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SEMI-ANNUAL PROGRESS REPORT

1 December 1985 to 1 June 1986

to

National Aeronautics and Space Administration

on

NASA Grant NSG-3264

Entitled

"THE BOUNDARY LAYER ON COMPRESSOR CASCADE BLADES"

Submitted by:

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(NASA-CR-177279) THE BOUNDARY LAYER ON COMPRESSOR CASCADE BLADES Semiannual Progress Report, 1 Dec. 1985 - 1 Jun. 1986 (Pennsylvania State Univ.) 20 p HC A02/MF A01 CSCL 20D G3/34

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A. ~~INTRODUCTION~~

The purpose of NASA Research Grant NSG-3264 is to characterize the flowfield about an airfoil in a cascade at chord Reynolds number (R_c) near 5 x 10^5. The program is experimental and combines laser Doppler velocimeter (LDV) measurements with flow visualization techniques in order to obtain detailed flow data [e.g., boundary layer profiles, points of separation and the transition zone] on a cascade of highly-loaded compressor blades. The information provided by this study is to serve as benchmark data for the evaluation of current and future compressor cascade predictive models, in this way aiding in the compressor design process.

~~This report~~ summarized the research activity for the period 1 December 1985 through 1 June 1986. Progress made from 1 June 1979 through 1 December 1985 is presented ~~in References 1 through 13.~~ Detailed measurements have been completed at the initial cascade angle of 53° (incidence angle 5 degrees). A three part study, based on that data, has been accepted as part of the 1986 Gas Turbine Conference and will be submitted for subsequent journal publication. ~~Two NASA contractor's reports, one presenting the experimental methods and their interpretation and the second presenting the data have also been completed. The first of these NASA contractor reports was also issued as an ARL TR [14]. The current report~~ presents data for a second cascade angle of 45° (an incidence angle of 3 degrees).

B. PROGRESS DURING THE PERIOD 1 December 1985 to 1 June 1986

B.1 Description of the Experiment

The ARL/PSU cascade tunnel is shown in Figure 1. With the current fan system, maximum inlet speed to the cascade section is near 35 m/sec. Inlet turbulence intensity, as measured with a hot-wire anemometer, is below 0.2% as shown in Figure 2. To facilitate understanding, the cascade experiments are described (in Section B.1) by using the data taken at an inlet flow angle of 53 degrees for illustration.

The cascade test section is detailed in Figure 3. Note that blade-pack side suction, as normally employed in cascade testing to maintain two-dimensionality, is not possible because of the need for an LDV window. Instead, a strong upstream side suction, controllable in the blade-to-blade direction, is employed. Tailboards are used to control the periodicity of the flow.

Since current computer codes assume a two-dimensional, periodic cascade flow, data must be taken in such a flow field to be useful. Here, two-dimensionality is taken to imply that the velocities and angles of the flow are substantially the same in spanwise planes, while periodicity means that velocities and flow angles in planes normal to the blades leading and trailing edges are functions only of the distance from a blade. In a successful two-dimensional, periodic, cascade flow, the ratio of axial velocity at the leading to that at the trailing edge is one. A typical (53°) outlet flow profile is shown in Figure 4, the corresponding turning angle in Figure 5, and the blade static pressure distribution in Figure 6. Interpretation of these figures can be facilitated by referring to the definitions of cascade flow angles given in Figure 7. The periodicity of the flow is clearly excellent. Also apparent from the blade pressure distribution is the strong adverse gradient on the suction surface and strong favorable gradient on the pressure surface near the leading edge of the blade. One might then anticipate at this incidence angle, flow separation at the leading edge of the suction surface and laminar flow near the leading edge of the pressure surface. The axial velocity ratio, found to be one, is determined by averaging the local axial velocity over three blade passages, centered at the minimum velocity ratio point of the central blade wake. On a day-to-day basis, the variation in axial velocity ratio was within 3%, while the variation in chord Reynolds number was within 1%. A more detailed exposition of the experimental techniques may be found in [14].

A specially designed traversing mechanism which matches the arc of motion of an optics cradle to that of the blade curvature is used for the LDV measurements. All measurements were made in the plane of the local blade normal. Translation of the optics cradle normal to the blade can be accomplished in step intervals as small as 0.0254 mm. Prior to LDV measurements, a reference distance was established by focusing the LDV control volume on an insert which fit over the central measuring blade. Narrow lines are etches on the insert so as to be at known locations from the blade surface. Repeatability in establishing a measurement reference was estimated to be $\pm$ 0.05 mm, and this uncertainty is probably the major source of scatter in the velocity data.

A schematic of the LDV optics system is shown in Figure 8. A two Watt Spectra-Physics Argon-Ion laser was used for the measurements.

Power on the blue line employed (488 nm) ranged between 0.6 to 0.8 Watts. Standard TSI backscatter optical components were used: the focusing lens (focal distance = 371.3 mm) allowed the measurements to be made at the blade mid-span. The focal volume was ellipsoidal and was predicted to be 0.56 mm x 0.037 mm in the direction normal to the blade. Optical shifting at 5 Mhz was employed. To measure close to the surface, the optical cradle was tiled 1°. Silicon carbide particles having a mean diameter of 1.5 μm were used for laser seeding. In an attempt to maintain a uniform distribution, seed was injected well upstream of the measurement station (see Figure 1) at the flexible coupling.

LDV data acquisition and reduction was accomplished by using a direct link to a VAX 11/782 computer. Software allowed selection of focusing lens half angle, laser wavelength, frequency shift, minimum cycles employed in the calculation and number of particle counts per run (up to 4000). Initial output was in the form of a velocity histogram. Minimum and maximum velocity limits were set by a cursor from the histogram to eliminate obvious noise. Final output was mean velocity, turbulence intensity and percent of particle counts employed in the calculation. The latter served as a signal-to-noise indicator. It is probably fair to state that at least 98% of the total particle counts were employed for measurement stations in the boundary layer; at least 95% were employed for points in the free stream. Mean velocity here was taken as a simple arithmetic average

$$u = \frac{1}{N} \sum_{n=1}^{N} u_n \quad , \tag{1}$$

and local turbulence intensity (L.T.I.) as

$$\frac{u'}{u} = \frac{1}{u}\frac{1}{N}\sum_{n=1}^{N} (u_n - u)^{2\ 1/2} \qquad (2)$$

Experience has shown that quite satisfactory repeatability of the mean and turbulence intensity can be guaranteed in boundary layer flows by using N = 1000 particle counts in regions in which the L.T.I. exceeds 5%, 500 points for L.T.I. less than 5% and 200 points for the free stream. At each measurement station, profiles were defined by statistically treating the data for six individual experiments.

The preliminary data analysis is automated on the ARL/VAX computer. The effects of normal pressure gradient are accounted for first. Details of the technique are given in Reference [14] and are equivalent to that used by Ball., et.al. [15] and Mellor, et.al. [16]. Briefly the technique assumes that the profile may be represented as

$$u_{meas} = u_{BL} + u_{inv} - U_e \qquad (3)$$

so that the edge velocity (U_e) can be determined by extrapolating the outer inviscid flow (u_{inv}) to the wall (where $u_{meas} = u_{BL} = 0$) in some reasonable manner. The reconstructed boundary layer can then be analyzed in several ways. For example, the mean profiles can be fit to Cole's composite profile [17] or compared to a Falkner-Skan profile [18] (at equivalent pressure gradient). For all the measured profiles, integral parameters can also be calculated from a smooth cubic spline fit. Finally, skin friction calculations can also be made, where appropriate, using the Ludwig-Tilman [18] correlations.

B.2 <u>Progress</u>

For the cascade angle of 53°, eleven profiles were measured on both the pressure and suction surfaces of the double circular arc blades; two profiles were measured in the near wake. Each profile contains mean velocity and turbulence intensity information; for most of the profiles, the skewness and kurtosis were also calculated. Analysis of these data is complete. A three part article, based on these results, has been accepted for presentation at the 1987 Gas Turbine Conference; Journal publication is anticipated. Two NASA contractor's reports, the first a description of experimental methods and an analysis of results and the second, a compendium of both the raw and analyzed data, have also been completed. The first of these contractor's reports has been issued as an ARL/PSU TR [14].

A two-dimensional periodic flow field has been established at a second incidence angle of -3°. The incidence was changed by rotating the entire blade pack from 53° to 45°. The measured pressure distribution, outlet-to-inlet axial flow profile and outlet turning angles are shown in Figure 9-11. The axial flow ratio is near 1.00 for a chord Reynolds number of 5×10^5. The pressure distribution is most interesting when compared to the one taken at a cascade angle of 53°. In particular, at 45°, note the region of strong flow acceleration over the first 20% chord on the suction surface. Flow visualization studies at this second incidence have also been completed. Transition was found on both the suction 54.3 1$\pm$ 1% chord) and pressure (26.9 1$\pm$ 1.25% chord) surfaces of the blade.

Detailed boundary layer measurements at this second incidence angle are well underway. Boundary layer profiles on the suction surface are complete. Transition on the suction surface is through a laminar separation/turbulent reattachment mechanism. The turbulent boundary layer then separates near the trailing edge. Data analysis of the suction surface profiles is continuing. Velocity profiles on the pressure surface are also underway.

C. GOALS FOR THE NEXT REPORTING PERIOD

During the next six-month period, it is anticipated that:

* Detailed boundary layer and near wake velocity profiles at the second cascade angle (45°) will be completed.
* Documentation of the data at 45° will be underway.
* A two-dimensional periodic flow field will be setup at a third incidence angle (near design conditions).

D. REFERENCES

[1] Deutsch, S., Semiannual Progress Report for NASA Grant NSG-3264, January 1980.

[2] Deutsch, S., Semiannual Progress Report for NASA Grant NSG-3264, June 1980.

[3] Deutsch, S., Semiannual Progress Report for NASA Grant NSG-3264, January 1981.

[4] Deutsch, S., Semiannual Progress Report for NASA Grant NSG-3264, June 1981.

[5] Deutsch, S., Semiannual Progress Report for NASA Grant NSG-3264, January 1982.

[6] Deutsch, S., Semiannual Progress Report for NASA Grant NSG-3264, June 1982.

[7] Deutsch, S. and W. Gearhart, Semiannual Progress Report for NASA Grant NSG-3264, December 1982.

[8] Deutsch, S., Semiannual Progress Report for NASA Grant NSG-3264, May 1983.

[9] Deutsch, S. and W. C. Zierke, Semiannual Progress Report for NASA Grant NSG-3264, December 1983.

[10] Deutsch, S. and W. C. Zierke, Semiannual Progress Report for NASA Grant NSG-3264, June 1984.

[11] Deutsch, S. and W. C. Zierke, Semiannual Progress Report for NASA Grant NSG-3264, February 1985.

[12] Deutsch, S. and W. C. Zierke, Semiannual Progress Report for NASA Grant NSG-3264, June 1985.

[13] Deutsch, S. and W. C. Zierke, Semiannual Progress Report for NASA Grant NSG-3264, December 1985.

[14] Deutsch, S. and W. C. Zierke, "The Measurement of Boundary Layers on a Compressor Blade in Cascade," ARL/PSU TR 86-02, Applied Research Laboratory, The Pennsylvania State University, March 1986.

[15] Ball, C. L., L. Reid and J. F. Schmidt, "End-Wall Boundary Layer Measurements in a Two-Stage Fan," NASA TM 83409 (June 1983).

[16] Mellor, G. L. and G. M. Wood, "An Axial Compressor End-Wall Boundary Layer Theory," Trans. of Basic Engr., Journal of Basic Engr. (June 1971).

[17] Coles, D. E. and E. A. Hirst, "Computation of Turbulent Boundary Layers," Proceedings of the 1968 AFOJR-IFP-Stanford Conference.

[18] White, F. M., Viscous Fluid Flow, McGraw-Hill, Inc. (1974).

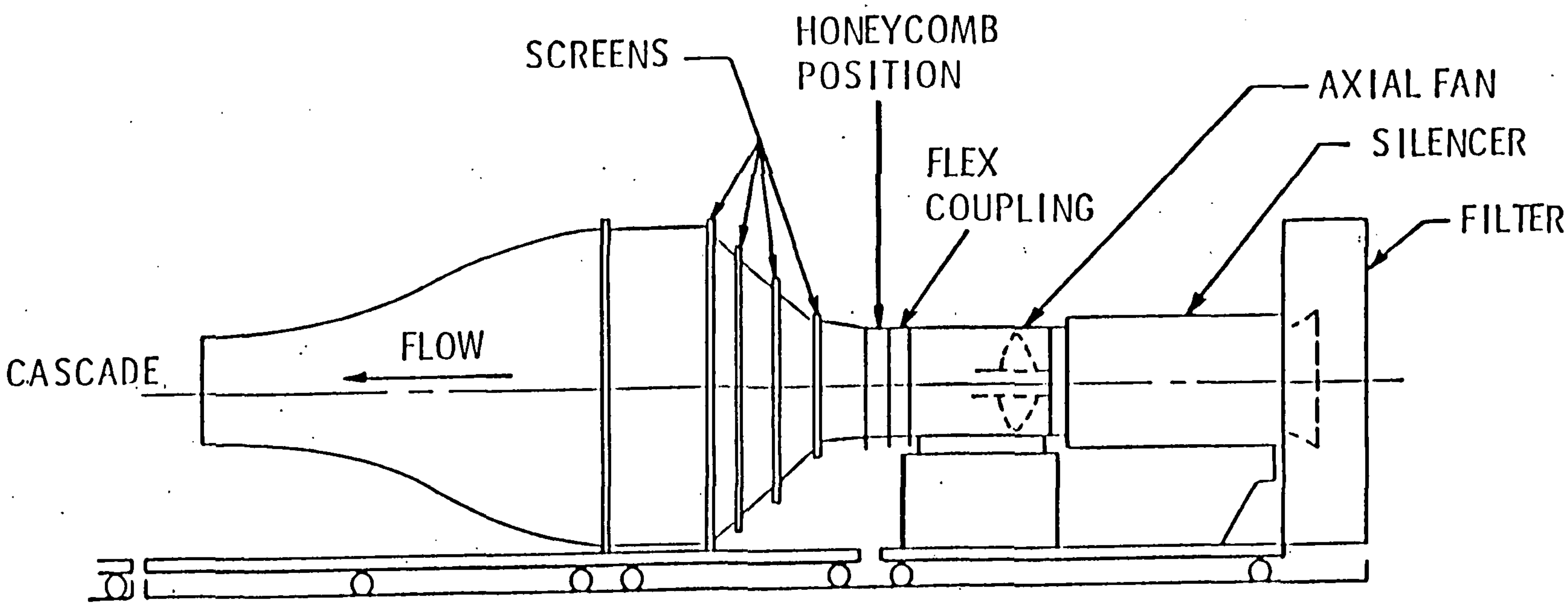


Figure 1. Open Return Wind Tunnel

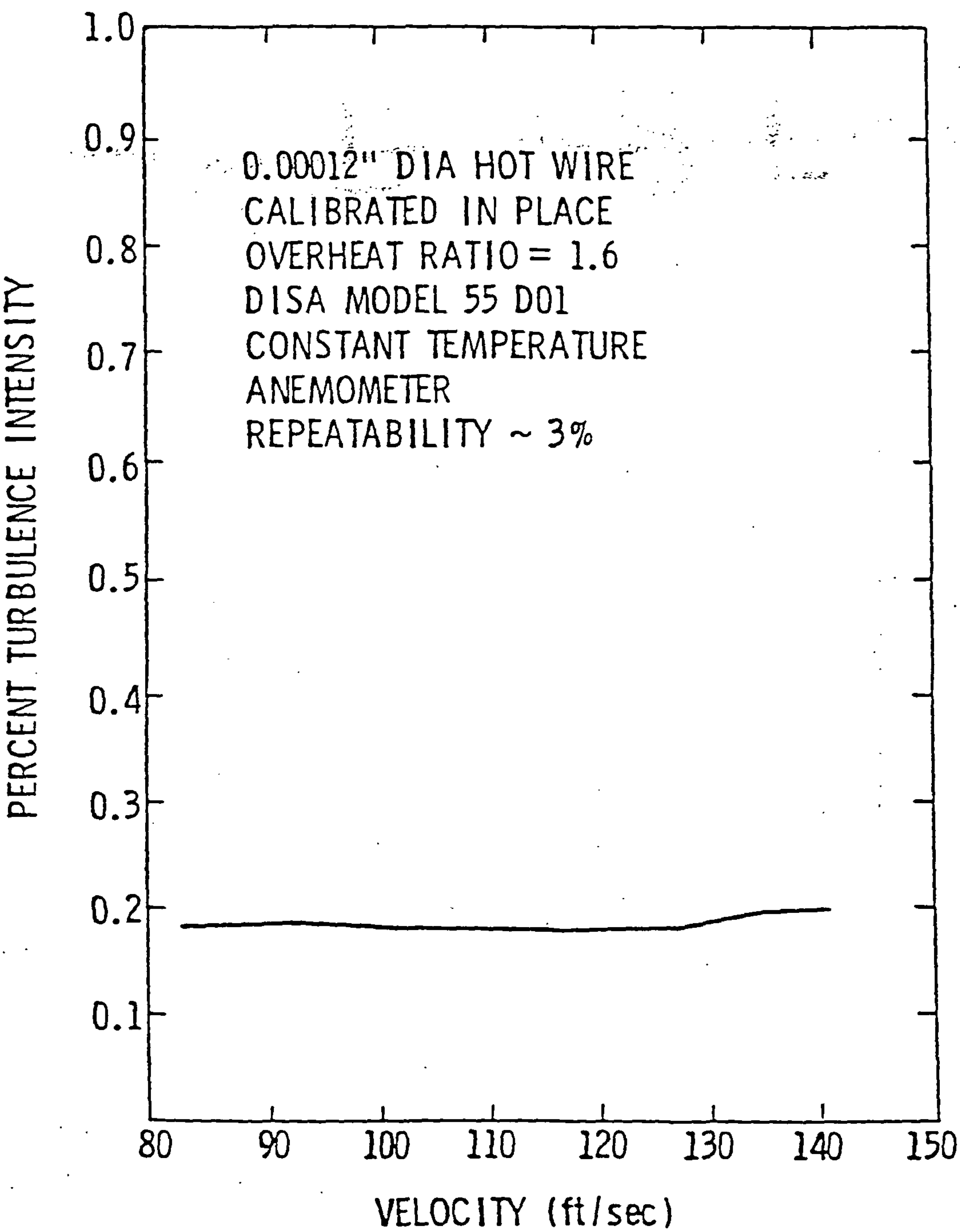


Figure 2. Inlet Turbulence Intensity

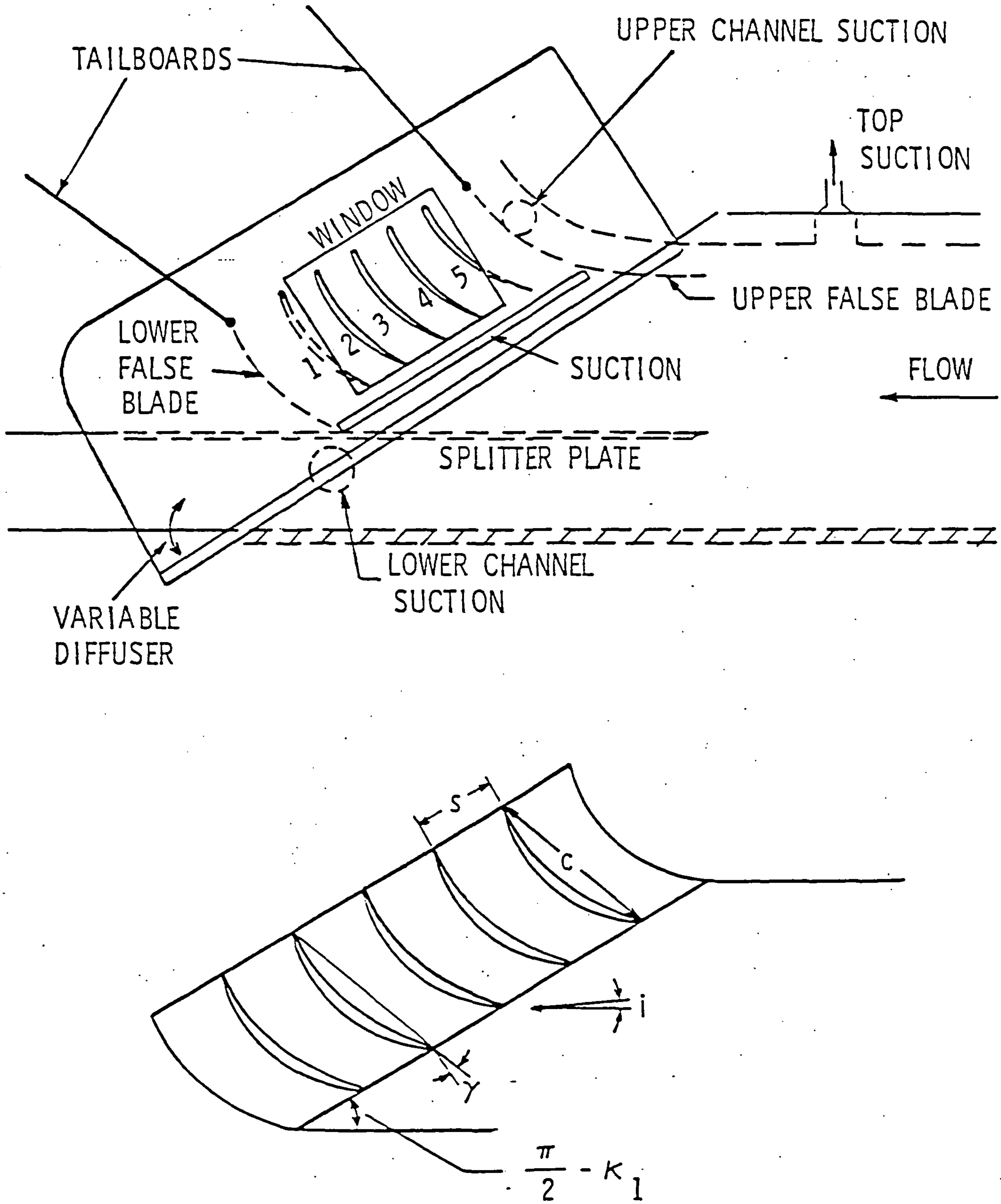
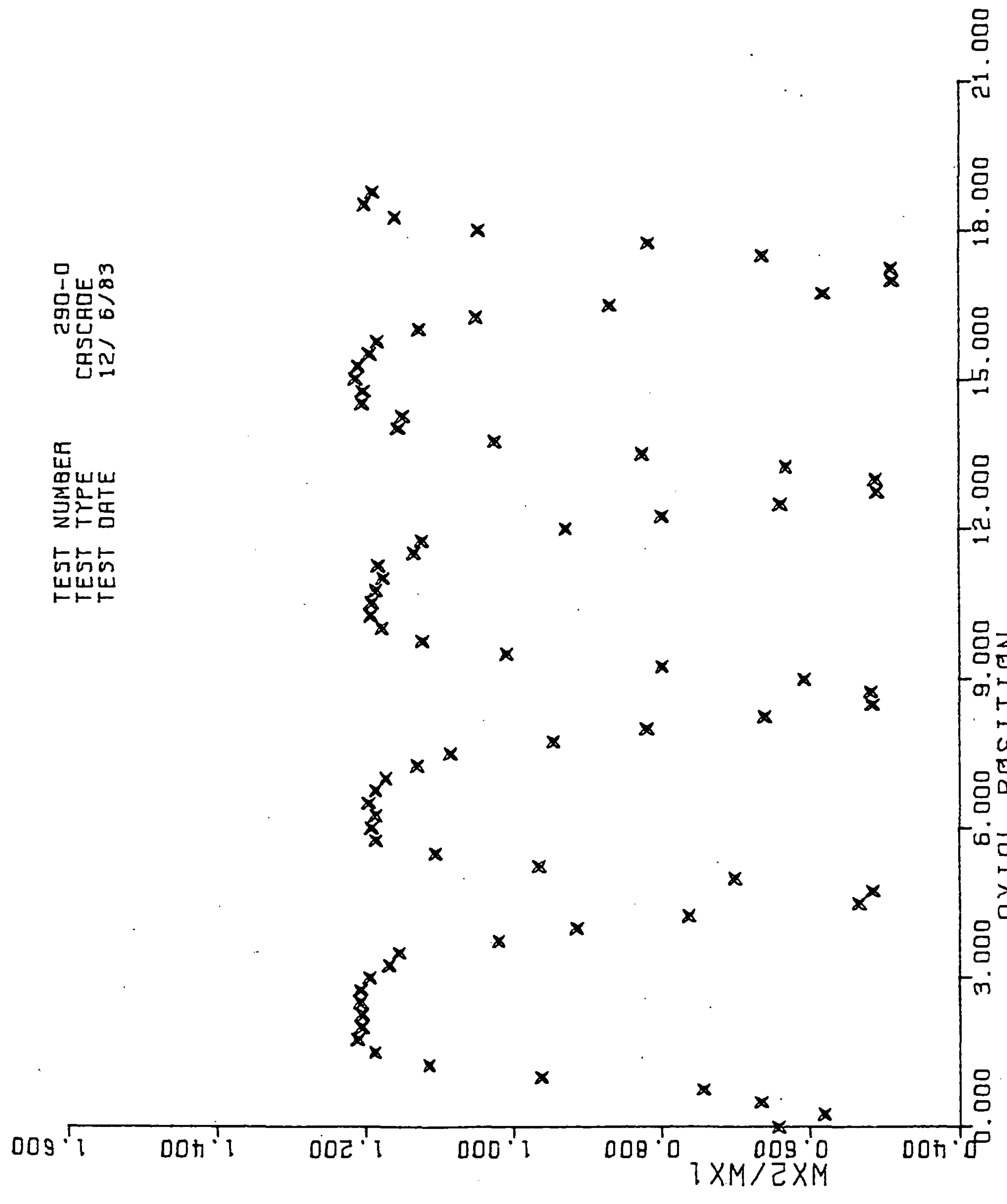


Figure 8. Cascade Test Section with Flow Controls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TEST DATE 12/ 6/83
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0.600
0.800
1.000
1.200
1.400
1.600
AXIAL POSITION
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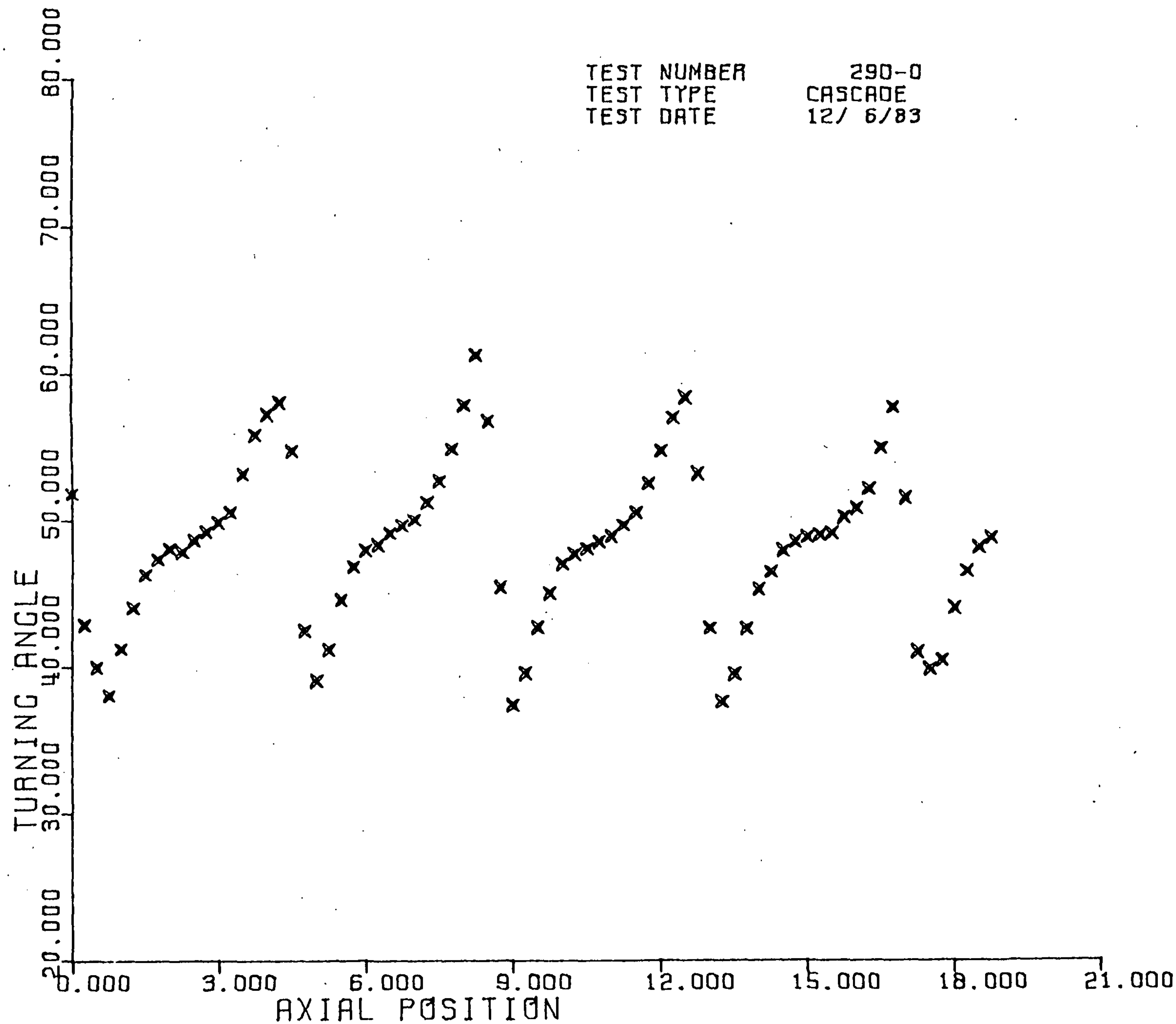
3.000
6.000
9.000
12.000
15.000
18.000
21.000

Figure 4.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TEST TYPE CASCADE
TEST DATE 12/ 6/83
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50.000
60.000
70.000
80.000
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3.000
6.000
9.000
12.000
15.000
18.000
21.000

Figure 5.

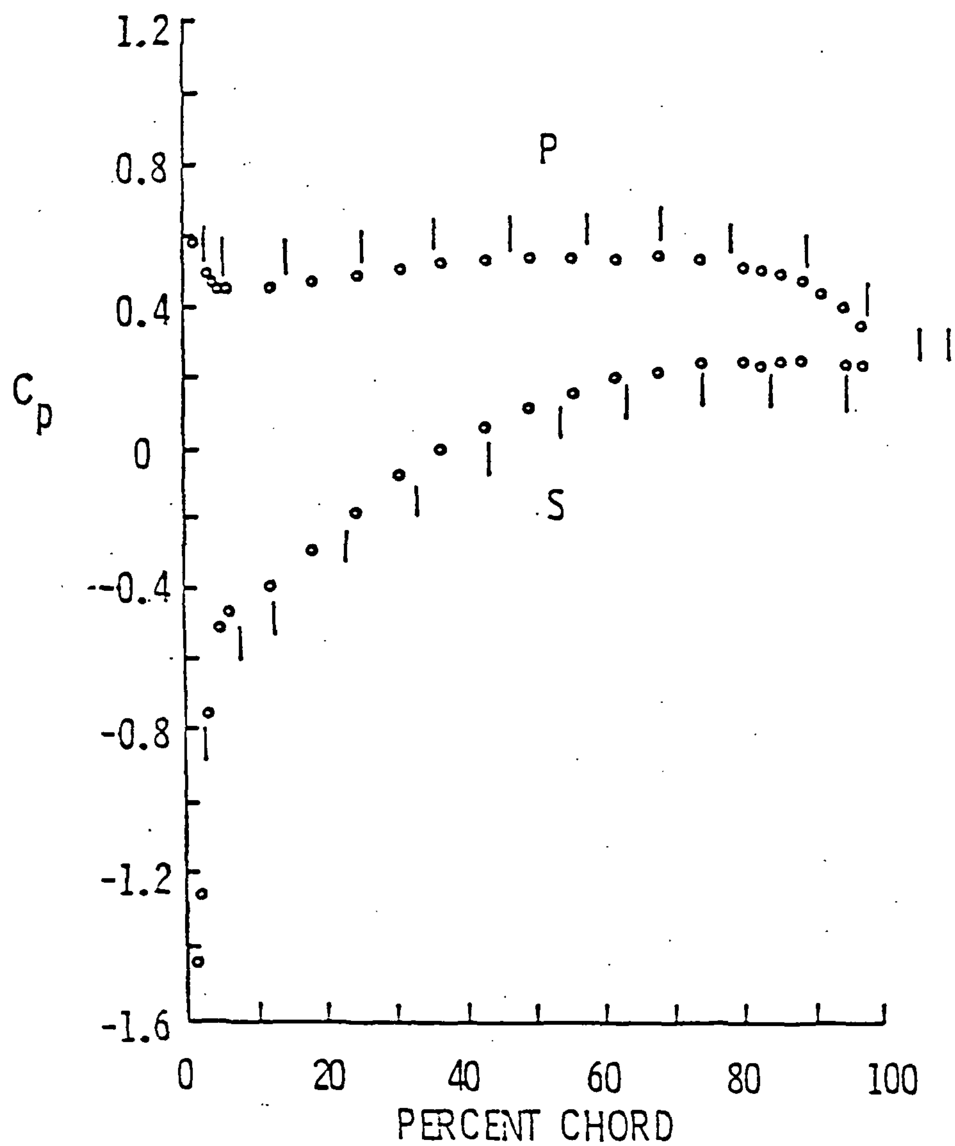


Figure 6. Blade Static-Pressure Distribution (The Vertical-Line Segments Represent the Locations of LDV Measurements) (P - Pressure Surface; S - Suction Surface)

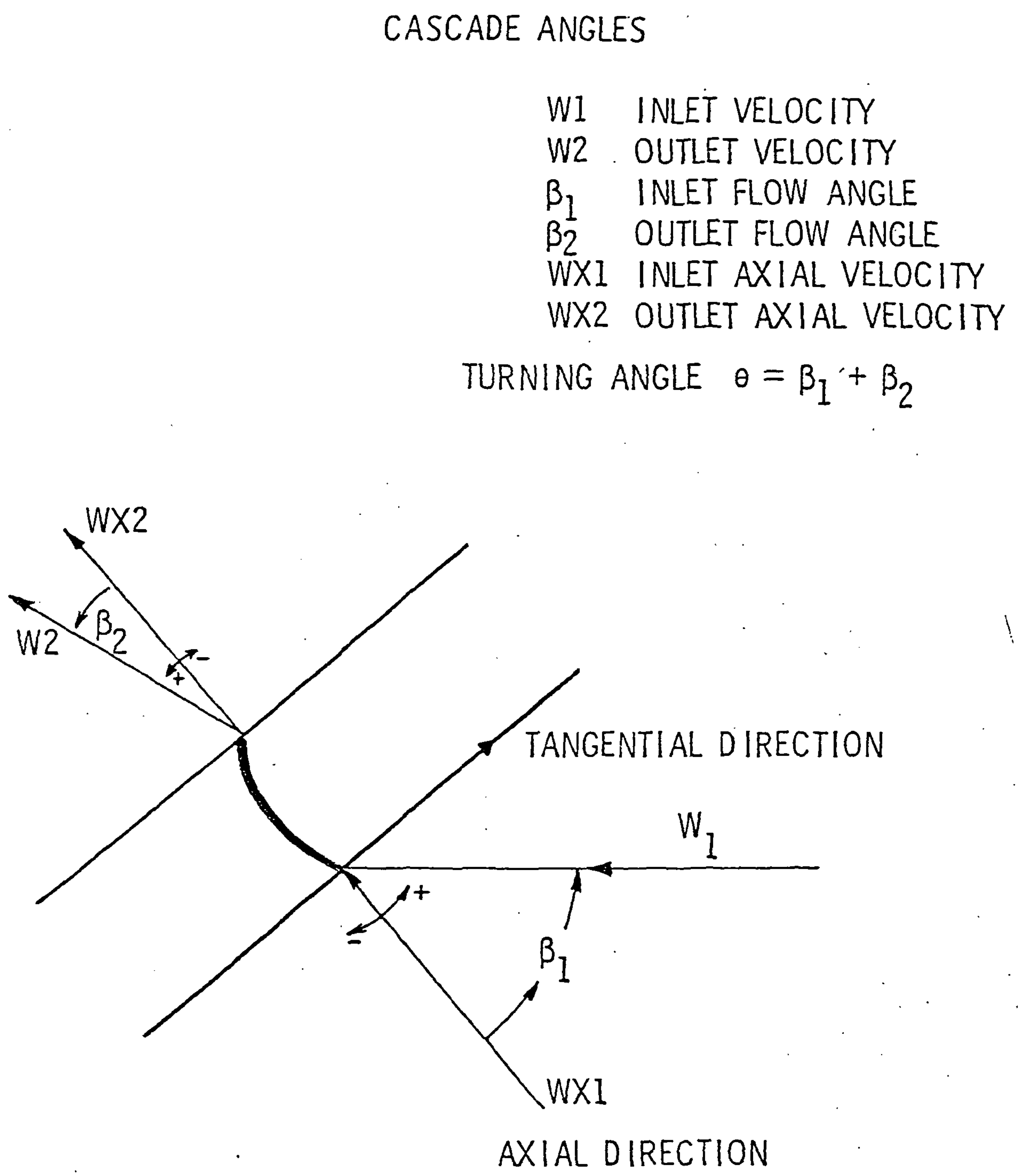
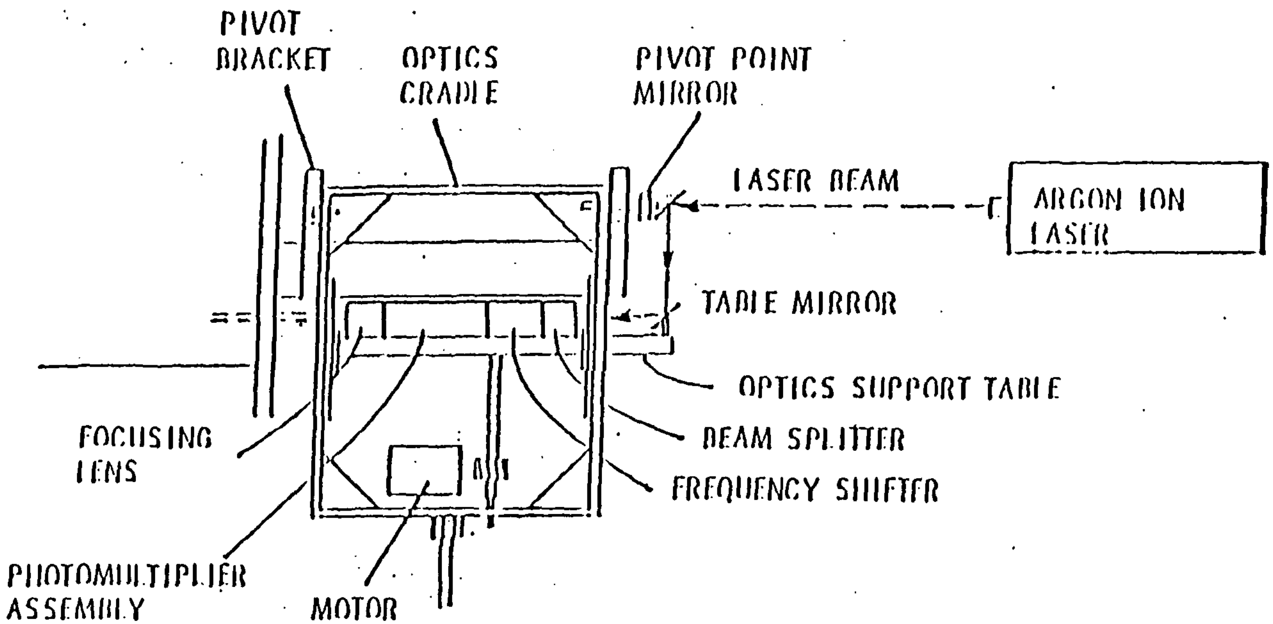


Figure 7. Cascade Angles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OPTICS CRADLE
PIVOT POINT MIRROR
LASER BEAM
ARGON ION LASER
TABLE MIRROR
OPTICS SUPPORT TABLE
BEAM SPLITTER
FREQUENCY SHIFTER
FOCUSING LENS
PHOTOMULTIPLIER ASSEMBLY
MOTOR

Figure 8

Figure 9.

TEST NUMBER 2152-0
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TEST DATE 6/ 5/85
RUN NUMBER 1

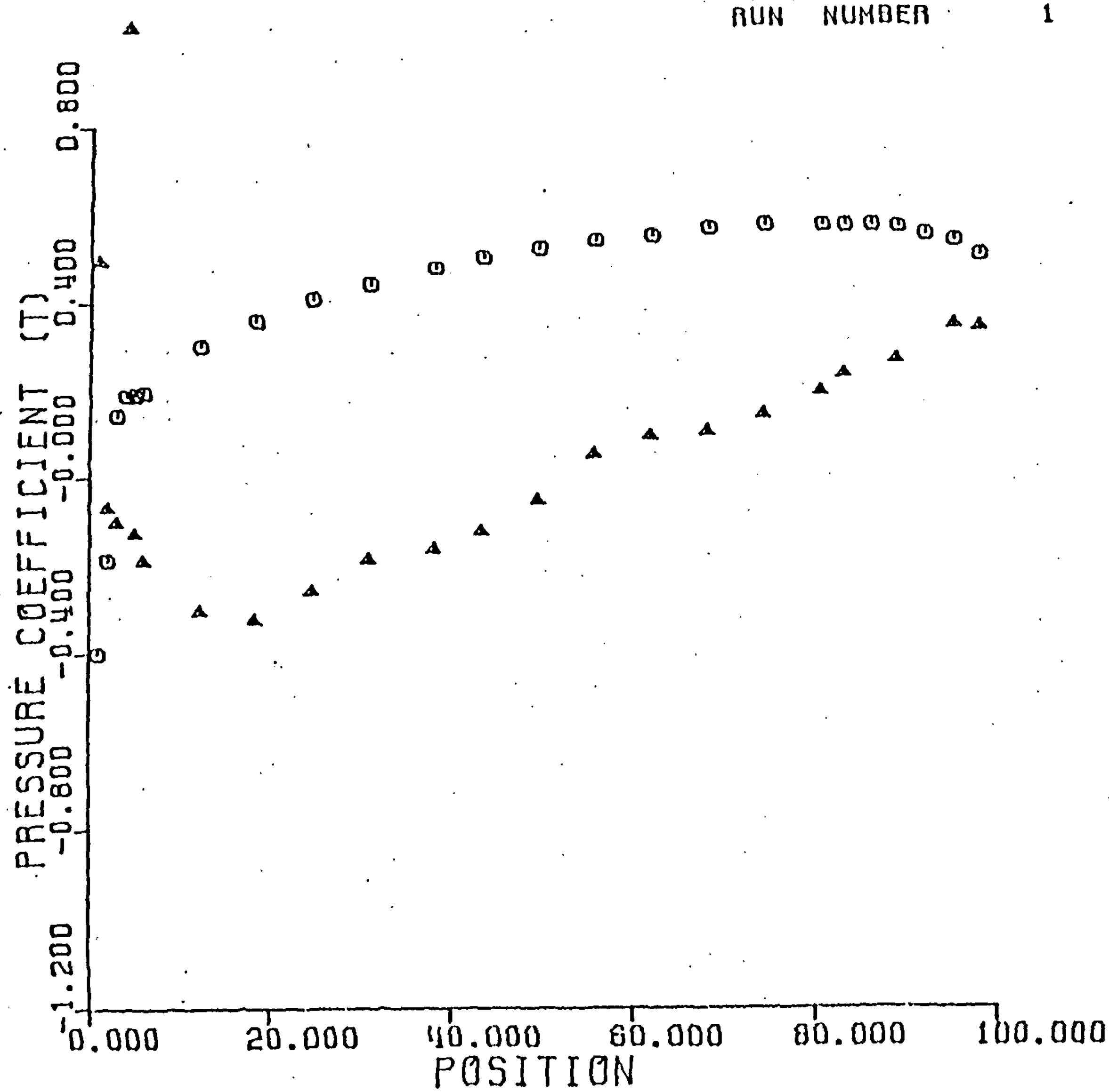
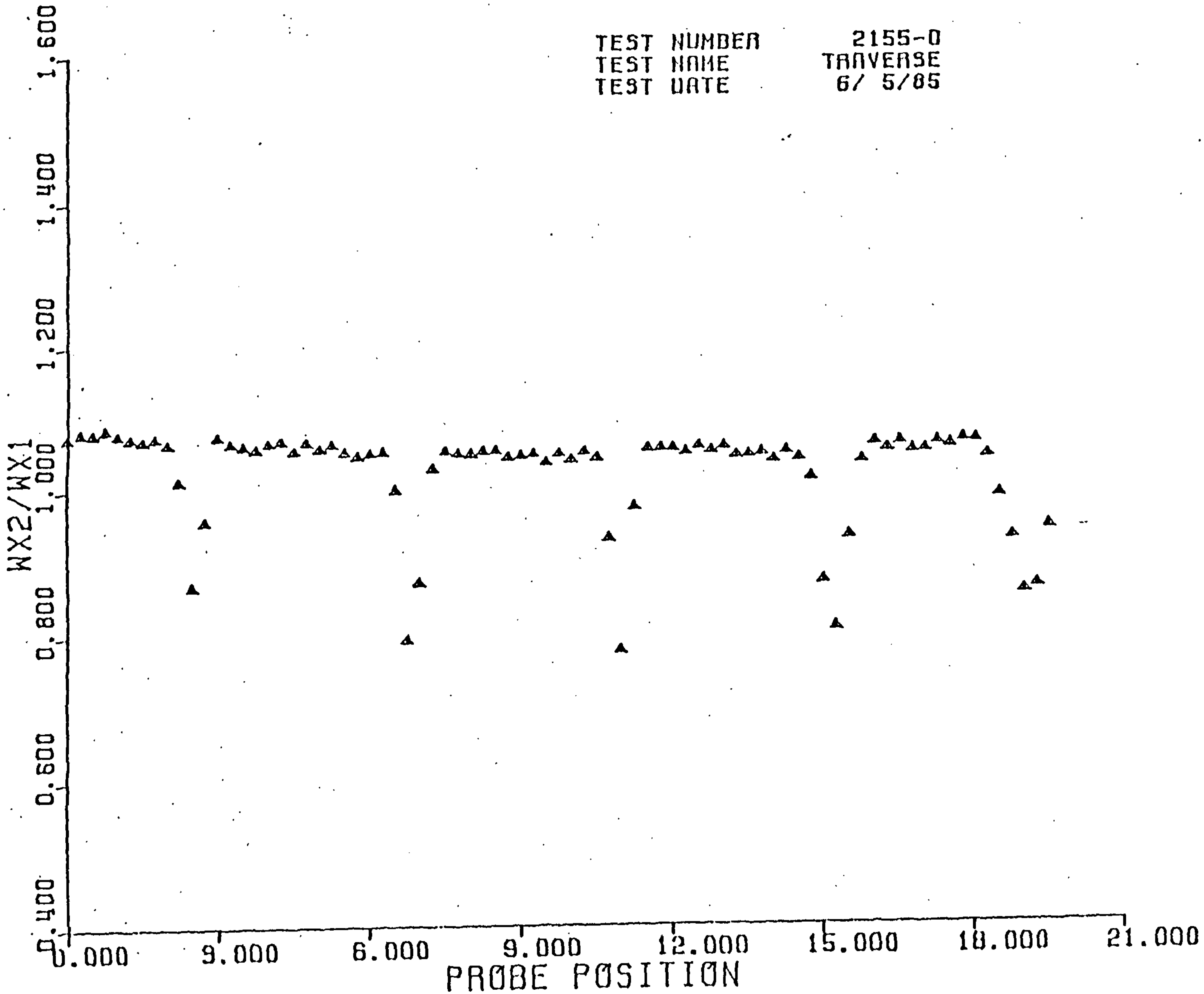


Figure 10.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TEST DATE 6/ 5/85
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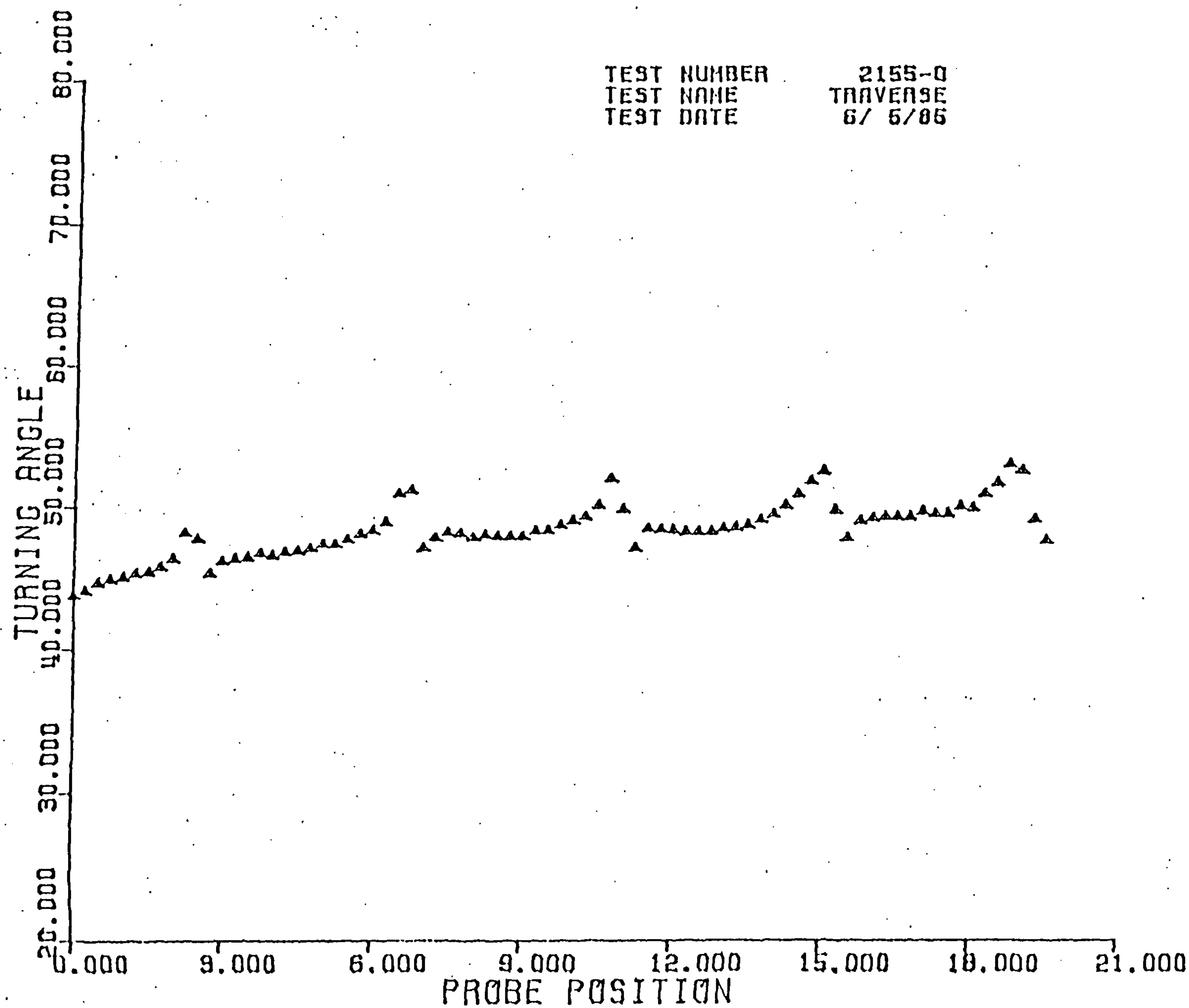
1.200
1.000
0.800
0.600
0.400
0.000
3.000
6.000
9.000
12.000
15.000
18.000
21.000
PROBE POSITION

Figure 11.



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TEST DATE 6/ 5/86
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6.000
9.000
12.000
15.000
18.000
21.000
PROBE POSITION