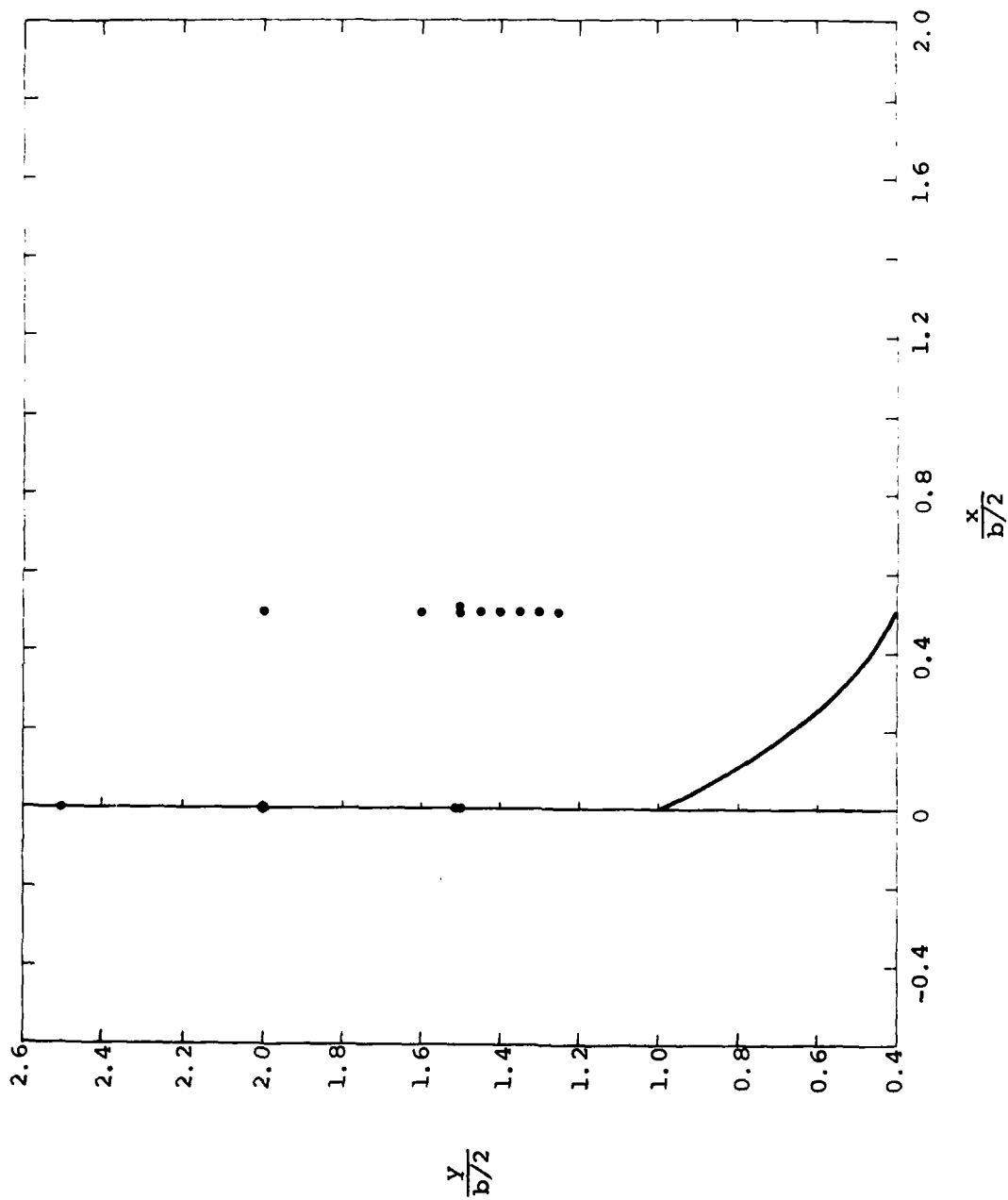
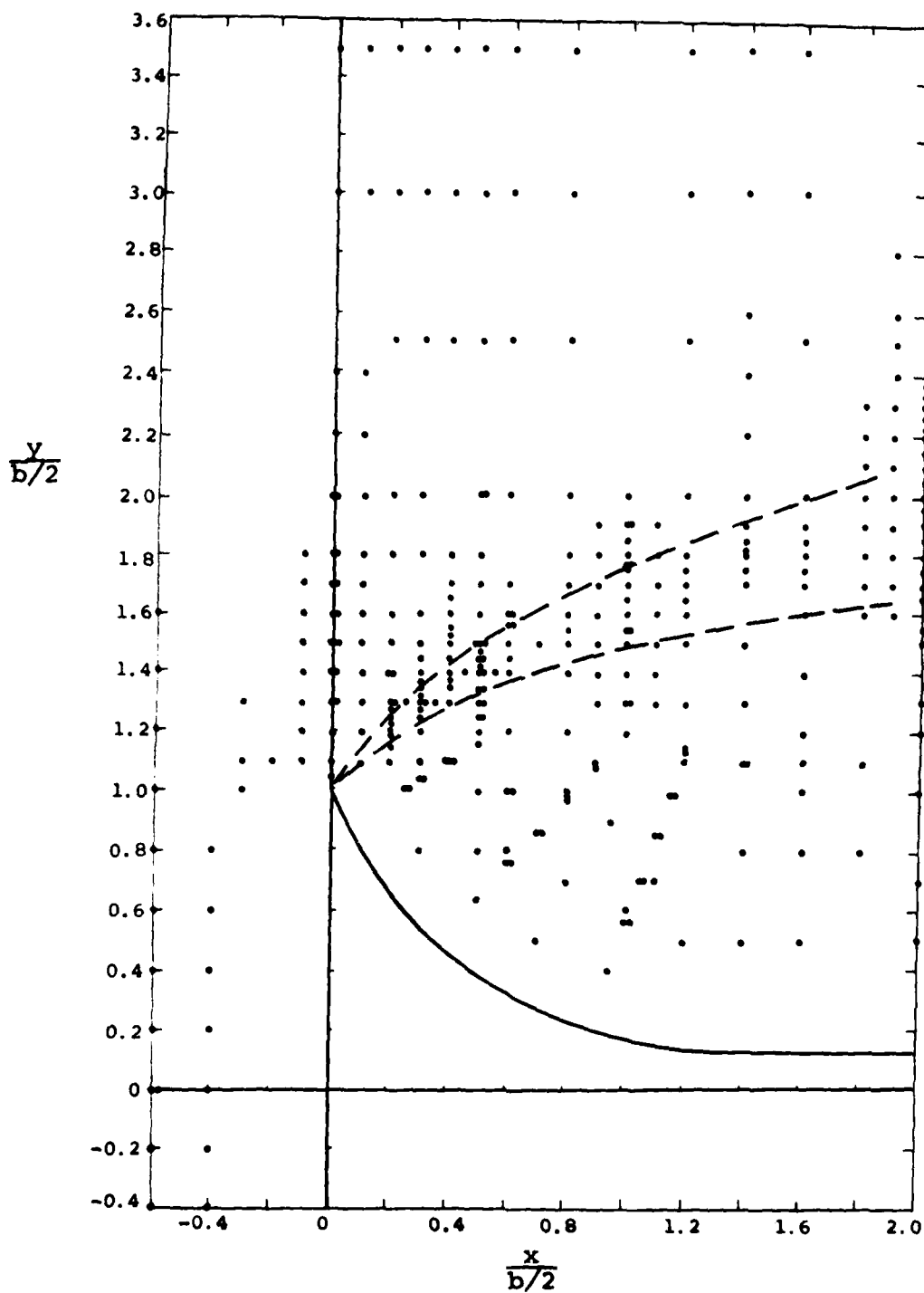


Figure 14.- Power spectral density results for front face transducer on sharp edge model at  $M = 0.5$  and  $Re = 0.15 \times 10^6 / ft.$

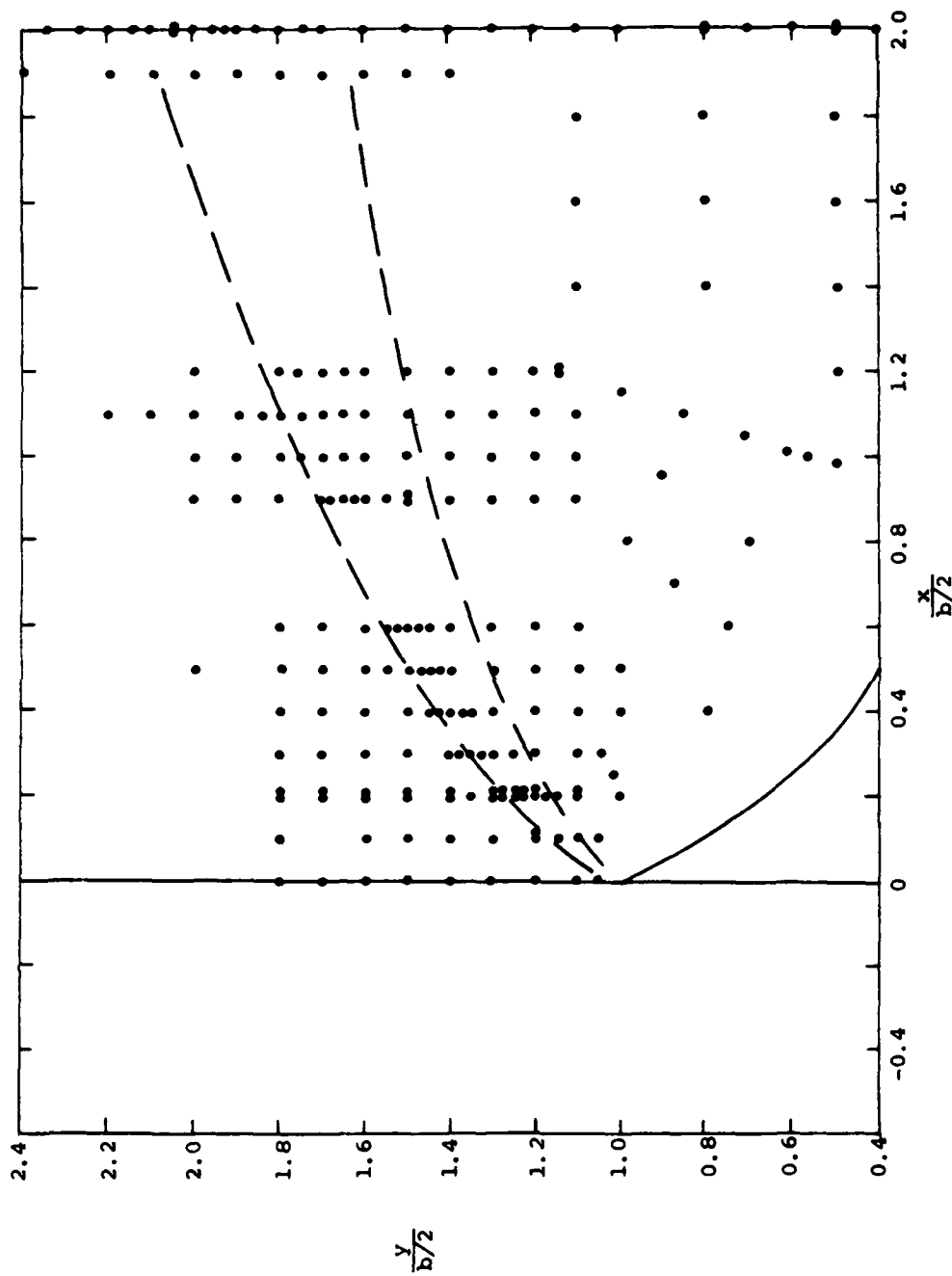


(a) Sharp edge model at  $M = 0.25$  and  $Re = 0.063 \times 10^6$  (points 1-13).  
Figure 15.- Positions of velocity measurements.



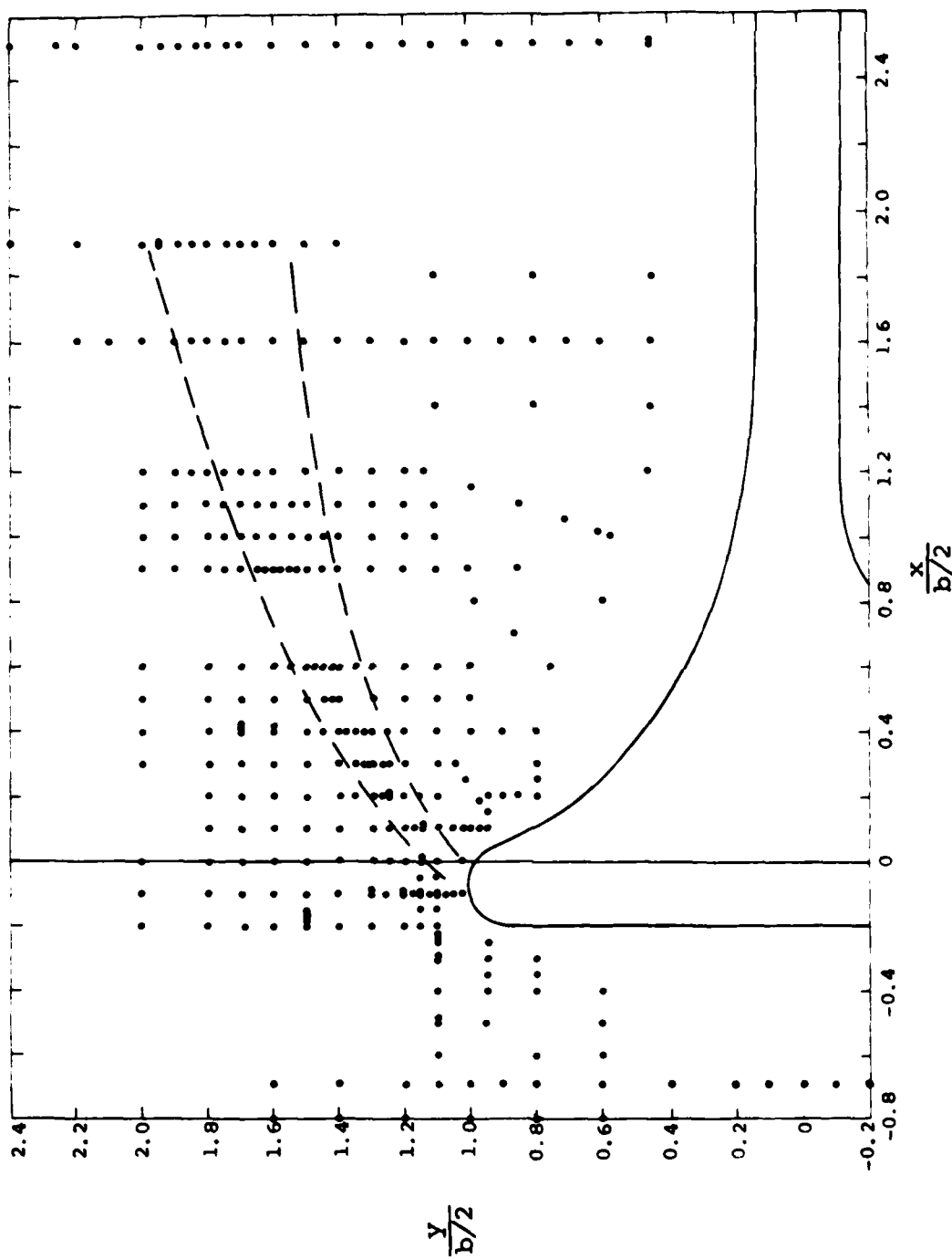
(b) Sharp edge model at  $M=0.25$  and  $Re=0.25 \times 10^6$  (points 14-383).

Figure 15.- Continued.



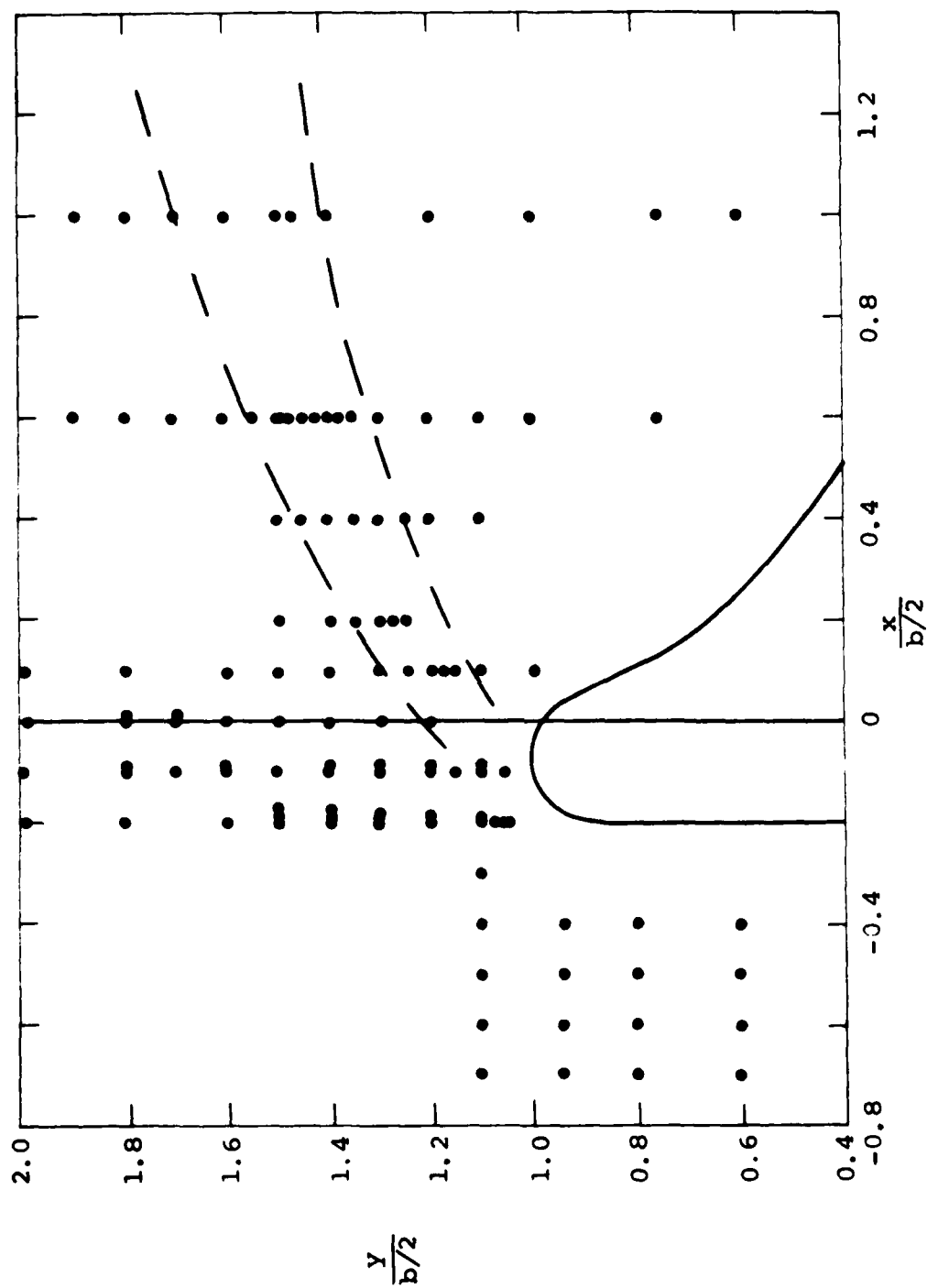
(c) Sharp edge model at  $M=0.5$  and  $Re = 0.15 \times 10^6$  (points 384-608).

Figure 15.- Continued.



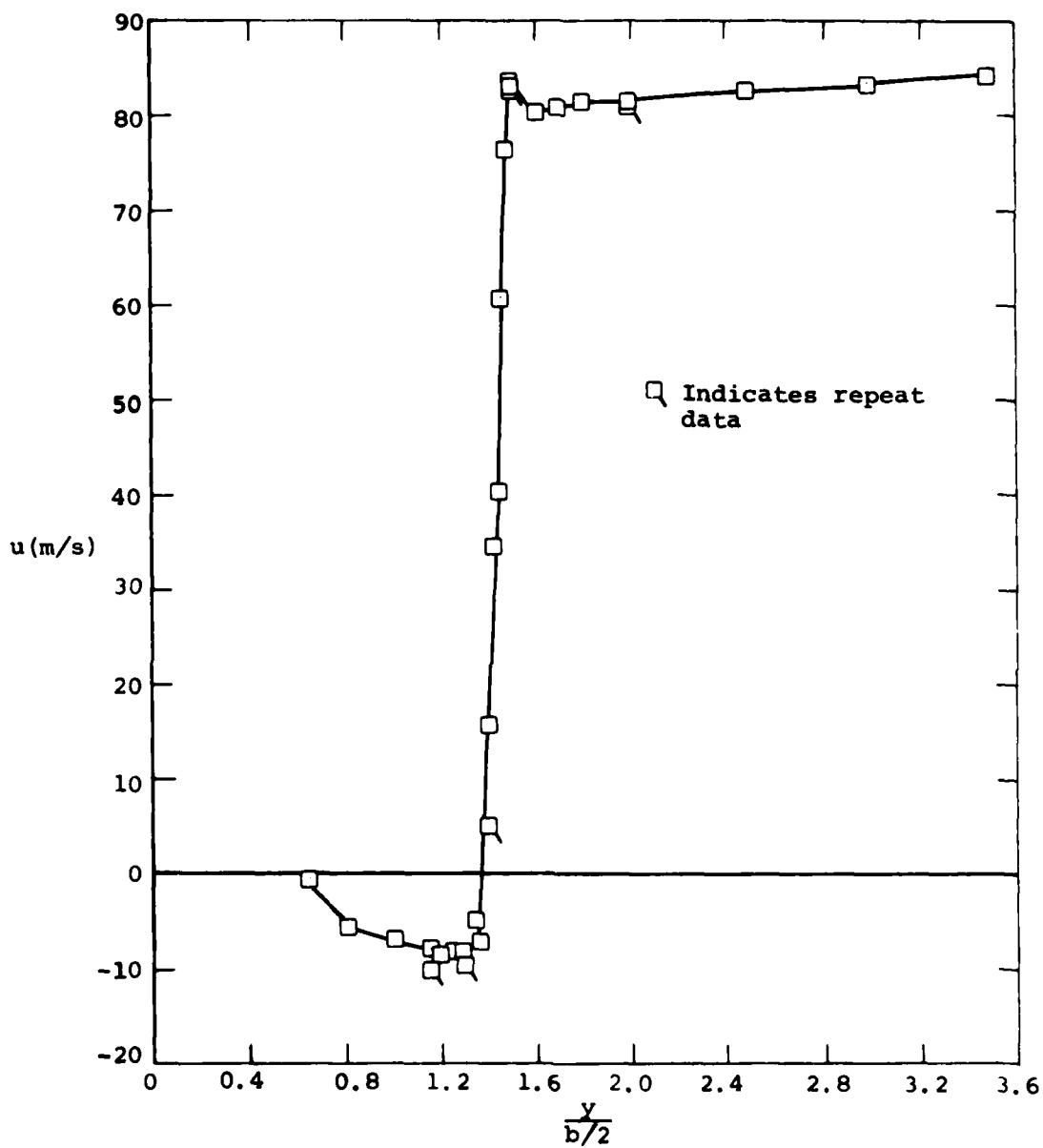
(d) Round edge model at  $M = 0.25$  and  $Re = 0.25 \times 10^6$  (points 609-1093).

Figure 15.- Continued.



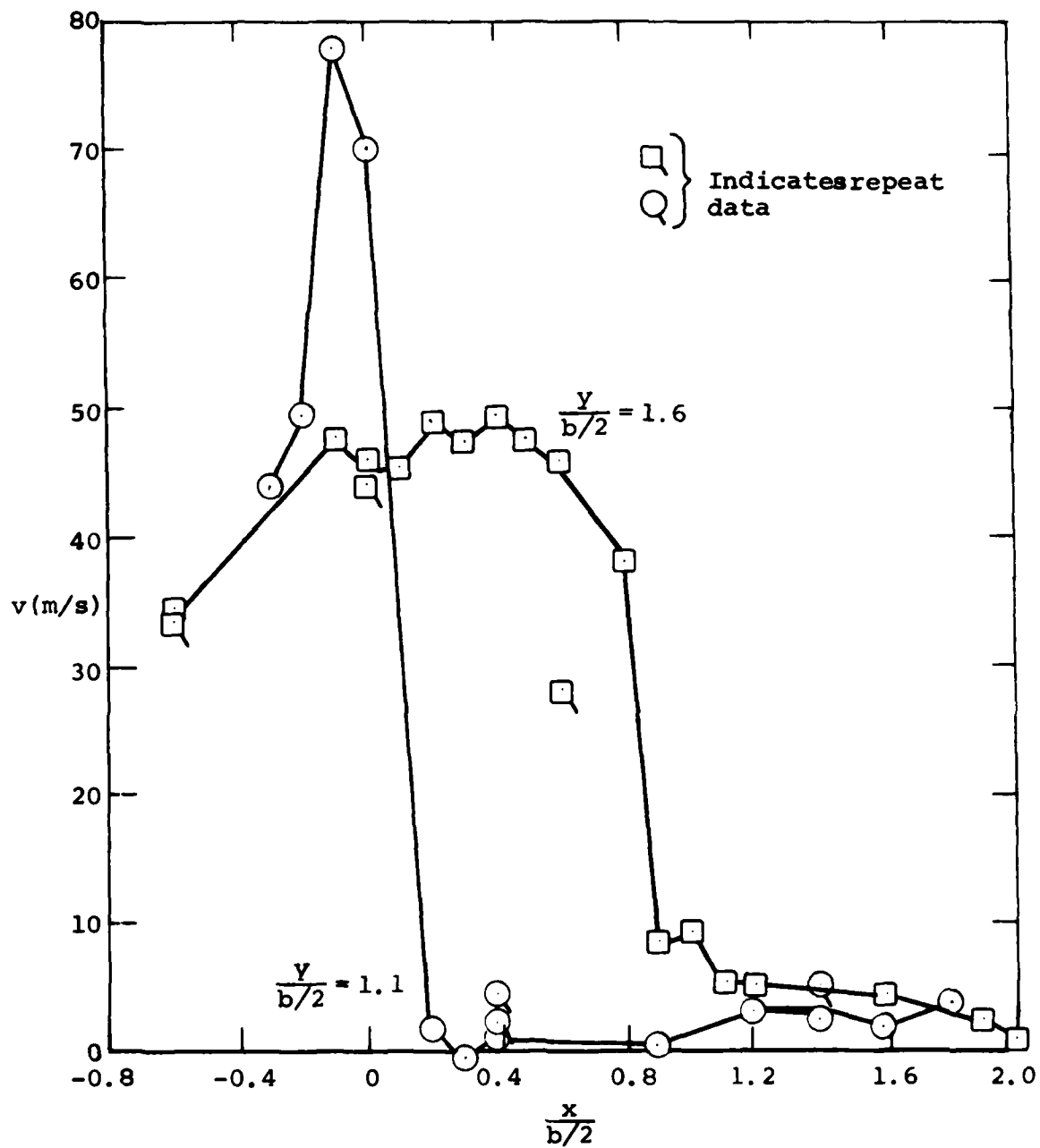
(e) Round edge model at  $M=0.5$  and  $Re = 0.15 \times 10^6$  (points 1094-1211).

Figure 15.- Concluded.



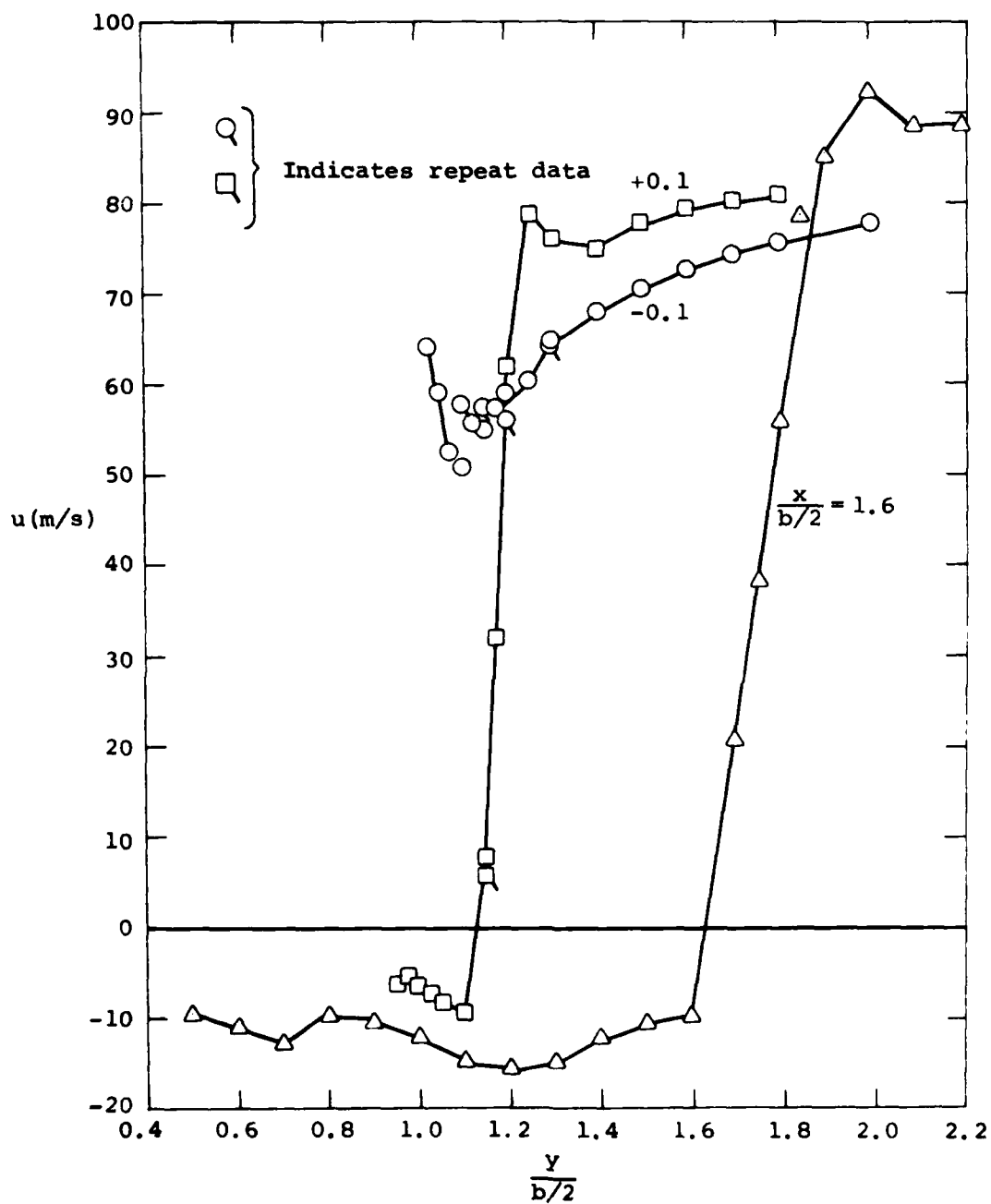
(a) Axial velocity variation with vertical position at  $\frac{x}{b/2} = 0.5$ .

Figure 16.- Measured velocities in the vicinity of the sharp edge model at  $M = 0.25$ ,  $Re = 0.25 \times 10^6$ .



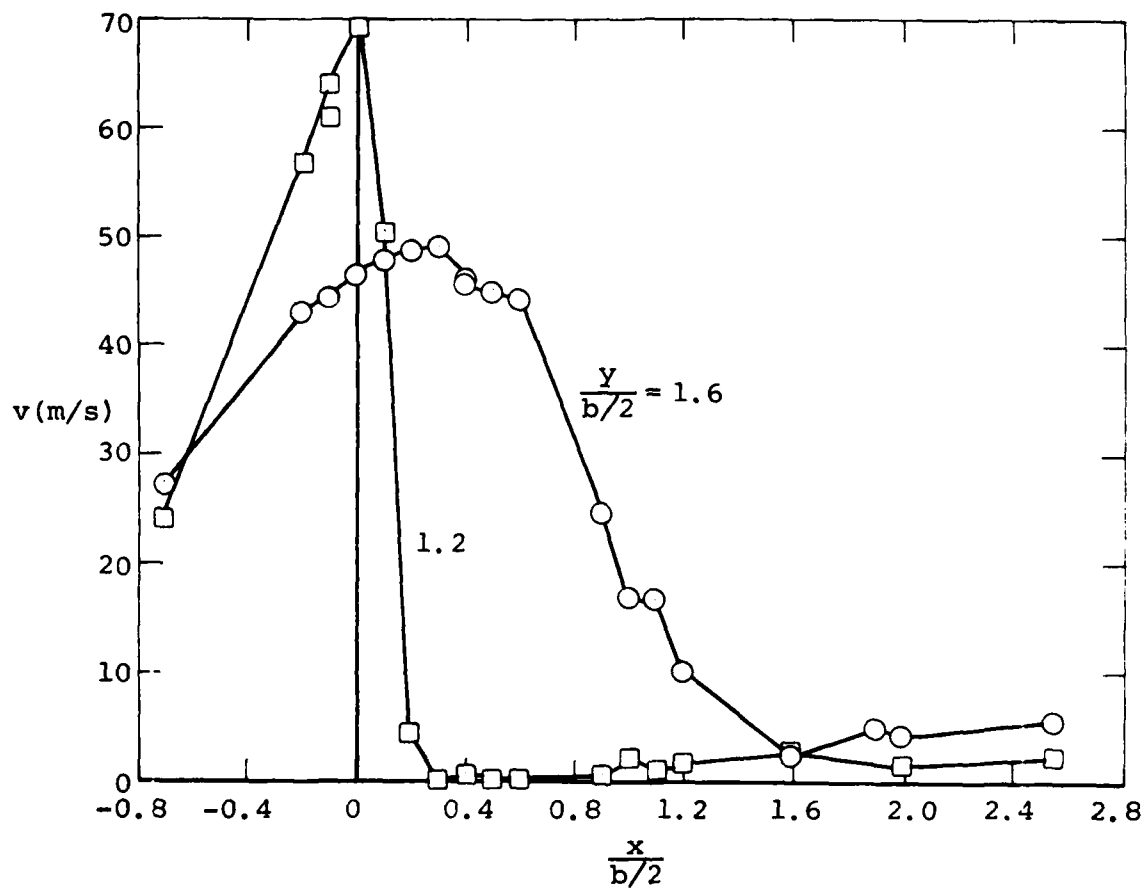
(b) Vertical velocity variation with axial position  
for  $\frac{y}{b/2} = 1.1$  and  $1.6$ .

Figure 16.- Concluded.



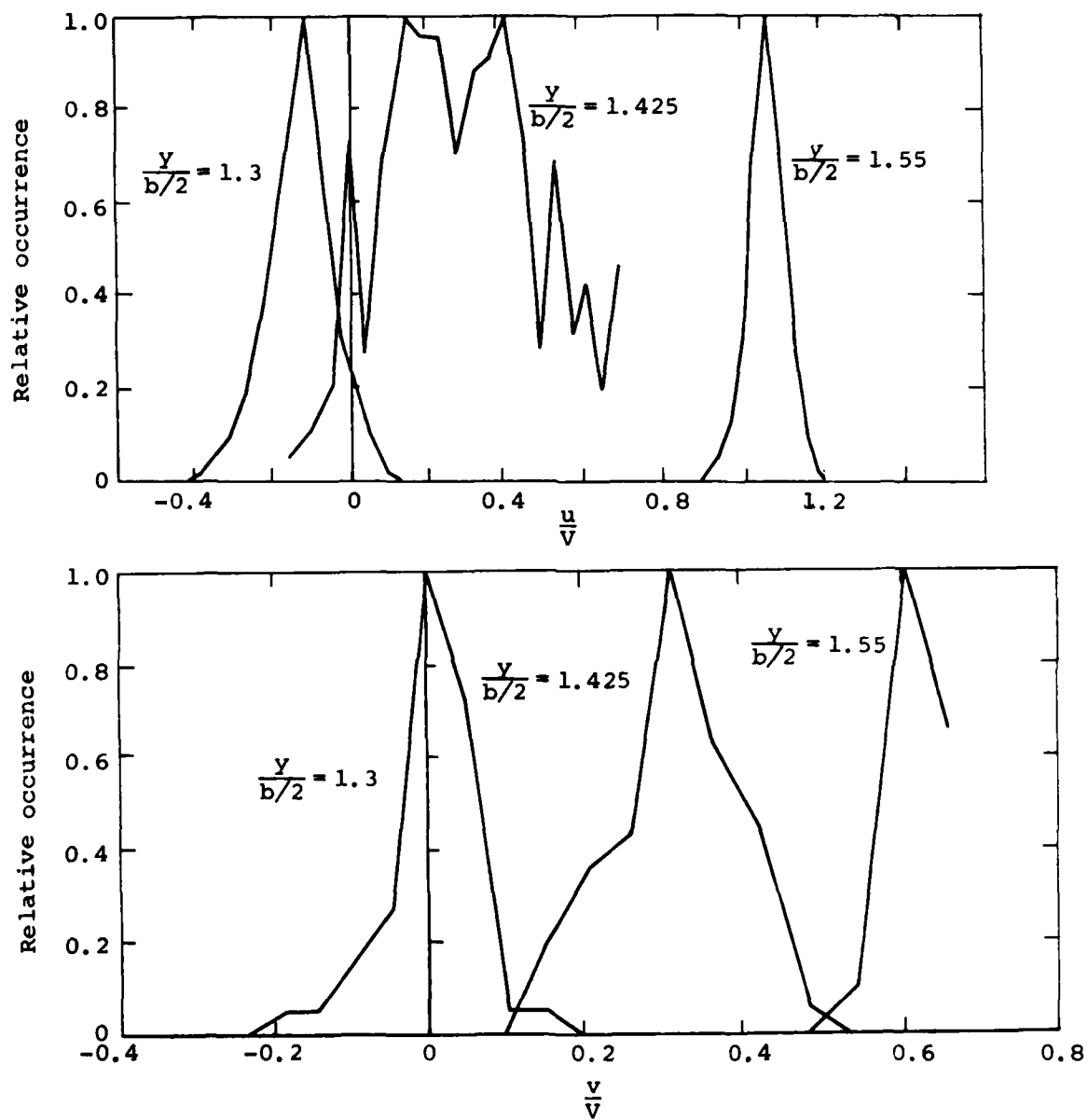
(a) Axial velocity variation with vertical position.

Figure 17.- Measured velocities in the vicinity of the round edge model at  $M = 0.25$  and  $Re = 0.25 \times 10^6$ .



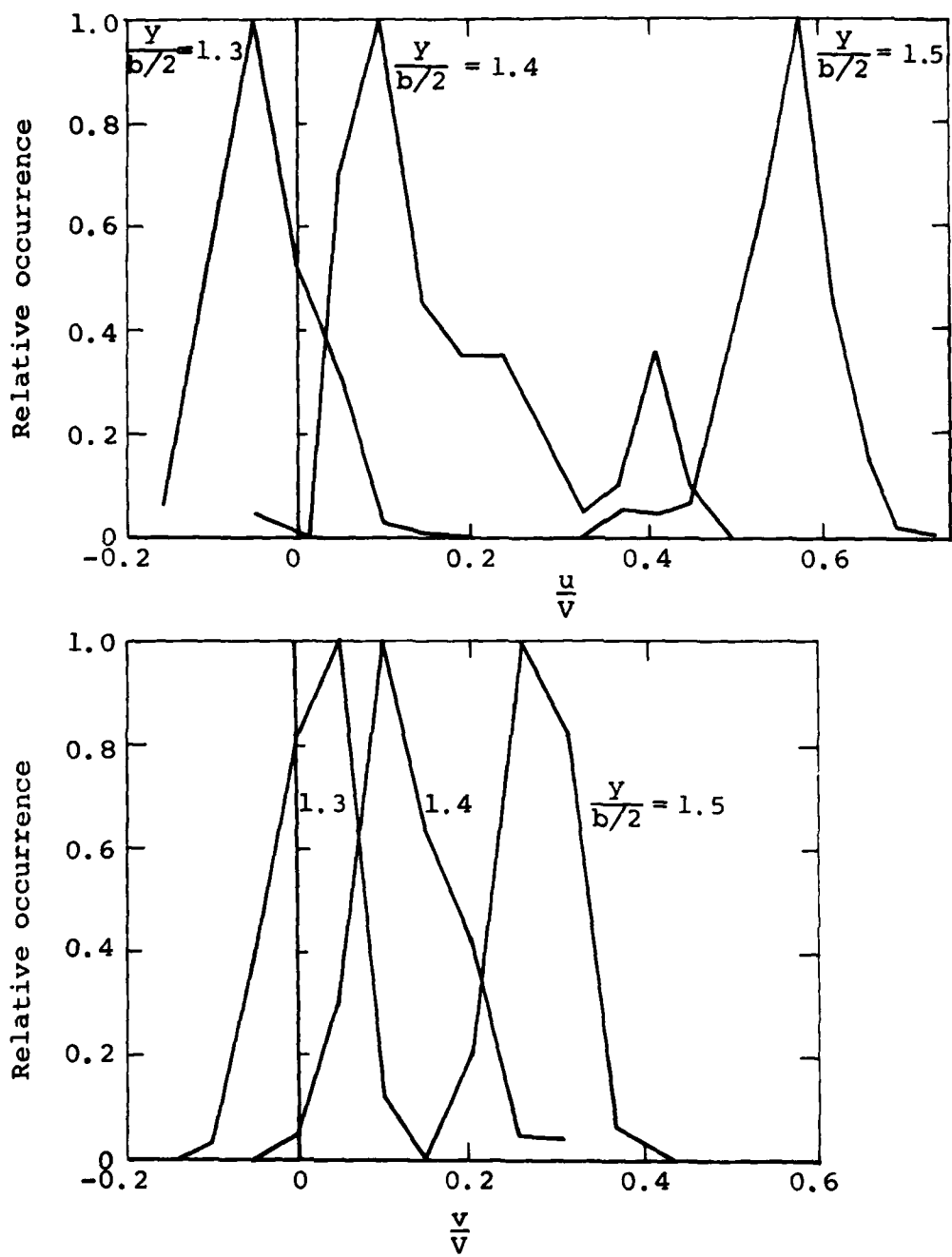
(b) Vertical velocity variation with axial position.

Figure 17.- Concluded.



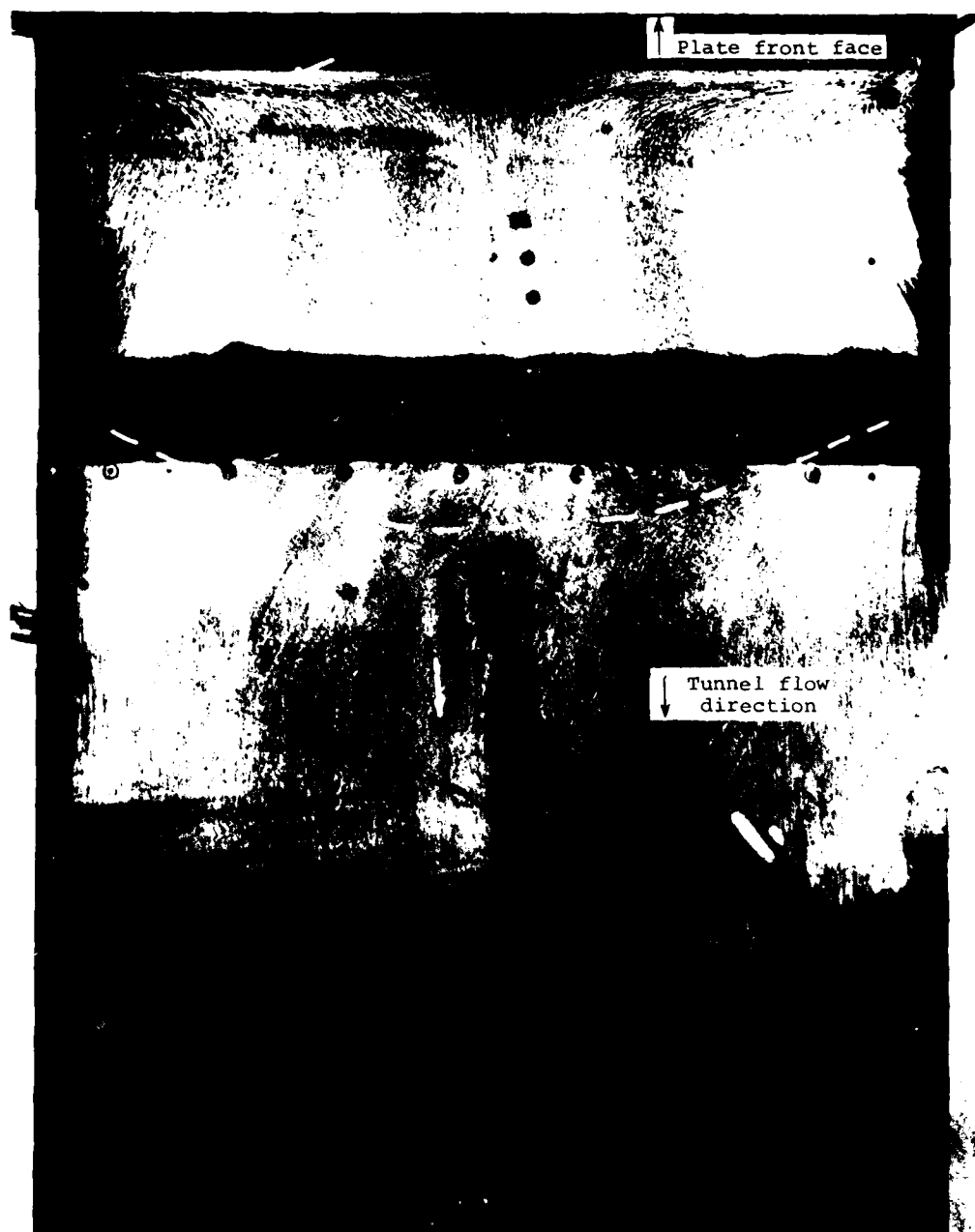
(a)  $M = 0.5$ ,  $Re = 0.15 \times 10^6$ , sharp edge model.

Figure 18.- Velocity histograms through shear layer at  $x/(b/2) = 0.5$

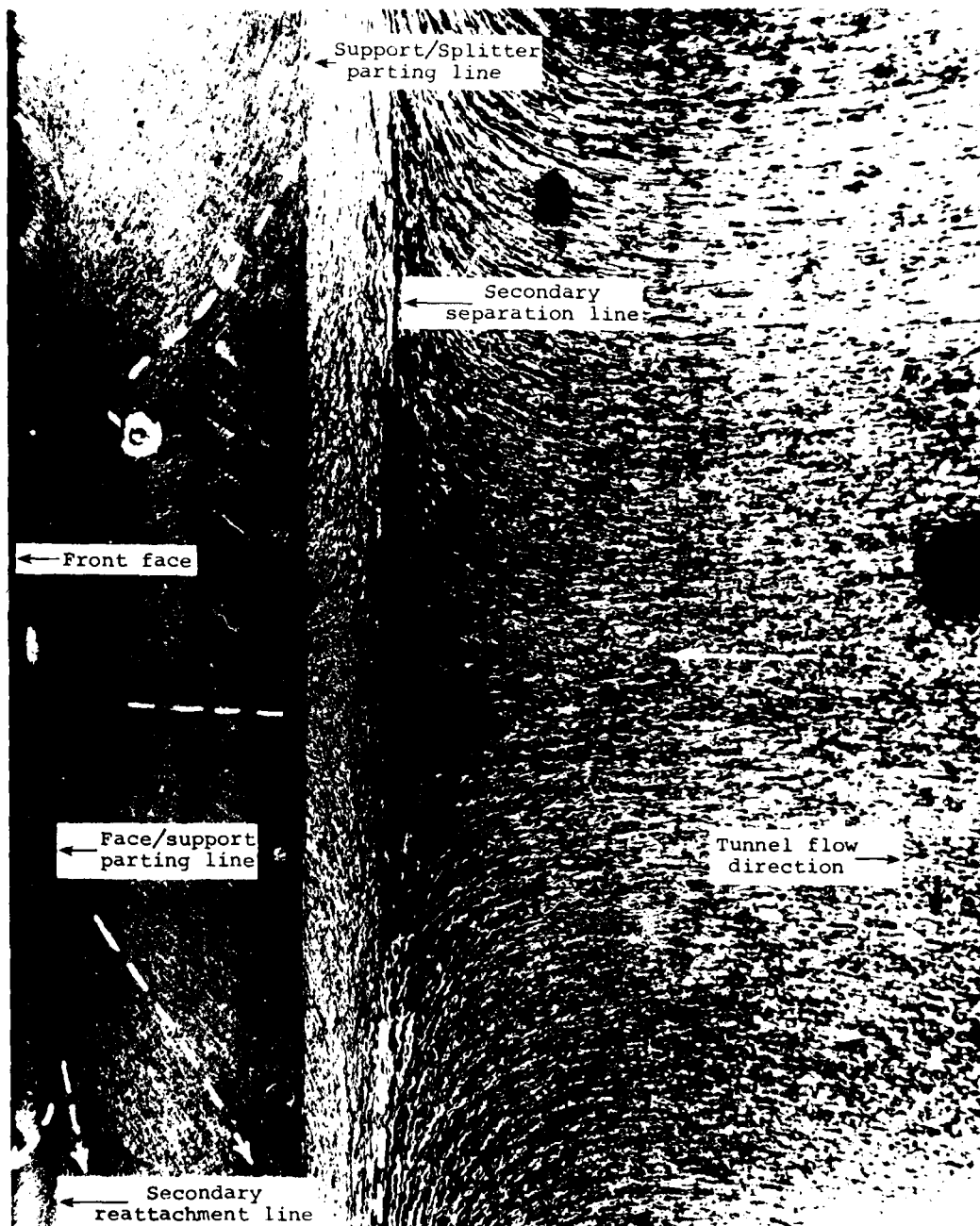


(b)  $M = 0.5$ ,  $Re = 0.15 \times 10^6$ , round edge.

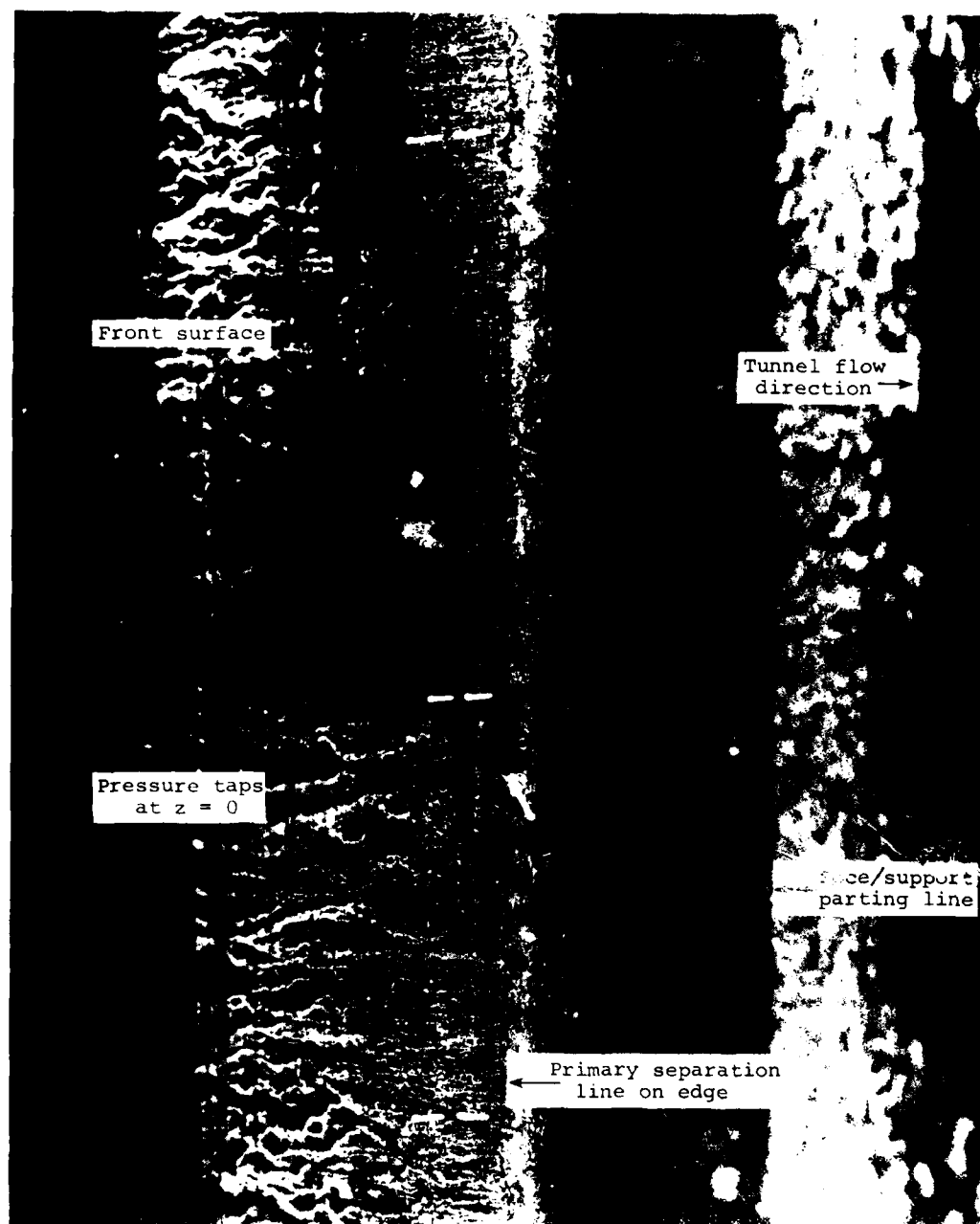
Figure 18. - Concluded.



(a) Overall view.  
Figure 19.- Flow visualization on round edge model.

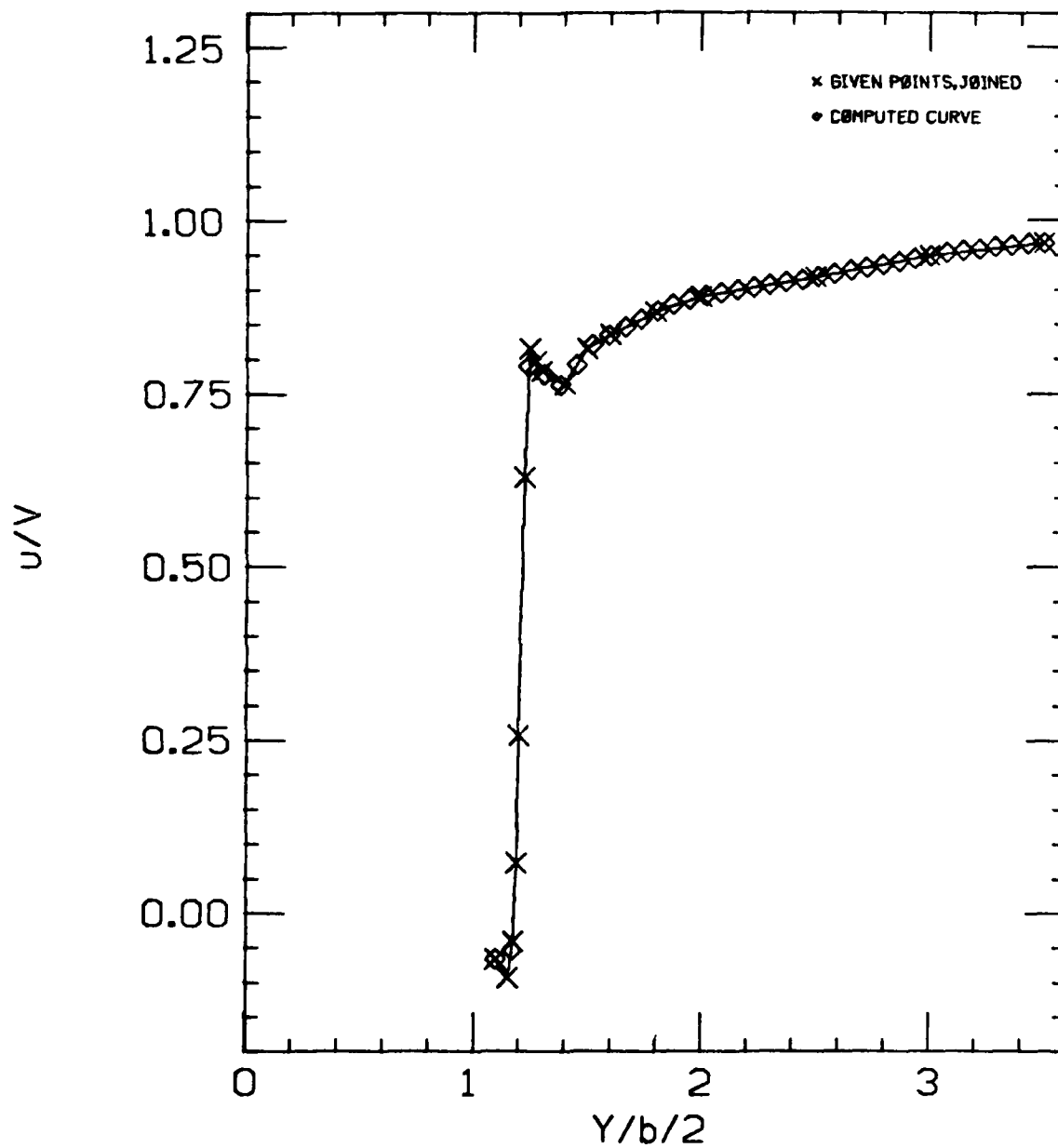


(b) Close up view of surface aft of the edge.  
Figure 19. - Continued.



(c) Close up view of front surface and edge.  
Figure 19.- Continued.

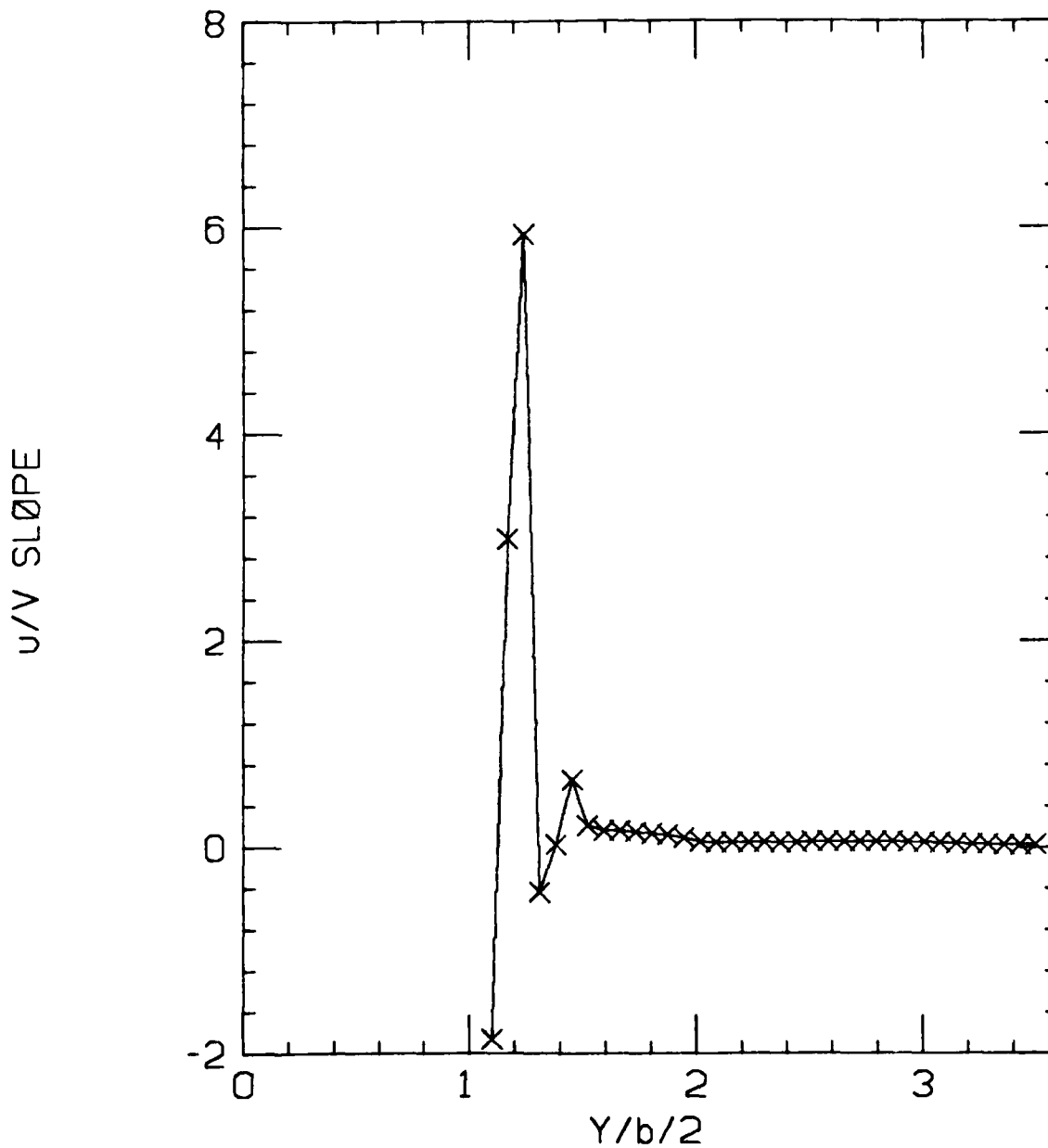
X=0.2 SHARP EDGE, MACH= 0.25, POINTS= 14-383



(a) Velocity.

Figure 20.- Spline fit to streamwise velocity component.

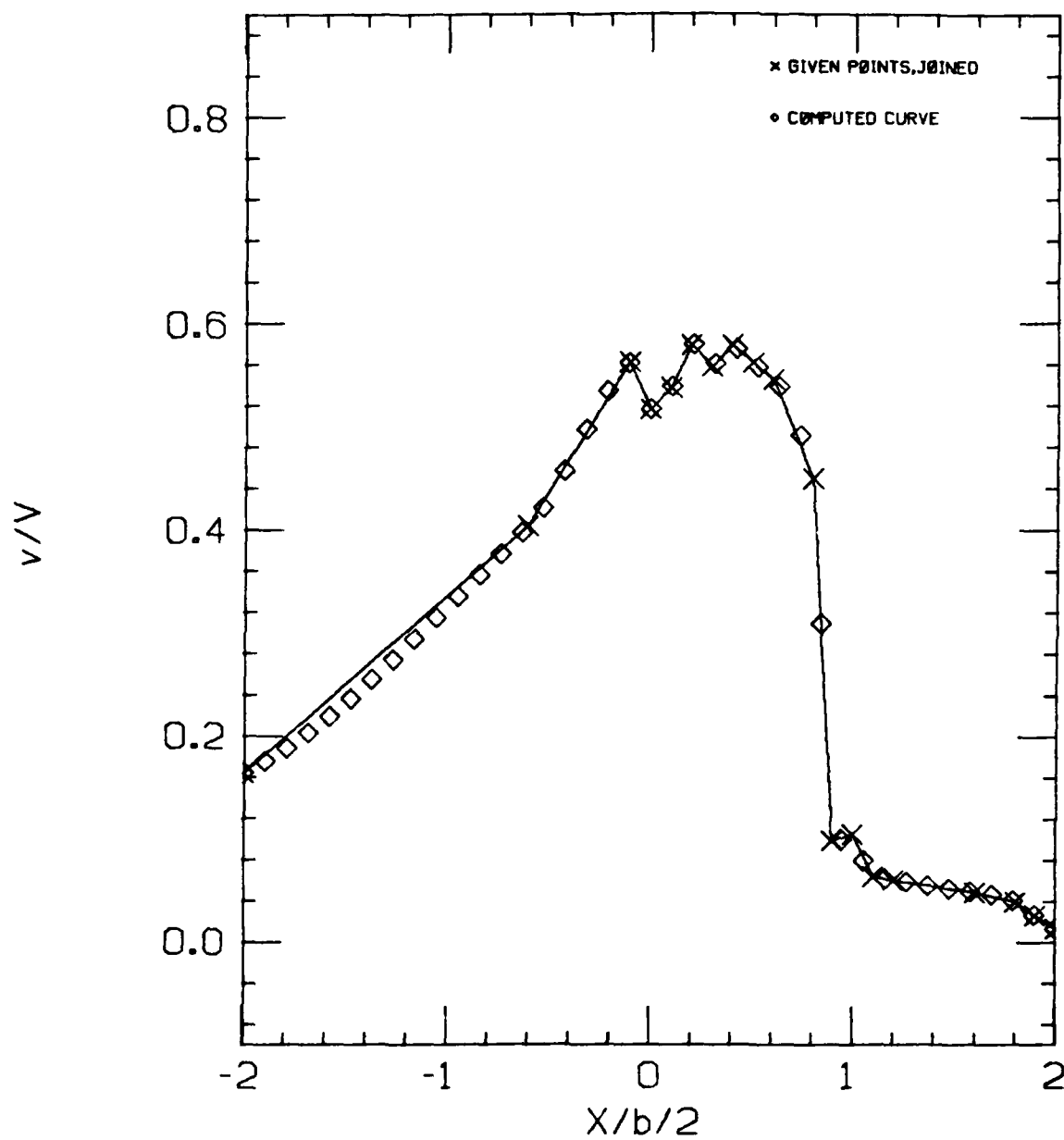
X=0.2 SHARP EDGE, MACH= 0.25, POINTS= 14-383



(b) Velocity derivative,  $\frac{\partial u}{\partial \frac{y}{b/2}}$

Figure 20.- Concluded.

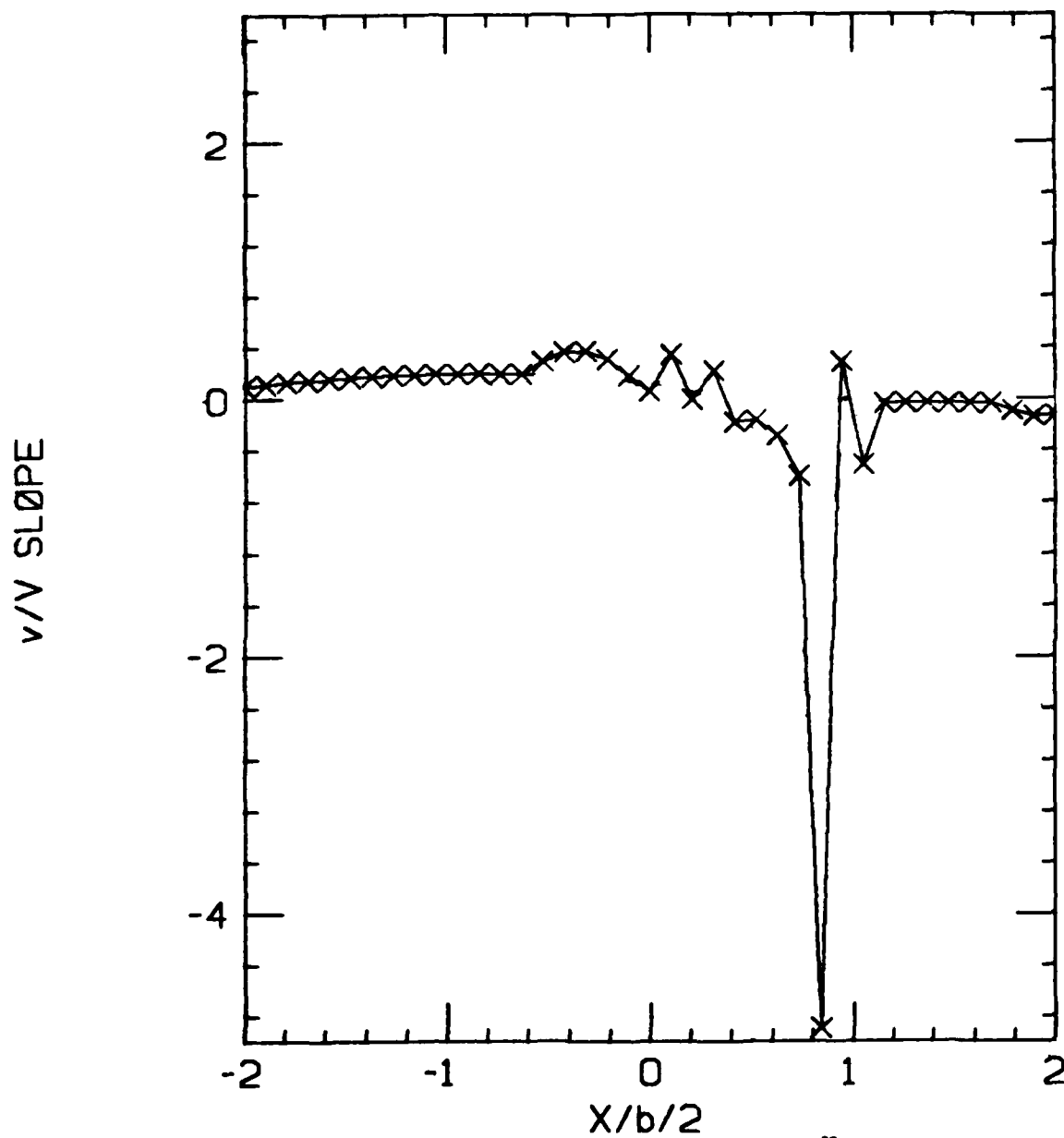
Y=1.6 SHARP EDGE, MACH= 0.25, POINTS= 14-383



(a) Velocity.

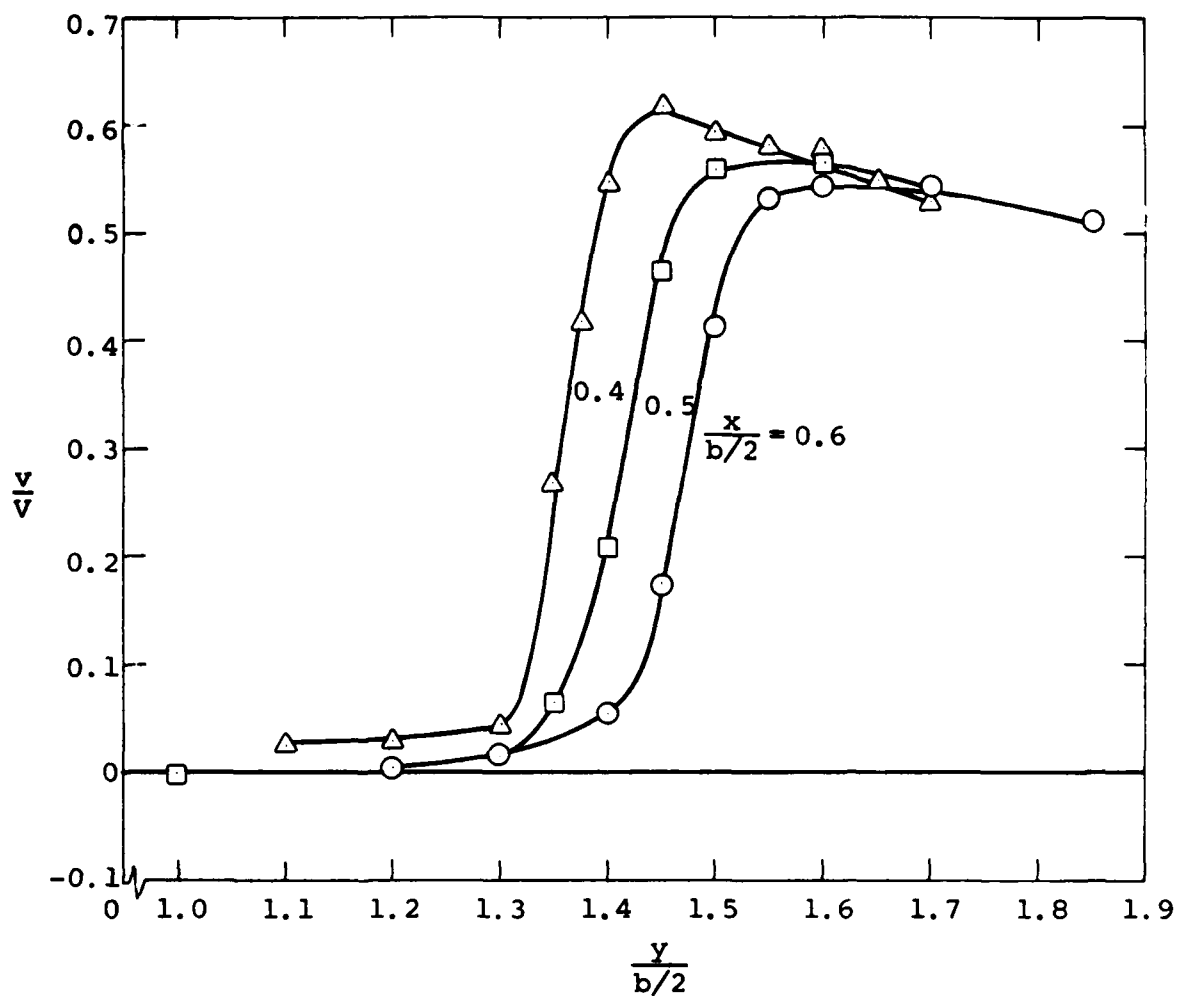
Figure 21.- Spline fit to vertical velocity component.

Y=1.6 SHARP EDGE, MACH= 0.25, POINTS= 14-383



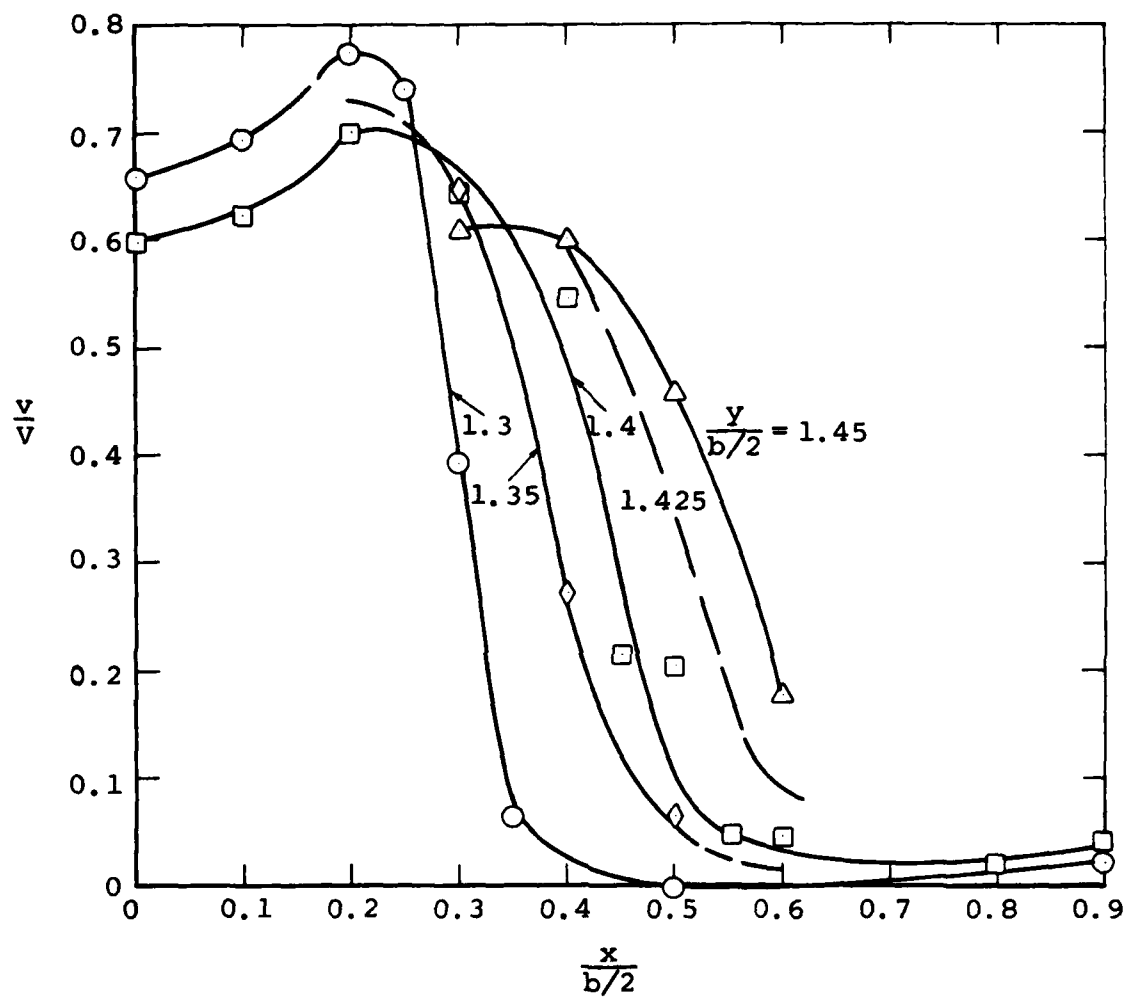
(b) Velocity derivative,  $\frac{\partial v}{\partial \frac{x}{b/2}}$

Figure 21.- Concluded.

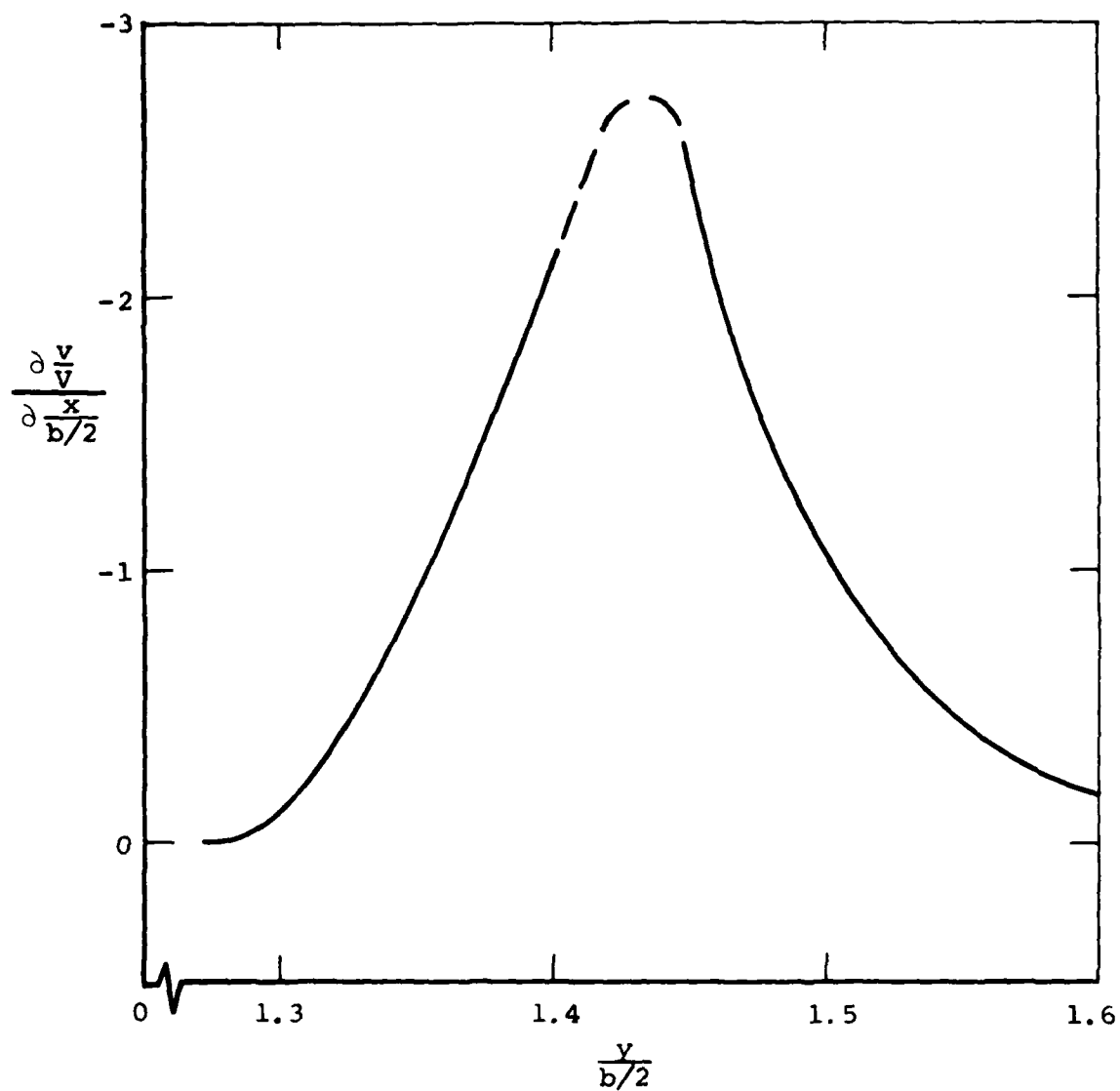


(a) Vertical velocity vs lateral position

Figure 22.- Vertical velocity derivative construction for sharp edge model,  $M = 0.25$ ,  $Re = 0.25 \times 10^6$ .

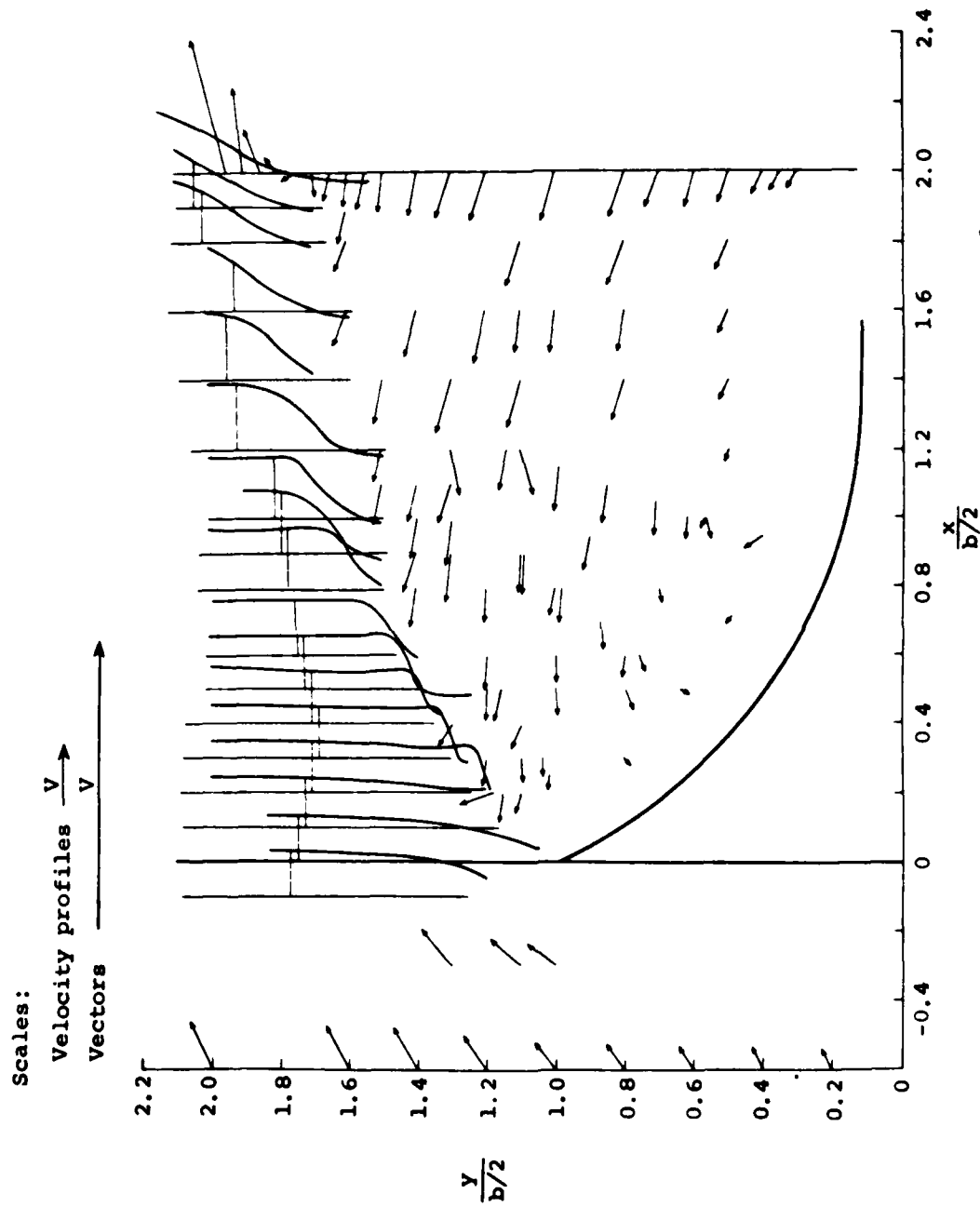


(b) Vertical velocity vs streamwise position  
Figure 22.- Continued.



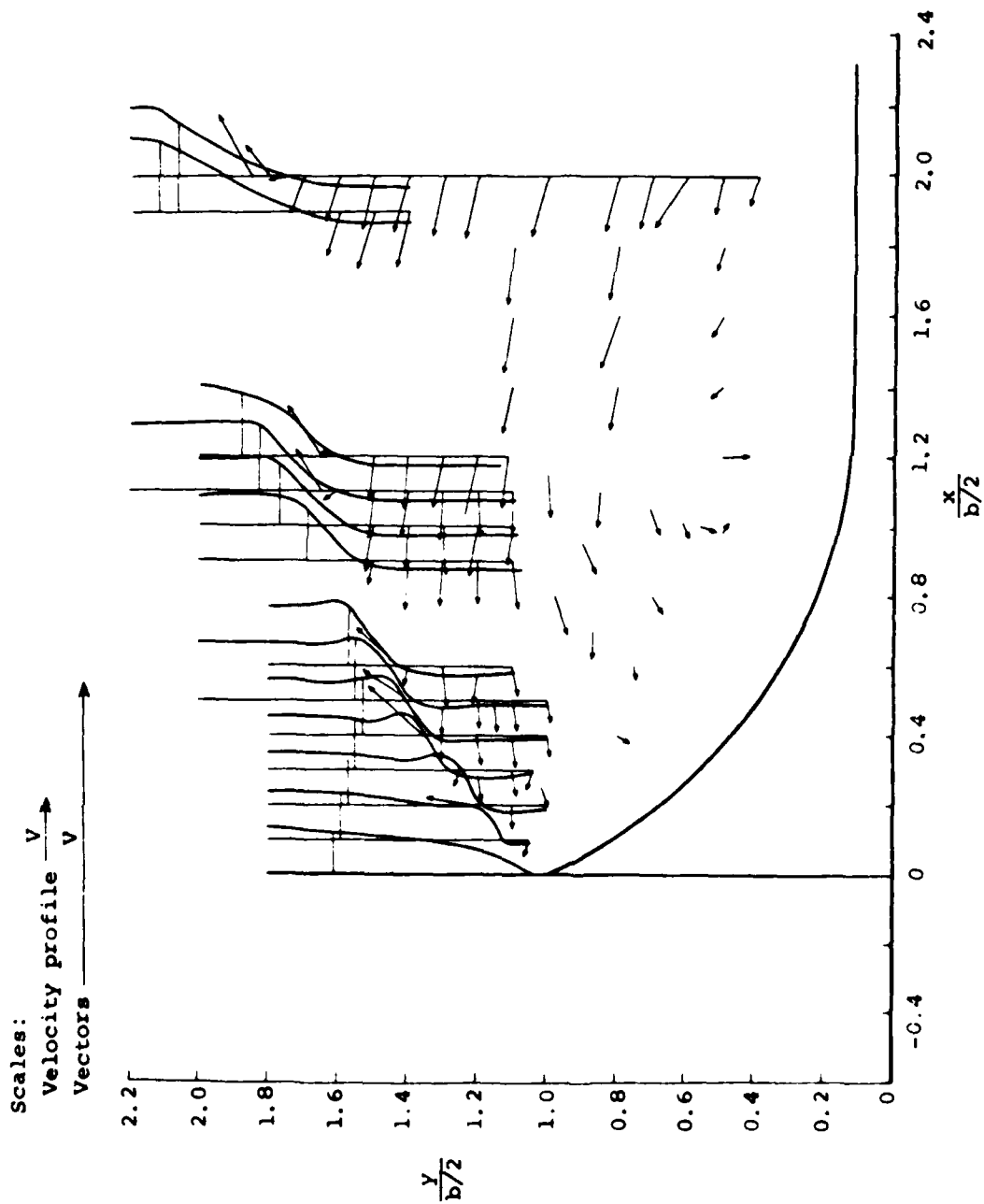
(c) Velocity derivative at  $\frac{x}{b/2} = 0.5$

Figure 22.- Concluded.

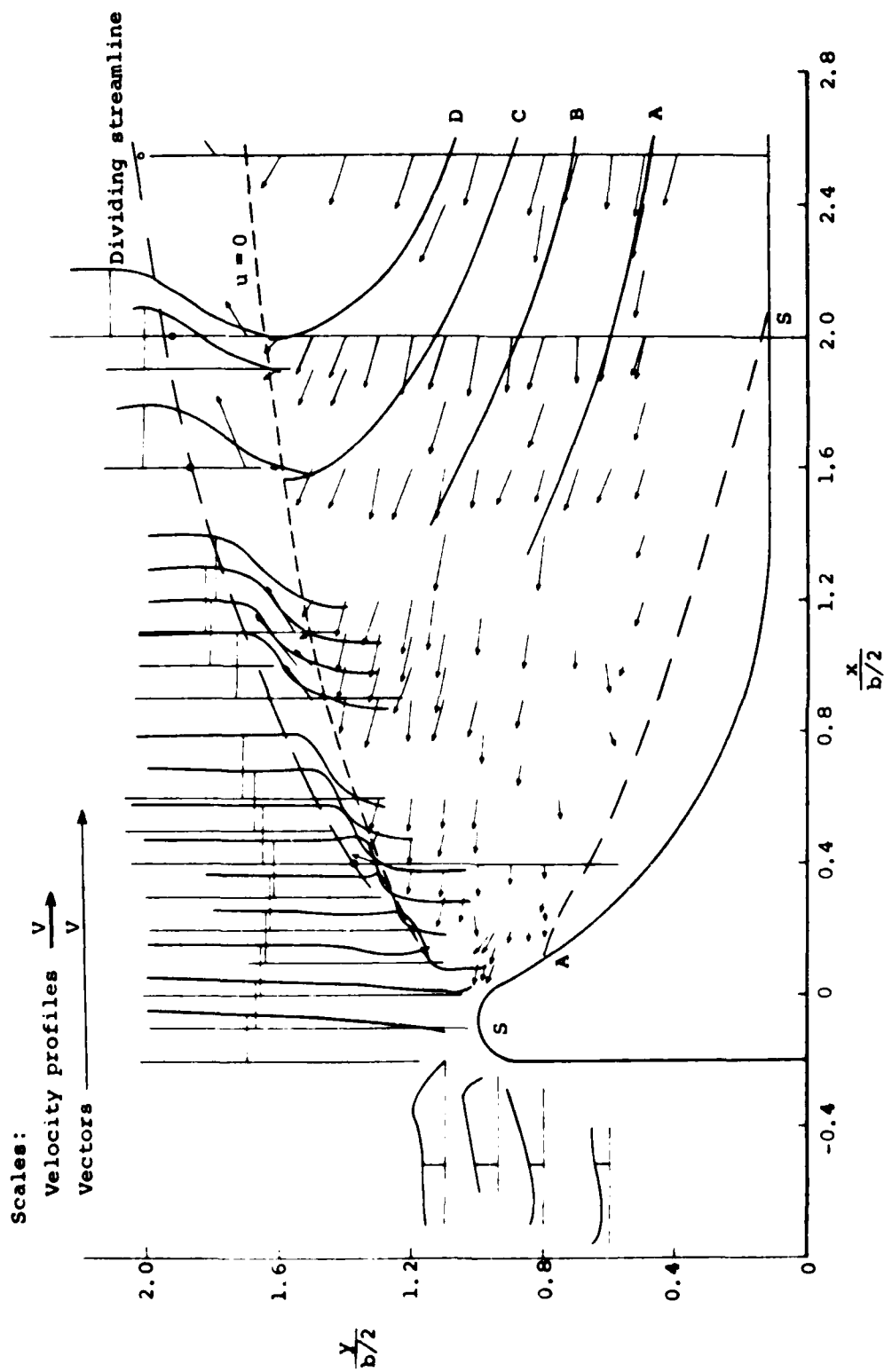


(a) Sharp edge model,  $M = 0.25$ ,  $Re = 0.25 \times 10^6$

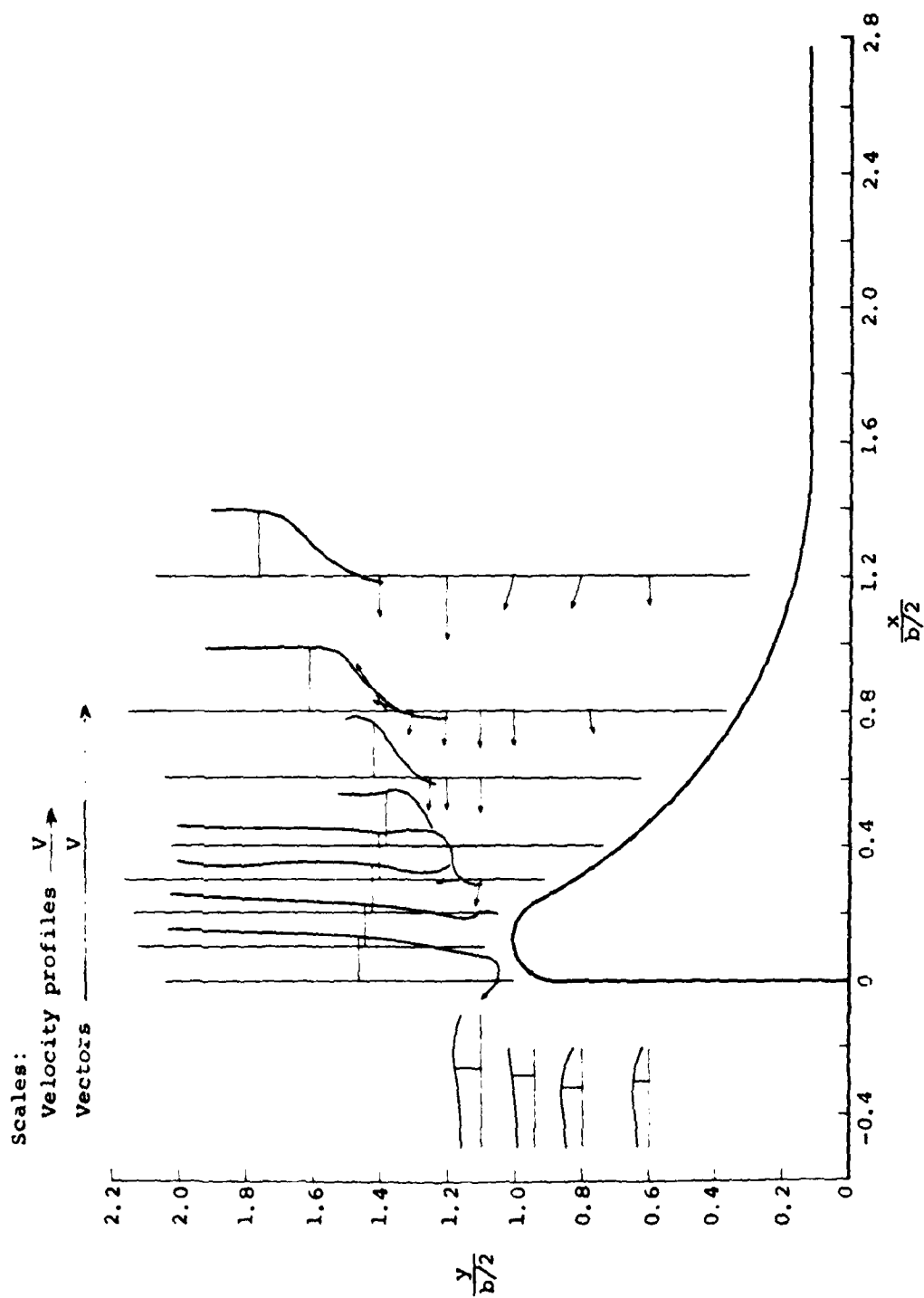
Figure 23.- Velocity profile and recirculation region velocity vector data.



(b) Sharp edge model,  $M = 0.5$ ,  $Re = 0.15 \times 10^6$   
 Figure 23.- Continued.



(c) Round edge model,  $M = 0.25$ ,  $Re = 0.25 \times 10^6$   
Figure 23.- Continued.



(d) Round edge model,  $M = 0.5$ ,  $Re = 0.15 \times 10^6$

Figure 23. - Concluded.

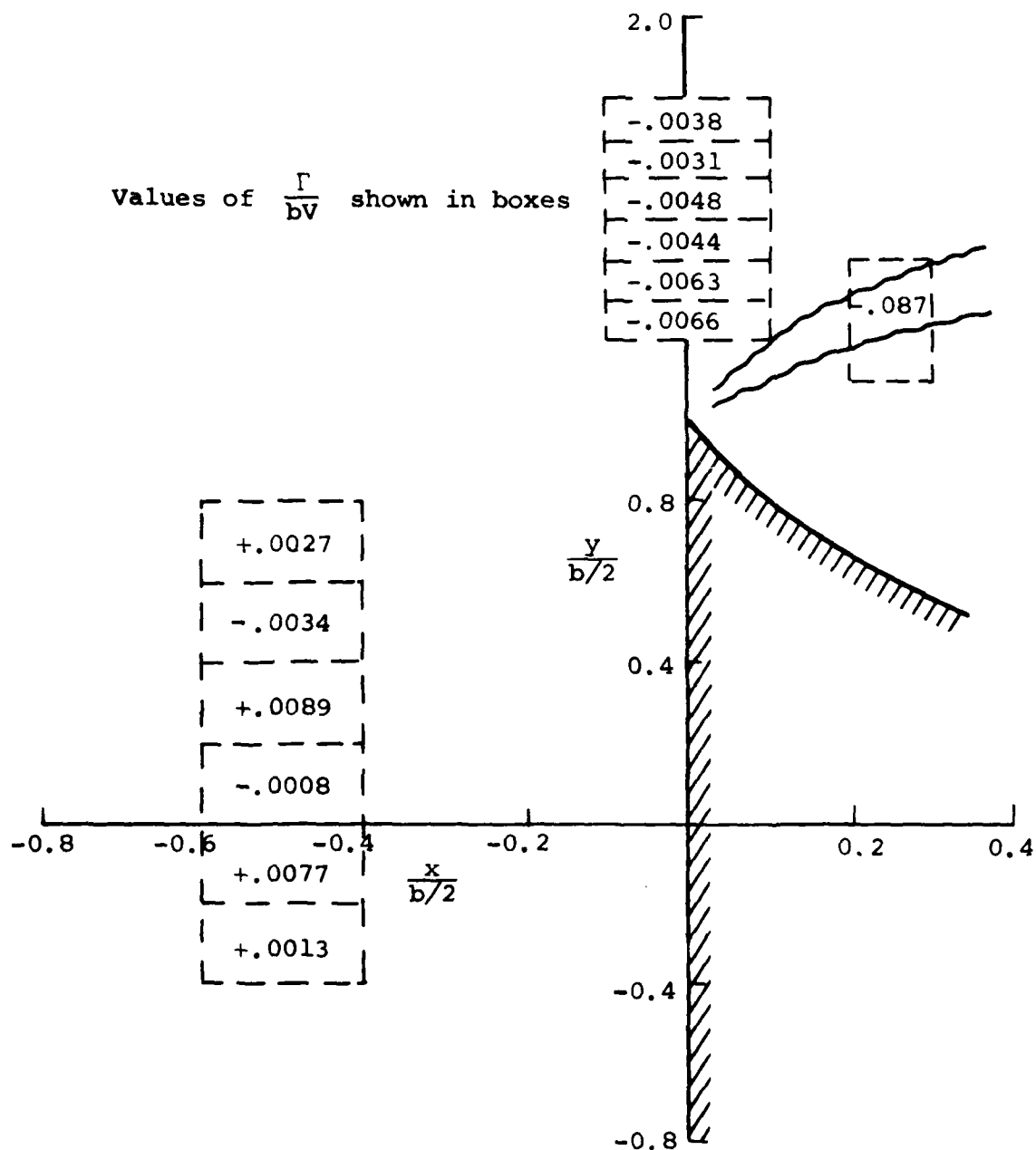


Figure 24.- Contour integration results in free stream;  
sharp edge model at  $M = 0.25$ .

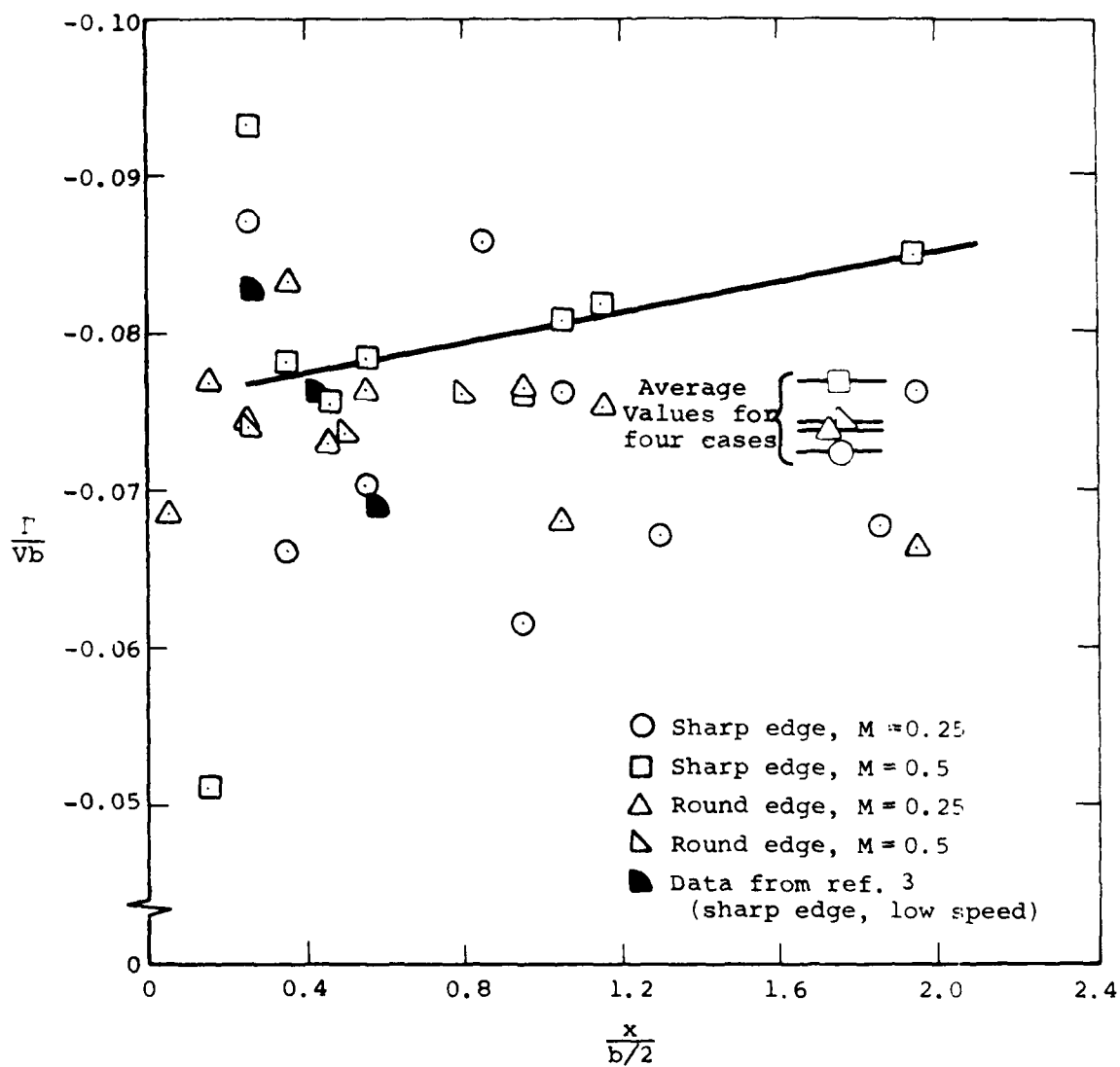
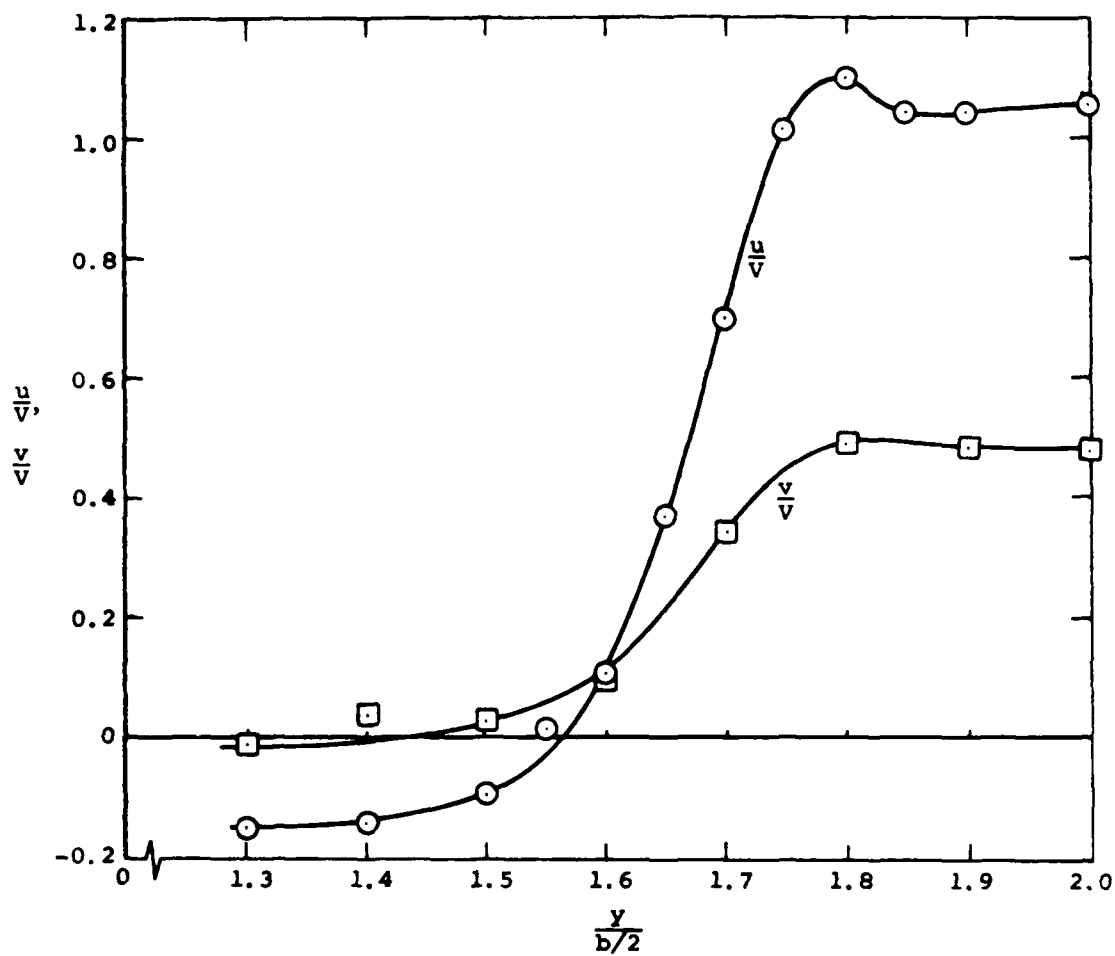
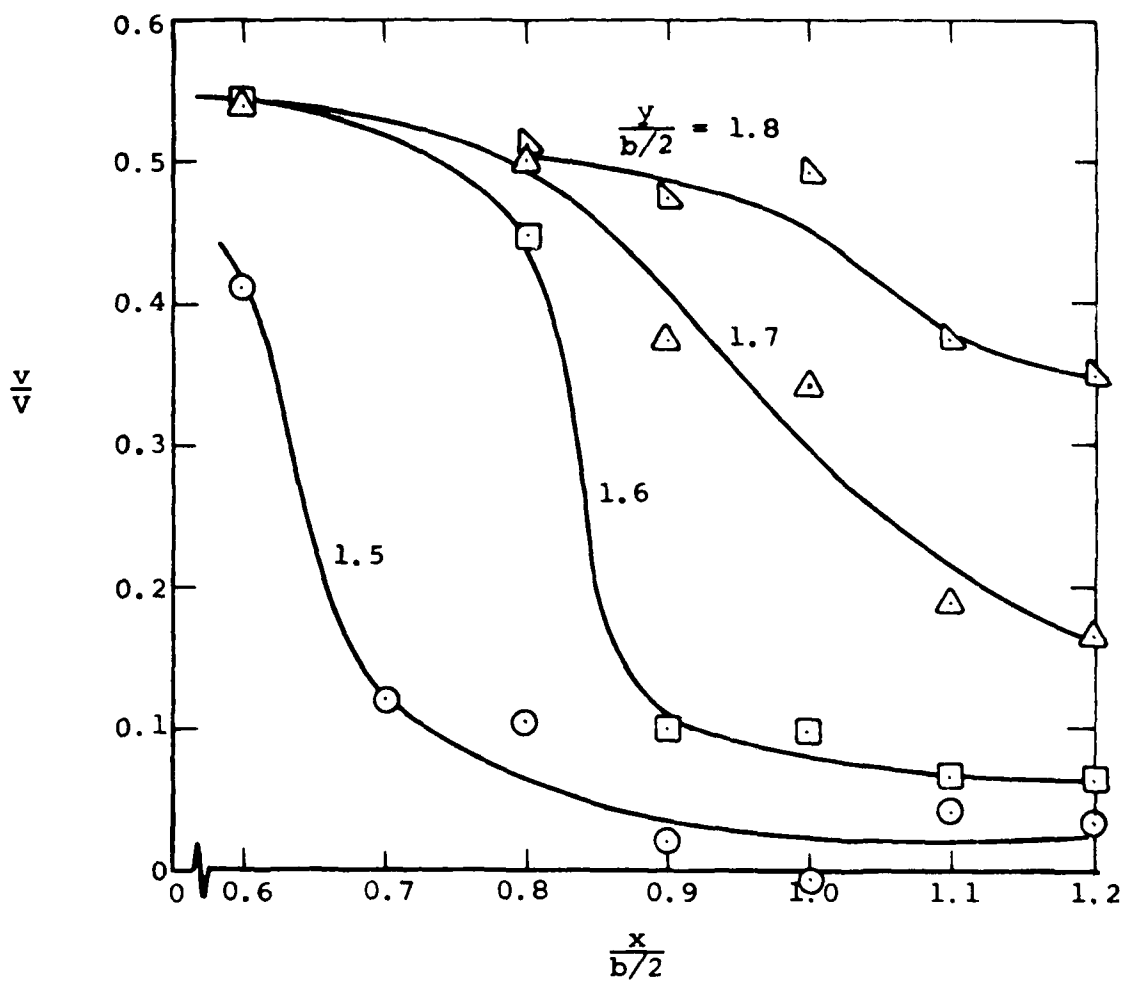


Figure 25.- Contour integration results for circulation.



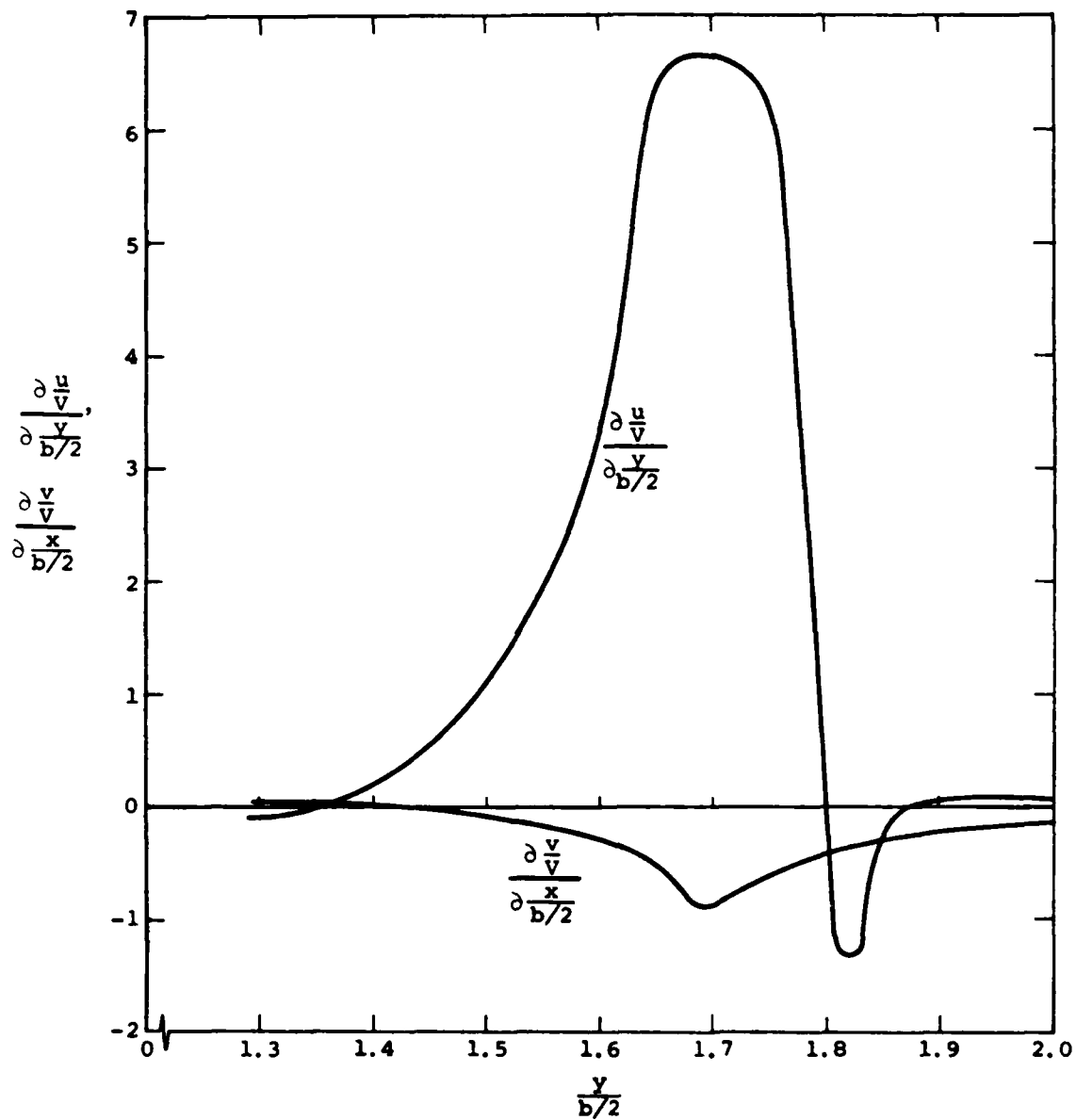
(a) Lateral variation of velocity

Figure 26. - Construction of vorticity distribution for sharp edge model at  $M = 0.25$  for  $x/(b/2) = 1.0$ .



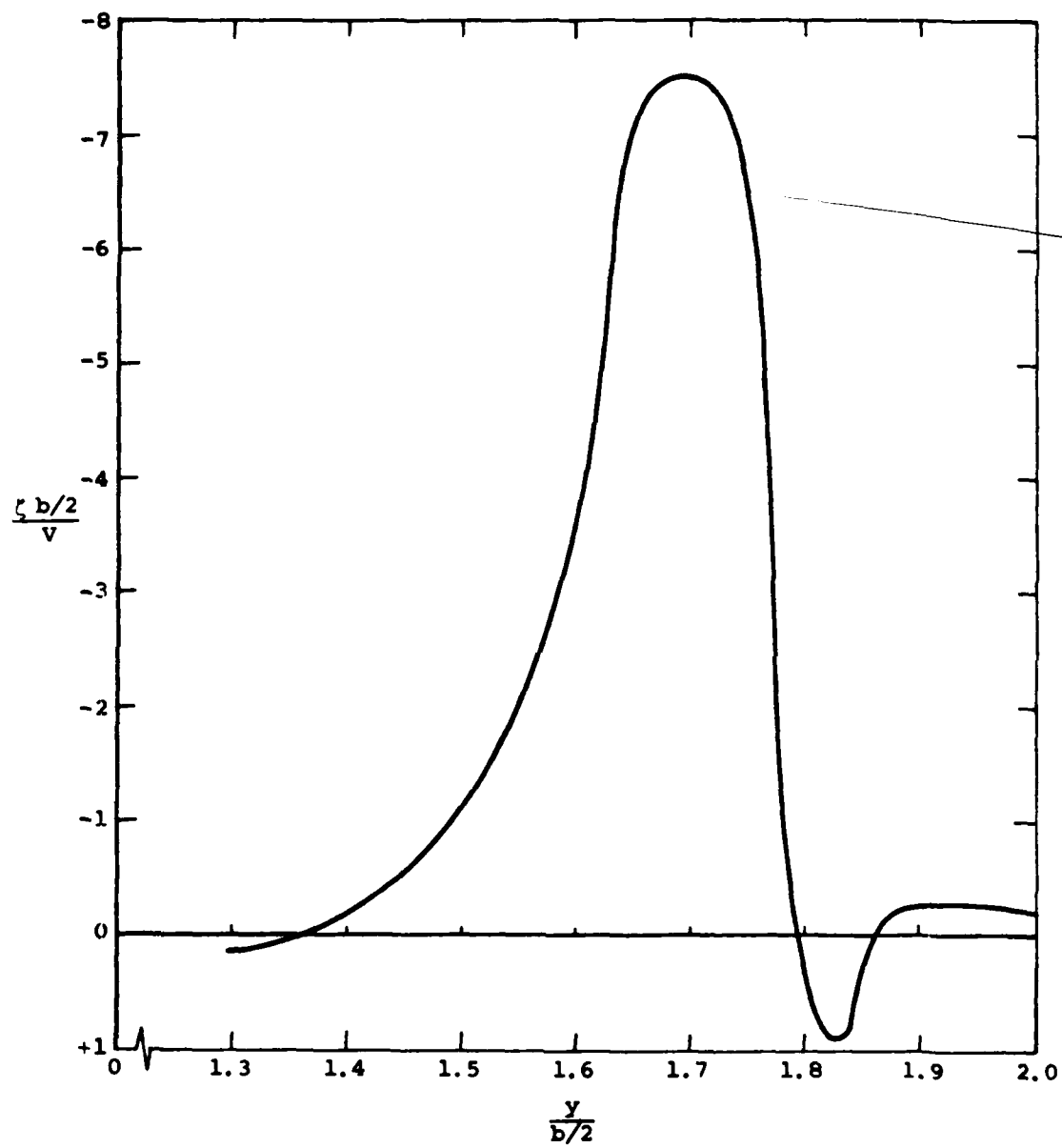
(b) Longitudinal variation of velocity

Figure 26.- Continued.

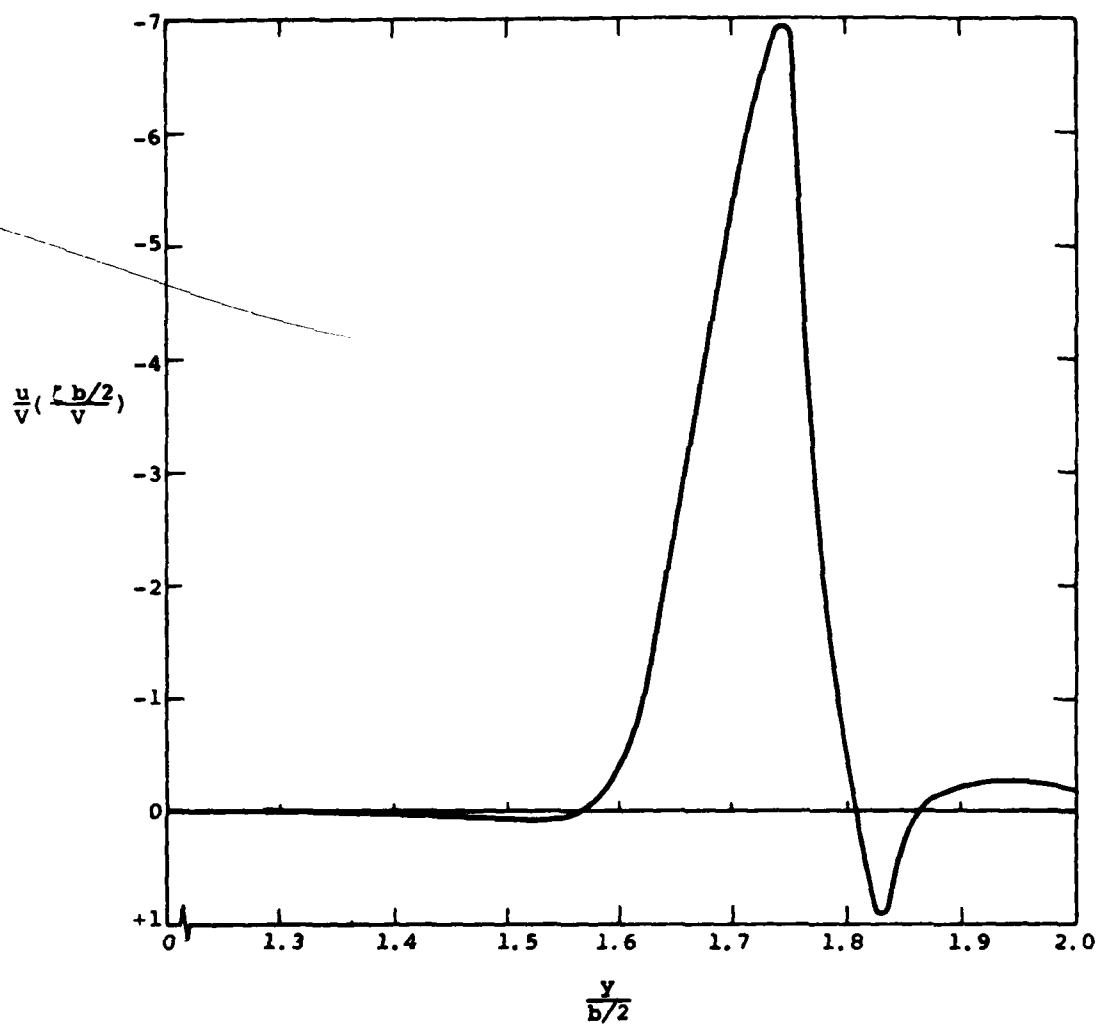


(c) Velocity derivatives

Figure 26.- Continued.



(d) Vorticity  
Figure 26.- Continued.



(a) Rate of transport of vorticity

Figure 26.- Concluded.

Non-flag symbols - Contour integration  
 Flag symbols - Average vorticity from  
 velocity derivatives

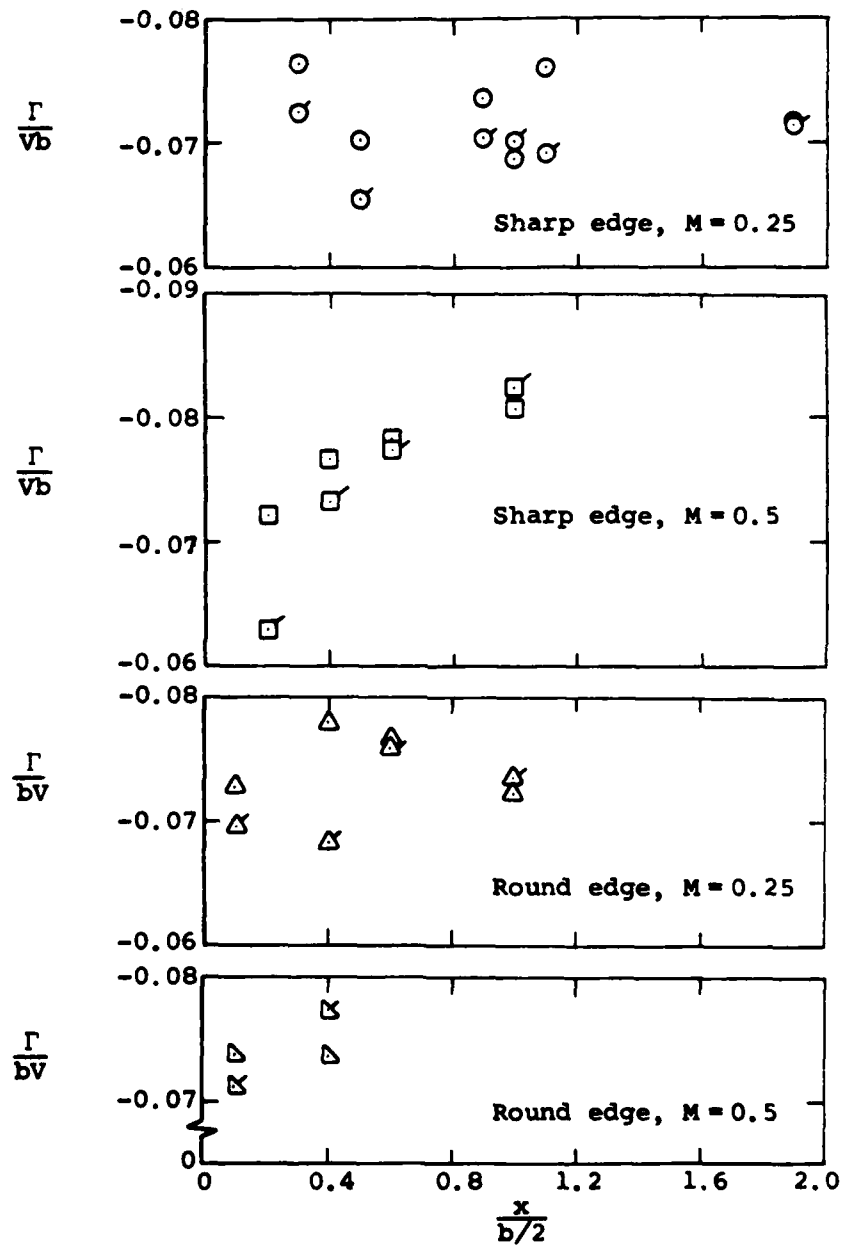


Figure 27.- Comparison of contour integration and velocity derivative results for circulation.

Flag symbols - Integrated vorticity from  
velocity derivatives

Non-flag symbols - Thin shear layer  
approximation

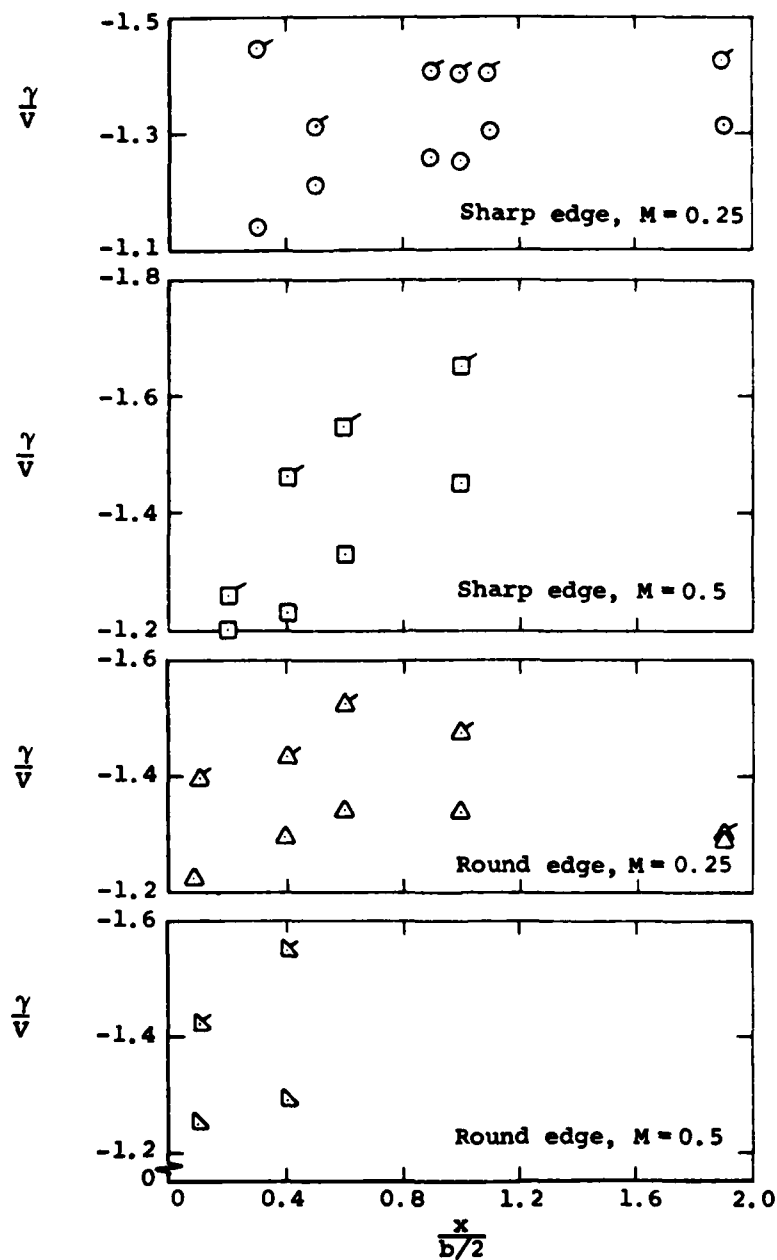


Figure 28.- Comparison of velocity derivative and thin shear layer approximation for total shear layer vorticity.

Flag symbols - Velocity derivative results  
 Non-flag symbols - Thin shear layer approximation

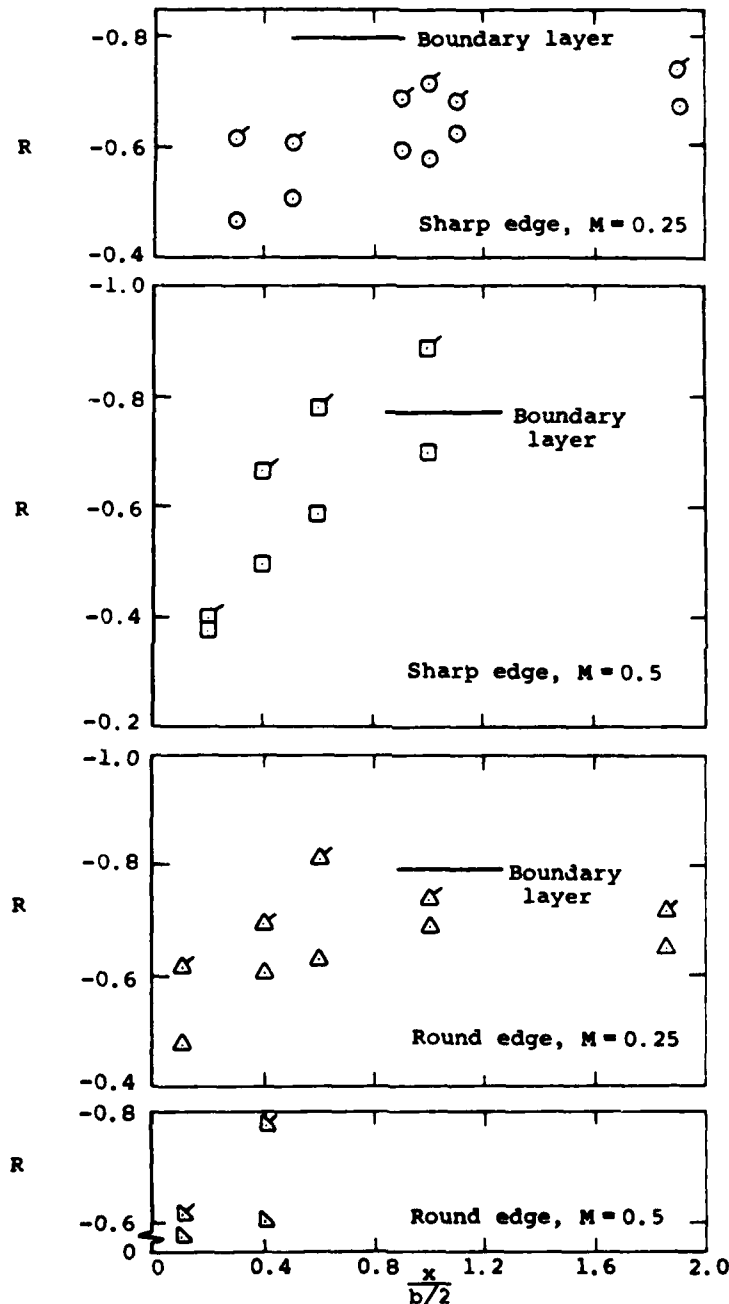


Figure 29.- Comparison of velocity derivative and thin layer approximation results for vorticity transport rate.

# LIST OF SYMBOLS

|                        |                                                                                                      |
|------------------------|------------------------------------------------------------------------------------------------------|
| $b$                    | width of model face                                                                                  |
| $C_p$                  | pressure coefficient, $(p - p_\infty)/q$                                                             |
| $f$                    | frequency                                                                                            |
| $\vec{n}$              | unit vector normal to the contour element                                                            |
| $N$                    | the number of readings by the laser velocimeter of velocity components at a given location           |
| $p$                    | static pressure                                                                                      |
| $p_\infty$             | free-stream static pressure                                                                          |
| $q$                    | free-stream dynamic pressure, $1/2\rho V^2$                                                          |
| $R$                    | rate of transport vorticity, Eq. (16)                                                                |
| $Re$                   | Reynolds number, based on $V$ and $b/2$                                                              |
| $s$                    | length along a contour                                                                               |
| $St$                   | Strouhal number, $fb/V$                                                                              |
| $u_\delta$             | velocity at edge of the boundary layer                                                               |
| $u, v$                 | velocity components in the $x$ and $y$ directions, respectively                                      |
| $u_i, v_i$             | the $i^{th}$ reading by the laser velocimeter of velocity components at a given location in the flow |
| $\bar{u}^2, \bar{v}^2$ | the mean square values of the turbulence intensity, Eqs. (3), (4)                                    |
| $V$                    | free stream velocity                                                                                 |
| $V_s$                  | velocity at point in flow, $\sqrt{u^2 + v^2}$                                                        |
| $\Gamma$               | circulation                                                                                          |
| $\rho$                 | free-stream density                                                                                  |
| $\zeta$                | vorticity, defined in Eq. 13                                                                         |
| $(\vec{\phantom{x}})$  | indicates vector quantity                                                                            |

DISTRIBUTION LIST

Technical Library  
Building 313  
Ballistic Research Laboratories  
Aberdeen Proving Ground, MD 21005

Mr. Aviars Celmins  
Ballistic Research Laboratory  
Ballistic Modelling Division  
Aberdeen Proving Ground, MD 21005

Dr. P. J. Roache  
Ecodynamics Research Associates, Inc.  
P. O. Box 8172  
Albuquerque, NM 87108

Defense Technical Information Center  
Cameron Station, Building 5  
Alexandria, VA 22314 (12)

Library  
Naval Academy  
Annapolis, MD 21402

Director, Tactical Technology Office  
Defense Advanced Research Projects  
Agency  
1400 Wilson Blvd.  
Arlington, VA 22209

Code 200B  
Office of Naval Research  
800 N. Quincy Street  
Arlington, VA 22217

Code 438  
Office of Naval Research  
800 N. Quincy Street  
Arlington, VA 22217 (2)

Dr. J. L. Potter  
Deputy Director, Technology  
von Karman Gas Dynamics Facility  
Arnold Air Force Station, TN 37389

Professor J. C. Wu  
School of Aerospace Engineering  
Georgia Institute of Technology  
Atlanta, GA 30332

Library  
Aerojet-General Corporation  
6352 North Irwindale Avenue  
Azusa, CA 91702

NASA Scientific and Technical  
Information Facility  
P. O. Box 8757  
Baltimore/Washington International  
Airport, MD 21240

Dr. K. C. Wang  
College of Engineering  
San Diego State University  
San Diego, CA 92182

Professor A. J. Chorin  
Department of Mathematics  
University of California  
Berkeley, CA 94720

Professor M. Holt  
Department of Mechanical Engineering  
University of California  
Berkeley, CA 94720

Dr. H. R. Chaplin  
Code 1600  
David W. Taylor Naval Ship Research  
and Development Center  
Bethesda, MD 20084

Dr. Hans Lugt  
Code 1802  
David W. Taylor Naval Ship Research  
and Development Center  
Bethesda, MD 20084

Dr. Francois Frenkiel  
Code 1802  
David W. Taylor Naval Ship Research  
and Development Center  
Bethesda, MD 20084

Dr. T. C. Tai  
Code 1606  
David W. Taylor Naval Ship Research  
and Development Center  
Bethesda, MD 20084

DISTRIBUTION LIST (Continued)

Dr. G. R. Inger  
Dept. of Aerospace Engineering  
Virginia Polytechnic Institute and  
State University  
Blacksburg, VA 24061

Professor C. H. Lewis  
Dept. of Aerospace and Ocean Engrg.  
Virginia Polytechnic Institute and  
State University  
Blacksburg, VA 24061

Professor A. H. Nayfeh  
Dept. of Engineering Science  
Virginia Polytechnic Institute and  
State University  
Blacksburg, VA 24061

Dr. A. Rubel  
Research Department  
Grumman Aerospace Corporation  
Bethpage, NY 11714

Commanding Officer  
Office of Naval Research  
Eastern/Central Regional Office  
666 Summer St., Bldg. 114, Section D  
Boston, MA 02210

Dr. J. C. Erickson, Jr.  
CALSPAN Corporation  
Advanced Technology Center  
P. O. Box 400  
Buffalo, NY 14225

Dr. T. J. Falk  
CALSPAN Corporation  
Advanced Technology Center  
P. O. Box 400  
Buffalo, NY 14225

Dr. C. Witliff  
CALSPAN Corporation  
Advanced Technology Center  
P. O. Box 400  
Buffalo, NY 14225

Prof. R. F. Probst  
Dept. of Mechanical Engineering  
Massachusetts Institute of Technology  
Cambridge, MA 02139

Commanding Officer  
Office of Naval Research Branch Office  
536 South Clark Street  
Chicago, IL 60605

Code 753  
Naval Weapons Center  
China Lake, CA 93555

Mr. J. Marshall  
Code 4063  
Naval Weapons Center  
China Lake, CA 93555

Professor R. T. Davis  
Dept. of Aerospace Engineering  
University of Cincinnati  
Cincinnati, OH 45221

Professor S. G. Rubin  
Dept. of Aerospace Engineering and  
Applied Mechanics  
University of Cincinnati  
Cincinnati, OH 45221

Library MS 60-3  
NASA Lewis Research Center  
21000 Brookpark Road  
Cleveland, OH 44135

Dr. J. D. Anderson, Jr.  
Chairman, Dept. of Aerospace Engrg.  
College of Engineering  
University of Maryland  
College Park, MD 20742

Professor O. Burggraf  
Dept. of Aeronautical and Astro-  
nautical Engineering  
Ohio State University  
1314 Kinnear Road  
Columbus, OH 43212

DISTRIBUTION LIST (Continued)

Technical Library  
Naval Surface Weapons Center  
Dahlgren Laboratory  
Dahlgren, VA 22448

Dr. F. Moore  
Naval Surface Weapons Center  
Dahlgren Laboratory  
Dahlgren, VA 22448

Technical Library 2-51131  
LTV Aerospace Corporation  
P. O. Box 5907  
Dallas, TX 75222

Library, United Aircraft Corporation  
Research Laboratories  
Silver Lane  
East Hartford, CT 06108

Professor G. Moretti  
Polytechnic Institute of New York  
Long Island Center  
Dept. of Aerospace Engrg. and  
Applied Mechanics  
Route 110  
Farmingdale, NY 11735

Dr. W. R. Briley  
Scientific Research Associates, Inc.  
P. O. Box 498  
Glastonbury, CT 06033

Professor P. Gordon  
Calumet Campus  
Dept. of Mathematics  
Purdue University  
Hammond, IN 46323

Library (MS 185)  
NASA Langley Research Center  
Langley Station  
Hampton, VA 23665

Professor A. Chapmann  
Chairman, Mechanical Engineering Dept.  
William M. Rice Institute  
Box 1892  
Houston, TX 77001

Technical Library  
Naval Ordnance Station  
Indian Head, MD 20640

Professor D. A. Caughey  
Sibley School of Mechanical and  
Aerospace Engineering  
Cornell University  
Ithaca, NY 14850

Professor E. L. Resler  
Sibley School of Mechanical and  
Aerospace Engineering  
Cornell University  
Ithaca, NY 14850

Professor S. F. Shen  
Sibley School of Mechanical and  
Aerospace Engineering  
Cornell University  
Ithaca, NY 14850

Library  
Midwest Research Institute  
425 Volker Boulevard  
Kansas City, MO 64110

Dr. M. M. Hafez  
Flow Research, Inc.  
P. O. Box 5040  
Kent, WA 98031

Dr. E. M. Murman  
Flow Research, Inc.  
P. O. Box 5040  
Kent, WA 98031

Dr. J. J. Riley  
Flow Research, Inc.  
P. O. Box 5040  
Kent, WA 98031

DISTRIBUTION LIST (Continued)

Dr. S. A. Orszag  
Cambridge Hydrodynamics, Inc.  
54 Baskin Road  
Lexington, MA 02173

Dr. P. Bradshaw  
Imperial College of Science and  
Technology  
Department of Aeronautics  
Prince Consort Road  
London SW7 2BY, England

Professor T. Cebeci  
Mechanical Engineering Department  
California State University, Long  
Beach  
Long Beach, CA 90840

Dr. H. K. Cheng  
University of Southern California  
Department of Aerospace Engrg.  
University Park  
Los Angeles, CA 90007

Professor J. D. Cole  
Mechanics and Structures Department  
School of Engineering and Applied  
Science  
University of California  
Los Angeles, CA 90024

Engineering Library  
University of Southern California  
Box 77929  
Los Angeles, CA 90007

Dr. C. -M. Ho  
Dept. of Aerospace Engineering  
University of Southern California  
University Park  
Los Angeles, CA 90007

Dr. T. D. Taylor  
The Aerospace Corporation  
P. O. Box 92957  
Los Angeles, CA 90009

Commanding Officer  
Naval Ordnance Station  
Louisville, KY 40214

Mr. B. H. Little, Jr.  
Lockheed-Georgia Company  
Department 72-74, Zone 369  
Marietta, GA 30061

Professor E. R. G. Eckert  
University of Minnesota  
241 Mechanical Engineering Bldg.  
Minneapolis, MN 55455

Dr. Gary Chapman  
Mail Stop 227-4  
Ames Research Center  
Moffett Field, CA 94035

Library  
Naval Postgraduate School  
Monterey, CA 93940

Dr. J. L. Steger  
Dept. of Aeronautics and Astronautics  
Durand Building  
Stanford University  
Stanford, CA 94305

Dr. S. S. Stahara  
Nielsen Engineering & Research, Inc.  
510 Clyde Avenue  
Mountain View, CA 94043

Engineering Societies Library  
345 East 47th Street  
New York, NY 10017

Professor A. Jameson  
Mechanical and Aeronautical Engrg.  
Dept.  
Princeton University  
E Quad  
Princeton, NJ 08540

DISTRIBUTION LIST (Continued)

Professor G. Miller  
Dept. of Applied Science  
New York University  
26-36 Stuyvesant Street  
New York, NY 10003

Office of Naval Research  
New York Area Office  
715 Broadway - 5th Floor  
New York, NY 10003

Dr. A. Vaglio-Laurin  
Dept. of Applied Science  
New York University  
26-36 Stuyvesant Street  
New York, NY 10003

Mr. D. Farmer  
Naval Ocean Research and Development  
Activity  
Code 332  
NSTL Station, MS 39522

Librarian, Aeronautical Library  
National Research Council  
Montreal Road  
Ottawa 7, Canada

Lockheed Missiles and Space Company  
Technical Information Center  
3251 Hanover Street  
Palo Alto, CA 94304

Commanding Officer  
Office of Naval Research Western  
Regional Office  
1030 East Green Street  
Pasadena, CA 91106

Engineering Division  
California Institute of Technology  
Pasadena, CA 91109

Library  
Jet Propulsion Laboratory  
4800 Oak Grove Drive  
Pasadena, CA 91103

Professor H. Liepmann  
Department of Aeronautics  
California Institute of Technology  
Pasadena, CA 91109

Mr. L. I. Chasen, MGR-MSD Lib.  
General Electric Company  
Missile and Space Division  
P. O. Box 8555  
Philadelphia, PA 19101

Technical Library  
Naval Missile Center  
Point Mugu, CA 93042

Professor S. Bogdonoff  
Gas Dynamics Laboratory  
Dept. of Aerospace & Mechanical Sci.  
Princeton University  
Princeton, NJ 08540

Professor S. I. Cheng  
Dept. of Aerospace & Mechanical Sci.  
Princeton University  
Princeton, NJ 08540

Dr. J. E. Yates  
Aeronautical Research Associates of  
Princeton, Inc.  
50 Washington Road  
Princeton, NJ 08540

Professor L. Sirovich  
Division of Applied Mathematics  
Brown University  
Providence, RI 02912

Redstone Scientific Information Center  
Chief, Document Section  
Army Missile Command  
Redstone Arsenal, AL 35800

U.S. Army Research Office  
P. O. Box 12211  
Research Triangle Park, NC 27709

DISTRIBUTION LIST (Continued)

Editor, Applied Mechanics Review  
Southwest Research Institute  
8500 Culebra Road  
San Antonio, TX 78228

Library and Information Services  
General Dynamics-CONVAIR  
P. O. Box 1128  
San Diego, CA 92112

Dr. R. Magnus  
General Dynamics-CONVAIR  
Kearny Mesa Plant  
P. O. Box 80847  
San Diego, CA 92138

Office of Naval Research  
San Francisco Area Office  
One Hallidie Plaza, Suite 601  
San Francisco, CA 94102

Library  
The RAND Corporation  
1700 Main Street  
Santa Monica, CA 90401

Dr. P. E. Rubbert  
Boeing Aerospace Company  
Boeing Military Airplane Development  
Organization  
P. O. Box 3707  
Seattle, WA 98124

Dr. H. Yoshihara  
Boeing Aerospace Company  
P. O. Box 3999  
Mail Stop 41-18  
Seattle, WA 98124

Librarian  
Naval Surface Weapons Center  
White Oak Laboratory  
Silver Spring, MD 20910

Dr. J. M. Solomon  
Naval Surface Weapons Center  
White Oak Laboratory  
Silver Spring, MD 20910

Professor J. H. Ferziger  
Dept. of Mechanical Engineering  
Stanford University  
Stanford, CA 94305

Professor K. Karamchetti  
Dept. of Aeronautics and Astronautics  
Stanford University  
Stanford, CA 94305

Professor O. Bunemann  
Institute for Plasma Research  
Stanford University  
Stanford, CA 94305

Engineering Library  
McDonnell Douglas Corporation  
Department 218, Building 101  
P. O. Box 516  
St. Louis, MO 63166

Dr. R. J. Hakkinen  
McDonnell Douglas Corporation  
Department 222  
P. O. Box 516  
St. Louis, MO 63166

Dr. N. Malmuth  
Rockwell International Science Center  
1049 Camino Dos Rios  
P. O. Box 1085  
Thousand Oaks, CA 91360

Library  
Institute of Aerospace Studies  
University of Toronto  
Toronto 5, Canada

Professor W. R. Sears  
Aerospace and Mechanical Engineering  
University of Arizona  
Tucson, AZ 95721

Professor A. R. Seebass  
Dept. of Aerospace and Mechanical  
Engineering  
University of Arizona  
Tucson, AZ 95721

DISTRIBUTION LIST (Concluded)

Dr. K. T. Yen  
Code 3015  
Naval Air Development Center  
Warminster, PA 18974

Air Force Office of Scientific  
Research (SREM)  
Building 410, Bolling AFB  
Washington, DC 20332

Chief of Research and Development  
Office of Chief of Staff  
Department of the Army  
Washington, DC 20310

Library of Congress  
Science and Technology Division  
Washington, DC 20540

Director of Research (Code RR)  
National Aeronautics and Space  
Administration  
600 Independence Avenue, SW  
Washington, DC 20546

Library  
National Bureau of Standards  
Washington, DC 20234

National Science Foundation  
Engineering Division  
1800 G Street, NW  
Washington, DC 20550

AIR 320D  
Naval Air Systems Command  
Washington, DC 20361

AIR 950D  
Naval Air Systems Command  
Washington, DC 20375

Code 2627  
Naval Research Laboratory  
Washington, DC 20375

SEA 03512  
Naval Sea Systems Command  
Washington, DC 20362

SEA 09G3  
Naval Sea Systems Command  
Washington, DC 20362

Dr. Charles Watkins  
Head, Mechanical Engineering Dept.  
Howard University  
Washington, DC 20059

Dr. A. L. Slafkosky  
Scientific Advisor  
Commandant of the Marine Corps (Code AX)  
Washington, DC 20380

Director  
Weapons Systems Evaluation Group  
Washington, DC 20350

Research Library  
AVCO Corporation  
Missile Systems Division  
201 Lowell Street  
Wilmington, MA 01887

AFAPL (APRC)  
AB  
Wright-Patterson AFB, OH 45433

Dr. Donald J. Harney  
AFFDL/FX  
Wright-Patterson AFB, OH 45433

Mr. G. Malcolm  
Mail Stop 227-8  
Ames Research Center  
Moffett Field, CA 94035