NAVAL POSTGRADUATE SCHOOL
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THESIS

CONTROLLED DIFFUSION COMPRESSOR
BLADE WAKE MEASUREMENTS

by

John William Dreon, Jr.

September 1986

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Controlled Diffusion Compressor Blade Wake Measurements

by

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ABSTRACT

A Controlled-Diffusion compressor stator blade-element design was re-tested in a subsonic cascade wind tunnel to obtain data with which to assess viscous computational prediction methods. Tests were conducted near design and toward stall conditions at Mach 0.28 and Reynolds number of 774000. Loss coefficient, diffusion factor and AVDR were determined by mass averaging pneumatic pressure probe survey measurements. Wake velocity profiles were measured from 0.12 to 1.77 chordlengths downstream. Concentration was placed on the verifications of accuracy by careful calibration ,multiplicity and exchange of survey probes. Cylindrical probes were found not to measure wake yaw angles as accurately as conical probes. Experimental results showed that losses were dependent on Reynolds number and that all blade-element performances were independent of the downstream axial location at which they were determined.

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LIST OF SYMBOLS

English Letter Symbols

AVDR	-	Axial Velocity Density Ratio
c	-	Chord
c_p	-	Specific heat at constant pressure
Cp	-	Coefficient of pressure
D	-	NASA diffusion factor
h_i	-	Spanwise depth of control volume
k_i	-	$[\int_0^s \rho_i V_i \cos\beta_i dx]/[\int_0^s \rho_{ref} V_{ref} \cos\beta_i dx]$
M	-	Mach number
P	-	Pressure, in H_2O
R	-	Gas constant
Re	-	Reynolds number
$s_{1,2}$	-	Integration limits (position)
T	-	Temperature
V	-	Free stream velocity
V_t	-	Limiting velocity ($V_t=\sqrt{2c_pT_t}$)
W_i	-	Relative velocity
X	-	Dimensionless velocity, ($X=V/\sqrt{2c_pT_t}$)
x	-	Position of probe in blade to blade direction
y	-	Position of probe in axial direction
z	-	Position of probe in spanwise direction

Greek Letter Symbols

α	-	Yaw angle
β	-	Probe pressure coefficient
Γ	-	Probe pressure coefficient
γ	-	Ratio of specific heats, stager angle
Δ	-	Change in a quantity
ρ	-	Density
μ	-	Viscosity
ϕ	-	Flow pitch angle
Ω	-	Loss coefficient parameter
σ	-	Solidity
Θ	-	Probe pressure coefficient
ω	-	Loss coefficient

Subscripts

1,2,3,4 5	-	Probe pressure port number when subscripted to P eg. (P_1)
23	-	Average of ports 2 and 3 static pressure measured by a probe
ave	-	Arithmatic average
atm	-	Atmospheric
bar	-	Mass averaged quantity
i	-	Traversing plane ;inlet (i=1) outlet (i=2)
ref	-	Referenced to plenum
s	-	Static
t	-	Total
u	-	In the blade to blade direction

ACKNOWLEDGMENT

I would like to take this opportunity to thank the many people affiliated with the Naval Postgraduate School for the valuable help and assistance they gave in enabling me to complete this study. I would like to thank Dr. Greg Walker, University of Tasmania for his personal and professional evaluation in refining the calibration process. Special thanks are due to Dr. R. P. Shreeve, Director of the Turbopropulsion Laboratory, who gave unstintingly of his time and talent in this endeavor. To these two men can be applied the passage -- wisdom I learned and parted ungrudgingly.

I. INTRODUCTION

A design procedure for Controlled Diffusion (CD) compressor blading which is based on numerical optimization methods was developed by Nelson L. Sanger of NASA Lewis Research Center [Ref. 1]. The underlying concept in this and other CD design methods is that by controlling the diffusion of the air flow over the suction surface of the blading, boundary layer seperation can be avoided [Ref. 2]. This, in in principle, allows the design of blading with greater loading per stage, or a reduction in the number of blades for a given stage loading. Both features will be exploited in advanced compressors in future turbojet engines.

As a verification of the design procedure, Sanger redesigned an existing stator blade row to use CD blading in place of Double Circular Arc (DCA) shapes. Subsequently, the scaled-up mid span section of the redesigned blade was built and tested in the rectilinear cascade at the Naval Postgraduate School. Detailed testing of the blading was conducted at an inlet Mach number of approximately 0.2 and Reynolds Number of 4.7 to 6.9×10^5 . Inlet flow angle was varied to encompass design and off design conditions. The test program was reported by Koyuncu [Ref. 3] and a comparison of test and computational results was reported by Sanger and Shreeve [Ref. 4].

In the present study a series of tests to obtain detailed wake data at various positions downstream of the trailing edge of Sanger's CD cascade was conducted in a wind tunnel containing 20 blades. The positions ranged from 0.12c to 1.77c (chord=5.01 in.), for a total of six positions. The inlet flow angle was set approximately to the design condition (40.3° vice 39.8°) and then nearer to stall (43.4°). A calibrated United Sensor Corporation five hole conical probe was used to obtain the downstream flow field developement for one blade passage. Two United Senor Corporation cylindrical probes were used to survey far upstream and downstream over three blade passages. A special yaw probe was used to reference and verify wake yaw angle measurements and probes were exchanged to verify measurement accuracy.

In the present report, the facility, proceedures, significant results and conclusions are described in Sections II through V. A complete documentation of the probe survey data is given in Appendix A and of the blade surface pressure data in Appendix B. The evaluation of the blade surface pressure coefficients and Reynolds number are described in Appendix C, and proceedures followed to define and reduce measurement uncertainties, are given in Appendix D.

II. TEST FACILITY

A. RECTILINEAR CASCADE

A schematic diagram of the Rectilinear Subsonic Cascade Wind Tunnel facility is shown in Fig. 1. A detailed description of its design and operation was given in an earlier thesis [Ref. 5]. Flow inlet conditions were investigated in detail by McGuire [Ref. 6]. While uniform on average, the inlet flow contains periodic wakes due to variable inlet guide vanes which are spaced one inch apart in the blade to blade direction.

For the present wake measurements a third probe traverse was added to the cascade. Slots were machined into the removeable plexiglas North wall at five stations downstream of the test blading trailing edge. A heavy aluminun angle extrusion was attached to both support the traverse and insure stiffness of the plexiglas wall while the cascade was in operation (Fig. 2). The test section dimensions (Fig. 3) were changed slighty from those in Ref. 3.

B. INSTRUMENTATION

A total of four pneumatic survey probes were used. These were United Sensor Corporation probes of the five hole type. Two cylindrical probes were used to measure data needed to determine the inlet conditions and the mixed out flow

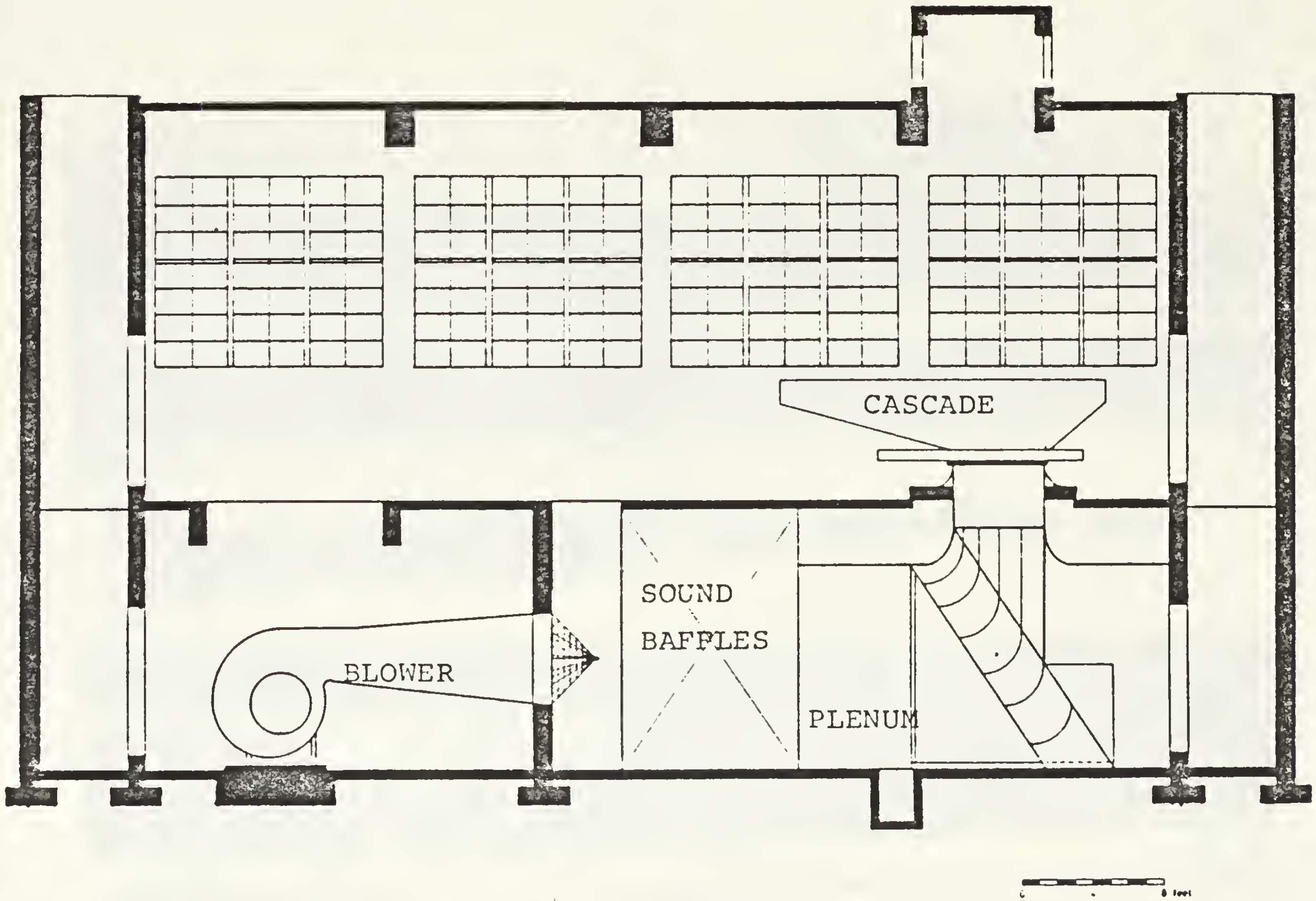

Figure 1. Cascade Wind Tunnel Test Facility.

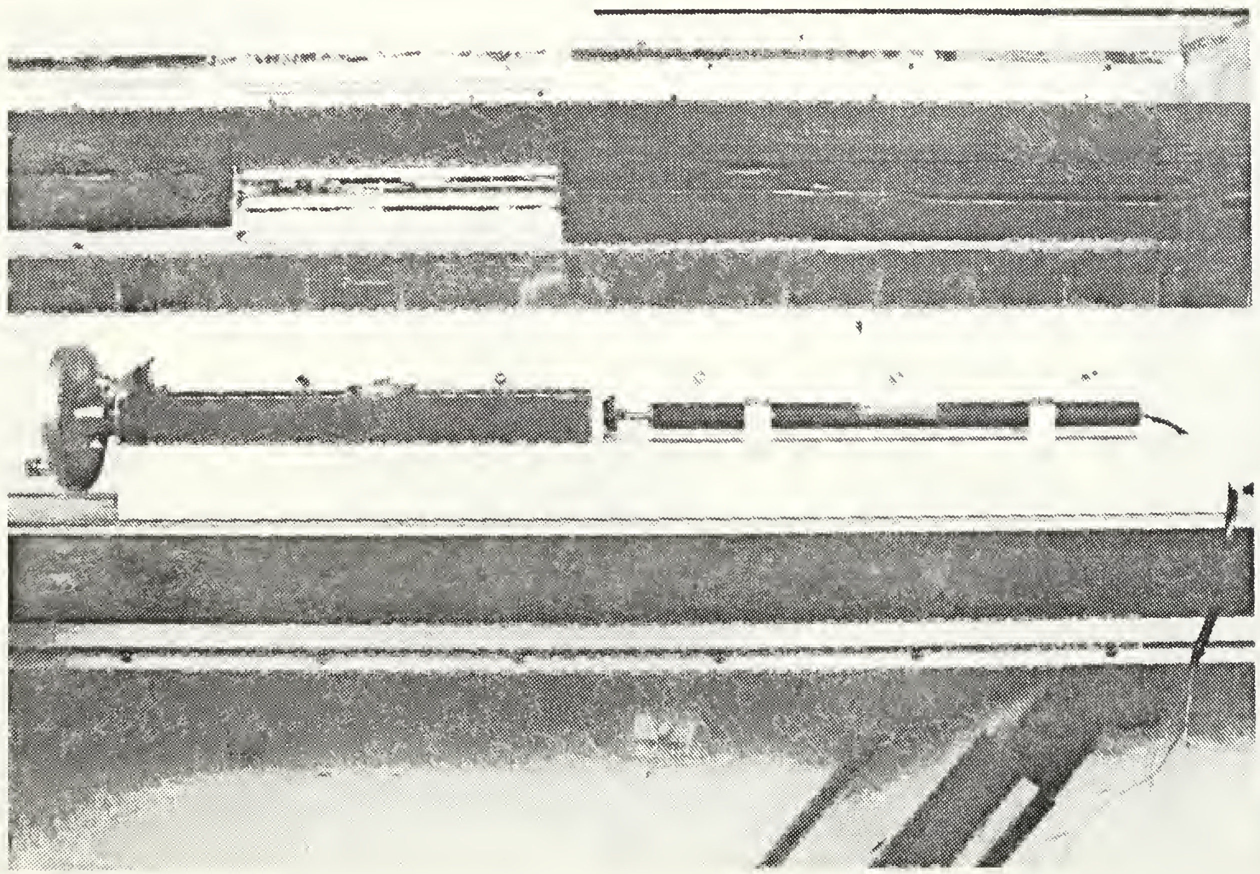

Figure 2. Plexiglas Wall With Slots and Probe Traverse

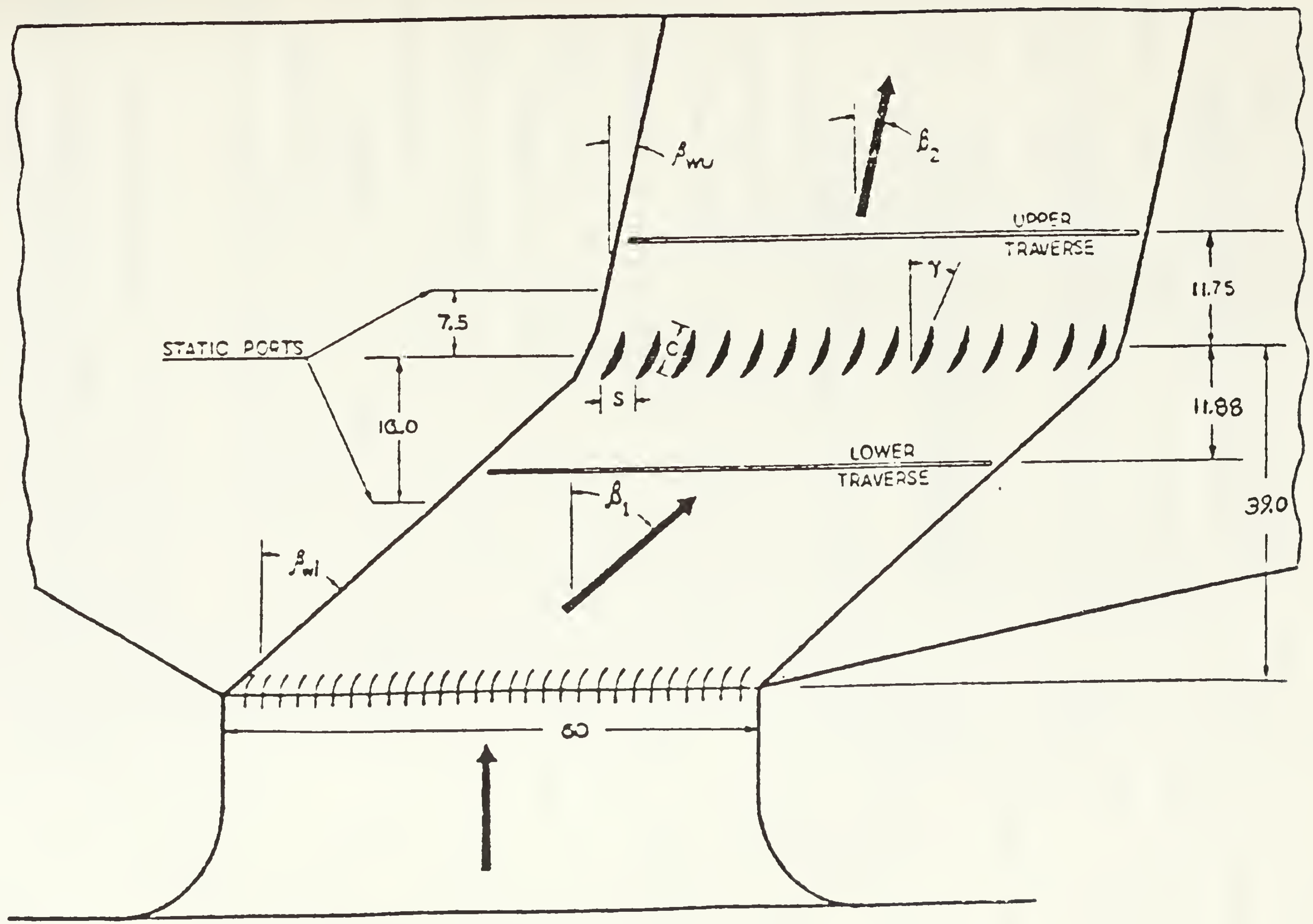

Figure 3. Cascade Test Section Schematic.

conditions far downstream from the blade row. The inlet probe was located 1.8 chord lengths (1.8c) ahead of the blade row. The outlet probe was 1.77c after the blade row. A conical probe was used to collect wake measurements close to the blade row. Measurements were made at 0.12c, 0.27c, 0.47c, 0.66c, and 1.185c (Fig. 4). The fourth yaw probe was design to determine flow angle in a 2D shear layer (Fig. 5). The probes were calibrated in a seven inch diameter free jet using the methods and software developed by Zebner [Ref. 7] and Neuhoff [Ref. 8].

Tunnel or plenum stagnation pressure was measured with a tube suspended in the plenum chamber. An Iron-Constantan thermocouple, similarly suspended in the plenum, measured stagnation temperature. Wall static pressure was recorded from two centrally located taps in the two rows of static taps provided in the South wall. One tap was located upstream and the other downstream of the cascade of blades. The two rows of static taps were connected to a water manometer, used to monitor the cascade's static pressure distibution. The static pressure is made uniform in the blade to blade direction by adjusting the inlet guide vanes and outlet tailboards.

A Hewlett Packard Data Acquisition System (HP-3052) and Hewlett Packard Interface Bus (HP-98034 HP-IB) was used to collect data. The system was controlled by a HP-9845A computer.

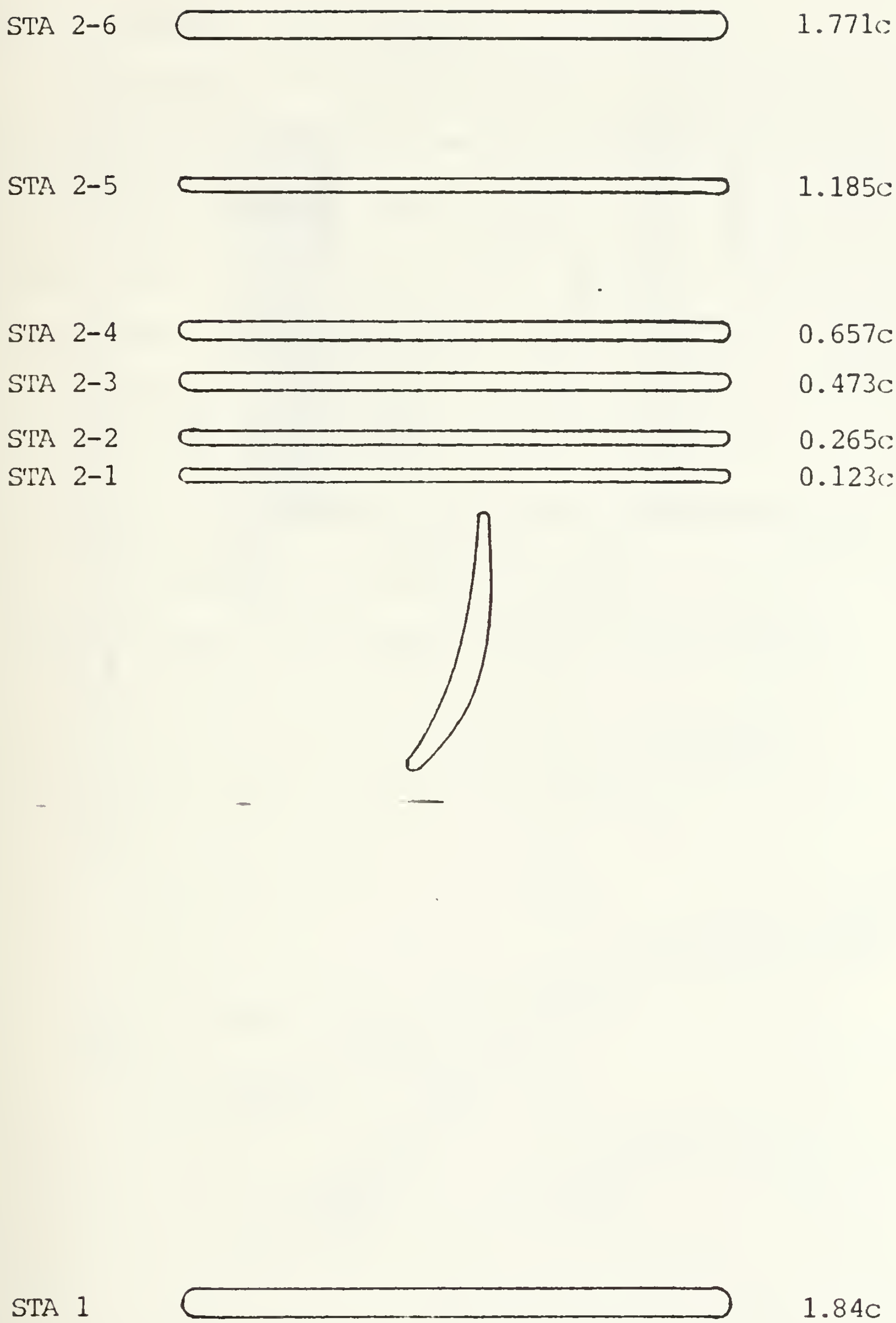

Figure 4. Probe Surveying Stations

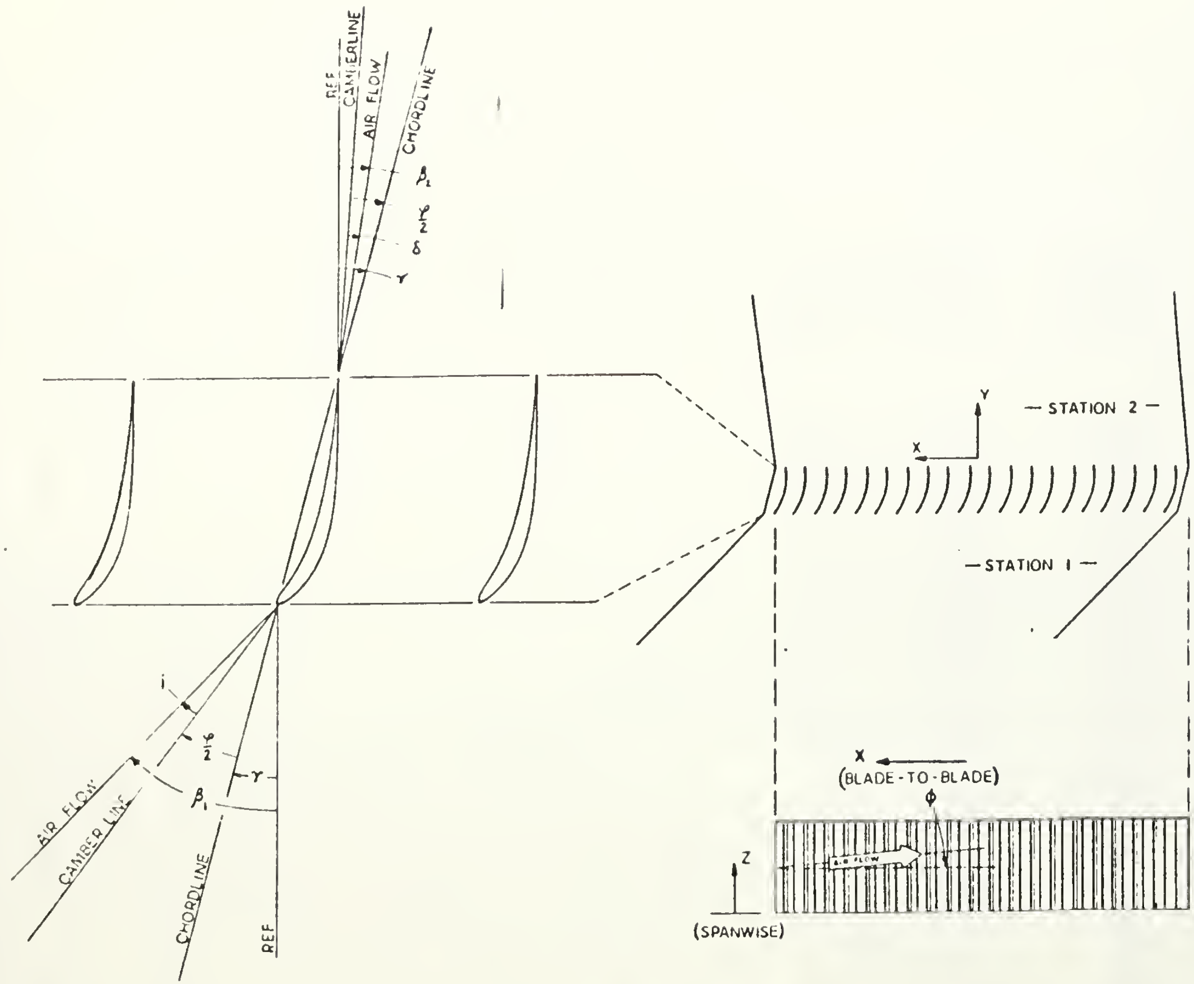

Figure 5. Cascade Geometry, and Definition of Angles.

Measurement uncertainties are listed in Table I. Uncertainties are discussed in detail in Appendix D.

C. CD BLADING AND CASCADE CONFIGURATION

The controlled diffusion test blades were from the midspan section of a CD stator blade and one was manufactured with pressure taps (Fig. 6). The coordinates for the blades were supplied by Sanger and are listed in Table II. Twenty cast aluminum blades were made with a span of ten inches to fit the test section of the rectilinear cascade. The instrumented blade was positioned in the center to serve as the test blade. The fixed geometrical parameters for the cascade are given in Table III. In the tests to be reported, only the inlet air angle was varied.

TABLE I

MEASUREMENT UNCERTAINTY

Item	Description	Method	Reading Uncertainty
x	Blade to Blade dimension	Position Potentiometer	$\pm$0.01 in.
z	Spanwise dimension	Machine divided scale hand adjustment	$\pm$0.05 in.
y	Axial dimension	Hand held Micrometer	$\pm$0.01 in.
β_1	Inlet flow (yaw) angle	Angle Potentiometer	$\pm$0.2 deg.
β_2	Outlet flow yaw angle	Angle Potentiometer deg	$\pm$0.2 deg.
P_{tref}	Plenum Total pressure	Static tap in plenum chamber $V \simeq 0$	$\pm$0.05 in H_2O
P	Pressure	Scanivalve transducer	$\pm$0.05 in H_2O
P_{atm}	Atmospheric pressure	Mercury manometer	$\pm$0.01 in Hg

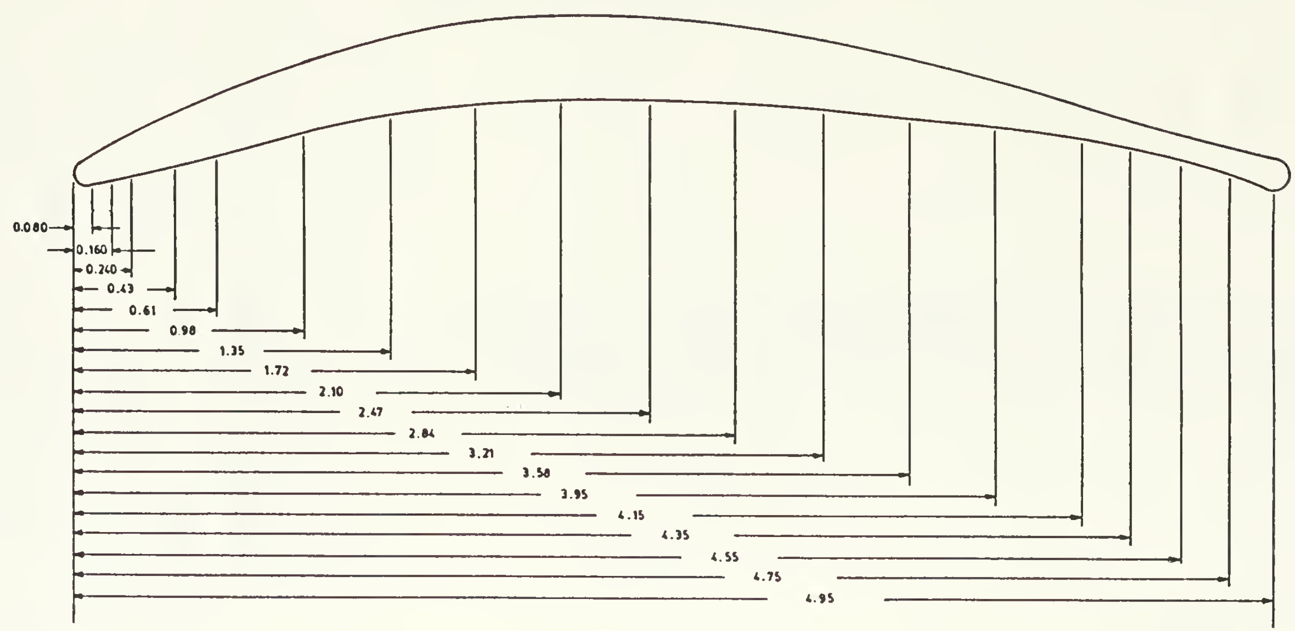

Figure 6. CD Blade Pressure Tap Locations.

TABLE II

TEST BLADE COORDINATES (INCHES)

X-COORD.	Y-COORD.	Z-COORD.
0.0	0.045	0.045
0.022	-----	0.084
0.057	0.002	-----
0.222	0.044	0.196
0.444	0.101	0.307
0.666	0.155	0.403
0.888	0.207	0.488
1.110	0.255	0.561
1.332	0.299	0.621
1.554	0.330	0.663
1.776	0.350	0.691
1.998	0.359	0.705
2.220	0.359	0.708
2.442	0.352	0.701
2.664	0.342	0.681
2.886	0.331	0.650
3.108	0.317	0.610
3.330	0.301	0.563
3.552	0.281	0.510
3.774	0.257	0.453
3.996	0.227	0.393
4.218	0.191	0.332
4.440	0.146	0.270
4.662	0.089	0.208
4.884	0.019	0.145
4.925	0.004	-----
4.964	-----	0.122
5.010	0.062	0.062

TABLE III

CASCADE DESIGN PARAMETERS

Number of Blades	20
Blade Spacing (inches)	3.0
Solidity	1.67
Thickness (% chord)	7.0
Stagger Angle	14.303

III. EXPERIMENTAL PROCEDURES

A. PREPARATION

Prior to testing, with one wall removed, the adjustable sidewalls and inlet guide vanes (IGV's) were set for the required flow angle. The probe position scales were set to zero with the downstream probes axially downstream of the instrumented blade trailing edge. The upstream scale's zero position was set based on the expected inlet flow angle to the leading edge of the instrumented blade. The cascade was then closed. On starting, the flow adjustments were made to the IGV's and tailboards to obtain nearly uniform wall static pressure distributions both upstream and downstream in the blade-to-blade direction. The pressure distribution downstream of the blades was at atmospheric. The inlet flow dynamic pressure was set to give a Mach number equal to 0.28

B. TEST PROCEDURE

With the flow stabilized, the surface pressures on the instrumented blades were recorded and surveys were made first with the two cylindical probes at stations 1 and 2-6. The probes were spaced three inches apart (one blade passage) to avoid the lower probe wake from interfering with the upper probe measurements. Measurements were taken while traversing the two probes over three blade passages.

Samples were taken at 0.1 inch intervals. The two surveys overlapped over two blade passages. Surveys were then made at five axial stations downstream of the blades using the conical probe. The surveys were conducted over a three inch segment of the cascade and were centered on the instrumented blade. Samples were taken at 0.1 inch intervals outside the blade wake and 0.05 inch intervals inside the wake. Finally the yaw probe was used to obtain an independent flow angle measurement. The data from the yaw probe were recorded by hand. Samples, rather than complete surveys were taken from inside and outside the wake.

Tests were conducted with near design inlet air angle (β_1=40.3°) and at one off-design condition toward stall (β_1=43.4°). A summary of probe surveys is given in Table IV.

Once collected the data was reduced using the formulas given in Table V and Appendix C.

TABLE IV

PROGRAM OF PROBE SURVEYS

Station	Nominal Air Inlet Angle	
	40°	44°
1	Cylin (1) Yaw Cylin (2)	Cylin (1) Yaw Cylin (2)
2-1	Conical	Conical
2-2	Conical Yaw	Conical
2-3	Conical	Conical
2-4	Conical	Conical
2-5	Conical	Conical
2-6	Cylin (2) Yaw Cylin (1)	Cylin (2) Yaw

TABLE V

CASCADE PERFORMANCE FORMULAS

Parameter	General Expression	Programmed Expression
Loss Coefficient	(Note 1)	(Note 2)
$\overline{\omega}$	$(\overline{C}p_{t_1} - \overline{C}p_{t_2})/(\overline{C}p_{t_1} - \overline{C}p_1)$	$\dfrac{\int_o^s Cp_{t_1}\, k_1\, dx - \frac{1}{AVDR}\int_o^s Cp_{t_2}\, k_2\, dx}{\int_o^s Cp_{t_1}\, k_1\, dx - \int_o^s Cp_1\, k_1\, dx}$
Diffusion Factor		
D	$1 - \frac{W_2}{W_1} + \frac{\Delta W_u}{2\sigma W_1}$	$1 - \frac{\cos\overline{\beta}_1}{\cos\overline{\beta}_2} + \frac{\cos\overline{\beta}_1(\tan\overline{\beta}_1 - AVDR(\tan\overline{\beta}_2))}{(1 + AVDR)\sigma}$
Axial Velocity Density Ratio		(Note 2)
AVDR	h_1/h_2	$\dfrac{\int_o^s (\frac{Pt_2}{Pt_{ref}})(\frac{X_2}{X_{ref}})(\frac{1-X_2^2}{1-X_{ref}^2})^{\frac{\gamma}{\gamma-1}} \cos\beta_2\, dx}{\int_o^s (\frac{Pt_1}{Pt_{ref}})(\frac{X_1}{X_{ref}})(\frac{1-X_1^2}{1-X_{ref}^2})^{\frac{\gamma}{\gamma-1}} \cos\beta_1\, dx}$

TABLE V (CON'T)

Static Pressure Rise Coefficient Cp_{static}	$\frac{\bar{P}_2 - \bar{P}_1}{\bar{P}_{t_1} - \bar{P}_1}$	$\frac{\frac{1}{AVDR}\int_o^s Cp_2\ k_2 dx - \int_o^s Cp_1\ k_1\ dx}{\int_o^s Cp_{t_1}\ k_1 dx - \int_o^s Cp_1\ k_1\ dx}$
Loss Coefficient Parameter Ω	$\frac{\bar{\omega}\cos^3\beta_2}{2\sigma\cos^2\beta_1}$	$\frac{\omega\cos^3\bar{\beta}_2}{2\sigma\cos^2\beta_1}$
Incidence Angle i	$\beta_1 - \gamma - \phi/2$	$\bar{\beta}_1 - \gamma - \phi/2$
Deviation Angle δ	$\phi/2 - \gamma + \beta_2$	$\phi/2 - \gamma + \bar{\beta}_2$

Note 1: "Barred" quantities are average values computed over a selected integration interval--usually one blade space.

Note 2: Derivation of programmed expression is given in Reference 1.

IV. RESULTS AND DISCUSSION

A. CASCADE PERFORMANCE AND FLOW QUALITY

The cascade performance was calculated from surveys measured at the midspan in the blade to blade direction. No surveys were made in the spanwise direction since uniformity in the spanwise direction was verified by Koyuncu [Ref. 3]. Loss coefficient, diffusion factor and AVDR were obtained from integration of the surveys made upstream and downstream of the blading. In order to examine the consistency of the measurements, the integrations were performed over different intervals. Performance parameters are shown (Figs. 7 through 9) for integration performed over two different blade passages at inlet air angles of (nominally) 40.3° and 43.4°. It can be seen that over the two separate intervals of integration, the value obtained for loss coefficient, diffusion factor and AVDR are in very close agreement for both test inlet angles. At 43.4°, the values are barely distinguishable from each other. The uniformity, periodicity and quality of the flow can be seen in the detailed survey data and plots given in Appendix A. Verification of the accuracy of the probe measurements was made by exchanging probes as described in Appendix D.

A comparison of the results obtained for loss coefficient is made with Koyuncu's data (Fig. 10). The

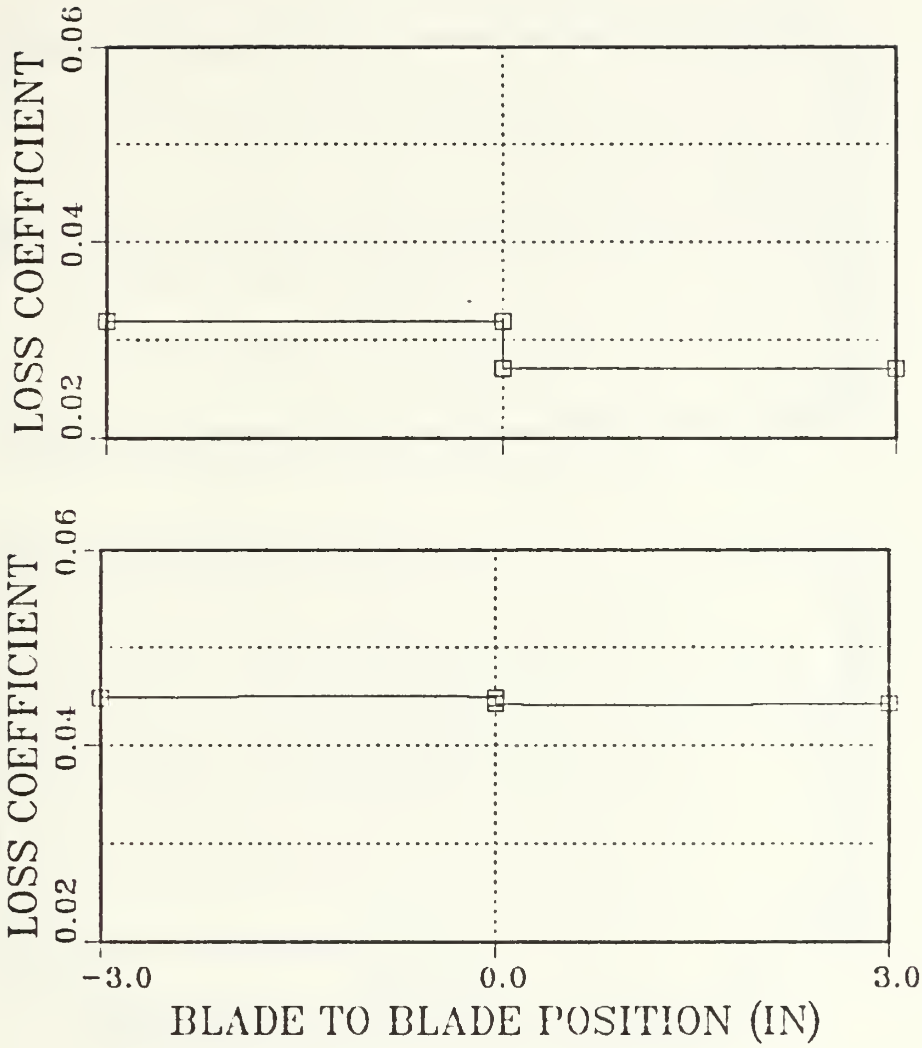

Figure 7. Comparison of Loss Coefficient From Integration Over Two Blade Passages. (Upper plot β_1=40.3°, Lower plot β_1=43.4°)

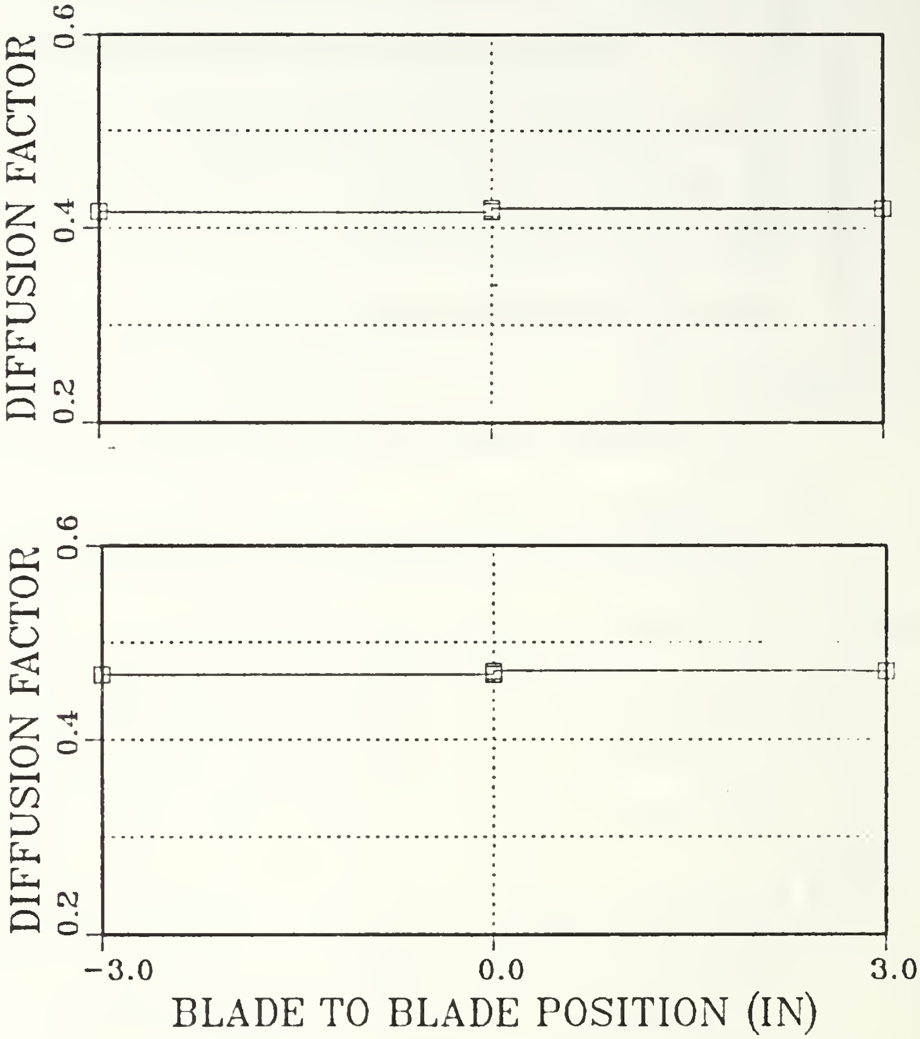

Figure 8. Comparison of Diffusion Factor From Integration Over Two Blade Passages. (Upper plot β_1=40.3, Lower plot β_1=43.4°)

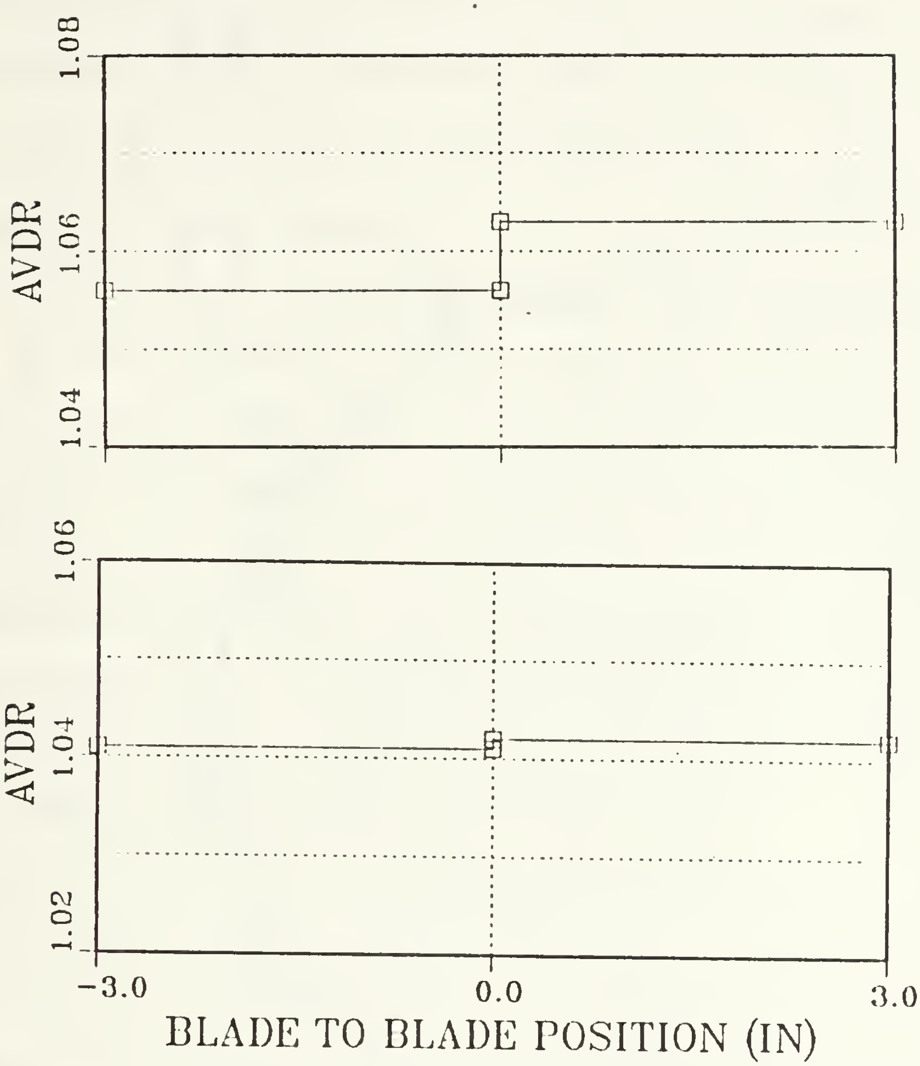

Figure 9. Comparison of AVDR From Integration Over Two Blade Passages. (Upper plot β_1=40.3°, Lower plot β_1=43.4°)

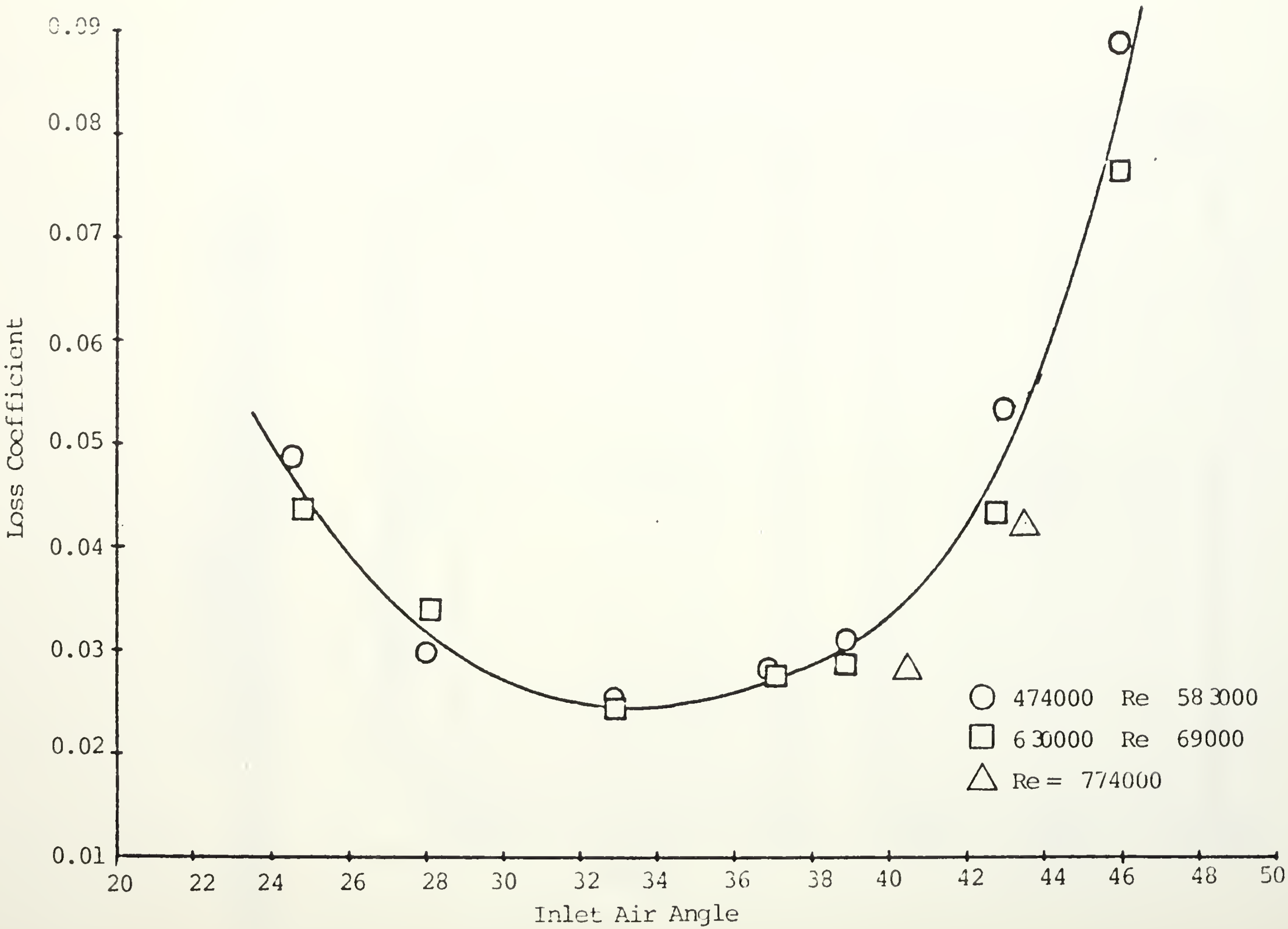

Figure 10. Loss Coefficient Vs Inlet Air Angle

present data are slightly lower than the single curve drawn through Koyuncu's data, however the data were obtained at a somewhat higher Reynolds number. At positive angles of incidence an effect of Reynolds number on the loss coefficient is suggested by the combined data.

B. RESULTS OF WAKE SURVEYS

Composite plots of the downstream (wake) surveys are shown in Fig. 11 and Fig. 12 for inlet air angle of 40.3° and 43.4° respectively. The velocity is shown referenced to the mass-averaged velocity upstream. The blade to blade position of each survey is referenced to the trailing-edge of the instrumented blade. The velocity scales are displaced in the y-direction in proportion to the axial displacement of the survey stations shown in Fig. 4.

1. Wake Velocity Decay

The wake decay downstream of the blading is qualitatively as expected. The centerline velocity at station 2-1 is 30% of inlet velocity compared to 80% outside the wake. This is due to the fact that the trailing edge of the blade is quite blunt. At station 2-6 the velocity has increased to 72% and is approaching a mixed out condition.

2. Velocity Profiles

Differences in individual velocity profiles in the blade to blade direction can be most clearly seen at station 2-1. The pressure side has a steep velocity gradient while

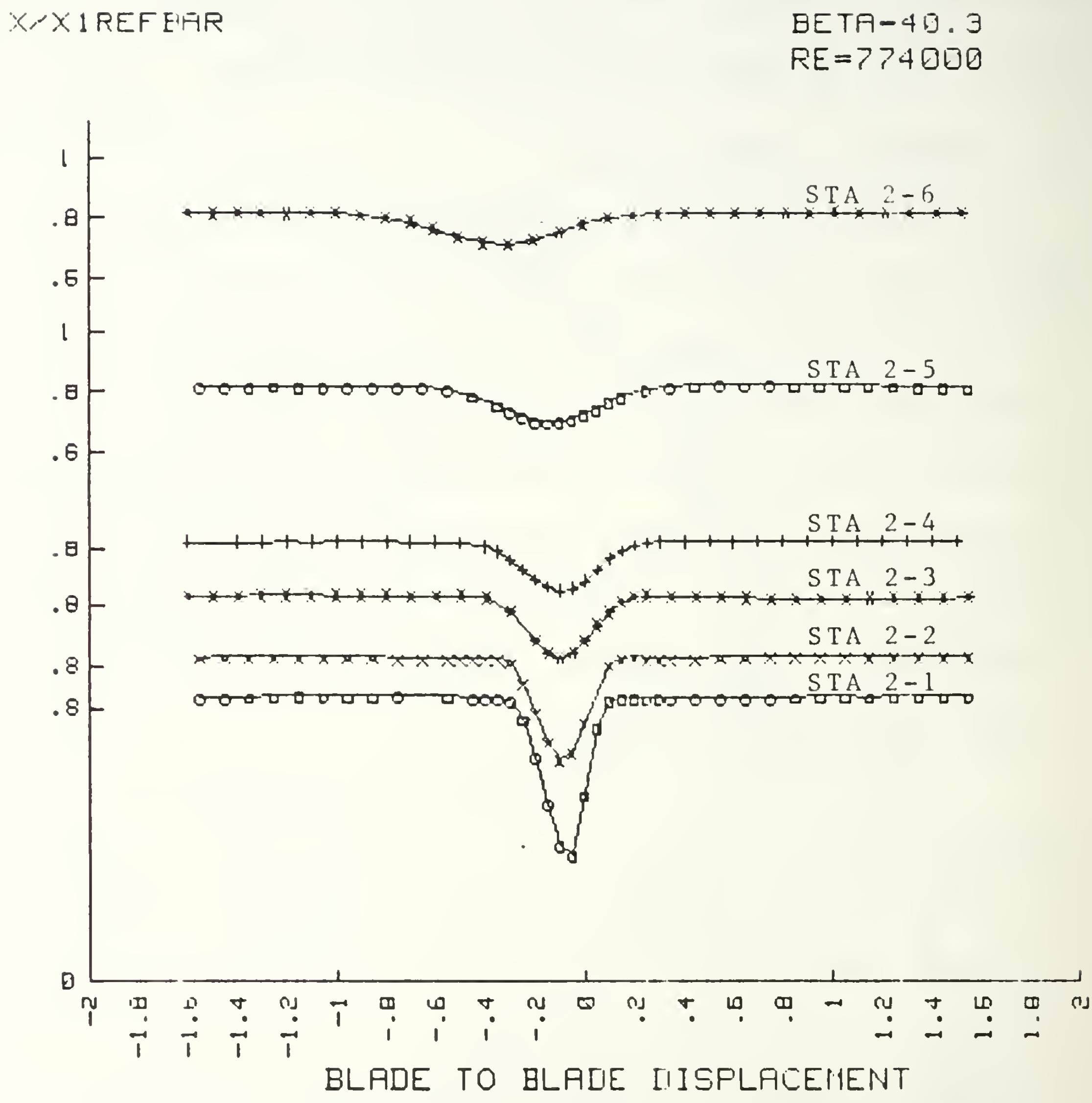

Figure 11. Outlet to Inlet Velocity Vs Blade to Blade Displacement (β_1=40.3°)

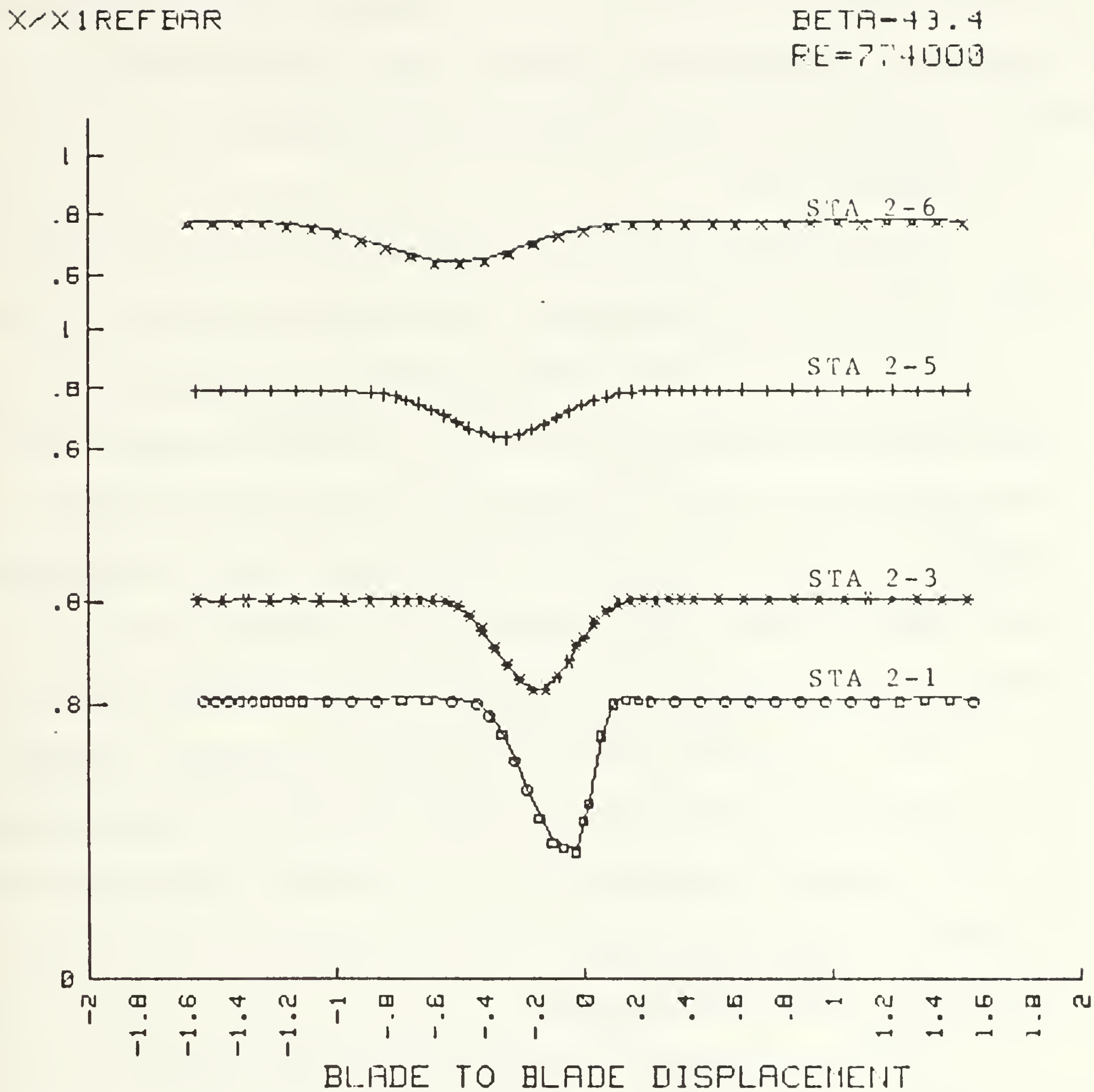

Figure 12. Outlet to Inlet Velocity Vs Blade to Blade Displacement. (β_1=43.4°)

the suction side has a more gradual variation. The wake thickness was significantly increased at β_1=43.4°. The adverse pressure gradient on the suction side results in an increase in the surface boundary layer thickness and subsequent reduction in wake velocity gradient.

3. Wake Path

The displacement of the wake centerline from the blade trailing edge centerline can be seen in Figs. 11 and 12. At the farther downstream stations the displacement becomes more noticable. At β_1=43.4° the wake centerline displacement is almost linear but not so at 40.3°. The cascade was design to give an outlet air angle of zero. The displacement of the wake centerline at station 2-6 (1.771 chord lengths) implies an average deviation angle (δ) at β_1=40.3° of δ=1.94° and for β_1=43.4°, δ=3.23°. However it is interesting to note that at the design inlet condition the wake centerline appears to move axially between 0.2 and 0.8 chordlengths downstream.

4. Yaw Angle Measurement

Both cylindrical and conical probes gave measurements of yaw angle distribution in the blade to blade direction. When relatively large excursions in yaw angle were recorded within the blade wake, the fourth probe, which was specifically designed to measure yaw angle correctly within a two-dimensional wake, was used to verify the observation at the specific stations as listed in Table IV.

The yaw angle probe was very carefully nulled in the calibration free jet, and the null setting referenced to horizontal using a reference bar on the probe shaft and precision spirit level. The reference was reestablished when the probe was mounted on the cascade. Thus the absolute uncertainty in the yaw angle measured with the yaw probe in the cascade was less than 0.4°. Since the absolute reference for the cylindrical and conical probes was not mantained in some of the measurements, these measurements were adjusted such that equal angles were measured outside the blade wakes on the pressure side. It was then possible to examine the distribution of yaw angle measured through the blade wakes.

Figures 13 and 14 show comparisons between the cylindical and yaw probe measurements at station 2-6, and the conical and yaw probe measurements at station 2-2 respectively at β_1=40.3°. It is seen that whereas the cylindrical probe indicates an excursion of almost $\pm$ 1.5° in yaw angle far downstream, the yaw probe registered no more than $\pm$ 0.75°. Closer to the blades (station 2-2) the conical probe indicated $\pm$ 2.3° and this was reasonably well confirmed by the yaw probe.

The exagerated indication of yaw angle given by the cylindrical probe is seen again in the results at β_1=43.4° (Fig. 15). It is noted that while few points are shown here for the yaw probe measurements, points representing larger excursions were not passed during the manual traverse. Thus

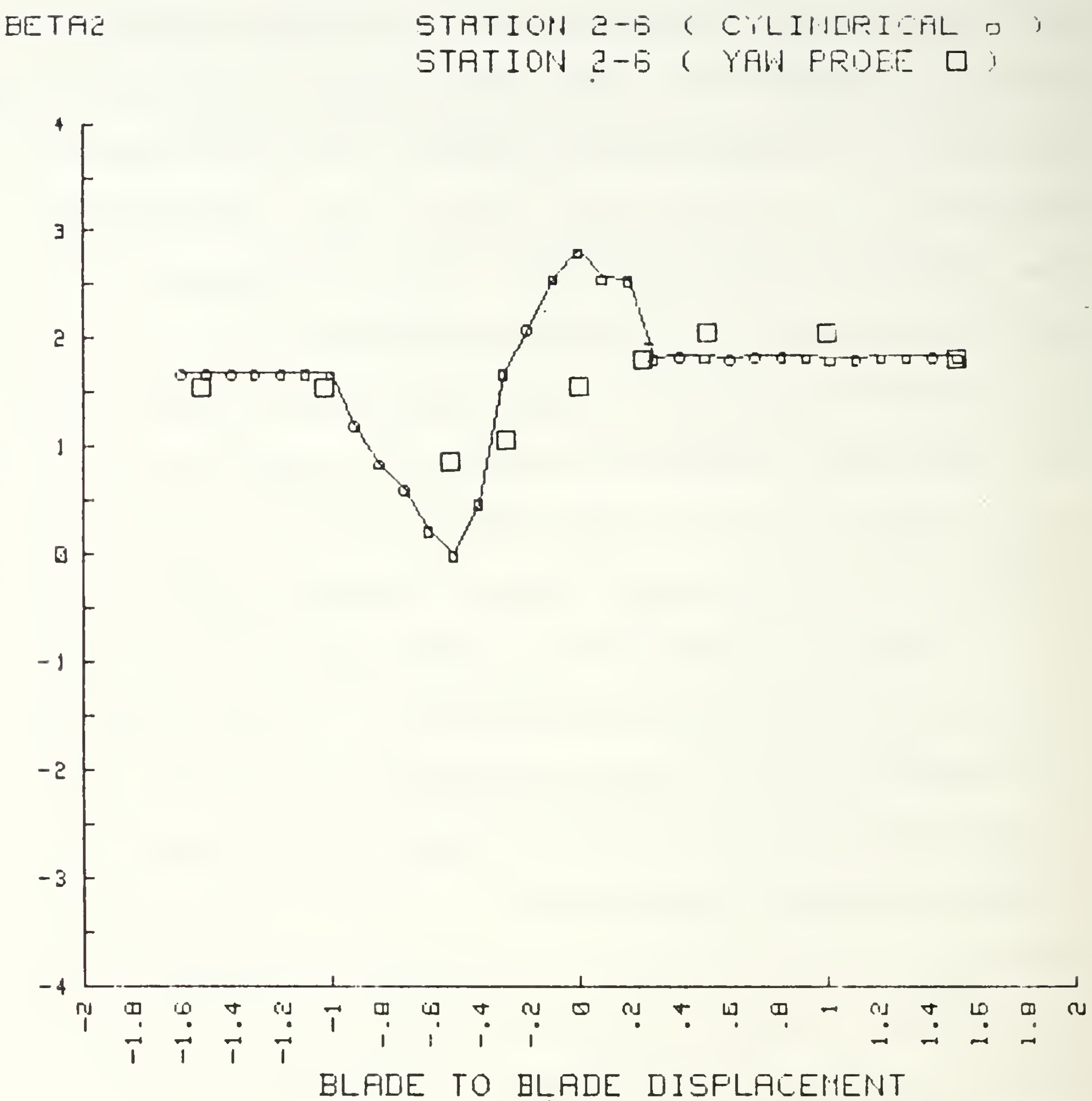

Figure 13. Outlet Air Angle Vs Blade to Blade Displacement at Station 2-6 for $\beta_1 = 40.3°$. (US Corp. 5 hole cylindrical probe and yaw probe.)

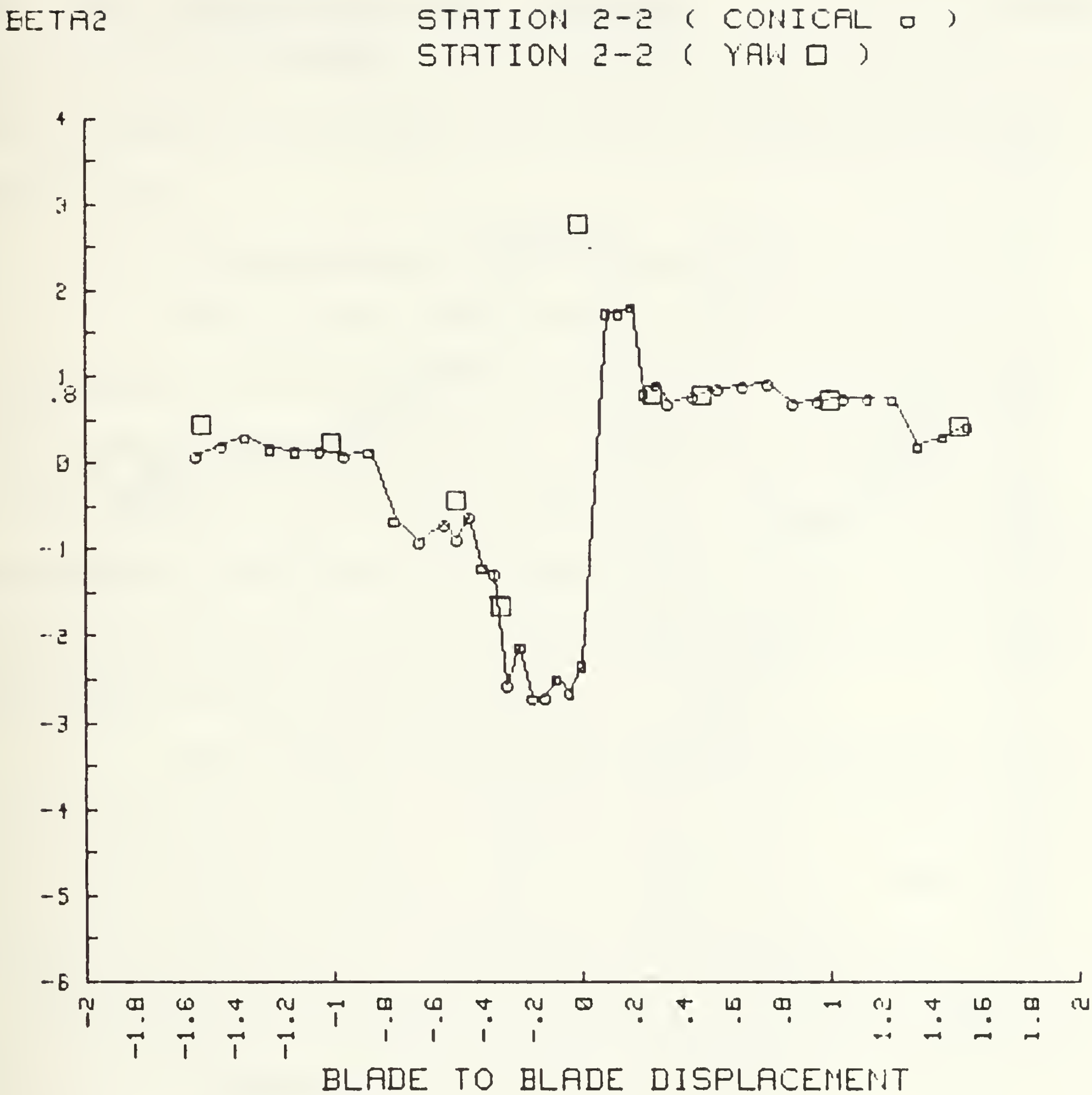

Figure 14. Outlet Air Angle Vs Blade to Blade Displacement at Station 2-2 for β_1=40.3°. (Conical probe and yaw probe.)

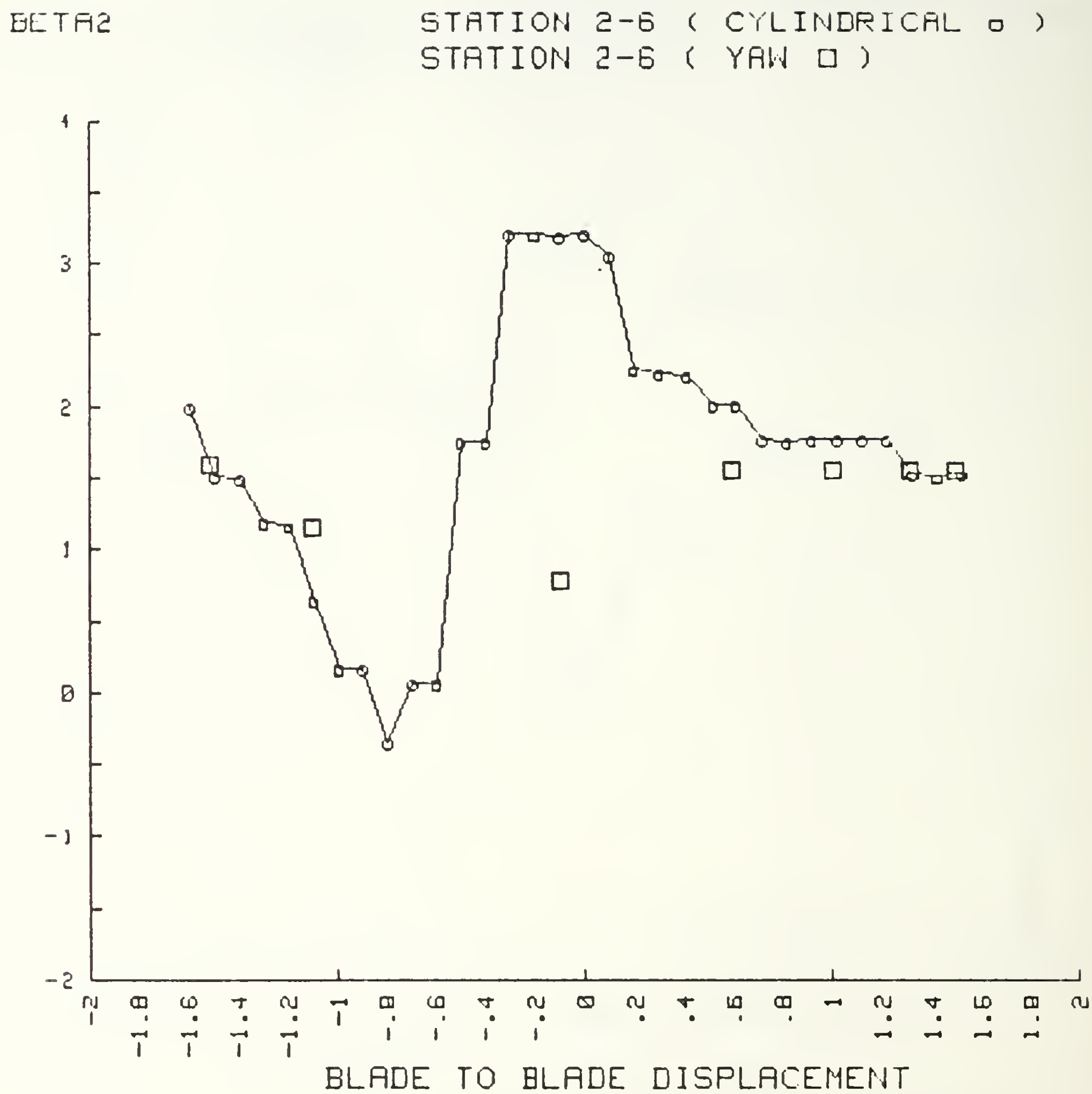

Figure 15. Outlet Air Angle Vs Blade to Blade Displacement at Station 2-6 For β_1=43.4°. (Cylindrical probe and yaw probe.)

the cylindrical probe indicated a variation of $\pm$ 1.8° whereas the yaw probe showed no more than $\pm$ 0.5°.

Data for yaw angle from the cylindrical and conical probe surveys are given in Table A.1 through Table A.12. Note that the negative of β is given in some cases. Data for the yaw probe measurements are given in Table A.14 through Table A.18.

5. Integration To Obtain Performance

Each of the cone probe surveys could be used in conjunction with survey data from station 1, to establish the blade element performance. The adopted procedures of referencing all survey measurements to plenum supply and atmospheric conditions allowed that upstream and downstream surveys to be carried out separately, as long as no change was made to the cascade geometry.

The results for blade element performance based on surveys at stations 2-1 to 2-6 at β_1=40.3° and β_1=43.4° are shown in Fig. 16 and Fig. 17 respectively . Extremely consistent results are noted with one exception at β_1=43.4°. An inconsistently low value of AVDR was obtained from the cylindrical probe at station 2-6. More measurements are required to examine the one inconsistency.

C. BLADE SURFACE PRESSURE DISTRIBUTIONS

Surface pressure coefficients are shown plotted in Fig. 18 and Fig. 19 for β_1=40.3° and β_1=43.4° respectively.

The data are given Appendix B in Table B.1 through Table B.4. The pressure coefficients were calculated using Eq. (C-5) of Appendix C.

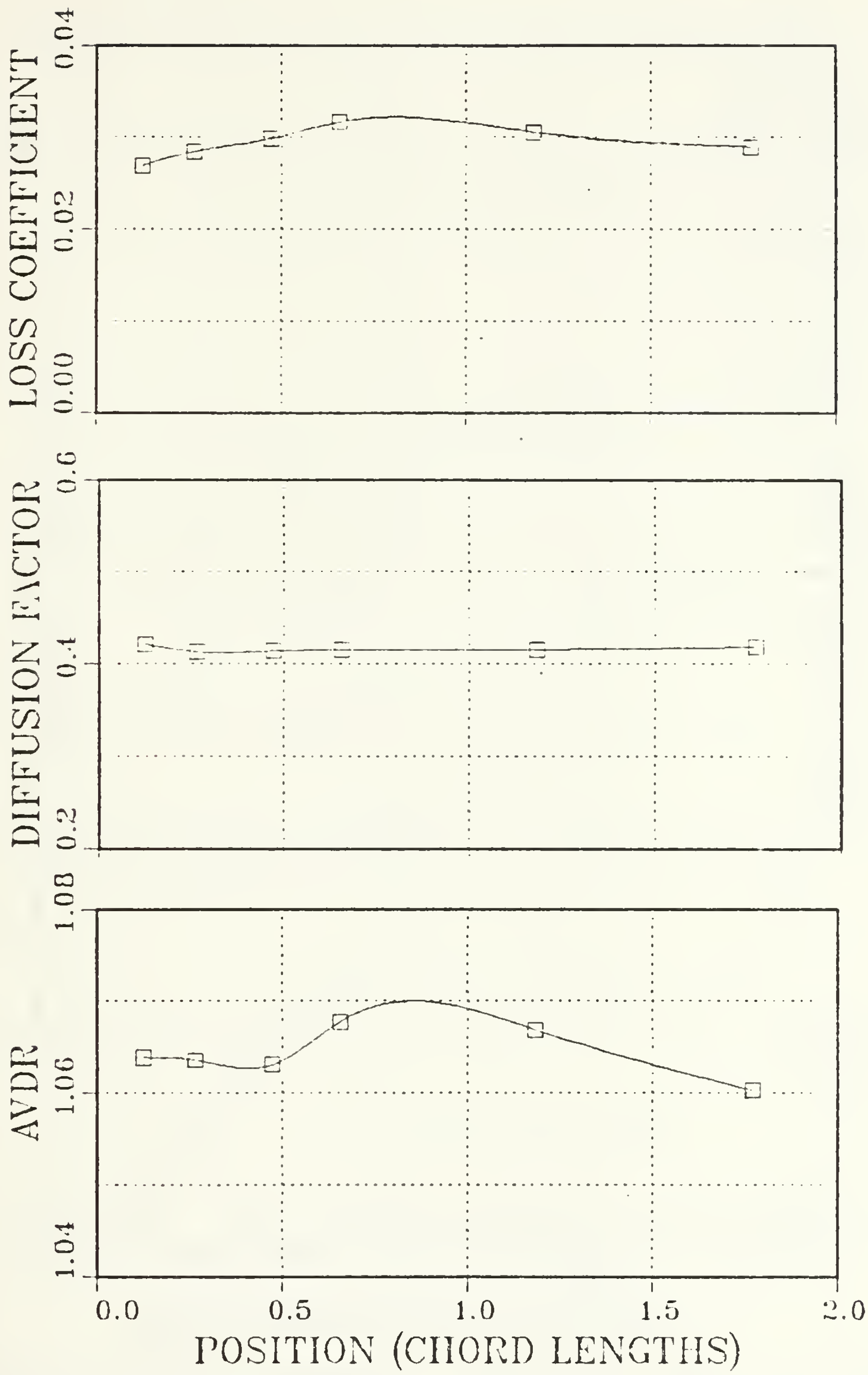

Figure 16. Loss Coefficient, Diffusion Factor and AVDR From Probe Surveys At Six Stations. (β_1=40.3°)

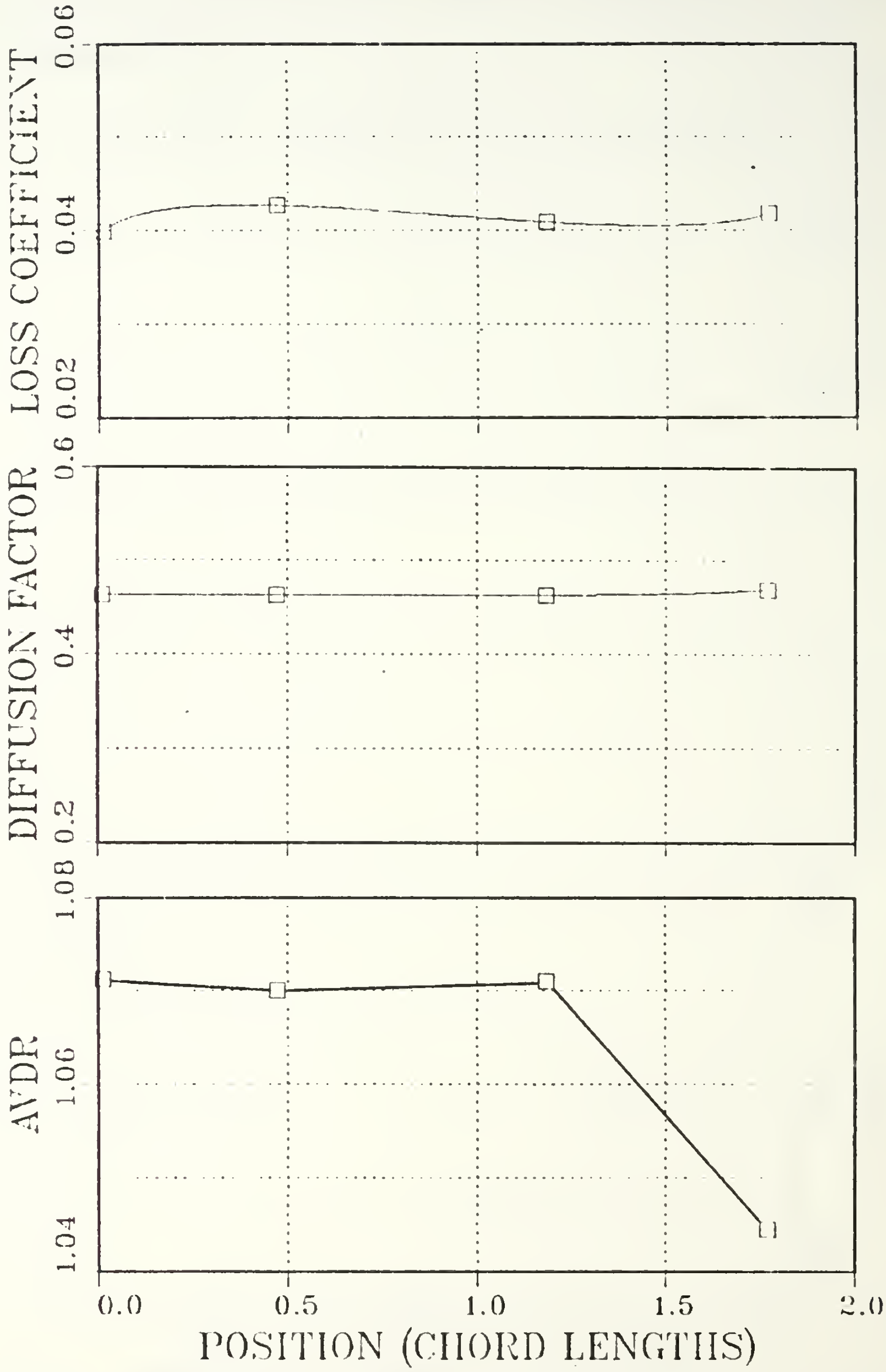

Figure 17. Loss Coefficient, Diffusion Factor and AVDR From Probe Surveys at Six Stations. (β_1=43.4°)

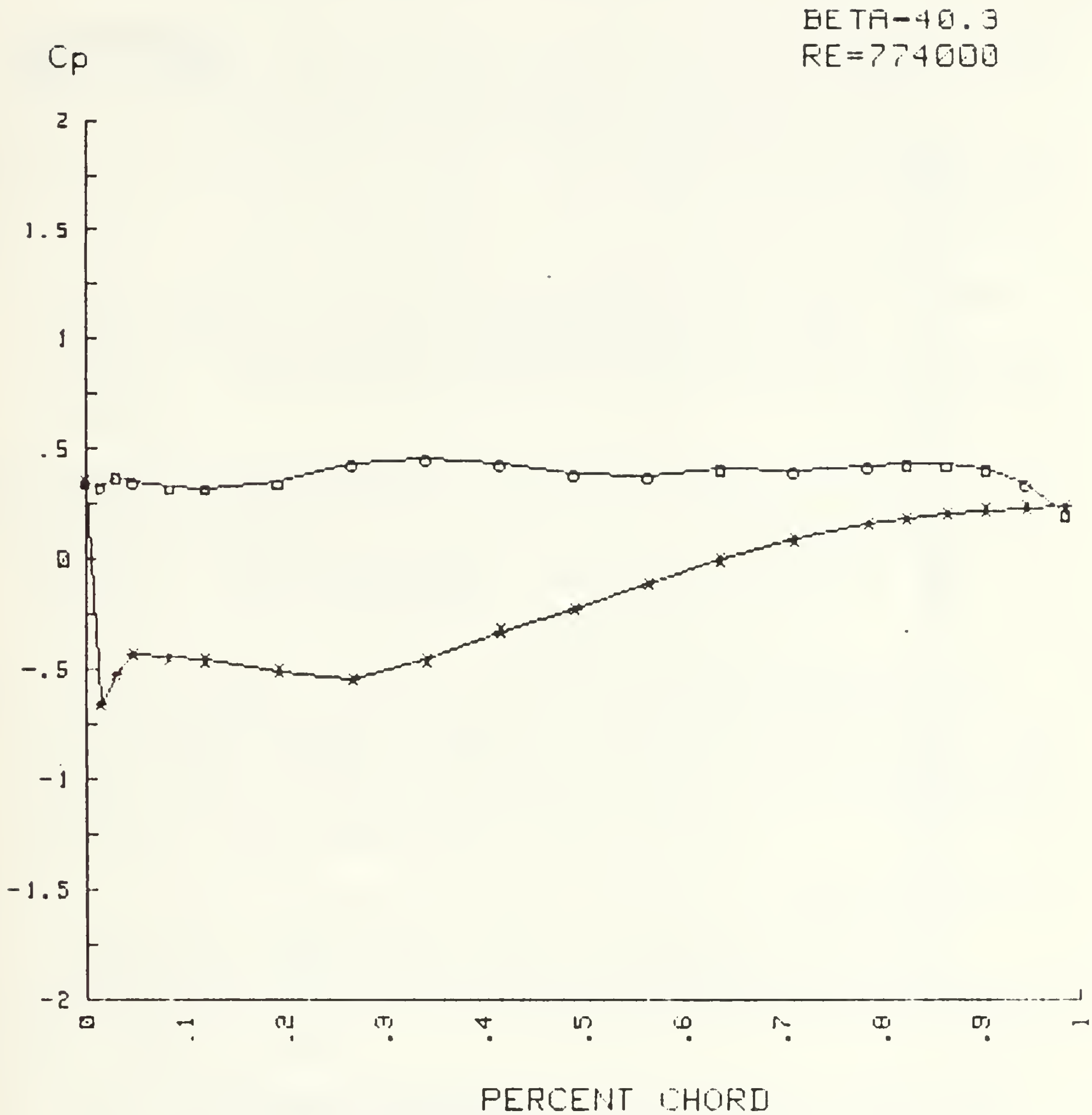

Figure 18. Blade Surface Pressure at Midspan for β_1=40.3°. (M_1=0.272)

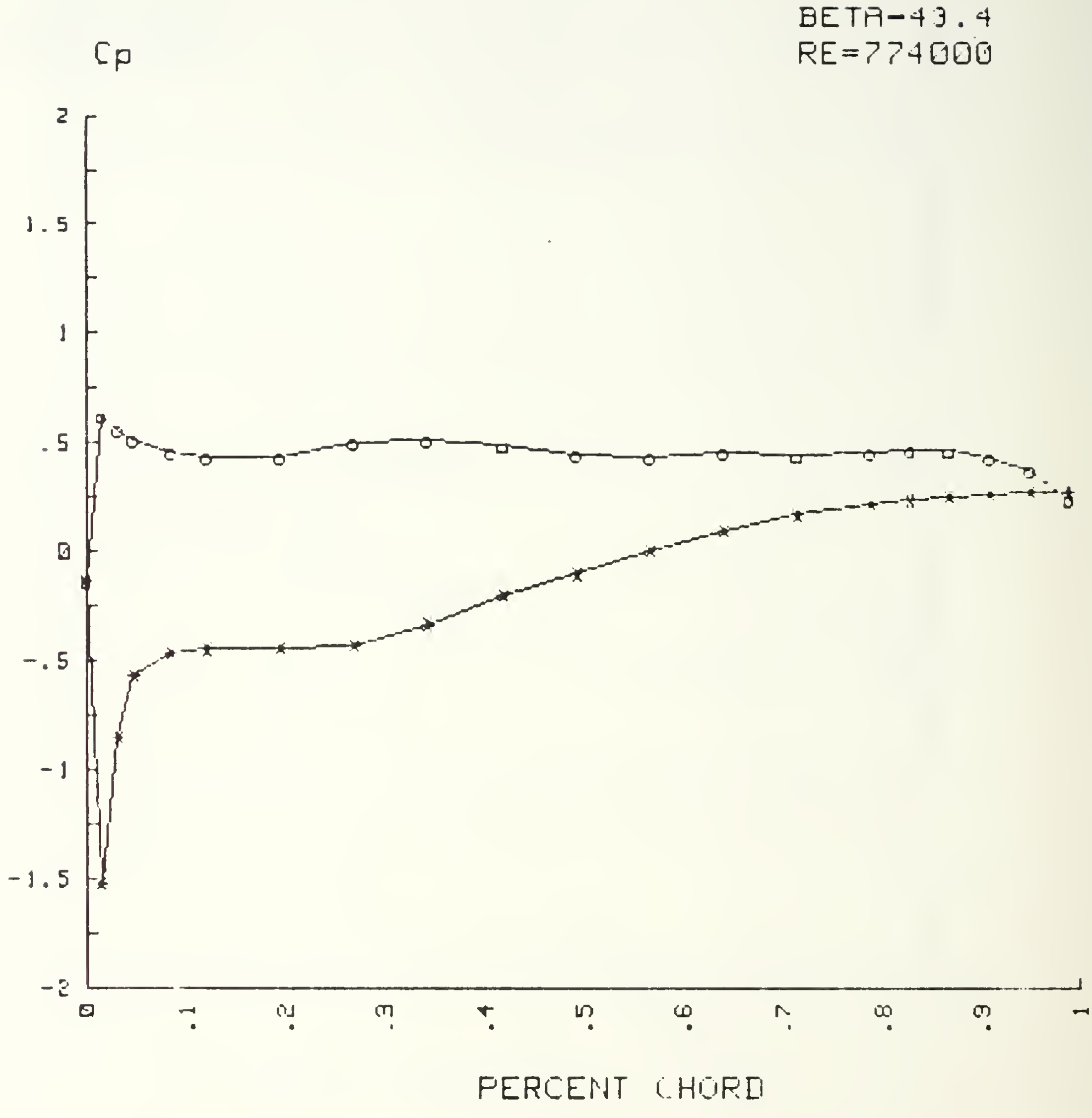

Figure 19. Blade Surface Pressure at Midspan for $\beta_1=43.4°$. ($M_1=0.274$)

V. CONCLUSIONS AND RECOMMENDATIONS

Probe surveys were carried out at various stations from 0.12 to 1.77 chordlengths downstream of Sanger's CD compressor cascade at two air inlet angles (near design and toward stall), which resulted in the following conclusions:

1. Blade element performance parameters did not depend significantly on the location of the survey station. One possible exception was found in AVDR at β_1=43.4° which dropped by 2.5% at the most downstream position.

2. The data obtained were consistent with those obtained earlier by Koyuncu at a somewhat lower Reynolds number [Ref. 3]. Considered together with Koyuncu's data, the loss coefficient appears to decrease with increasing Reynolds number.

3. Complete wake velocity profiles were otained which were asymetric near the blade trailing edge. Increasing deviation angles (from 1.9° to 3.4°) were traced out by the paths of the wake as the inlet air angle was increased from 40.3° to 43.4°. The width of the wake also increased substantially.

4. The conical probe measured yaw angle variations through the wake which were confirmed by a yaw probe. The cylindrical probe recorded yaw angle variations which were much larger than those indicated by the yaw probe.

5. Blade surface pressure distributions were obtained which did not show anomalies near the trailing edge which had appeared in Koyuncu's data. The differences were attributed to the elimination of pneumatic leaks.

Recommendations for future tests include the following modifications:

1. All probes should be calibrated by varying pitch and yaw together as described in Appendix D. This

may increase the general accuracy of yaw angle measurements when small pitch angles are present.

2. Only conical probes need be used in the downstream position to avoid yaw angle inaccuracies in the wake exhibited by the cylindrical probe.

3. Modifications to the cascade computer reduction programs need to be incorporated to automate the inclusions of yaw angle referencing procedures and procedures which result from the first recommendation.

4. Computer-controlled, automatic probe drives should be installed to greatly reduce the present labor and energy costs involved in acquiring data.

APPENDIX A

FLOW QUALITY AND CASCADE PERFORMANCE DATA

A1. CALIBRATED PROBE SURVEY DATA

Survey data for different stations in the cascade are tabulated in Tables A.1 through A.12. and shown in Figs. A1. through A36. Values listed include flow angles (-β is shown) and nondimensionalized dynamic pressure, static pressure, total pressure and velocity. The notation is as follows:

Local dynamic pressure	Q/Q1refbar
Local static pressure	[Ps-Ps1refbar]/Q1refbar
Local total pressure	[Pt1bar-Pt)/Q1refbar
Local velocity	X/X1refbar

The tabulated quantities are derived in such a way that they are independent of supply fluctuations during the probe surveys. Dimensional quantities can be obtained for code verifcation purposes by substituting for the upstream reference conditions denoted by subscript "1refbar", the average obtained by multiplying the mass average ratio of upstream local to reference conditions (subscript "bar") by the ensemble average of the cascade reference conditions (subscript "refave") recorded during the survey.
i.e., $(\ )_{1refbar} = (\ )_{bar}\ (\ )_{refave}$. Note that 'reference

conditions' are T_{ref} and P_{ref} (measured in the plenum), and P_{atm} (corrected barometric pressure) from which a reference dimensionless velocity, X_{ref} is calculated from the isentropic relationship

$$X_{ref} = \left(1 - \left(\frac{P_{atm}}{P_{ref}} \right)^{\left(\frac{\gamma-1}{\gamma}\right)} \right)^{1/2} \qquad \text{(A-1)}$$

The required reference quantities for the inlet air angle are given in Table A.13.

Notes: 1) The quantitity 'Q' is the difference between stagnation and static pressure, and is reference to plenum pressure, i.e.,

$$Q_{bar} = \frac{\overline{P_t - P}}{P_{ref}}$$

2) The subscript "2bar" denotes downstream mass averaged local to reference conditions.

A2. YAW PROBE SURVEY DATA

Yaw probe surveys were conducted at selected stations listed in Table IV. Data recorded manually, are listed in Tables A.14 through A.18.

A3. DATA STORAGE

All data were stored on magnetic tape. Table A.19 identifies the storage file names with the survey station and test parameters.

TABLE A.1

BLADE TO BLADE PROBE DATA AT MIDSPAN DATA FILE BD6250

Upper Plane: Beta1=40.3 Re=774000 X1ave=.1211 Q1ave=21.86

Point	Loc(in)	-Beta	Q / Q1refbar	Ps-Ps1bar / Q1refbar	Pt1bar-Pt / Q1refbar	X / X1refbar
1	-6.04	-1.59	.5536	.3397	.1008	.7480
2	-6.00	-2.19	.5836	.3316	.0785	.7680
3	-5.90	-2.21	.6267	.3283	.0375	.7958
4	-5.80	-2.20	.6539	.3248	.0132	.8128
5	-5.70	-2.19	.6616	.3266	.0035	.8181
6	-5.60	-1.60	.6658	.3287	-.0028	.8213
7	-5.40	-1.71	.6674	.3305	-.0063	.8243
8	-5.30	-1.69	.6648	.3290	-.0022	.8214
9	-5.20	-1.68	.6629	.3292	-.0004	.8207
10	-5.10	-1.70	.6671	.3307	-.0062	.8238
11	-5.00	-1.70	.6602	.3318	-.0002	.8196
12	-4.90	-1.70	.6623	.3296	-.0002	.8201
13	-4.80	-1.72	.6611	.3298	.0009	.8187
14	-4.70	-1.68	.6573	.3323	.0022	.8180
15	-4.61	-1.70	.6478	.3311	.0133	.8122
16	-4.50	-1.71	.6533	.3278	.0109	.8145
17	-4.41	-1.69	.6494	.3315	.0112	.8125
18	-4.31	-1.71	.6466	.3320	.0135	.8110
19	-4.20	-1.73	.6477	.3338	.0105	.8126
20	-4.11	-1.57	.6473	.3325	.0123	.8126
21	-4.01	-1.37	.6520	.3285	.0115	.8147
22	-3.91	-1.36	.6467	.3339	.0115	.8108
23	-3.81	-1.14	.6567	.3201	.0150	.8093
24	-3.71	-.21	.6384	.3194	.0345	.7968
25	-3.61	-.25	.6174	.3183	.0571	.7832
26	-3.51	-.14	.5805	.3168	.0963	.7598
27	-3.41	.20	.5434	.3207	.1303	.7358
28	-3.31	-.97	.5207	.3192	.1550	.7202
29	-3.21	-1.19	.5205	.3195	.1549	.7195
30	-3.11	-1.71	.5522	.3216	.1204	.7421
31	-3.01	-2.32	.5951	.3201	.0780	.7708
32	-2.91	-2.32	.6329	.3207	.0389	.7952
33	-2.81	-2.32	.6533	.3192	.0194	.8084
34	-2.71	-1.94	.6651	.3257	.0008	.8192
35	-2.61	-1.69	.6623	.3281	.0013	.8179
36	-2.51	-1.69	.6670	.3280	-.0034	.8213
37	-2.41	-1.69	.6655	.3310	-.0049	.8209
38	-2.31	-1.70	.6661	.3273	-.0018	.8199
39	-2.21	-1.71	.6621	.3287	.0009	.8184
40	-2.10	-1.68	.6675	.3255	-.0014	.8225
41	-2.00	-1.70	.6625	.3277	.0016	.8180
42	-1.90	-1.68	.6607	.3274	.0036	.8168
43	-1.80	-1.68	.6569	.3299	.0050	.8146

TABLE A.1 CON'T

44	-1.70	-1.70	.6577	.3271	.0070	.8147
45	-1.60	-1.69	.6627	.3255	.0034	.8186
46	-1.50	-1.69	.6606	.3262	.0049	.8171
47	-1.40	-1.69	.6635	.3264	.0017	.8190
48	-1.30	-1.69	.6659	.3212	.0045	.8198
49	-1.20	-1.69	.6618	.3265	.0034	.8167
50	-1.10	-1.70	.6625	.3260	.0032	.8185
51	-1.00	-1.68	.6666	.3202	.0048	.8203
52	-.90	-1.22	.6507	.3313	.0100	.8113
53	-.80	-.86	.6376	.3318	.0229	.8023
54	-.70	-.62	.6171	.3331	.0426	.7910
55	-.61	-.24	.5791	.3319	.0826	.7648
56	-.50	-.01	.5371	.3321	.1253	.7370
57	-.40	-.48	.5096	.3330	.1524	[illegible]
58	-.30	-1.70	.5038	.3329	.1585	.7144
59	-.21	-2.10	.5243	.3320	.1385	.7275
60	-.10	-2.57	.5626	.3305	.1009	.7538
61	0.00	-2.82	.6068	.3296	.0566	.7840
62	.10	-2.57	.6365	.3274	.0285	.8013
63	.20	-2.56	.6550	.3269	.0101	.8131
64	.30	-1.83	.6615	.3280	.0022	.8166
65	.41	-1.85	.6649	.3270	-.0002	.8192
66	.51	-1.84	.6647	.3285	-.0016	.8200
67	.61	-1.83	.6647	.3269	-.0000	.8195
68	.71	-1.85	.6670	.3267	-.0021	.8204
69	.82	-1.85	.6672	.3290	-.0046	.8221
70	.92	-1.84	.6664	.3263	-.0010	.8179
71	1.02	-1.82	.6696	.3269	-.0049	.8231
72	1.12	-1.83	.6682	.3267	-.0033	.8217
73	1.22	-1.84	.6679	.3276	-.0039	.8218
74	1.32	-1.84	.6658	.3293	-.0035	.8214
75	1.43	-1.86	.6660	.3304	-.0048	.8218
76	1.53	-1.84	.6658	.3298	-.0040	.8210
77	1.63	-1.46	.6659	.3303	-.0046	.8207
78	1.73	-1.46	.6684	.3291	-.0059	.8217
79	1.83	-1.44	.6573	.3323	.0023	.8165
80	1.93	-1.47	.6625	.3332	-.0040	.8188
81	2.03	-1.46	.6589	.3312	.0017	.8152
82	2.22	-1.45	.6597	.3266	.0055	.8168
83	2.24	-1.45	.6416	.3329	.0177	.8068
84	2.34	-.23	.6173	.3347	.0408	.7905
85	2.45	-.25	.5822	.3304	.0810	.7671
86	2.55	.23	.5440	.3342	.1162	.7418
87	2.65	-.74	.5176	.3347	.1426	.7238
88	2.75	-1.47	.5026	.3432	.1494	.7138
89	2.85	-2.18	.5301	.3347	.1299	.7325
90	2.96	-2.32	.5667	.3383	.0890	.7577
91	3.06	-2.31	.6069	.3379	.0483	.7847
92	3.16	-2.58	.6387	.3310	.0225	.8038
93	3.26	-2.59	.6529	.3285	.0106	.8125

TABLE A.2

BLADE TO BLADE PROBE DATA AT MIDSPAN DATA FILE BD6250

Lower Plane: Beta1=40.3   Re=774000   X1ave=.1211 Q1ave=21.26

Point	Loc(in)	-Beta	Q / Q1refbar	Ps-Ps1bar / Q1refbar	Pt1bar-Pt / Q1refbar	X / X1refbar
1	-3.05	-39.97	.9833	.0029	-.0048	1.0025
2	-3.03	-40.11	.9838	.0029	-.0053	1.0028
3	-2.94	-40.08	.9847	.0057	-.0090	1.0033
4	-2.85	-40.10	.9809	.0046	-.0040	1.0014
5	-2.74	-40.11	.9784	.0056	-.0025	1.0009
6	-2.63	-40.10	.9748	.0061	.0009	.9999
7	-2.43	-40.09	.9715	.0116	-.0012	1.0005
8	-2.32	-40.11	.9798	.0050	-.0033	1.0033
9	-2.22	-40.11	.9799	.0075	-.0058	1.0038
10	-2.12	-40.09	.9834	.0104	-.0123	1.0063
11	-2.02	-40.10	.9785	.0114	-.0083	1.0038
12	-1.91	-40.10	.9749	.0097	-.0028	1.0010
13	-1.82	-40.08	.9728	.0080	.0010	.9992
14	-1.71	-40.12	.9645	.0126	.0050	.9970
15	-1.62	-40.10	.9656	.0110	.0055	.9976
16	-1.51	-40.09	.9652	.0069	.0100	.9960
17	-1.41	-40.35	.9651	.0080	.0091	.9965
18	-1.30	-40.33	.9668	.0106	.0047	.9976
19	-1.21	-40.32	.9680	.0136	.0004	.9993
20	-1.11	-40.49	.9746	.0125	-.0054	1.0031
21	-1.01	-40.46	.9749	.0098	-.0030	1.0021
22	-.91	-40.46	.9747	.0092	-.0021	1.0013
23	-.81	-40.09	.9910	-.0117	.0018	1.0003
24	-.70	-40.24	.9874	-.0138	.0076	.9970
25	-.60	-40.20	.9868	-.0123	.0068	.9959
26	-.49	-40.20	.9902	-.0129	.0038	.9979
27	-.39	-40.21	.9957	-.0132	-.0016	1.0014
28	-.30	-40.21	1.0015	-.0132	-.0076	1.0040
29	-.20	-40.38	1.0036	-.0155	-.0075	1.0043
30	-.10	-40.33	1.0004	-.0097	-.0100	1.0042
31	-.01	-40.36	.9957	-.0097	-.0051	1.0026
32	.10	-40.35	.9903	-.0084	-.0007	1.0006
33	.20	-40.36	.9813	-.0056	.0058	.9968
34	.30	-40.34	.9694	.0041	.0084	.9950
35	.40	-40.35	.9728	.0040	.0049	.9973
36	.51	-40.35	.9746	.0043	.0028	.9989
37	.61	-40.35	.9763	.0067	-.0013	1.0004
38	.72	-40.34	.9827	.0032	-.0045	1.0020
39	.81	-40.34	.9818	.0057	-.0060	1.0026
40	.91	-40.36	.9800	.0080	-.0064	1.0025
41	1.01	-40.34	.9807	.0040	-.0032	1.0013
42	1.12	-40.37	.9783	.0035	-.0001	.9999
43	1.22	-40.36	.9775	.0030	.0012	.9998

44	1.32	-40.35	.9766	.0016	.0035	.9988
45	1.42	-40.36	.9750	.0078	-.0012	.9989
46	1.53	-40.35	.9790	.0059	-.0033	1.0007
47	1.62	-40.36	.9821	.0080	-.0087	1.0023
48	1.73	-40.36	.9939	-.0001	-.0128	1.0075
49	1.82	-40.35	.9929	.0004	-.0123	1.0064
50	1.94	-40.35	.9935	.0039	-.0164	1.0083
51	2.08	-40.37	.9836	.0038	-.0060	1.0023
52	2.13	-40.36	.9849	.0038	-.0073	1.0042
53	2.24	-40.37	.9804	.0003	.0008	1.0009
54	2.33	-40.36	.9755	.0100	-.0038	1.0002
55	2.43	-40.62	.9799	-.0012	.0028	1.0005
56	2.53	-40.72	.9789	-.0002	.0029	1.0004
57	2.64	-40.73	.9823	.0017	-.0026	1.0024
58	2.75	-40.72	.9835	.0024	-.0045	1.0032
59	2.84	-40.72	.9865	-.0007	-.0045	1.0033
60	2.95	-40.73	.9859	-.0007	-.0039	1.0033
61	3.05	-40.72	.9797	.0019	-.0000	1.0019
62	3.15	-40.73	.9848	-.0019	-.0015	1.0028
63	3.25	-40.75	.9792	.0003	.0021	1.0003
64	3.34	-40.73	.9778	-.0004	.0042	.9990
65	3.44	-40.72	.9825	.0008	-.0019	1.0019
66	3.55	-40.73	.9814	.0031	-.0031	1.0025
67	3.65	-40.74	.9856	.0014	-.0056	1.0040
68	3.75	-40.72	.9836	.0025	-.0047	1.0024
69	3.87	-40.72	.9740	.0063	.0015	.9993
70	3.96	-40.73	.9773	.0034	.0010	.9966
71	4.05	-40.75	.9693	.0061	.0066	.9963
72	4.16	-40.74	.9665	.0034	.0121	.9944
73	4.25	-40.73	.9648	.0033	.0140	.9939
74	4.37	-40.73	.9613	.0070	.0140	.9932
75	4.46	-40.71	.9592	.0062	.0169	.9924
76	4.57	-40.72	.9682	.0051	.0087	.9962
77	4.68	-40.86	.9762	.0044	.0011	.9999
78	4.78	-40.87	.9740	.0036	.0042	.9981
79	4.88	-40.88	.9772	.0059	-.0015	1.0017
80	4.97	-40.86	.9763	.0044	.0009	1.0003
81	5.09	-40.87	.9735	.0018	.0065	.9972
82	5.18	-40.88	.9736	-.0045	.0126	.9986
83	5.30	-40.87	.9687	.0037	.0096	.9974
84	5.40	-40.88	.9695	-.0012	.0136	.9967
85	5.50	-40.86	.9781	-.0037	.0072	1.0001
86	5.59	-40.87	.9832	-.0037	.0018	1.0028
87	5.69	-40.85	.9825	-.0009	-.0001	1.0026
88	5.80	-40.85	.9877	.0002	-.0067	1.0061
89	5.89	-40.87	.9894	.0003	-.0086	1.0061
90	6.00	-40.87	.9883	.0017	-.0088	1.0063
91	6.11	-40.88	.9847	.0029	-.0062	1.0056
92	6.21	-40.60	.9791	.0002	.0022	1.0013
93	6.30	-40.60	.9754	-.0006	.0070	.9992

TABLE A.3

BLADE TO BLADE PROBE DATA AT MIDSPAN DATA FILE DC6251

Cone Probe: Beta1=40.3 Re=774000 X1ave=0.1211 Q1ave=21.26

Point	Loc(in)	-Beta	Q / Q1refbar	Ps-Ps1bar / Q1refbar	Pt1bar-Pt / Q1refbar	X / X1refbar
1	-1.65	-1.77	.7130	.2695	.0078	.8376
2	-1.55	-1.79	.7127	.2691	.0086	.8368
3	-1.45	-1.94	.7160	.2651	.0092	.8379
4	-1.35	-1.73	.7190	.2637	.0075	.8384
5	-1.25	-1.78	.7191	.2643	.0069	.8399
6	-1.15	-1.66	.7204	.2647	.0051	.8413
7	-1.05	-1.53	.7222	.2623	.0056	.8407
8	-.95	-1.93	.7231	.2613	.0057	.8402
9	-.85	-1.82	.7233	.2605	.0063	.8402
10	-.75	-1.73	.7249	.2608	.0043	.8413
11	-.55	-1.85	.7207	.2649	.0046	.8390
12	-.45	.52	.7198	.2626	.0078	.8369
13	-.40	-3.30	.7192	.2631	.0079	.8350
14	-.35	-2.88	.7192	.2622	.0088	.8343
15	-.30	-3.90	.7123	.2613	.0167	.8294
16	-.25	-3.28	.6053	.2651	.1226	.7653
17	-.20	-4.03	.4209	.2668	.3090	.6373
18	-.15	-4.02	.2391	.2821	.4777	.4812
19	-.10	-3.86	.1199	.2820	.5977	.3408
20	-.05	.20	.0965	.2796	.6237	.3058
21	0.00	2.02	.2685	.2793	.4508	.5093
22	.05	2.01	.5670	.2581	.1689	.7377
23	.10	2.06	.7164	.2500	.0238	.8284
24	.15	2.10	.7289	.2579	.0032	.8358
25	.20	2.17	.7288	.2547	.0064	.8340
26	.25	2.05	.7255	.2565	.0080	.8323
27	.30	2.20	.7345	.2456	.0097	.8360
28	.35	.29	.7268	.2549	.0083	.8322
29	.45	.19	.7323	.2516	.0060	.8346
30	.55	.04	.7358	.2496	.0043	.8370
31	.65	.10	.7349	.2490	.0058	.8358
32	.75	.50	.7367	.2469	.0061	.8368
33	.85	.41	.7388	.2463	.0046	.8382
34	.95	.41	.7404	.2446	.0046	.8387
35	1.05	-1.82	.7433	.2397	.0066	.8388
36	1.15	-1.64	.7424	.2401	.0070	.8384
37	1.25	-1.81	.7433	.2395	.0068	.8391
38	1.35	-1.69	.7454	.2395	.0046	.8401
39	1.45	-1.73	.7465	.2380	.0049	.8407
40	1.55	-2.70	.7489	.2363	.0042	.8407
41	1.65	-2.56	.7506	.2341	.0046	.8405
42	1.75	-2.56	.7529	.2329	.0034	.8424
43	1.85	-2.63	.7555	.2320	.0016	.8436

TABLE A.4

BLADE TO BLADE PROBE DATA AT MIDSPAN DATA FILE DC6252

Cone Probe: Beta1=40.3 Re=774000 X1ave=0.1211 Q1ave=21.26

Point	Loc(in)	-Beta	Q / Q1refbar	Ps-Ps1bar / Q1refbar	Pt1bar-Pt / Q1refbar	X / X1refbar
1	-1.65	-2.44	.7411	.2384	.0101	.8311
2	-1.55	-2.61	.7392	.2349	.0155	.8284
3	-1.45	-2.49	.7413	.2349	.0135	.8296
4	-1.35	-2.39	.7409	.2354	.0133	.8299
5	-1.25	-2.52	.7417	.2361	.0118	.8302
6	-1.15	-2.55	.7416	.2346	.0133	.8297
7	-1.05	-2.55	.7433	.2352	.0111	.8302
8	-.95	-2.61	.7430	.2356	.0110	.8302
9	-.85	-2.56	.7418	.2367	.0111	.8291
10	-.75	-3.36	.7404	.2353	.0140	.8274
11	-.65	-3.61	.7373	.2390	.0134	.8261
12	-.55	-3.40	.7358	.2409	.0131	.8252
13	-.50	-3.58	.7354	.2405	.0139	.8244
14	-.45	-3.33	.7360	.2419	.0118	.8250
15	-.40	-3.90	.7384	.2407	.0106	.8263
16	-.35	-3.98	.7366	.2366	.0164	.8249
17	-.30	-5.25	.7173	.2362	.0367	.8135
18	-.25	-4.81	.5969	.2338	.1625	.7427
19	-.20	-5.41	.4486	.2338	.3138	.6437
20	-.15	-5.40	.3172	.2446	.4363	.5425
21	-.10	-5.18	.2553	.2499	.4936	.4868
22	-.05	-5.33	.2827	.2462	.4696	.5116
23	0.00	-5.02	.4061	.2406	.3502	.6126
24	.10	-.97	.7027	.2259	.0620	.8042
25	.15	-.95	.7434	.2319	.0141	.8275
26	.20	-.89	.7494	.2325	.0075	.8300
27	.25	-1.90	.7464	.2346	.0085	.8269
28	.30	-1.79	.7461	.2339	.0094	.8265
29	.35	-2.02	.7484	.2330	.0080	.8278
30	.45	-1.93	.7486	.2319	.0088	.8280
31	.55	-1.84	.7511	.2310	.0072	.8290
32	.65	-1.81	.7529	.2284	.0079	.8300
33	.75	-1.78	.7545	.2283	.0064	.8309
34	.85	-2.01	.7574	.2254	.0062	.8321
35	.95	-1.98	.7570	.2245	.0076	.8319
36	1.05	-1.95	.7607	.2221	.0062	.8332
37	1.15	-1.95	.7596	.2201	.0094	.8319
38	1.25	-1.97	.7611	.2201	.0077	.8329
39	1.35	-2.50	.7613	.2205	.0072	.8329
40	1.45	-2.40	.7615	.2204	.0071	.8327
41	1.55	-2.28	.7642	.2206	.0041	.8344

TABLE A.5

BLADE TO BLADE PROBE DATA AT MIDSPAN DATA FILE DC6259

Cone Probe: Beta1=40.3   Re=774000 X1ave=0.1211 Q1ave=21.26

Point	Loc(in)	- Beta	Q / Q1refbar	Ps-Ps1bar / Q1refbar	Pt1bar-Pt / Q1refbar	X / X1refbar
1	-1.60	-2.20	.6640	.3215	.0062	.8243
2	-1.50	-1.91	.6659	.3155	.0102	.8244
3	-1.40	-2.05	.6680	.3171	.0064	.8248
4	-1.30	-1.90	.6704	.3183	.0028	.8273
5	-1.20	-2.28	.6711	.3171	.0033	.8273
6	-1.10	-2.16	.6707	.3191	.0018	.8273
7	-1.00	-2.26	.6720	.3166	.0029	.8268
8	-.90	-3.09	.6708	.3191	.0016	.8263
9	-.80	-2.76	.6701	.3209	.0006	.8267
10	-.70	-2.78	.6703	.3176	.0036	.8252
11	-.60	-2.96	.6700	.3170	.0045	.8250
12	-.50	-3.07	.6711	.3191	.0013	.8267
13	-.40	-3.58	.6616	.3110	.0192	.8187
14	-.30	-3.33	.5913	.3078	.0943	.7750
15	-.20	-3.45	.4460	.3085	.2417	.6742
16	-.15	-3.23	.3925	.3058	.2988	.6316
17	-.10	-3.29	.3728	.3085	.3161	.6152
18	-.05	-3.16	.3948	.3070	.2953	.6326
19	0.00	-2.25	.4486	.3063	.2414	.6746
20	.05	-2.01	.5228	.3069	.1651	.7271
21	.10	-1.77	.5887	.3150	.0898	.7706
22	.15	-2.14	.6465	.3070	.0386	.8074
23	.20	-1.98	.6708	.3067	.0141	.8212
24	.25	-2.12	.6773	.3103	.0037	.8256
25	.35	-1.98	.6767	.3137	.0010	.8250
26	.45	-2.50	.6702	.3235	-.0022	.8219
27	.55	-3.11	.6736	.3201	-.0023	.8229
28	.65	-2.55	.6708	.3241	-.0034	.8199
29	.75	-2.77	.6664	.3254	-.0002	.8169
30	.85	-2.65	.6650	.3298	-.0032	.8161
31	.95	-2.46	.6643	.3278	-.0004	.8141
32	1.05	-2.72	.6609	.3312	-.0003	.8131
33	1.15	-2.11	.6692	.3216	.0008	.8172
34	1.25	-2.55	.6720	.3175	.0019	.8184
35	1.35	-2.57	.6709	.3196	.0010	.8174
36	1.45	-2.54	.6737	.3162	.0015	.8183
37	1.55	-2.73	.6768	.3176	-.0031	.8213
38	1.65	-1.38	.6707	.3219	-.0011	.8151

TABLE A.6

BLADE TO BLADE PROBE DATA AT MIDSPAN DATA FILE DC6258

Cone Probe: Beta1=40.3   Re=774000 X1ave=0.1211 Q1ave=21.26

Point	Loc(in)	- Beta	Q / Q1refbar	Ps-Ps1bar / Q1refbar	Pt1bar-Pt / Q1refbar	X / X1refbar
1	-1.60	-1.77	.7065	.2740	.0102	.8229
2	-1.40	-1.57	.7066	.2738	.0102	.8236
3	-1.30	-1.60	.7064	.2755	.0087	.8238
4	-1.20	-1.69	.7075	.2750	.0080	.8246
5	-1.10	-2.16	.7051	.2776	.0080	.8242
6	-1.00	-2.13	.7075	.2765	.0065	.8250
7	-.90	-2.16	.7062	.2760	.0084	.8245
8	-.80	-2.14	.7067	.2766	.0073	.8244
9	-.70	-2.02	.7043	.2770	.0094	.8232
10	-.60	-2.01	.7052	.2765	.0090	.8238
11	-.50	-2.15	.7009	.2744	.0154	.8214
12	-.40	-2.73	.6766	.2742	.0406	.8083
13	-.35	-2.95	.6489	.2713	.0719	.7914
14	-.30	-3.01	.6014	.2697	.1221	.7628
15	-.25	-3.21	.5494	.2683	.1766	.7294
16	-.20	-3.03	.5019	.2677	.2257	.6978
17	-.15	-3.23	.4654	.2695	.2611	.6722
18	-.10	-3.27	.4460	.2714	.2788	.6586
19	-.05	-2.33	.4595	.2687	.2678	.6675
20	0.00	-2.29	.4943	.2686	.2326	.6921
21	.05	-1.72	.5457	.2685	.1802	.7273
22	.10	-1.98	.6076	.2708	.1147	.7674
23	.15	-1.75	.6540	.2703	.0676	.7953
24	.20	-1.73	.6836	.2738	.0337	.8133
25	.25	-1.86	.6999	.2748	.0161	.8219
26	.30	-2.10	.7051	.2759	.0097	.8248
27	.40	-2.05	.7071	.2771	.0064	.8256
28	.50	-1.87	.7109	.2762	.0033	.8274
29	.60	-2.22	.7070	.2764	.0072	.8255
30	.70	-1.82	.7116	.2779	.0010	.8288
31	.80	-2.26	.7113	.2784	.0008	.8287
32	.90	-1.95	.7107	.2772	.0026	.8283
33	1.00	-2.48	.7097	.2795	.0013	.8286
34	1.10	-2.21	.7096	.2767	.0042	.8272
35	1.20	-2.36	.7087	.2788	.0031	.8274
36	1.30	-2.37	.7071	.2787	.0048	.8266
37	1.40	-1.73	.7095	.2795	.0016	.8281
38	1.50	-2.37	.7089	.2784	.0032	.8279

TABLE A.7

BLADE TO BLADE PROBE DATA AT MIDSPAN DATA FILE DC6255

Cone Probe: Beta1=40.3 Re=774000 X1ave=0.1211 Q1ave=21.26

Point	Loc(in)	- Beta	Q / Q1refbar	Ps-Ps1bar / Q1refbar	Pt1bar-Pt / Q1refbar	X / X1refbar
1	-1.65	-1.72	.7271	.2483	.0146	.8212
2	-1.55	-1.87	.7288	.2499	.0113	.8226
3	-1.45	-1.72	.7311	.2461	.0127	.8226
4	-1.35	-1.79	.7312	.2464	.0123	.8225
5	-1.25	-1.90	.7319	.2492	.0088	.8241
6	-1.15	-1.88	.7339	.2448	.0112	.8228
7	-1.05	-1.84	.7312	.2476	.0111	.8223
8	-.95	-2.33	.7318	.2442	.0138	.8215
9	-.85	-2.30	.7341	.2455	.0101	.8232
10	-.75	-2.45	.7333	.2413	.0151	.8214
11	-.65	-2.36	.7305	.2428	.0166	.8206
12	-.55	-2.38	.7184	.2389	.0329	.8128
13	-.45	-2.66	.6784	.2391	.0737	.7909
14	-.35	-2.88	.6246	.2359	.1321	.7590
15	-.30	-3.38	.5935	.2321	.1677	.7391
16	-.25	-3.27	.5699	.2332	.1907	.7246
17	-.20	-3.30	.5445	.2318	.2180	.7074
18	-.15	-3.15	.5348	.2340	.2258	.7026
19	-.10	-2.54	.5370	.2357	.2217	.7043
20	-.05	-2.63	.5544	.2336	.2062	.7145
21	0.00	-2.33	.5783	.2294	.1860	.7281
22	.05	-2.17	.6092	.2315	.1523	.7480
23	.10	-1.99	.6464	.2315	.1141	.7699
24	.15	-2.06	.6781	.2319	.0812	.7882
25	.25	-1.70	.7211	.2319	.0372	.8112
26	.35	-1.90	.7393	.2335	.0168	.8213
27	.45	-2.04	.7463	.2368	.0063	.8255
28	.55	-1.90	.7480	.2357	.0057	.8269
29	.65	-1.93	.7502	.2347	.0045	.8265
30	.75	-2.23	.7486	.2366	.0042	.8266
31	.85	-1.69	.7482	.2342	.0070	.8257
32	.95	-1.97	.7497	.2331	.0065	.8258
33	1.05	-2.01	.7475	.2340	.0078	.8246
34	1.15	-1.76	.7490	.2324	.0079	.8249
35	1.25	-1.82	.7466	.2335	.0093	.8239
36	1.35	-1.67	.7465	.2325	.0104	.8235
37	1.45	-1.89	.7435	.2396	.0064	.8221
38	1.55	-1.94	.7379	.2423	.0096	.8176
39	1.65	-1.92	.7360	.2461	.0076	.8171

TABLE A.8

BLADE TO BLADE PROBE DATA AT MIDSPAN DATA FILE BD6260

Upper Plane: Beta1=43.43 Re=774000 X1ave=.1216 Q1ave=21.05

Point	Loc(in)	- Beta	Q / Q1refbar	Ps-Ps1bar / Q1refbar	Pt1bar-Pt / Q1refbar	X / X1refbar
1	-6.02	-3.08	.5462	.3391	.0592	.7407
2	-6.06	-3.09	.5643	.3370	.0427	.7515
3	-5.88	-3.08	.5920	.3376	.0139	.7700
4	-5.68	-2.22	.6070	.3382	-.0020	.7809
5	-5.58	-1.87	.6083	.3901	-.0053	.7829
6	-5.48	-1.87	.6101	.3902	-.0072	.7839
7	-5.38	-1.85	.6078	.3889	-.0036	.7819
8	-5.28	-1.87	.6067	.3901	-.0037	.7822
9	-5.18	-1.87	.6090	.3371	-.0030	.7827
10	-5.08	-1.86	.6028	.3897	.0008	.7791
11	-4.98	-1.63	.6024	.3394	.0015	.7795
12	-4.88	-1.63	.5963	.3906	.0066	.7751
13	-4.78	-1.49	.5979	.3888	.0067	.7762
14	-4.68	-1.47	.5988	.3885	.0060	.7758
15	-4.58	-1.50	.5920	.3890	.0125	.7707
16	-4.49	-.99	.5941	.3888	.0106	.7729
17	-4.38	-1.00	.5927	.3890	.0118	.7715
18	-4.29	-.99	.5912	.3909	.0114	.7708
19	-4.19	-.77	.5886	.3901	.0148	.7688
20	-4.09	-.25	.5823	.3898	.0215	.7644
21	-3.99	-.26	.5674	.3902	.0364	.7546
22	-3.89	.56	.5395	.3900	.0651	.7361
23	-3.79	.81	.5099	.3885	.0967	.7155
24	-3.69	.82	.4623	.3882	.1454	.6812
25	-3.60	.81	.4327	.3858	.1780	.6588
26	-3.49	-.14	.4104	.3854	.2011	.6420
27	-3.39	-1.48	.4150	.3846	.1971	.6456
28	-3.29	-1.46	.4355	.3873	.1736	.6619
29	-3.19	-2.60	.4762	.3853	.1343	.6908
30	-3.09	-2.61	.5226	.3851	.0871	.7237
31	-2.99	-2.61	.5586	.3869	.0487	.7478
32	-2.90	-2.59	.5867	.3852	.0217	.7660
33	-2.80	-2.11	.5969	.3899	.0066	.7751
34	-2.69	-1.62	.6021	.3913	-.0002	.7793
35	-2.59	-1.63	.6049	.3899	-.0016	.7803
36	-2.49	-1.62	.6072	.3889	-.0030	.7817
37	-2.39	-1.64	.6060	.3888	-.0017	.7809
38	-2.29	-1.62	.6041	.3902	-.0011	.7798
39	-2.19	-1.61	.6025	.3897	.0011	.7788
40	-2.09	-1.62	.6038	.3901	-.0007	.7798
41	-1.99	-1.58	.6026	.3887	.0020	.7785
42	-1.89	-1.63	.6003	.3897	.0033	.7778
43	-1.79	-1.62	.6026	.3869	.0038	.7784

TABLE A.8 CON'T

44	-1.69	-1.62	.6021	.3855	.0056	.7775
45	-1.59	-1.62	.6007	.3864	.0062	.7764
46	-1.49	-1.14	.6001	.3863	.0069	.7764
47	-1.39	-1.12	.5976	.3895	.0063	.7759
48	-1.29	-.81	.5965	.3908	.0061	.7756
49	-1.19	-.79	.5891	.3904	.0140	.7696
50	-1.09	-.27	.5763	.3903	.0272	.7613
51	-.99	.21	.5529	.3903	.0512	.7456
52	-.89	.21	.5211	.3888	.0850	.7238
53	-.79	.72	.4792	.3885	.1280	.6944
54	-.69	.31	.4451	.3859	.1653	.6687
55	-.60	.31	.4199	.3876	.1892	.6500
56	-.50	-1.38	.4141	.3864	.1963	.6453
57	-.40	-1.38	.4232	.3863	.1872	.6515
58	-.30	-2.83	.4604	.3790	.1567	.6763
59	-.20	-2.82	.5058	.3791	.1104	.7088
60	-.10	-2.81	.5457	.3817	.0670	.7361
61	.00	-2.83	.5755	.3794	.0389	.7547
62	.11	-2.67	.5970	.3772	.0192	.7679
63	.20	-1.88	.6100	.3772	.0059	.7767
64	.30	-1.86	.6153	.3760	.0017	.7792
65	.41	-1.84	.6176	.3756	-.0004	.7803
66	.52	-1.63	.6191	.3731	.0007	.7800
67	.61	-1.63	.6216	.3724	-.0011	.7815
68	.72	-1.39	.6230	.3720	-.0022	.7822
69	.82	-1.38	.6236	.3711	-.0019	.7821
70	.92	-1.39	.6244	.3706	-.0023	.7823
71	1.02	-1.40	.6262	.3722	-.0057	.7837
72	1.12	-1.40	.6241	.3705	-.0018	.7820
73	1.22	-1.40	.6273	.3717	-.0062	.7844
74	1.33	-1.15	.6275	.3696	-.0044	.7836
75	1.43	-1.13	.6272	.3693	-.0038	.7829
76	1.53	-1.15	.6259	.3690	-.0022	.7813
77	1.63	-.90	.6261	.3679	-.0014	.7811
78	1.73	-.91	.6244	.3671	.0013	.7790
79	1.83	-.28	.6164	.3693	.0072	.7744
80	1.93	-.02	.6042	.3662	.0227	.7658
81	2.04	.31	.5843	.3652	.0441	.7525
82	2.14	.48	.5505	.3642	.0797	.7308
83	2.24	.81	.5077	.3629	.1246	.7014
84	2.34	.81	.4680	.3595	.1684	.6731
85	2.45	-.19	.4416	.3614	.1934	.6541
86	2.54	-.19	.4258	.3597	.2111	.6421
87	2.65	-2.22	.4387	.3589	.1988	.6514
88	2.75	-2.22	.4700	.3587	.1673	.6736
89	2.85	-3.07	.5103	.3559	.1290	.7005
90	2.95	-2.84	.5508	.3577	.0859	.7271
91	3.05	-2.83	.5861	.3559	.0517	.7492
92	3.16	-2.36	.6130	.3536	.0264	.7653
93	3.25	-2.35	.6224	.3530	.0174	.7709

TABLE A.9

BLADE TO BLADE PROBE DATA AT MIDSPAN DATA FILE BD6260

Lower Plane: Beta1=43.43   Re=774000   X1ave=.1216 Q1ave=21.05

Point	Loc(in)	- Beta	Q / Q1refbar	Ps-Ps1bar / Q1refbar	Pt1bar-Pt / Q1refbar	X / X1refbar
1	-3.05	-43.20	.9715	.0015	.0090	.9947
2	-3.01	-43.20	.9708	-.0025	.0137	.9928
3	-2.90	-43.21	.9762	-.0010	.0066	.9960
4	-2.70	-43.20	.9809	.0021	-.0014	.9999
5	-2.61	-43.20	.9804	.0065	-.0052	1.0011
6	-2.49	-43.20	.9826	.0067	-.0077	1.0021
7	-2.39	-43.21	.9845	.0045	-.0075	1.0023
8	-2.29	-43.21	.9807	.0076	-.0066	1.0016
9	-2.18	-43.20	.9799	.0049	-.0030	1.0000
10	-2.08	-43.21	.9798	.0050	-.0031	1.0004
11	-2.00	-43.20	.9799	.0047	-.0029	1.0013
12	-1.90	-43.20	.9826	.0035	-.0045	1.0021
13	-1.79	-43.19	.9827	.0021	-.0032	1.0023
14	-1.69	-43.21	.9859	.0012	-.0057	1.0026
15	-1.60	-43.43	.9840	.0010	-.0034	1.0008
16	-1.48	-43.46	.9797	.0032	-.0012	.9996
17	-1.39	-43.47	.9812	.0020	-.0016	.9998
18	-1.29	-43.21	.9746	.0008	.0065	.9968
19	-1.19	-43.20	.9738	.0008	.0073	.9960
20	-1.09	-43.47	.9745	-.0006	.0067	.9960
21	-.99	-43.46	.9749	-.0006	.0076	.9962
22	-.90	-43.47	.9773	-.0005	.0050	.9976
23	-.79	-43.47	.9796	-.0005	.0026	.9983
24	-.71	-43.46	.9852	-.0019	-.0018	1.0006
25	-.59	-43.45	.9852	-.0026	-.0011	1.0000
26	-.48	-42.96	.9843	-.0024	-.0003	1.0001
27	-.38	-43.46	.9833	-.0014	-.0003	.9995
28	-.29	-43.47	.9813	-.0014	.0018	.9995
29	-.20	-43.46	.9821	-.0039	.0035	.9983
30	-.09	-43.44	.9822	-.0045	.0038	.9988
31	-.01	-43.46	.9841	-.0050	.0024	.9995
32	.10	-43.48	.9852	-.0040	.0003	.9998
33	.19	-43.46	.9803	.0027	-.0013	1.0005
34	.29	-43.48	.9803	.0049	-.0035	1.0015
35	.40	-43.46	.9806	.0022	-.0011	1.0007
36	.50	-43.48	.9818	.0014	-.0016	1.0012
37	.59	-43.46	.9788	.0014	.0016	.9997
38	.70	-43.46	.9767	.0026	.0026	.9988
39	.80	-43.47	.9801	.0018	-.0001	1.0005
40	.89	-43.46	.9788	.0034	-.0004	1.0000
41	1.01	-43.49	.9850	.0003	-.0038	1.0025
42	1.11	-43.44	.9845	.0031	-.0060	1.0033
43	1.21	-43.46	.9913	.0011	-.0110	1.0055

TABLE A.9 CON'T

44	1.31	-43.45	.9913	-.0001	-.0100	1.0048
45	1.40	-43.46	.9878	-.0014	-.0050	1.0027
46	1.51	-43.33	.9860	-.0019	-.0027	1.0025
47	1.61	-43.34	.9817	.0022	-.0023	1.0018
48	1.71	-43.45	.9825	.0018	-.0026	1.0026
49	1.81	-43.46	.9836	.0001	-.0020	1.0016
50	1.91	-43.58	.9874	-.0021	-.0038	1.0036
51	2.00	-43.58	.9923	-.0028	-.0083	1.0058
52	2.10	-43.58	.9941	-.0026	-.0103	1.0064
53	2.19	-43.58	.9968	-.0017	-.0141	1.0078
54	2.31	-43.47	.9999	-.0054	-.0136	1.0083
55	2.40	-43.46	.9960	-.0038	-.0111	1.0070
56	2.51	-43.47	.9975	-.0043	-.0123	1.0073
57	2.60	-42.94	.9981	-.0109	-.0062	1.0066
58	2.70	-43.20	1.0002	-.0180	-.0012	1.0030
59	2.80	-43.48	1.0008	-.0166	-.0032	1.0036
60	2.90	-43.48	.9996	-.0169	-.0017	1.0032
61	3.00	-43.46	1.0015	-.0193	-.0013	1.0028
62	3.11	-43.46	1.0029	-.0221	.0001	1.0025
63	3.18	-43.46	1.0078	-.0206	-.0066	1.0058
64	3.30	-43.48	1.0090	-.0226	-.0059	1.0053
65	3.40	-43.49	1.0077	-.0243	-.0028	1.0042
66	3.48	-43.47	1.0095	-.0270	-.0019	1.0035
67	3.59	-43.47	1.0065	-.0268	.0010	1.0020
68	3.69	-43.46	1.0074	-.0288	.0020	1.0022
69	3.80	-43.47	1.0084	-.0298	.0021	1.0020
70	3.89	-43.73	1.0097	-.0298	.0007	1.0023
71	3.99	-43.70	1.0068	-.0295	.0034	1.0014
72	4.10	-43.72	1.0089	-.0298	.0014	1.0018
73	4.20	-43.72	1.0092	-.0295	.0009	1.0025
74	4.29	-43.47	1.0110	-.0341	.0036	1.0022
75	4.39	-43.48	1.0075	-.0355	.0087	.9999
76	4.49	-43.47	1.0036	-.0362	.0133	.9970
77	4.59	-43.73	1.0035	-.0378	.0151	.9965
78	4.70	-43.73	1.0038	-.0401	.0171	.9953
79	4.80	-43.72	1.0052	-.0394	.0149	.9966
80	4.90	-43.73	1.0072	-.0418	.0153	.9962
81	5.00	-43.73	1.0157	-.0441	.0087	.9994
82	5.11	-43.74	1.0167	-.0442	.0078	1.0003
83	5.21	-43.72	1.0213	-.0454	.0042	1.0015
84	5.30	-43.72	1.0216	-.0482	.0066	1.0010
85	5.41	-43.46	1.0262	-.0492	.0029	1.0035
86	5.51	-43.46	1.0225	-.0504	.0079	1.0013
87	5.62	-43.47	1.0227	-.0511	.0084	1.0009
88	5.71	-43.46	1.0237	-.0532	.0094	1.0008
89	5.81	-43.47	1.0256	-.0567	.0111	.9998
90	5.90	-43.58	1.0302	-.0584	.0079	1.0016
91	5.99	-43.48	1.0352	-.0617	.0060	1.0032
92	6.08	-43.47	1.0432	-.0630	-.0009	1.0061
93	6.20	-43.48	1.0426	-.0630	-.0004	1.0054

TABLE A.10

BLADE TO BLADE PROBE DATA AT MIDSPAN DATA FILE DC6261

Cone Probe: Beta1=43.43 Re=774000 X1ave=0.1216 Q1ave=21.05

Point	Loc(in)	- Beta	Q / Q1refbar	Ps-Ps1bar / Q1refbar	Pt1bar-Pt / Q1refbar	X / X1refbar
1	-2.63	-.89	.6757	.3135	.0023	.8189
2	-2.53	-.68	.6758	.3170	-.0014	.8186
3	-2.43	-1.28	.6757	.3185	-.0027	.8202
4	-2.33	-1.30	.6760	.3146	.0008	.8183
5	-2.23	-1.10	.6772	.3149	-.0007	.8191
6	-2.13	-1.34	.6767	.3171	-.0023	.8195
7	-2.03	-1.10	.6748	.3174	-.0007	.8186
8	-1.93	-1.34	.6758	.3159	-.0002	.8196
9	-1.83	-1.36	.6746	.3147	.0022	.8179
10	-1.73	-1.28	.6745	.3144	.0025	.8180
11	-1.63	-1.36	.6755	.3114	.0046	.8178
12	-1.53	-1.45	.6748	.3131	.0036	.8181
13	-1.48	-1.54	.6756	.3107	.0051	.8193
14	-1.43	-1.48	.6743	.3110	.0062	.8180
15	-1.38	-1.52	.6745	.3106	.0064	.8188
16	-1.33	-1.94	.6757	.3090	.0067	.8184
17	-1.28	-1.90	.6748	.3082	.0085	.8182
18	-1.23	-2.07	.6759	.3084	.0071	.8185
19	-1.18	-1.93	.6753	.3081	.0081	.8184
20	-1.13	-1.80	.6761	.3085	.0068	.8195
21	-1.03	-2.51	.6772	.3075	.0067	.8195
22	-.93	-2.49	.6796	.3056	.0062	.8201
23	-.83	-2.70	.6798	.3054	.0062	.8203
24	-.73	-2.90	.6809	.3053	.0051	.8222
25	-.63	-5.12	.6824	.3044	.0045	.8223
26	-.53	-4.86	.6777	.3042	.0094	.8205
27	-.43	-5.44	.6627	.3018	.0272	.8115
28	-.38	-5.84	.5963	.3007	.0964	.7716
29	-.33	-6.26	.5008	.2988	.1958	.7069
30	-.28	-6.62	.3820	.3019	.3134	.6176
31	-.23	-6.42	.2756	.3067	.4163	.5244
32	-.18	-7.55	.1821	.3146	.5026	.4268
33	-.13	-7.45	.1180	.3192	.5626	.3440
34	-.08	-3.60	.1069	.2872	.6057	.3275
35	-.03	.83	.1010	.3004	.5983	.3177
36	0.00	2.18	.1768	.3138	.5038	.4195
37	.02	1.59	.2268	.3210	.4513	.4757
38	.07	1.44	.4964	.3047	.1943	.7034
39	.12	1.48	.6650	.2967	.0301	.8120
40	.17	.06	.6862	.3041	.0009	.8243
41	.22	-.48	.6811	.3095	.0007	.8219
42	.27	-.38	.6776	.3106	.0032	.8194
43	.37	-1.22	.6762	.3132	.0020	.8178

TABLE A.10 CON'T

44	.47	-1.51	.6744	.3157	.0014	.8186
45	.57	-1.12	.6758	.3156	.0000	.8191
46	.67	-2.15	.6747	.3134	.0035	.8172
47	.77	-2.27	.6775	.3122	.0018	.8197
48	.87	-1.77	.6792	.3116	.0006	.8197
49	.97	-1.75	.6797	.3116	.0000	.8201
50	1.07	-1.86	.6791	.3103	.0019	.8195
51	1.17	-1.96	.6771	.3149	-.0007	.8202
52	1.27	-2.02	.6795	.3117	.0001	.8205
53	1.37	-2.19	.6840	.3088	-.0016	.8230
54	1.47	-2.22	.6834	.3110	-.0032	.8240
55	1.57	-2.40	.6821	.3110	-.0018	.8210
56	1.67	-3.14	.6870	.3091	-.0049	.8249

TABLE A.11

BLADE TO BLADE PROBE DATA AT MIDSPAN DATA FILE DC6263

Cone Probe: Beta1=43.43 Re=774000 X1ave=0.1216 Q1ave=21.05

Point	Loc(in)	-Beta	Q / Q1refbar	Ps-Ps1bar / Q1refbar	Pt1bar-Pt / Q1refbar	X / X1refbar
1	-1.66	-2.15	.6305	.3585	.0036	.8038
2	-1.56	-2.09	.6287	.3590	.0049	.8027
3	-1.46	-2.23	.6278	.3592	.0057	.8007
4	-1.36	-2.17	.6304	.3582	.0040	.8032
5	-1.26	-2.34	.6282	.3571	.0073	.8019
6	-1.16	-2.24	.6303	.3590	.0033	.8040
7	-1.06	-2.41	.6280	.3581	.0065	.8007
8	-.96	-2.40	.6279	.3589	.0059	.8019
9	-.86	-2.51	.6312	.3589	.0025	.8036
10	-.76	-2.96	.6289	.3623	.0014	.8025
11	-.71	-3.21	.6307	.3613	.0006	.8032
12	-.66	-3.24	.6289	.3615	.0022	.8035
13	-.61	-3.14	.6280	.3581	.0066	.8020
14	-.56	-3.80	.6236	.3592	.0099	.7987
15	-.51	-3.59	.5968	.3574	.0392	.7810
16	-.46	-4.57	.5490	.3573	.0882	.7508
17	-.41	-3.84	.4781	.3562	.1615	.7024
18	-.36	-3.71	.3991	.3572	.2407	.6420
19	-.31	-4.30	.3279	.3598	.3103	.5824
20	-.26	-2.84	.2736	.3640	.3609	.5319
21	-.21	-2.75	.2423	.3631	.3935	.5004
22	-.16	-2.56	.2459	.3634	.3895	.5037
23	-.11	-1.00	.2836	.3568	.3581	.5406
24	-.06	-.85	.3453	.3538	.2986	.5971
25	-.03	.02	.4087	.3502	.2380	.6496
26	0.00	-.60	.4415	.3471	.2077	.6739
27	.04	-.28	.5123	.3479	.1349	.7268
28	.09	.05	.5721	.3481	.0737	.7673
29	.14	-1.12	.6132	.3527	.0271	.7935
30	.19	-.86	.6288	.3572	.0067	.8033
31	.24	-1.48	.6311	.3612	.0003	.8041
32	.29	-1.68	.6302	.3625	-.0000	.8029
33	.34	-1.70	.6300	.3634	-.0008	.8050
34	.39	-1.35	.6290	.3647	-.0010	.8048
35	.44	-1.76	.6302	.3645	-.0020	.8067
36	.54	-1.94	.6297	.3655	-.0026	.8056
37	.64	-1.86	.6325	.3601	0.0000	.8058
38	.74	-2.01	.6346	.3601	-.0022	.8059
39	.84	-1.96	.6339	.3595	-.0008	.8061
40	.94	-2.01	.6342	.3606	-.0023	.8067
41	1.04	-1.79	.6347	.3597	-.0019	.8042
42	1.14	-2.03	.6370	.3598	-.0044	.8090
43	1.24	-2.14	.6352	.3605	-.0032	.8082

TABLE A.11 CON'T

44	1.34	-1.95	.6377	.3608	-.0060	.8083
45	1.44	-1.90	.6361	.3536	-.0022	.8056
46	1.54	-1.86	.6382	.3562	-.0020	.8073
47	1.64	-2.23	.6367	.3589	-.0031	.8070

TABLE A.12

BLADE TO BLADE PROBE DATA AT MIDSPAN DATA FILE DC6265

Cone Probe: Beta1=43.43 Re=774000 X1ave=0.1216 Q1ave=21.05

Point	Loc(in)	- Beta	Q / Q1refbar	Ps-Ps1bar / Q1refbar	Pt1bar-Pt / Q1refbar	X / X1refbar
1	-1.66	-2.07	.6279	.3573	.0074	.7938
2	-1.56	-2.10	.6282	.3567	.0077	.7919
3	-1.46	-1.89	.6312	.3539	.0075	.7934
4	-1.36	-1.95	.6334	.3546	.0046	.7954
5	-1.26	-2.10	.6326	.3542	.0057	.7934
6	-1.16	-1.75	.6335	.3544	.0047	.7957
7	-1.06	-1.95	.6329	.3528	.0067	.7945
8	-.96	-2.31	.6341	.3509	.0075	.7932
9	-.86	-2.95	.6285	.3497	.0145	.7898
10	-.81	-2.62	.6206	.3462	.0260	.7837
11	-.76	-2.63	.6084	.3426	.0421	.7765
12	-.71	-2.86	.5918	.3400	.0617	.7640
13	-.66	-3.03	.5694	.3385	.0861	.7495
14	-.61	-2.93	.5433	.3366	.1145	.7320
15	-.56	-2.84	.5110	.3349	.1493	.7097
16	-.51	-3.37	.4828	.3320	.1808	.6892
17	-.46	-3.23	.4531	.3308	.2123	.6672
18	-.41	-3.30	.4338	.3303	.2324	.6539
19	-.36	-3.12	.4184	.3306	.2477	.6403
20	-.31	-2.92	.4135	.3277	.2557	.6360
21	-.26	-2.56	.4268	.3259	.2438	.6461
22	-.21	-2.37	.4474	.3262	.2227	.6616
23	-.16	-1.95	.4760	.3251	.1947	.6817
24	-.11	-2.05	.5067	.3241	.1644	.7023
25	-.06	-1.46	.5393	.3237	.1315	.7257
26	-.01	-1.51	.5722	.3238	.0979	.7461
27	.04	-1.67	.5994	.3258	.0681	.7627
28	.09	-1.76	.6182	.3255	.0492	.7746
29	.14	-1.93	.6365	.3267	.0292	.7853
30	.19	-1.78	.6459	.3285	.0179	.7900
31	.24	-1.76	.6547	.3267	.0106	.7936
32	.29	-1.61	.6580	.3241	.0098	.7947
33	.34	-1.75	.6617	.3241	.0061	.7958
34	.39	-1.68	.6649	.3221	.0047	.7963
35	.44	-2.16	.6648	.3224	.0045	.7963
36	.49	-1.96	.6663	.3246	.0008	.7978
37	.54	-1.97	.6643	.3201	.0074	.7944
38	.64	-2.05	.6696	.3218	.0001	.7988
39	.74	-1.99	.6668	.3198	.0051	.7963
40	.84	-2.07	.6697	.3206	.0013	.7992
41	.94	-2.07	.6697	.3174	.0046	.7958
42	1.04	-2.01	.6702	.3180	.0034	.7964
43	1.14	-2.12	.6728	.3163	.0025	.7974

TABLE A.12 CON'T

44	1.24	-2.03	.6726	.3168	.0022	.7991
45	1.34	-1.85	.6734	.3159	.0022	.7980
46	1.44	-1.83	.6738	.3157	.0020	.7969
47	1.54	-2.05	.6752	.3136	.0028	.7983
48	1.64	-2.28	.6756	.3154	.0005	.7977

TABLE A.13

MASS AVERAGED REFERENCING COEFFICIENTS

UPPER PLANE DATA FROM FILE BD6250
LOWER PLANE DATA FROM FILE BD6250
INTEGRATION FROM: -1.5
TO: 1.5

CONSTANTS STORED IN FILE:RC6250 (β_1 =40.3)

REFERENCING COEFFICIENTS
Xbar: 1.16122425638
Qbar: 5.03683922698E-02
Pbar: .945564416077
Ptbar: .995930691973
X2bar: .929704325305
Q2bar: 3.23871320901E-02
P2bar: .96210329247
Pt2bar: .994491548307
Xrefave .104288333333
Prefave 422.104827957 Trefave: 533
REYNOLDS No.: 774034.927767

UPPER PLANE DATA FROM FILE BD6260
LOWER PLANE DATA FROM FILE BD6260
INTEGRATION FROM: -1.5
TO: 1.5

CONSTANTS STORED IN FILE:RC6260 (β_2=43.4)

REFERENCING COEFFICIENTS
Xbar: 1.21130001999
Qbar: .050044645165
Pbar: .945638612489
Ptbar: .995683281476
X2bar: .91003448075
Q2bar: .028898669595
P2bar: .964630545141
Pt2bar: .99352997777
Xrefave .100412986022
Prefave 420.529365591 Trefave: 529
REYNOLDS No.: 773766.692672

TABLE A.14

YAW PROBE OUTLET AIR ANGLE MEASUREMENTS

Station 1 β_1=40.3°

Blade to Blade Position (in)	Angle (β_2 deg)
-1.5	40.4
-1.0	40.6
-0.5	40.6
0.0	40.6
0.5	40.7
1.0	40.7
1.5	40.7

TABLE A.15

YAW PROBE OUTLET AIR ANGLE MEASUREMENTS

Station 2-2 β_1=40.3°

Blade to Blade Position (in)	Angle (β_2 deg)
-1.5	0.8
-1.0	0.2
-0.5	-0.4
-0.3	-1.8
0.0	2.7
0.3	0.8
0.5	0.8
1.0	0.8
1.5	0.4

TABLE A.16

YAW PROBE OUTLET AIR ANGLE MEASUREMENTS

Station 2-6 β_1=40.3°

Blade to Blade	Angle (β_2 deg)
-1.5	1.6
-1.0	1.6
-0.5	0.9
-0.25	1.1
0.0	1.6
0.25	1.8
0.5	2.1
1.0	2.1
1.5	1.8

TABLE A.17

YAW PROBE INLET AIR ANGLE MEASUREMENTS

Station 1 β_1=43.4°

Blade to Blade Position (in)	Angle (β_2 deg)
-10	43.55
-8.0	43.5
-5.0	43.55
-3.0	43.2
-1.5	43.
-1.0	43.
-0.5	43.6
0.0	43.
0.5	43.
1.0	43.
1.5	43.
4.0	44.
6.6	43.

TABLE A.18

YAW PROBE OUTLET AIR ANGLE MEASUREMENTS

Station 2-6 β_1=43.4°

Blade to Blade Position (in)	Angle (β_2 deg)
-5.95	1.6
-4.9	2.0
-4.45	1.6
-4.1	1.2
-3.7	0.6
-3.2	1.0
-2.1	1.8
-1.5	1.6
-1.1	1.2
-0.1	0.8
1.5	1.6
2.8	1.3
3.2	1.8
4.0	2.2
5.0	1.0

TABLE A.19

DATA FILE NAMES AND STATION IDENTIFICATION

Station	Raw Data Name		Reduced Data Name	
	40.3°	43.4°	40.3°	43.4°
1	BW6250	BW6260	BD6250	BD6260
2-1	BC6251	BC6261	DC6251	DC6261
2-2	BC6252	-	DC6252	-
2-3	BC6259	BC6263	DC6259	DC6263
2-4	BC6258	-	DC6258	-
2-5	BC6255	BC6265	DC6255	DC6265
2-6	BW6250	BW6260	BD6250	BD6260
Blade	IW6250	IW6260	ID6250	ID6260

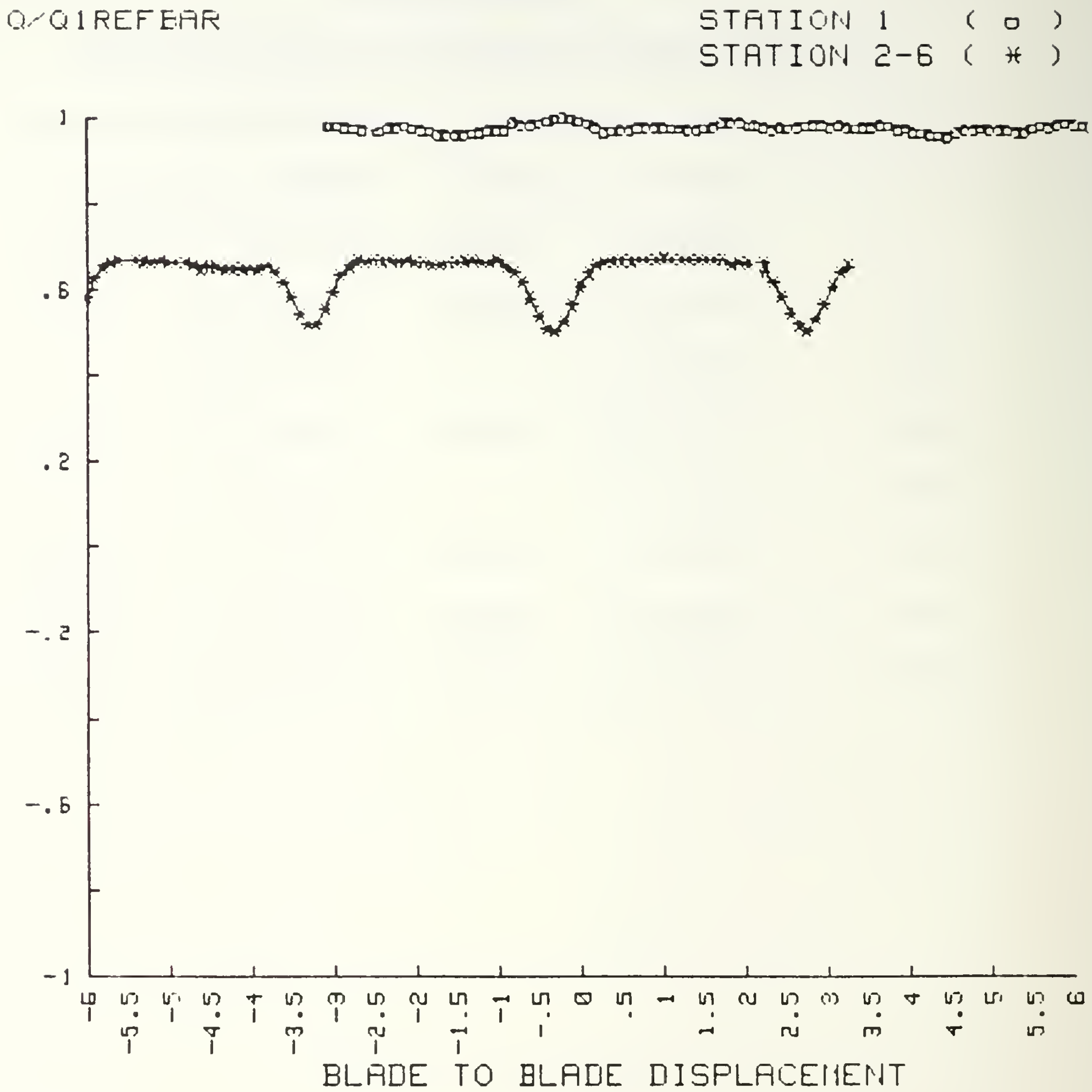

Figure A1. Q/Q1REFBAR Vs Blade to Blade Displacement
β_1=40.3 Re=774000

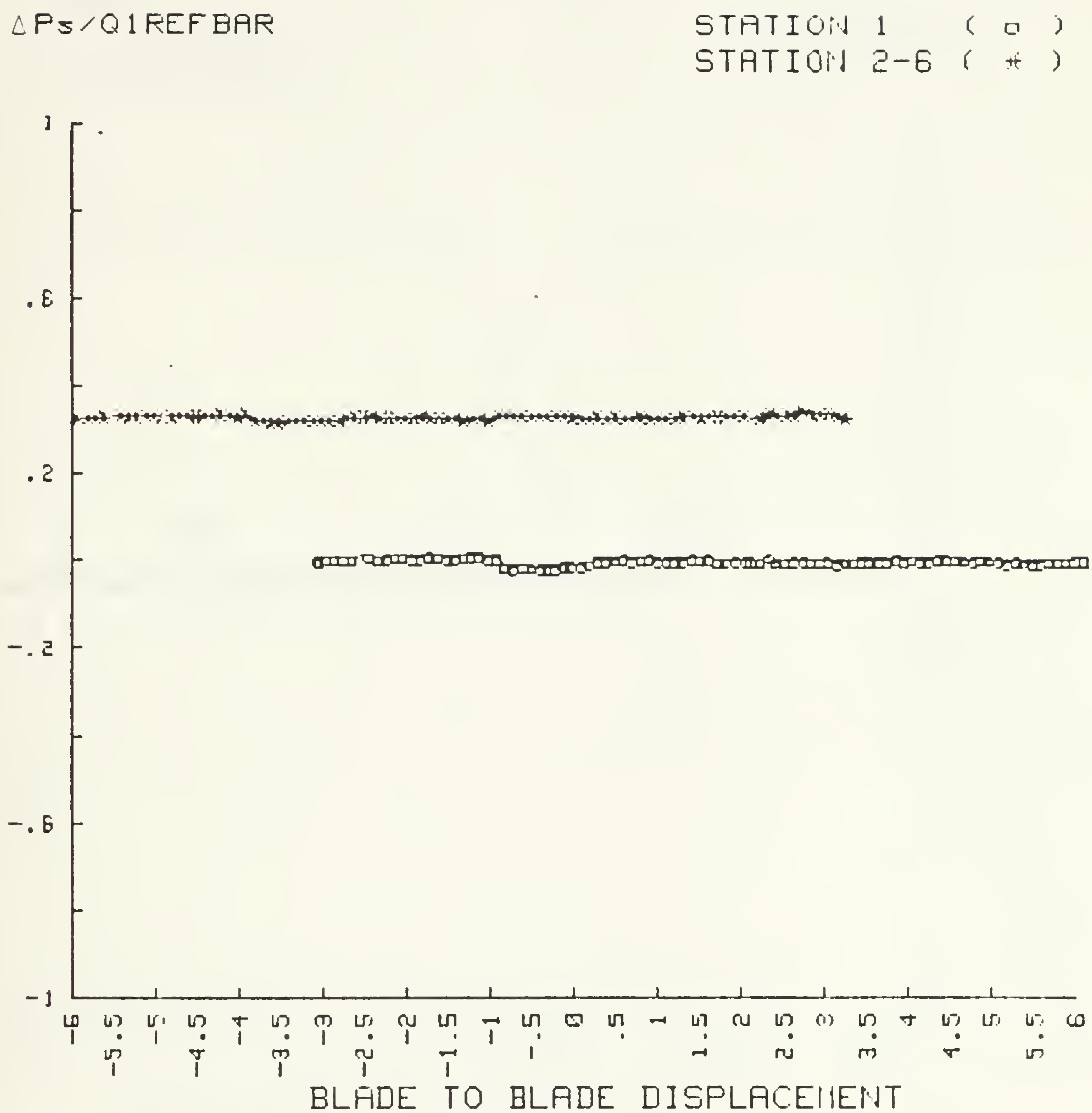

Figure A2. ΔPs/Q1REFBAR Vs Blade to Blade Displacement
β_1=40.3 Re=774000

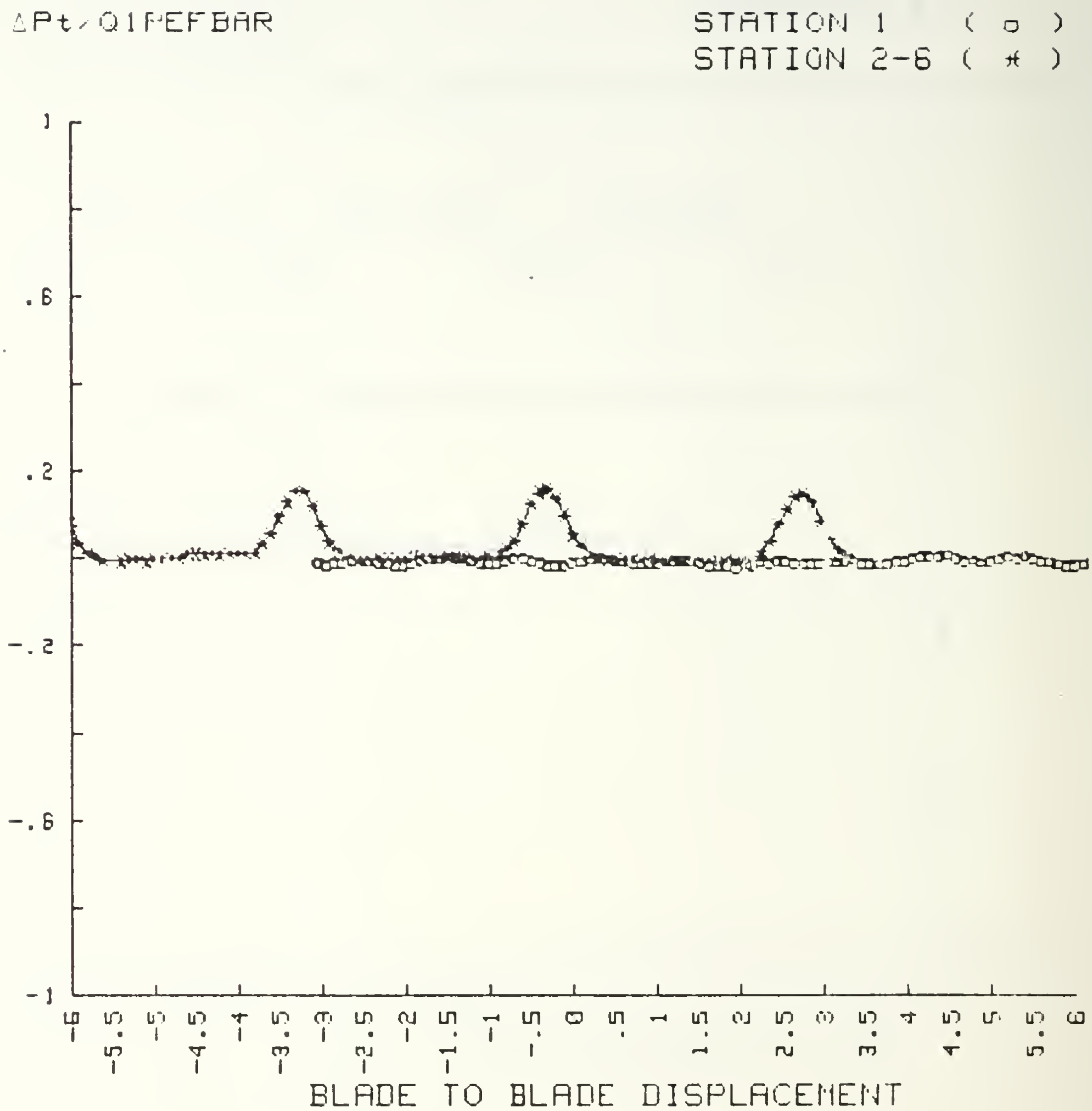

Figure A3. ΔPt/Q1REFBAR Vs Blade to Blade Displacement
β_1=40.3 Re=774000

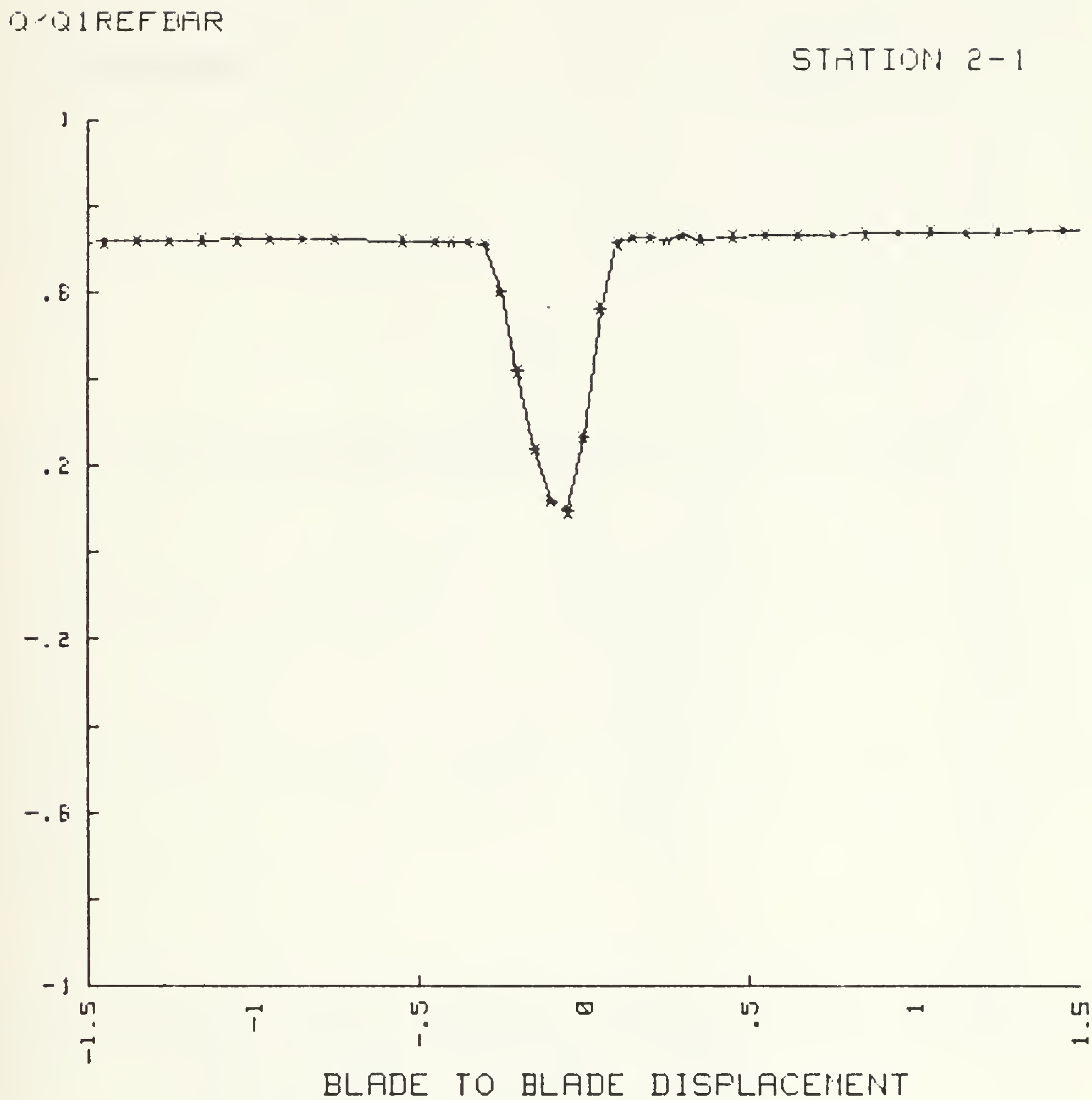

Figure A4. Q/Q1REFBAR Vs Blade to Blade Displacement
β_1=40.3 Re=774000

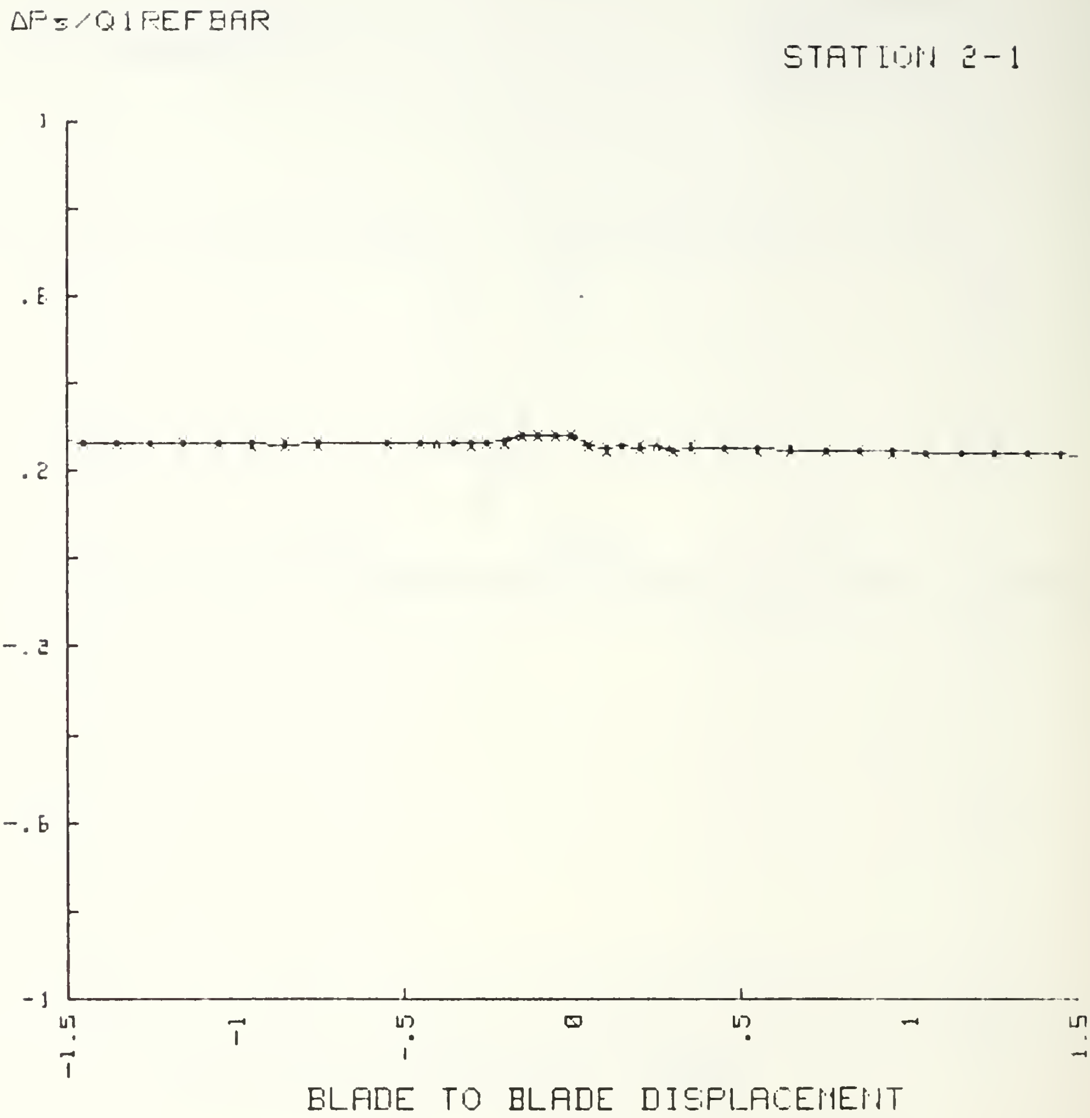

Figure A5. ΔPs/Q1REFBAR Vs Blade to Blade Displacement
β_1=40.3 Re=774000

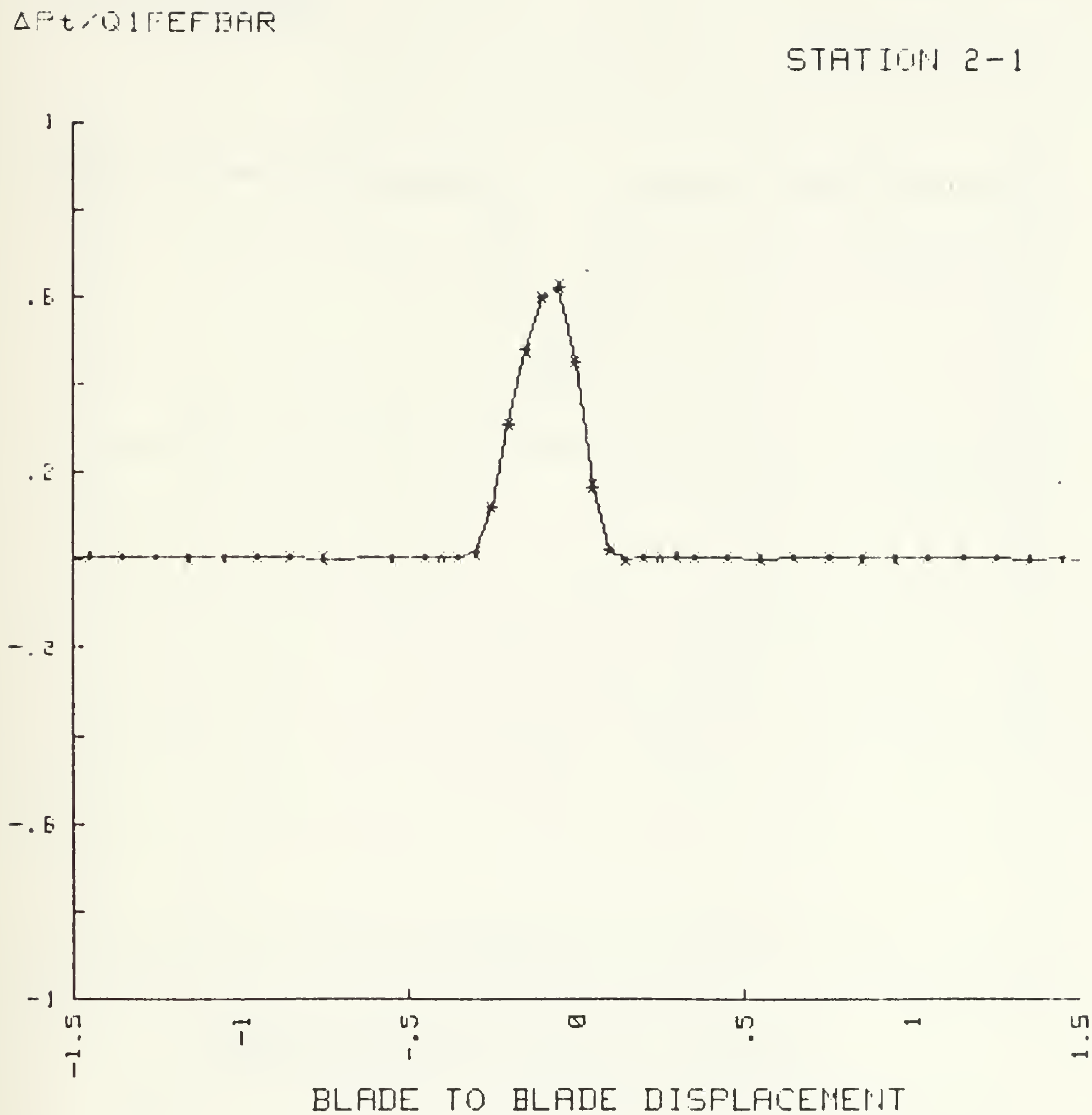

Figure A6. ΔPt/Q1REFBAR Vs Blade to Blade Displacement
β_1=40.3 Re=774000

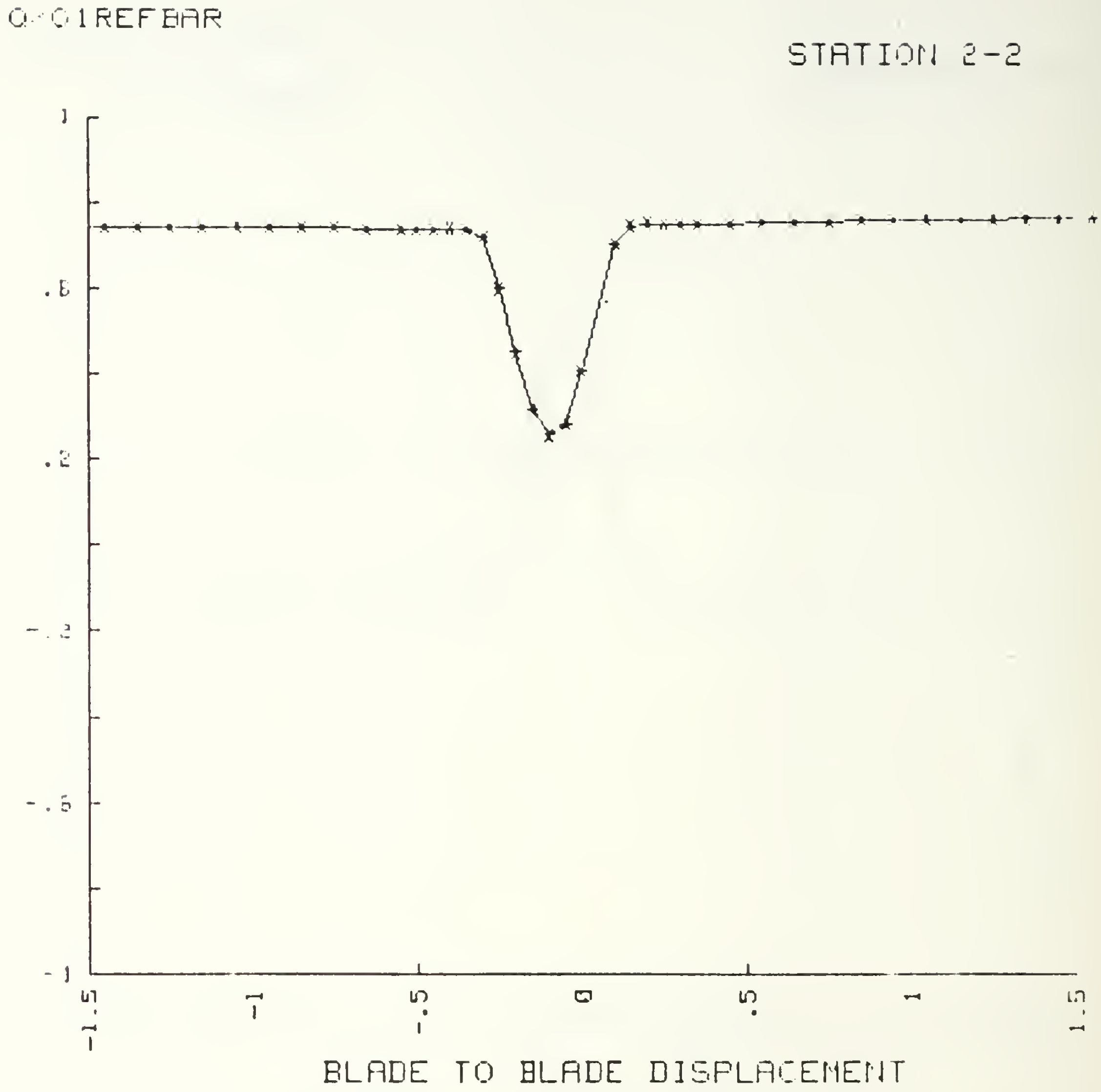

Figure A7. Q/Q1REFBAR Vs Blade to Blade Displacement
β_1=40.3 Re=774000

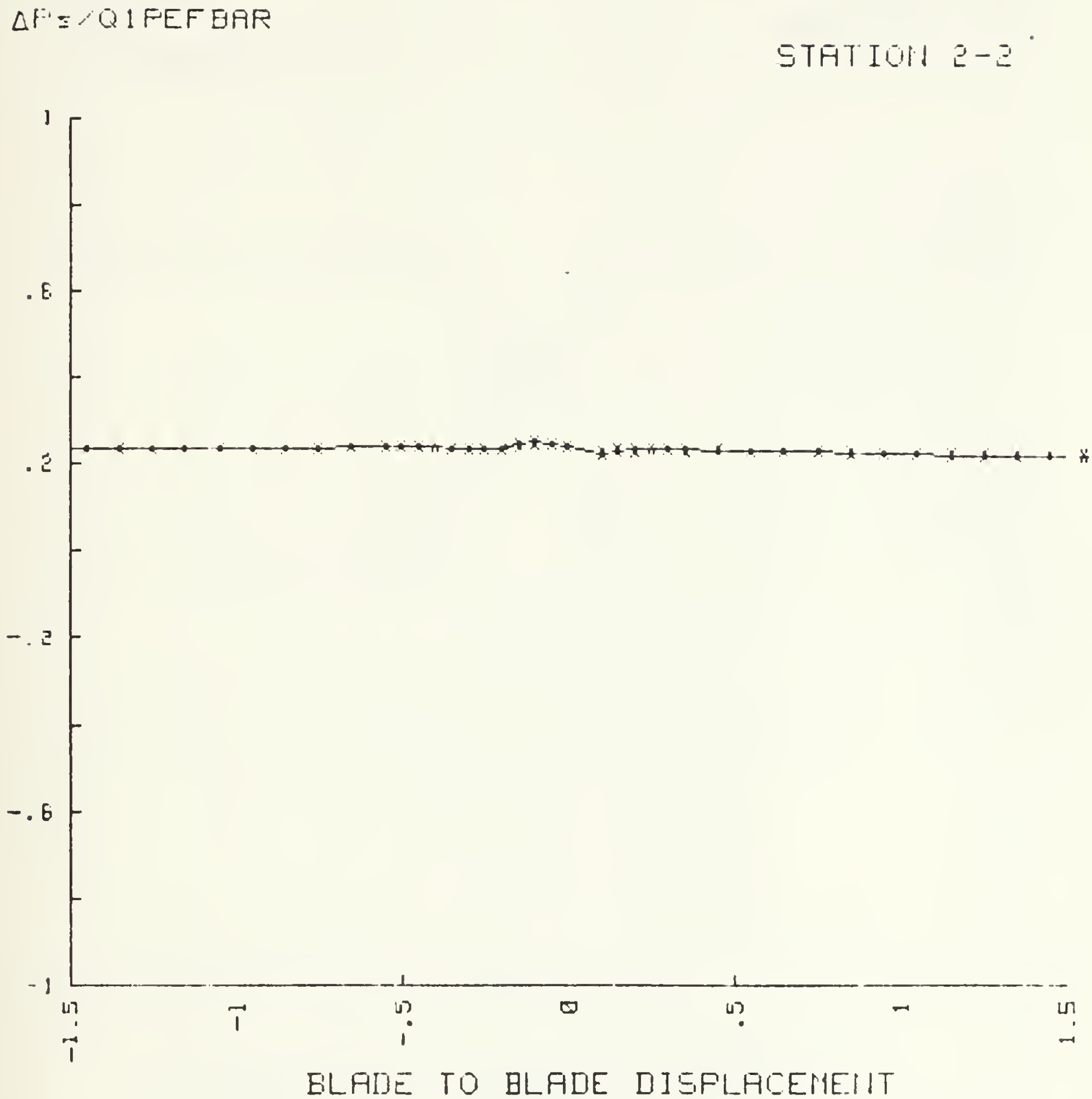

Figure A8. ΔPs/Q1REFBAR Vs Blade to Blade Displacement
β_1=40.3 Re=774000

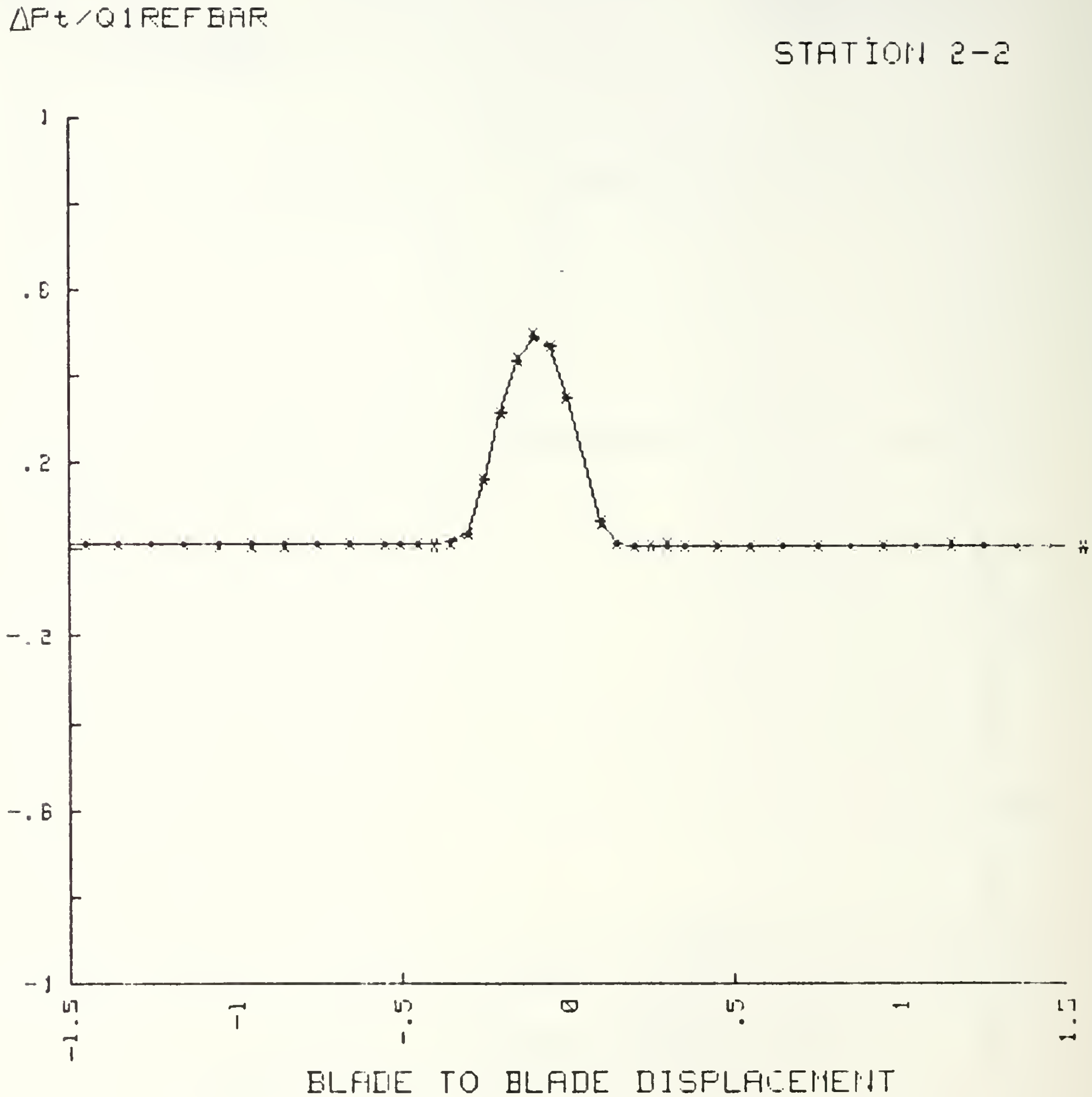

Figure A9. ΔPt/Q1REFBAR Vs Blade to Blade Displacement
β_1=40.3 Re=774000

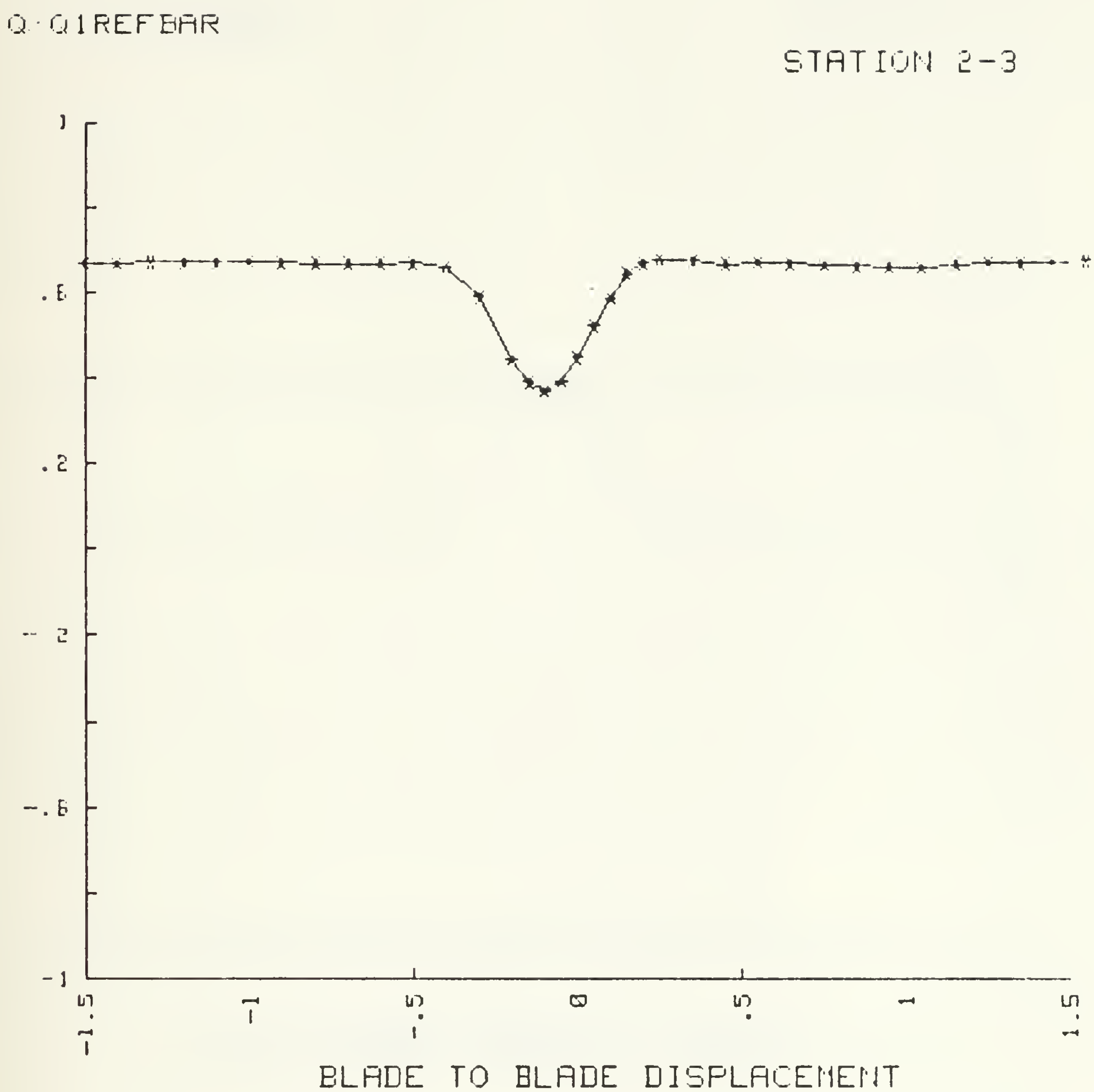

Figure A10. Q/Q1REFBAR Vs Blade to Blade Displacement
β_1=40.3 Re=774000

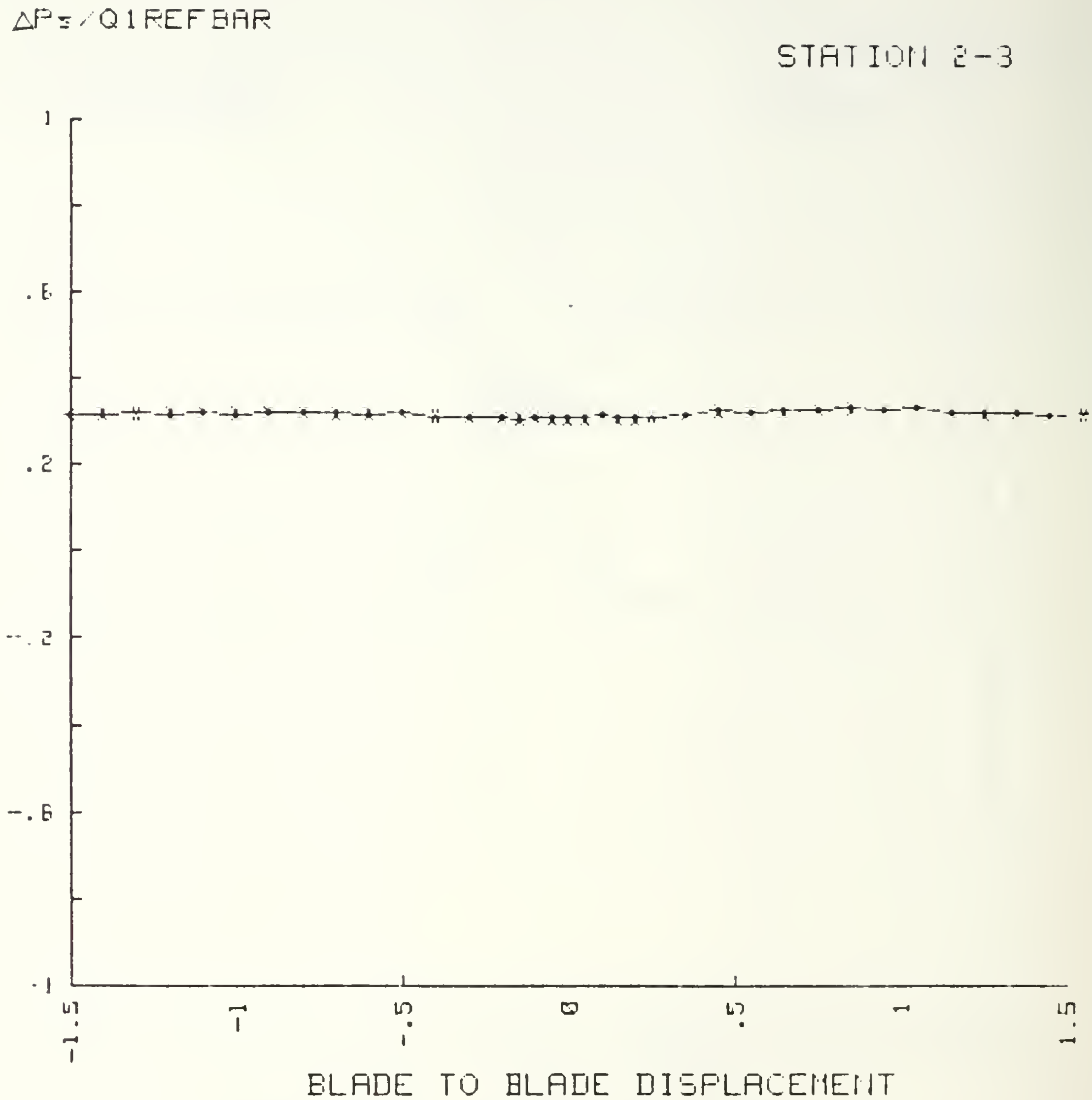

Figure A11. ΔPs/Q1REFBAR Vs Blade to Blade Displacement
β_1=40.3 Re=774000

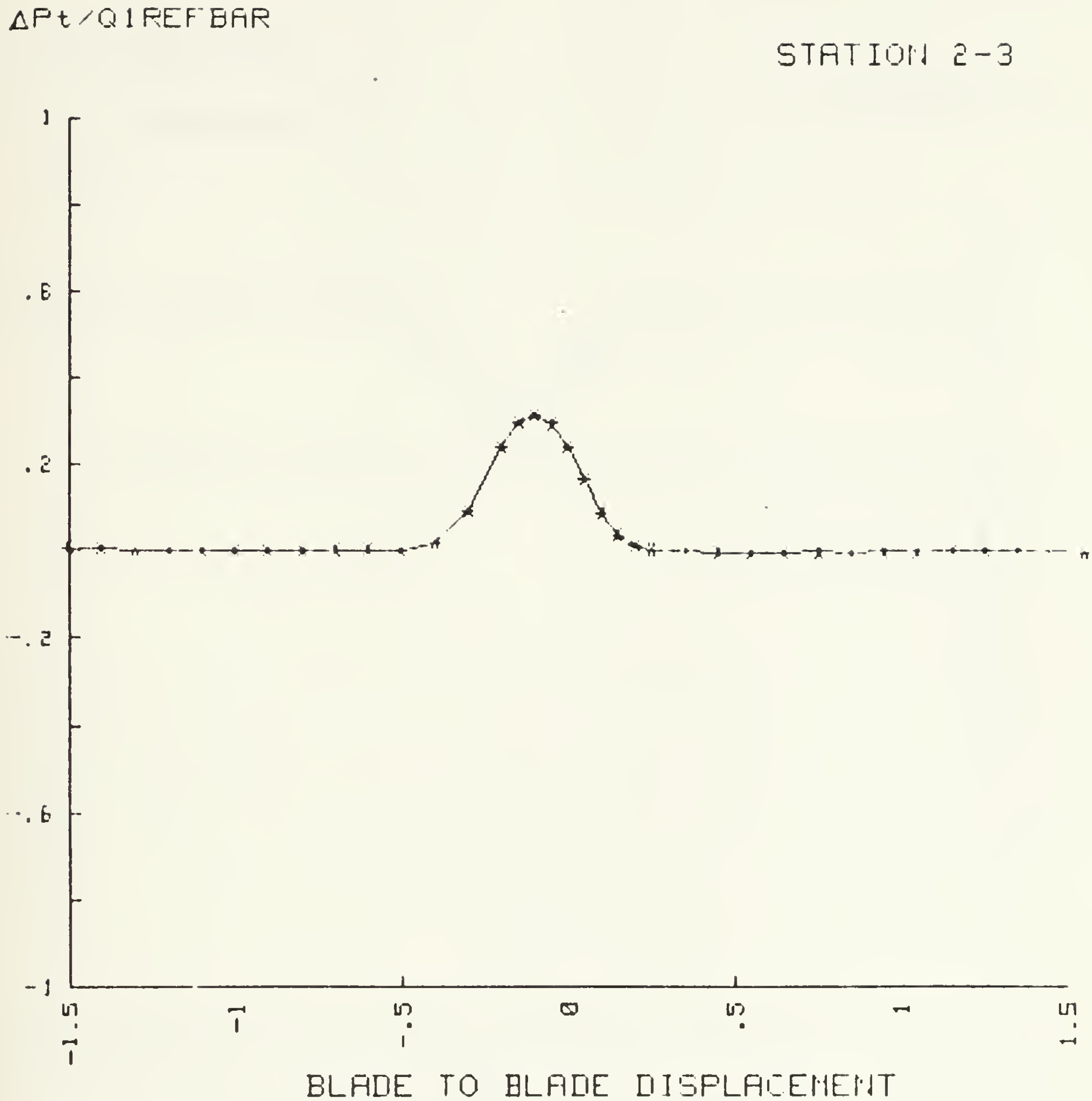

Figure A12. ΔPt/Q1REFBAR Vs Blade to Blade Displacement
β_1=40.3 Re=774000

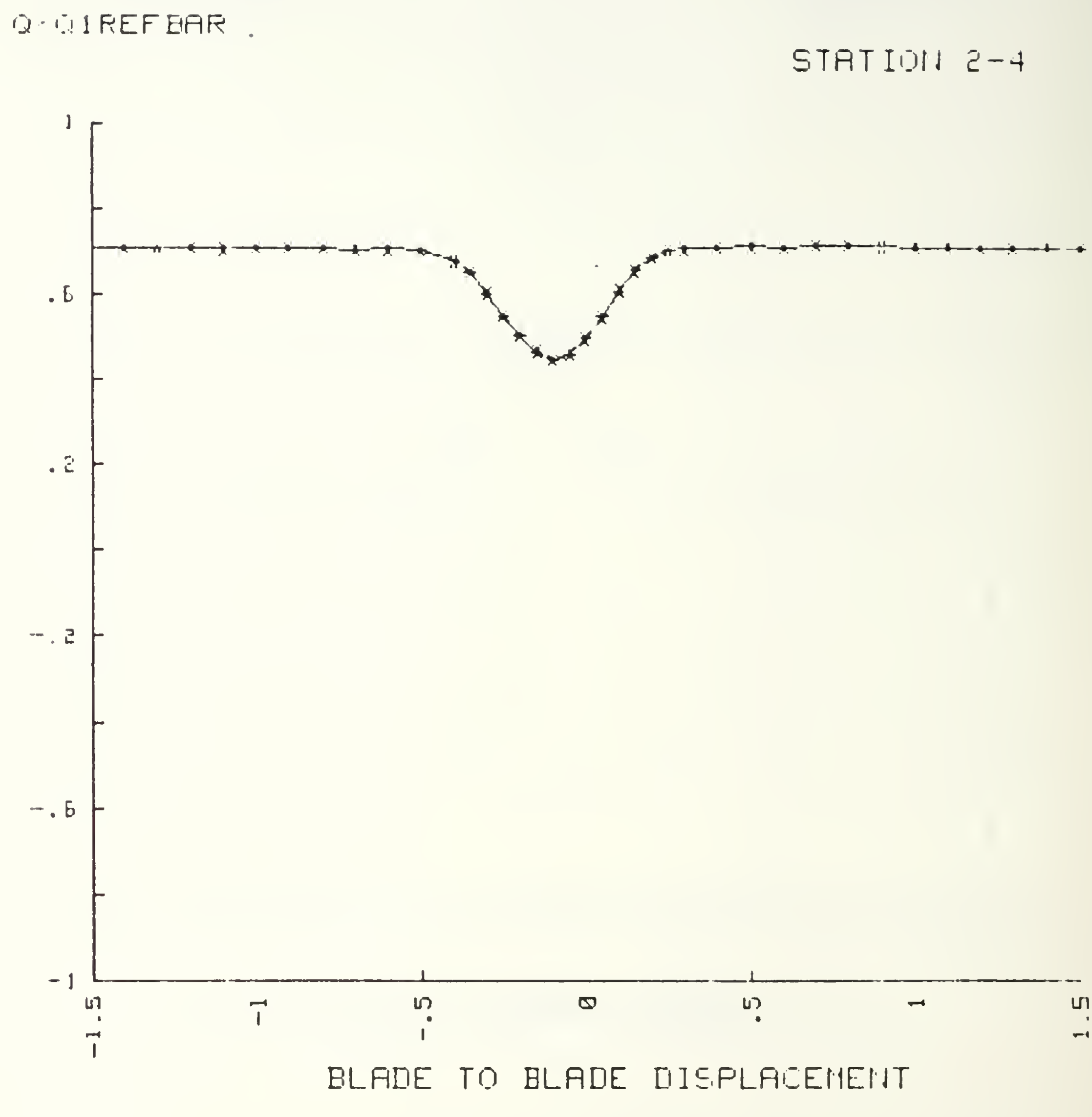

Figure A13. Q/Q1REFBAR Vs Blade to Blade Displacement
β_1=40.3 Re=774000

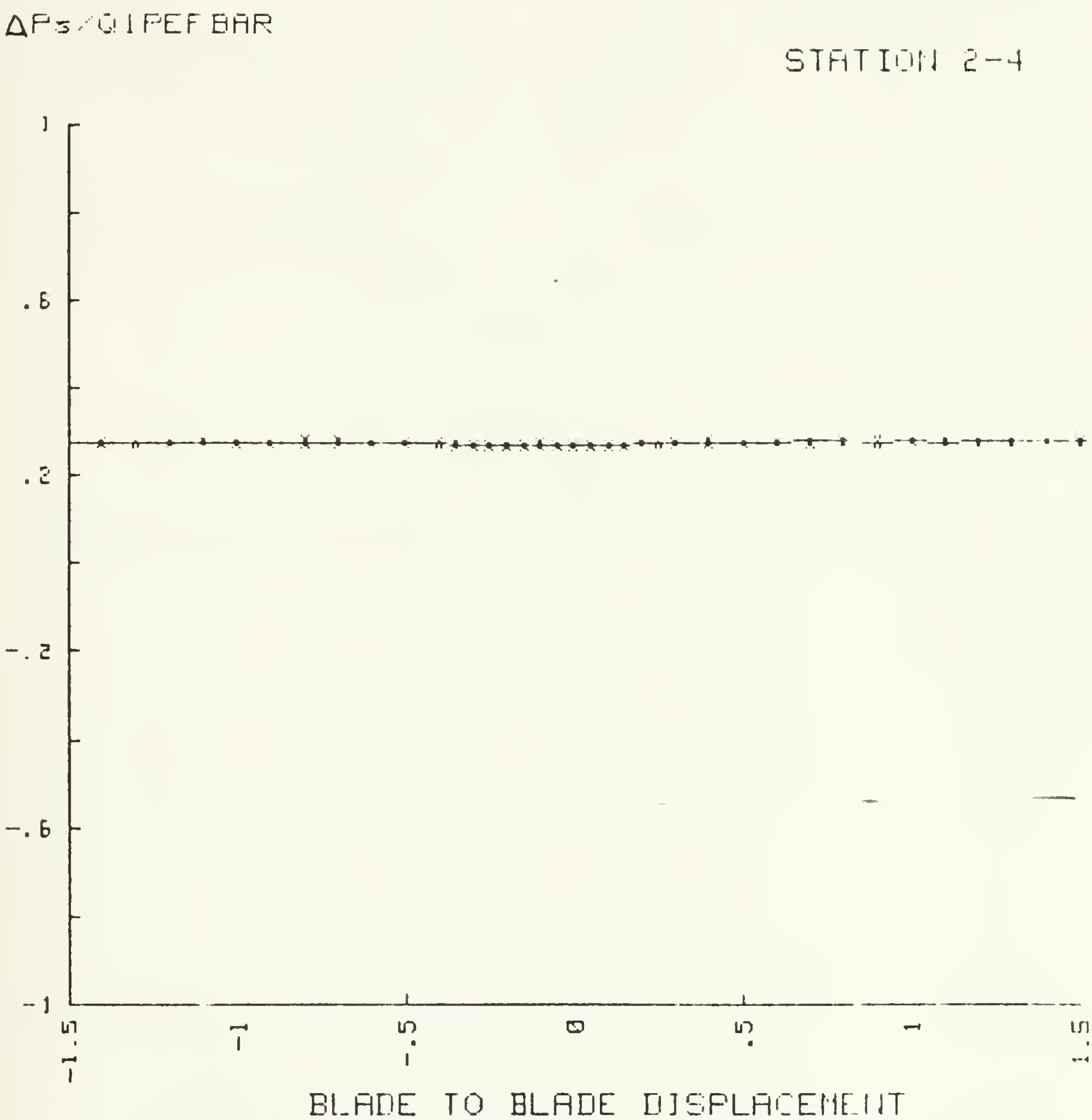

Figure A14. ΔPs/Q1REFBAR Vs Blade to Blade Displacement
β_1=40.3 Re=774000

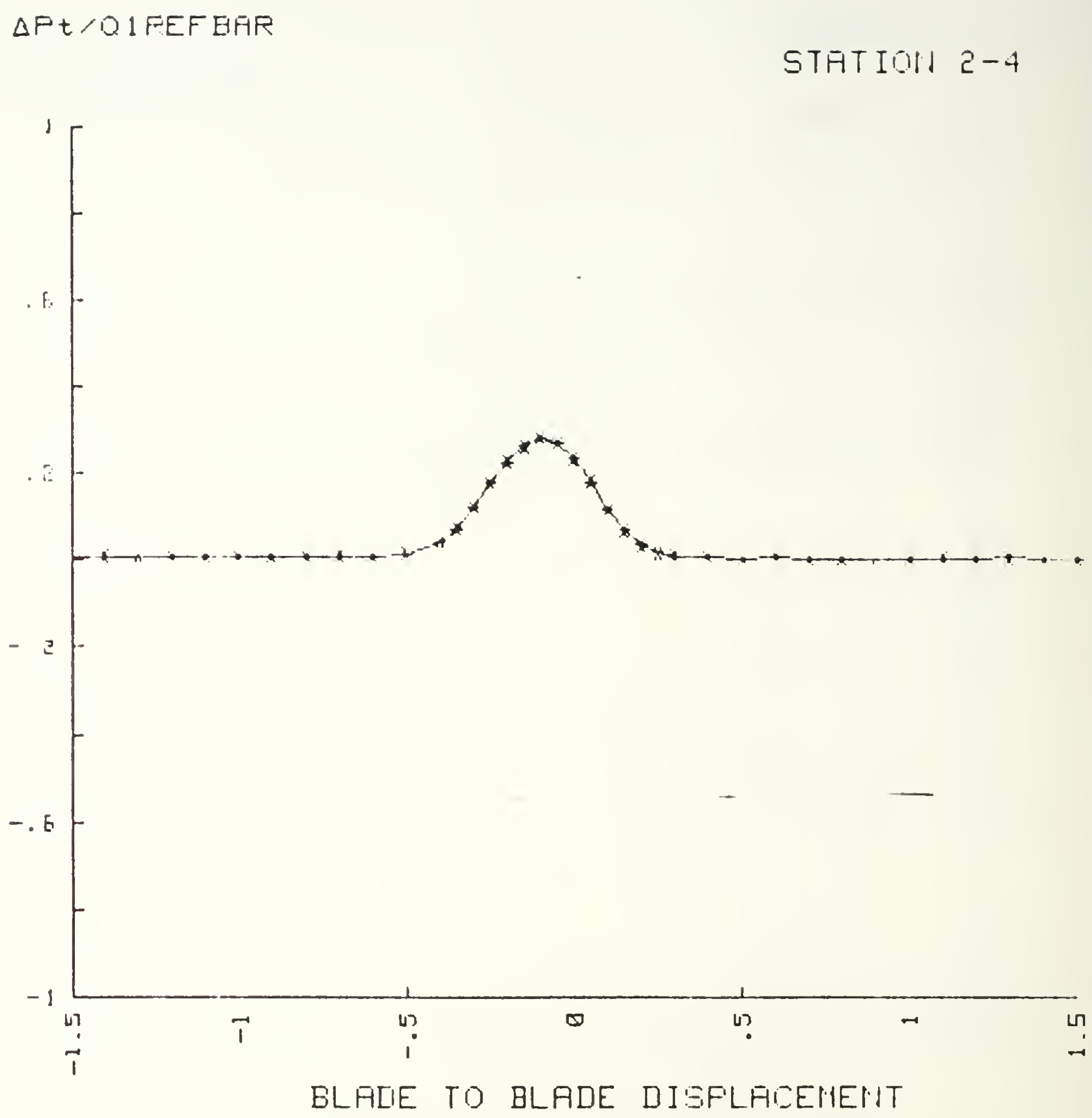

Figure A15. ΔPt/Q1REFBAR Vs Blade to Blade Displacement
β_1=40.3 Re=774000

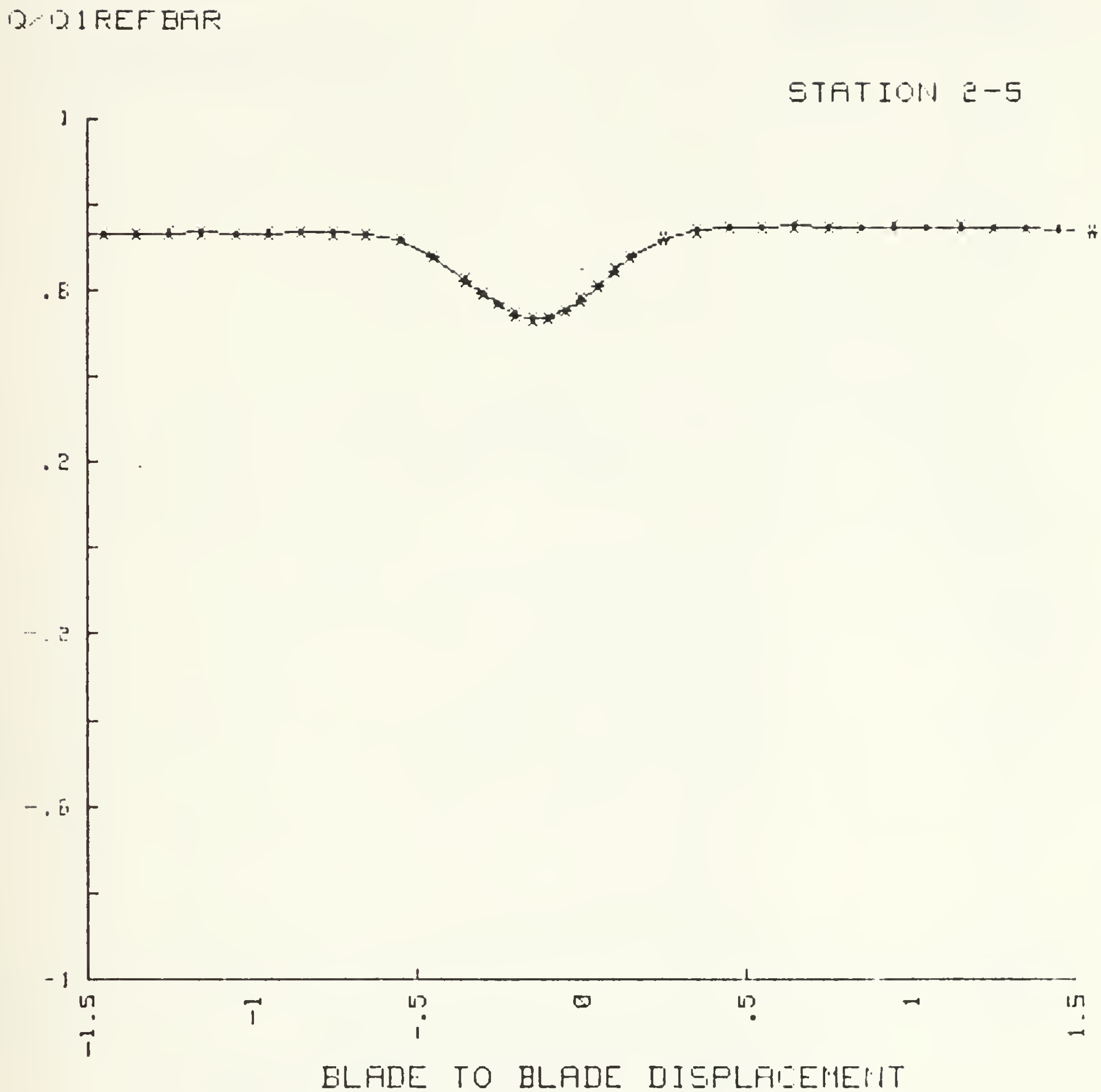

Figure A16. Q/Q1REFBAR Vs Blade to Blade Displacement
β_1=40.3 Re=774000

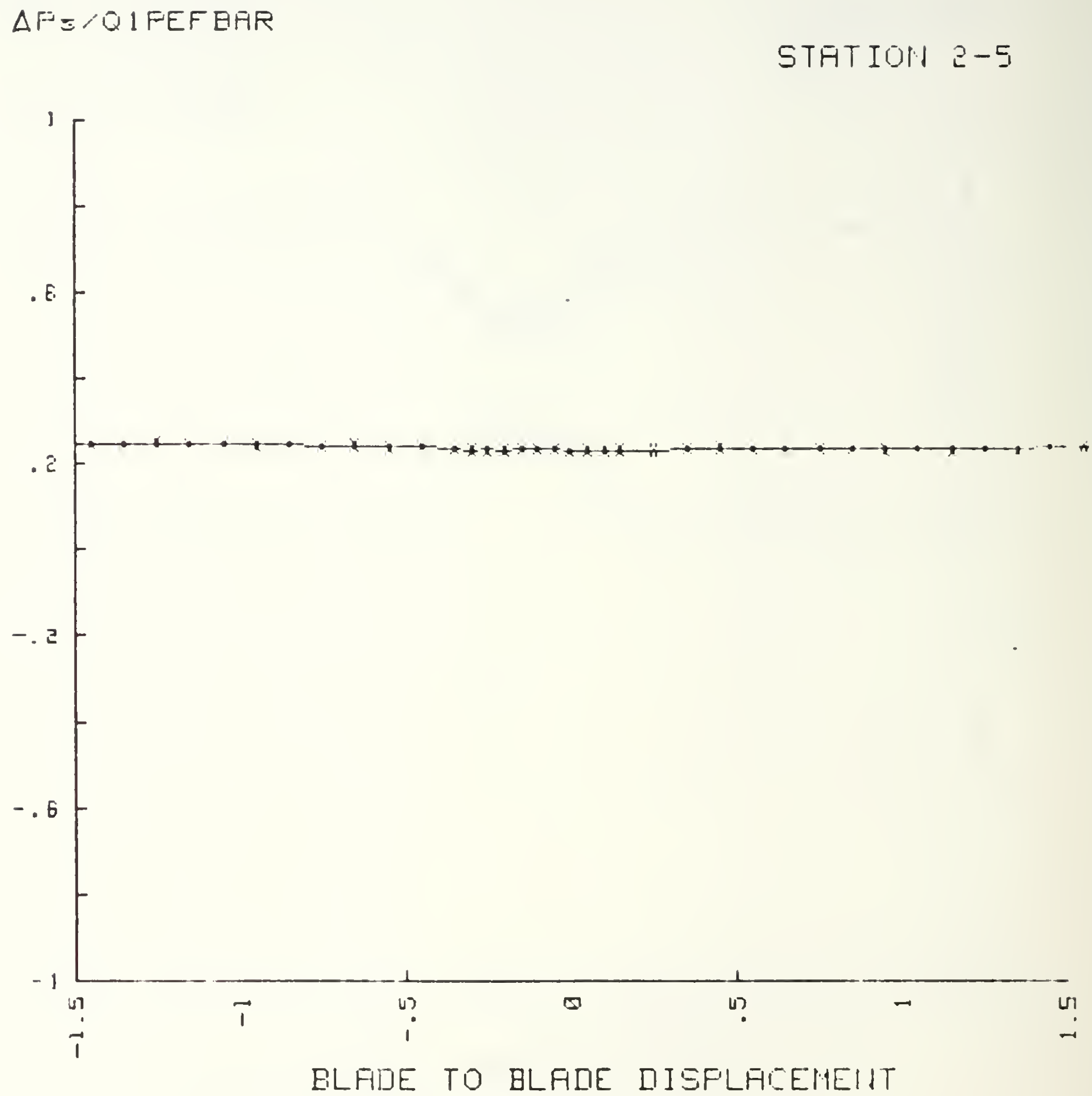

Figure A17. ΔPs/Q1REFBAR Vs Blade to Blade Displacement β_1=40.3 Re=774000

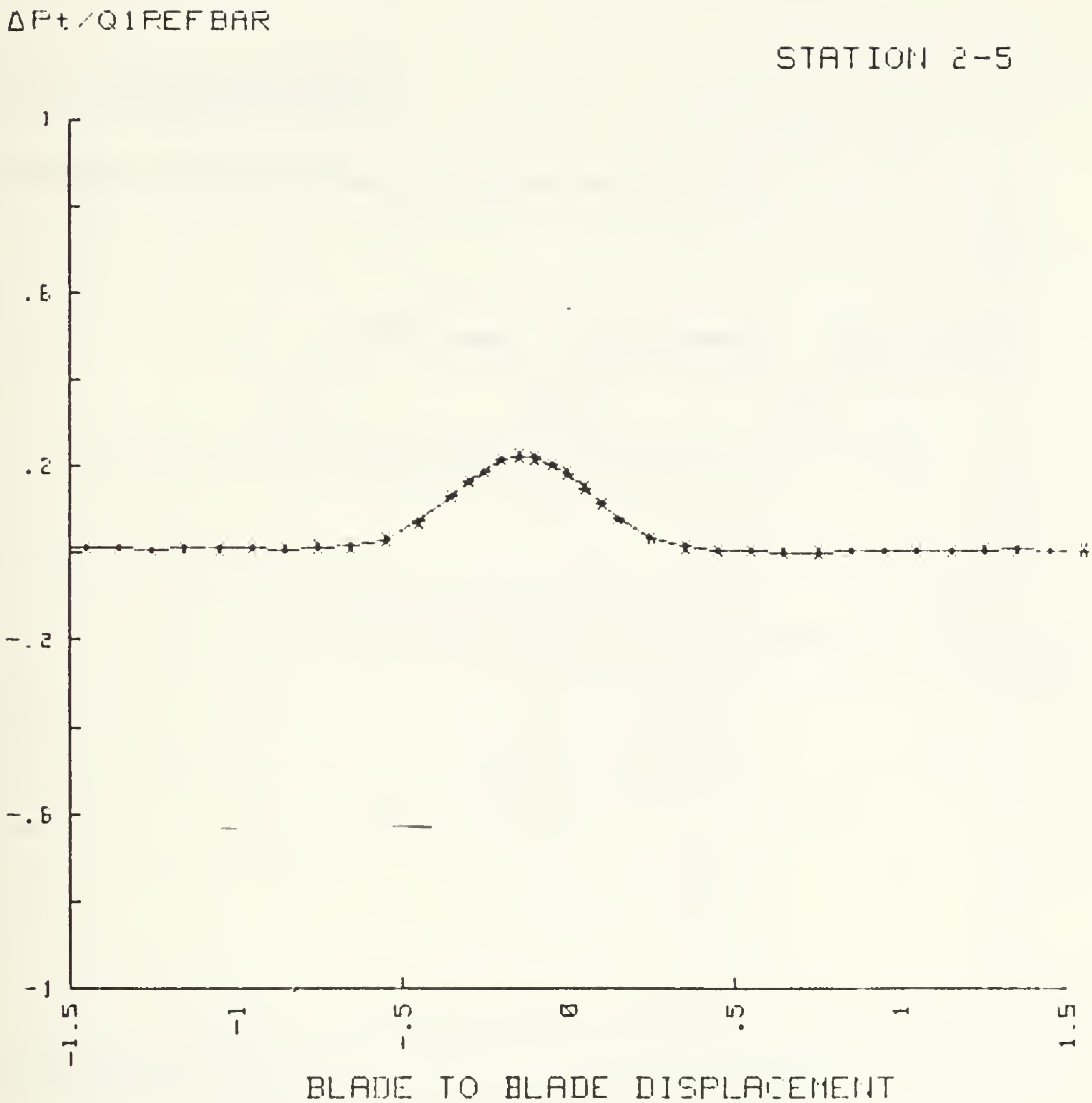

Figure A18. ΔPt/Q1REFBAR Vs Blade to Blade Displacement
β_1=40.3 Re=774000

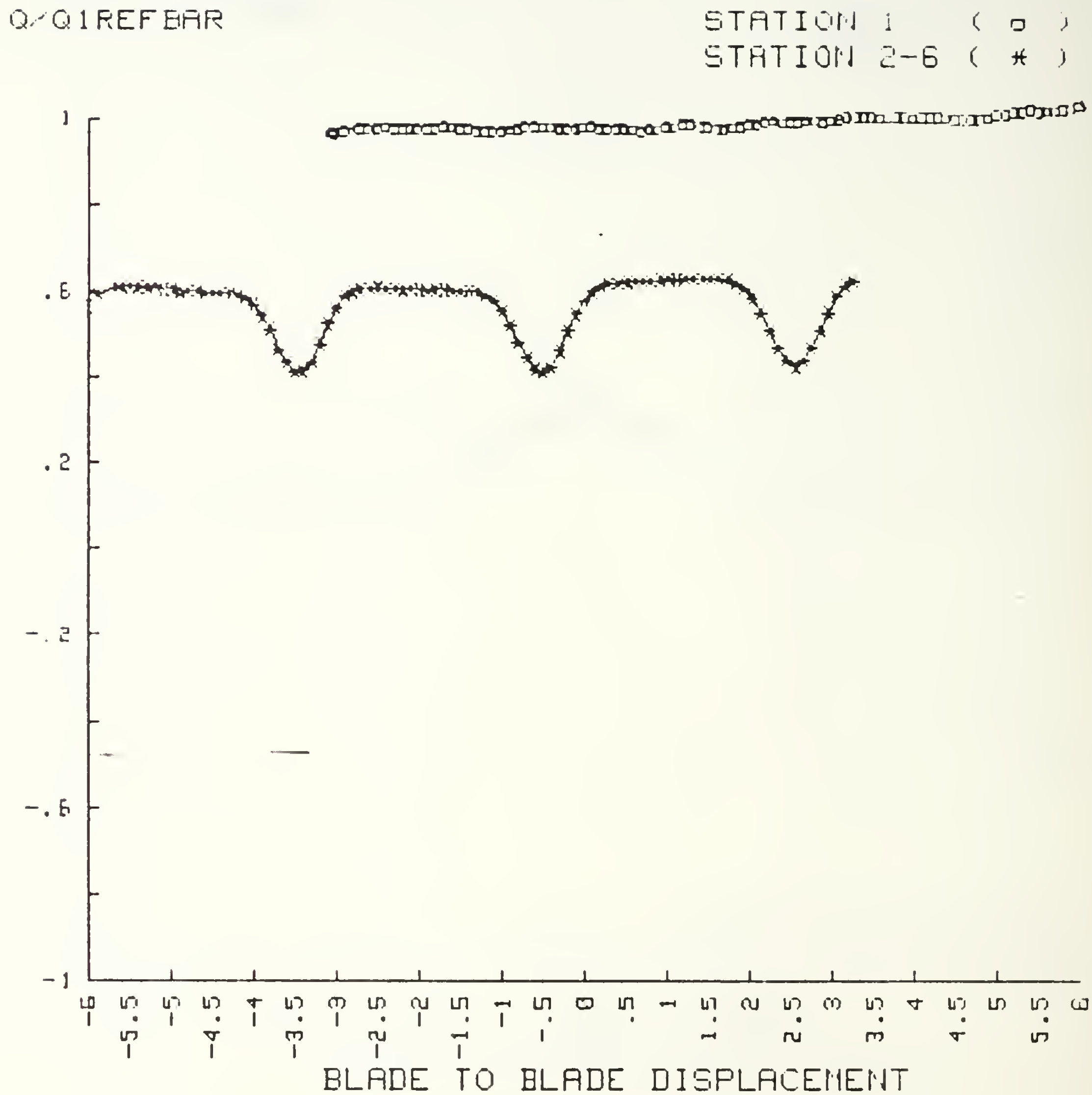

Figure A19. Q/Q1REFBAR Vs Blade to Blade Displacement
β_1=43.4 Re=774000

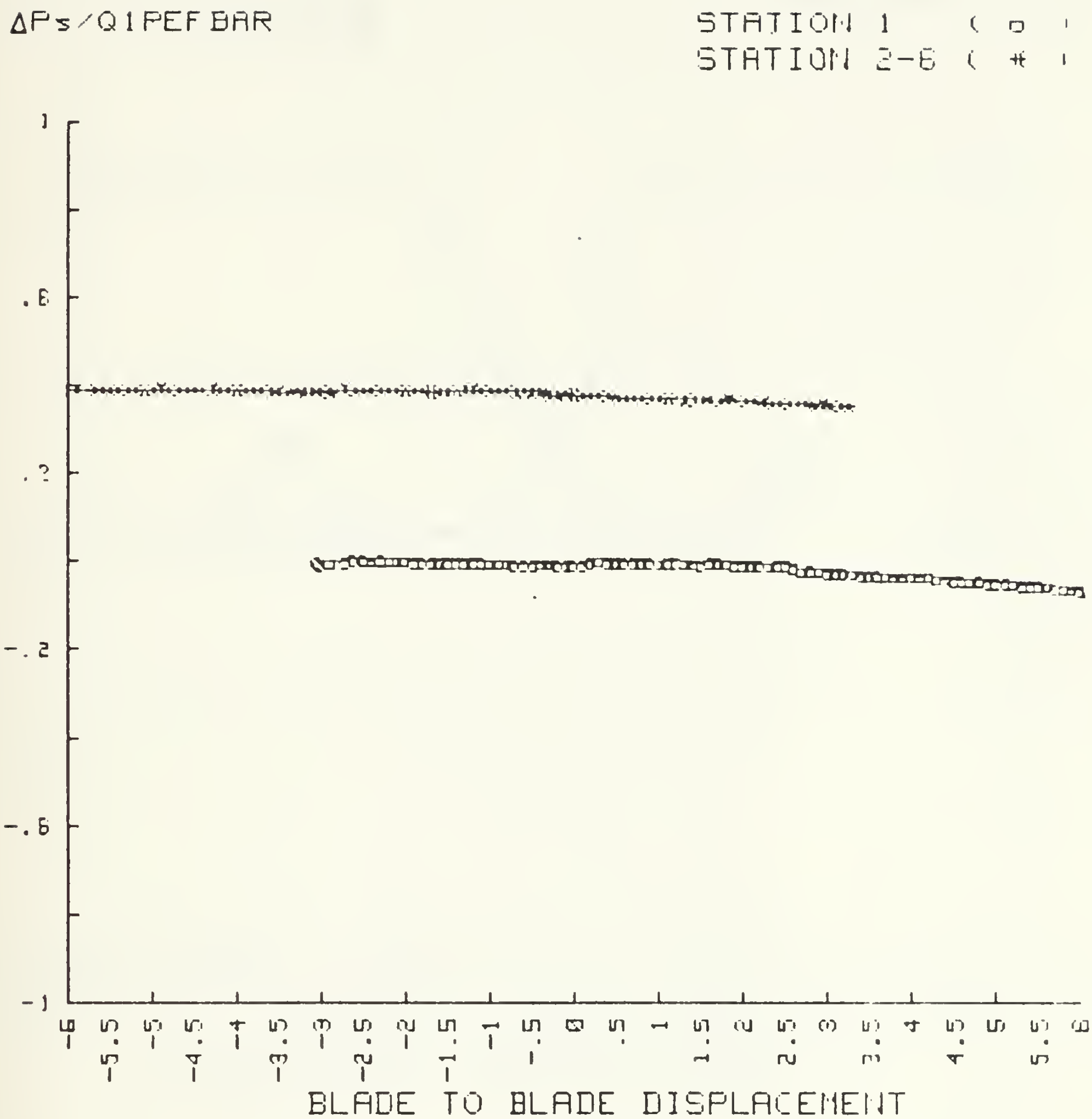

Figure A20. ΔPs/Q1REFBAR Vs Blade to Blade Displacement
β_1=43.4 Re=774000

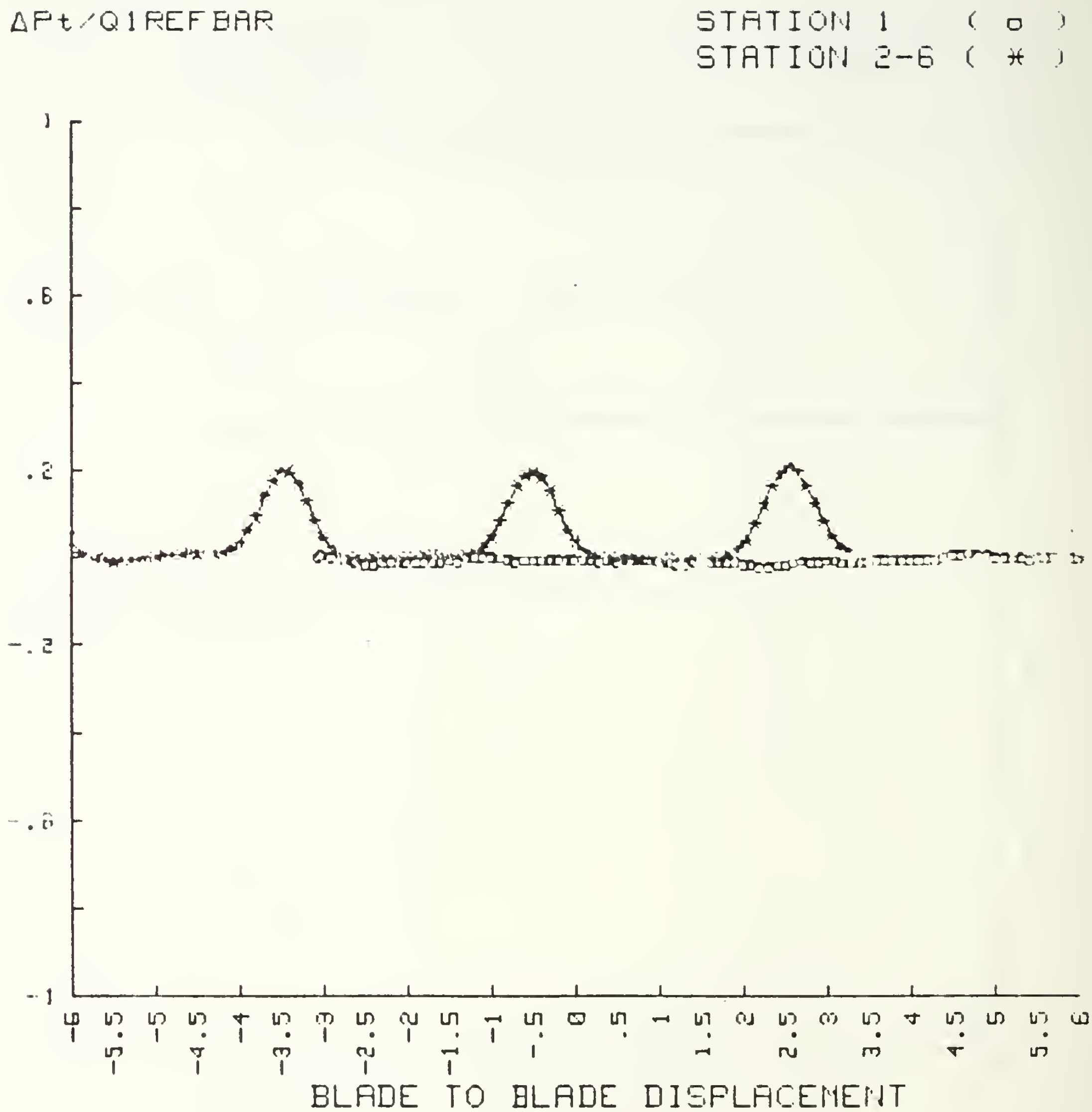

Figure A21. ΔPt/Q1REFBAR Vs Blade to Blade Displacement
β_1=43.4 Re=774000

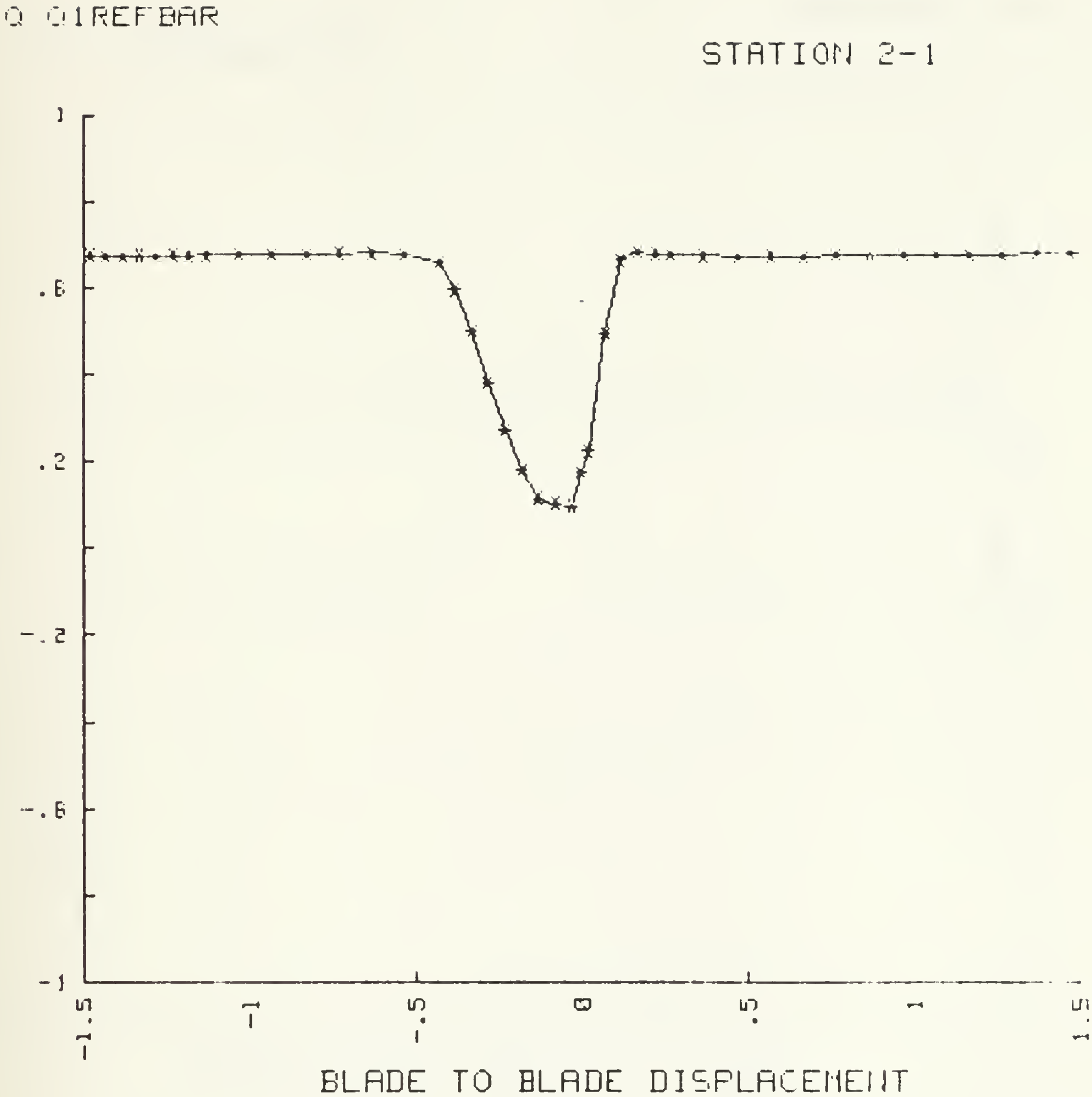

Figure A22. Q/Q1REFBAR Vs Blade to Blade Displacement
β_1=43.4 Re=774000

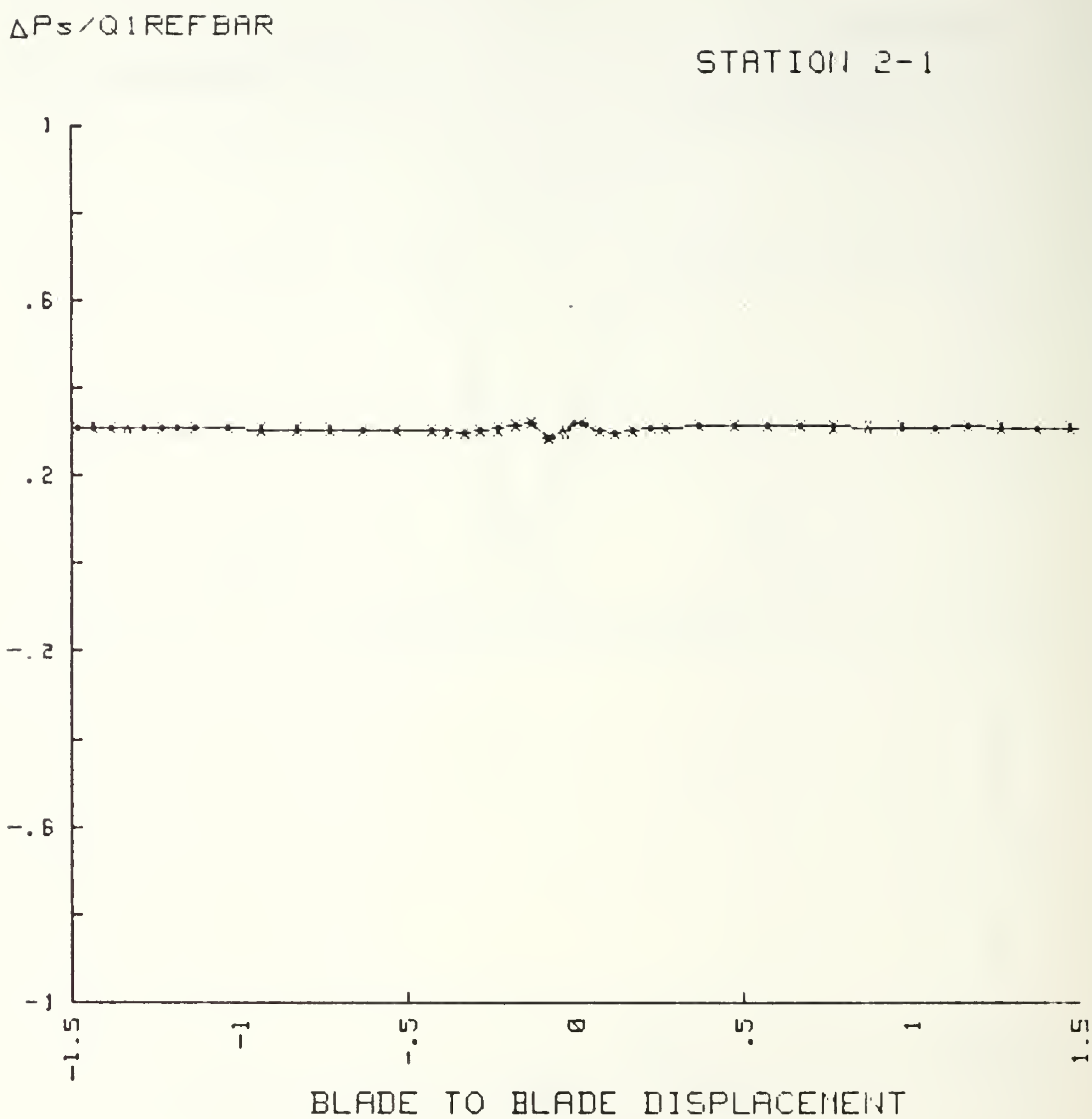

Figure A23. ΔPs/Q1REFBAR Vs Blade to Blade Displacement
β_1=43.4 Re=774000

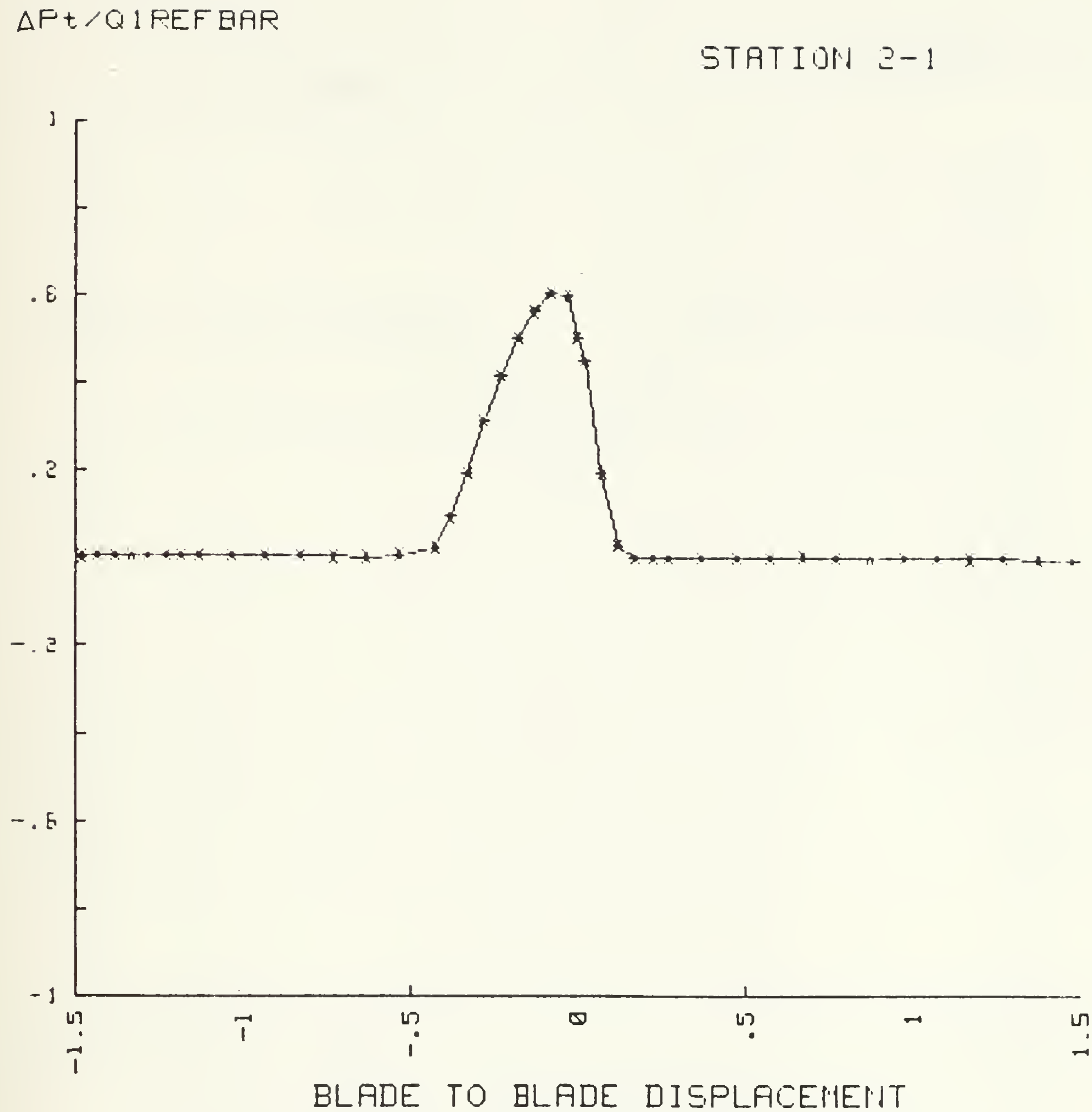

Figure A24. ΔPt/Q1REFBAR Vs Blade to Blade Displacement β_1=43.4 Re=774000

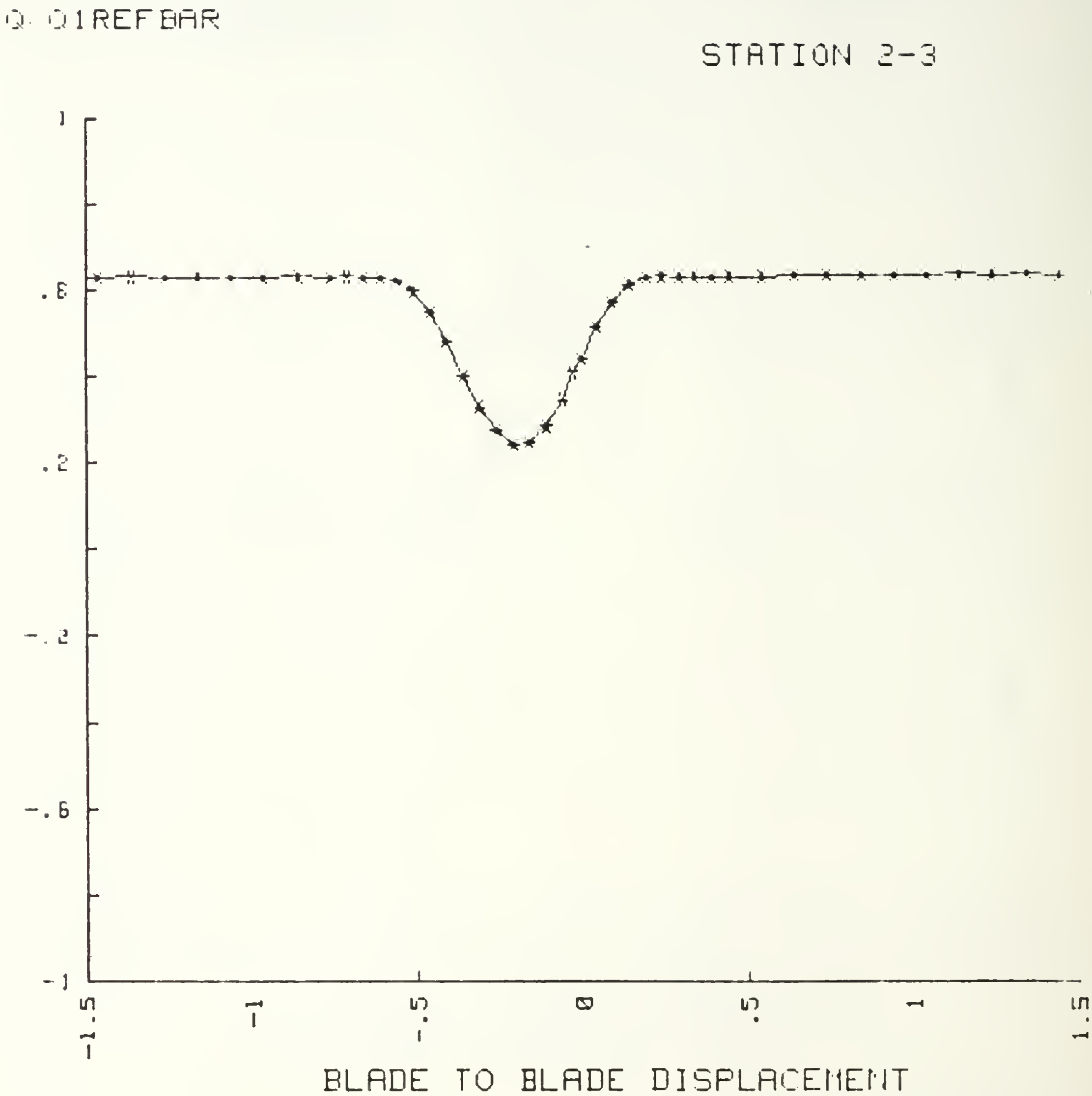

Figure A25. Q/Q1REFBAR Vs Blade to Blade Displacement
β_1=43.4 Re=774000

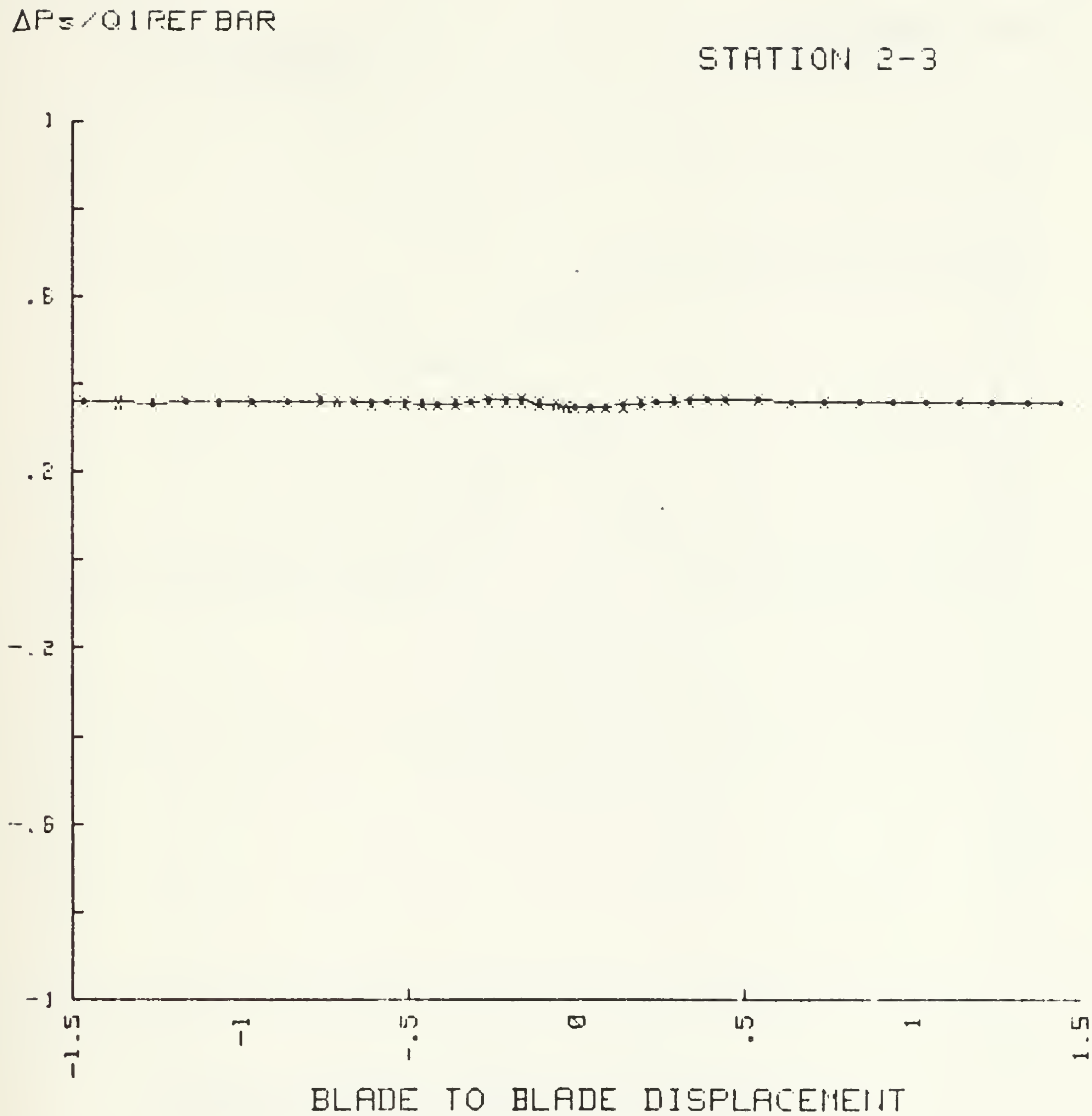

Figure A26. ΔPs/Q1REFBAR Vs Blade to Blade Displacement
β_1=43.4 Re=774000

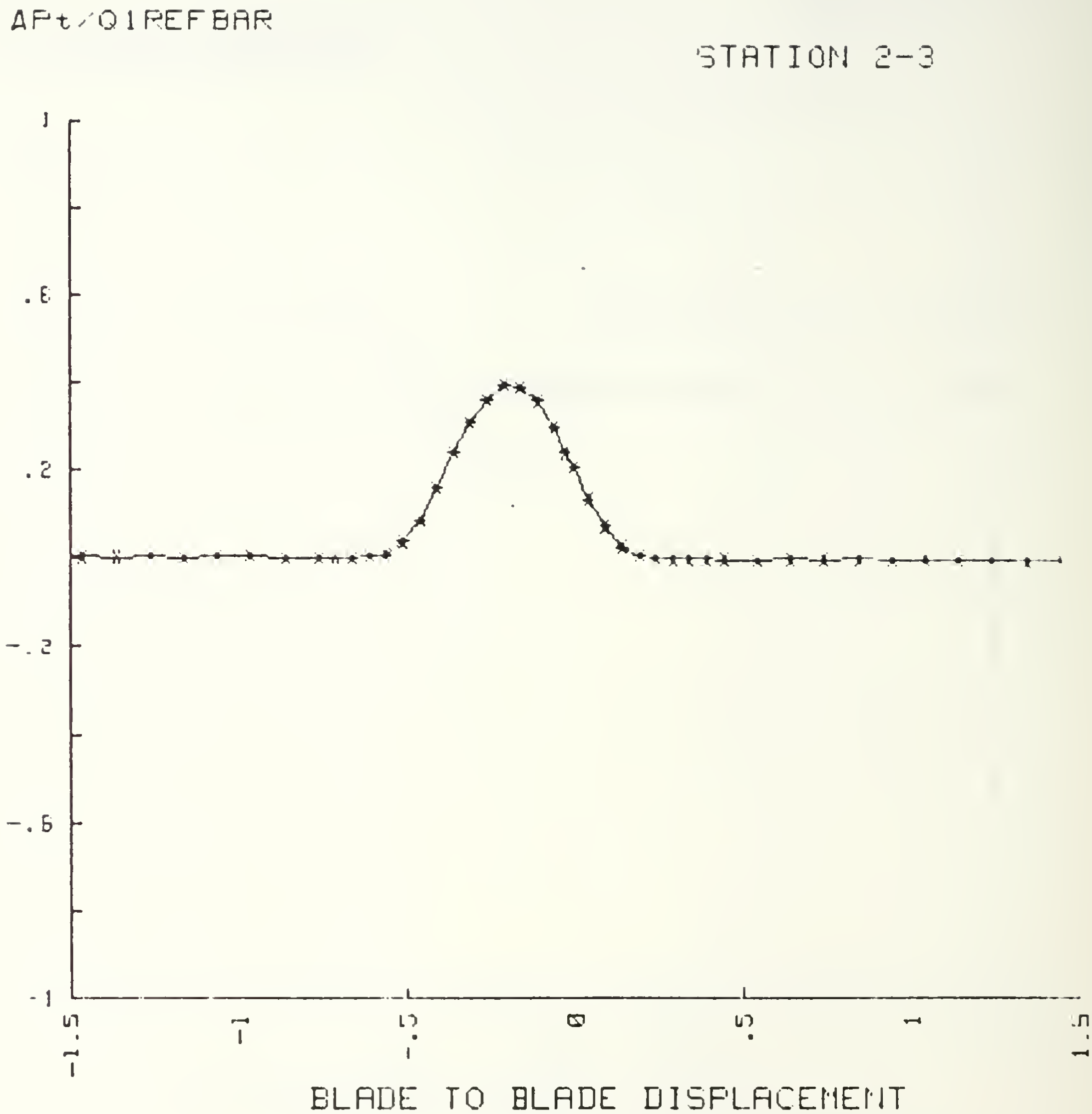

Figure A27. ΔPt/Q1REFBAR Vs Blade to Blade Displacement
β_1=43.4 Re=774000

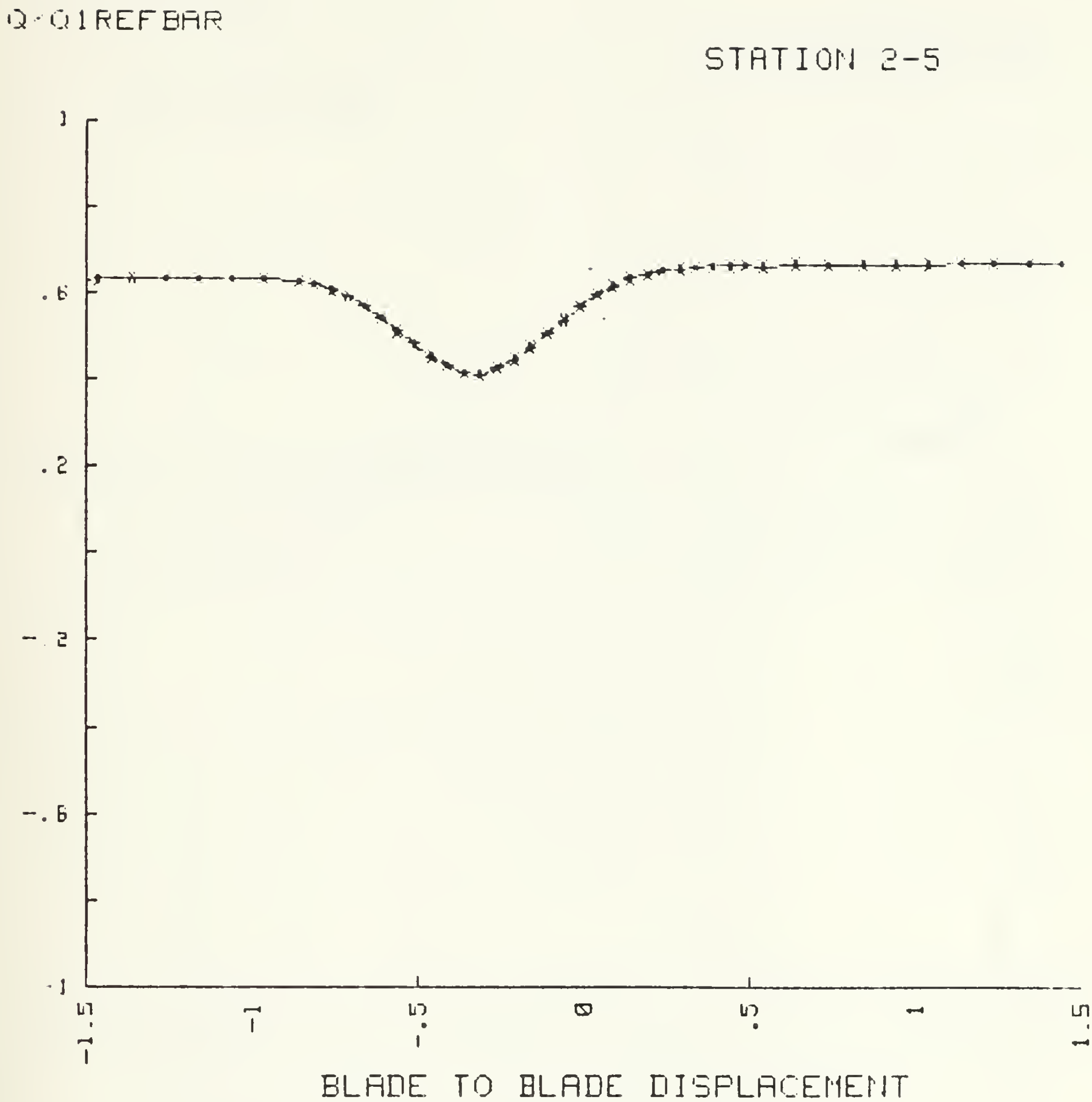

Figure A28. Q/Q1REFBAR Vs Blade to Blade Displacement
β_1=43.4 Re=774000

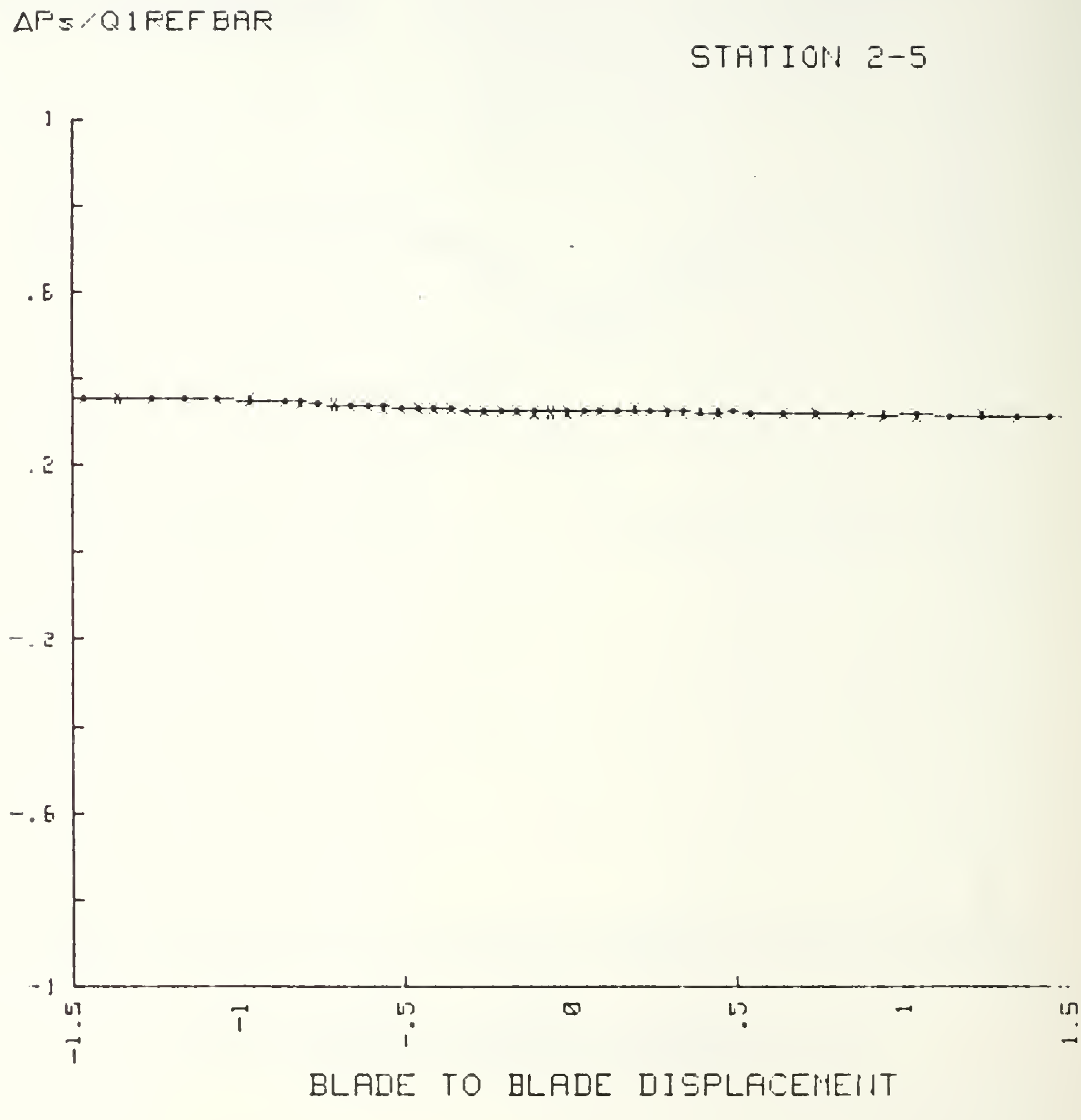

Figure A29. ΔPs/Q1REFBAR Vs Blade to Blade Displacement
β_1=43.4 Re=774000

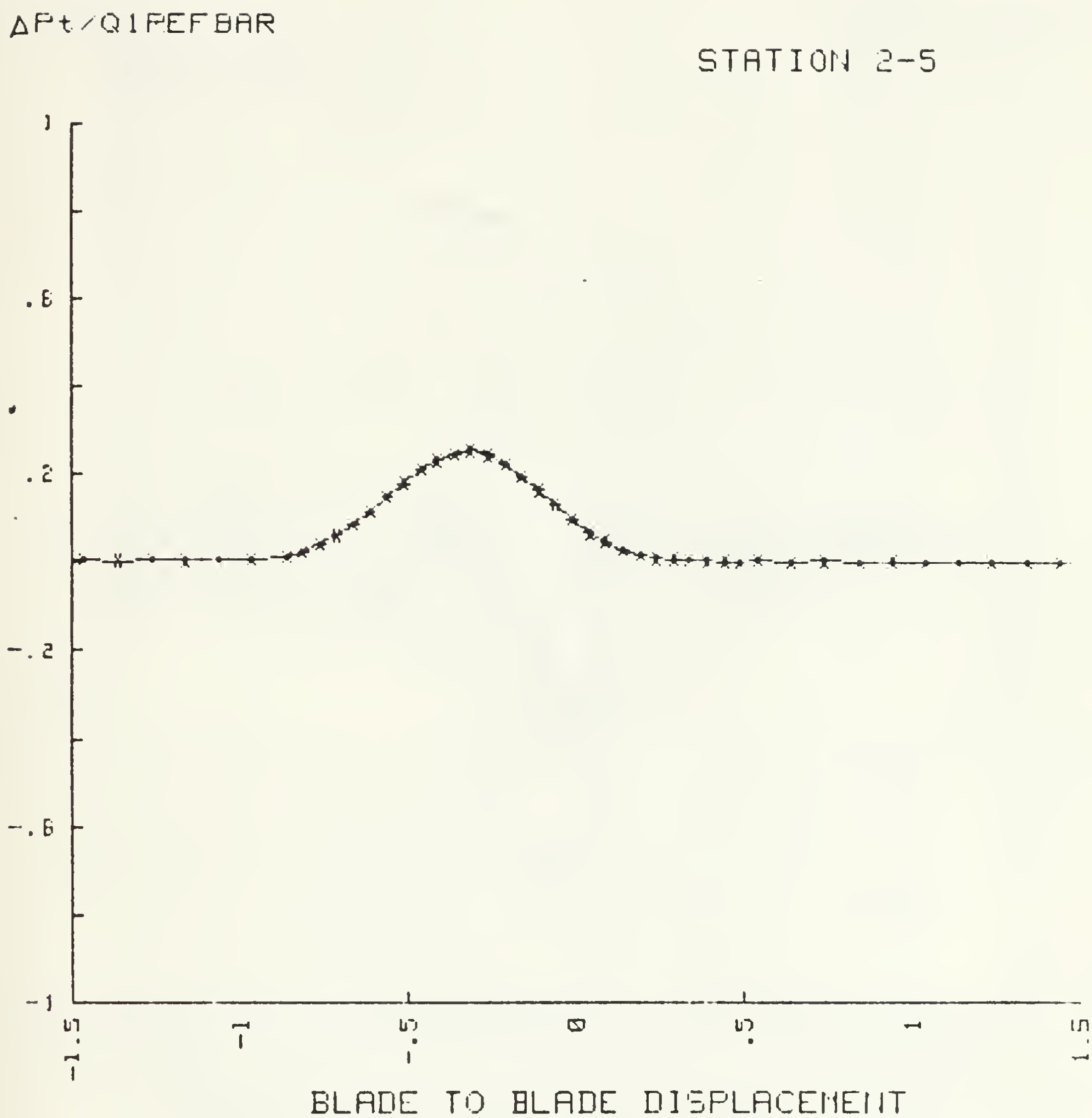

Figure A30. ΔPt/Q1REFBAR Vs Blade to Blade Displacement
β_1=43.4 Re=774000

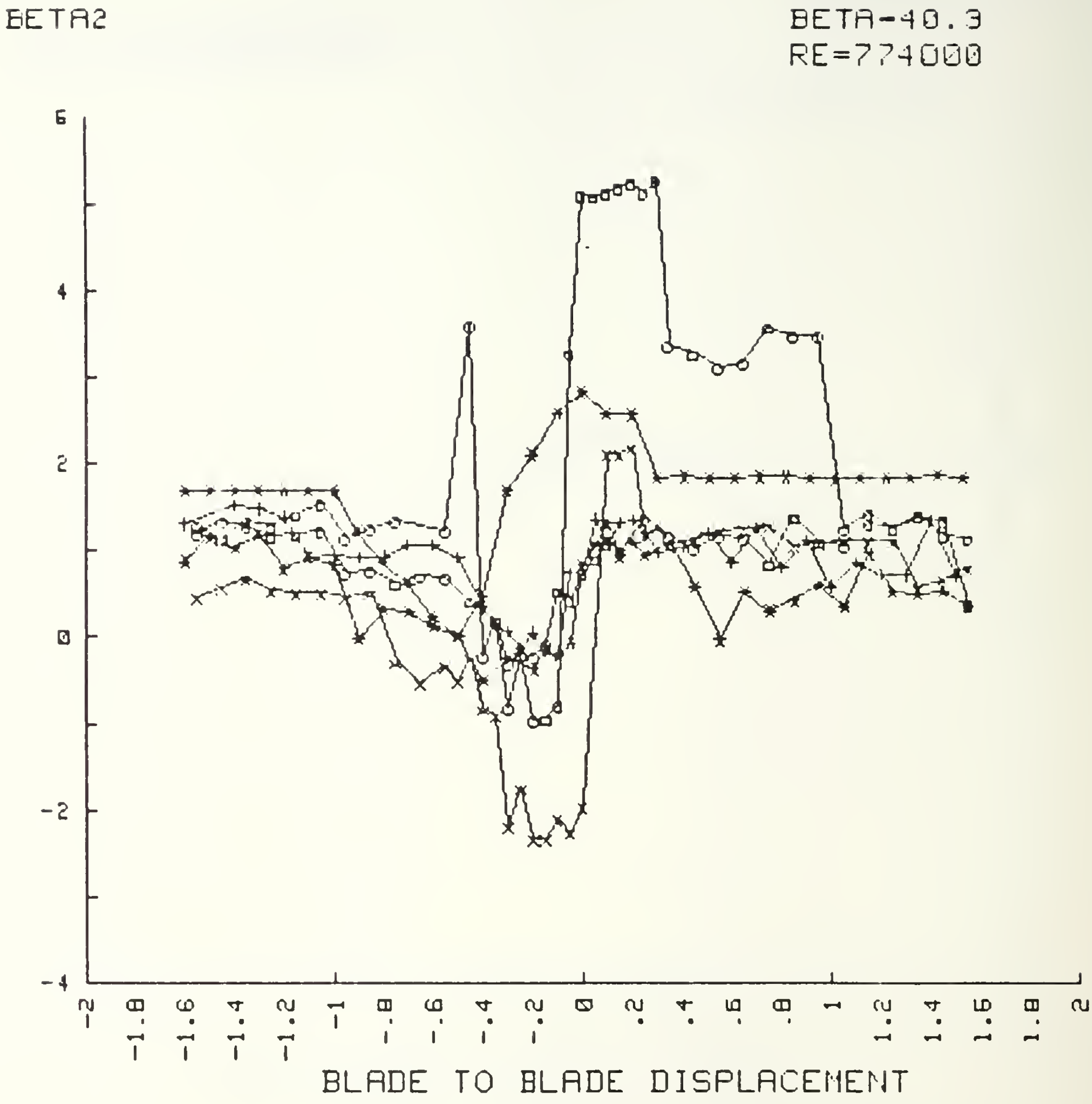

Figure A31. Comparative Plots of Beta2 Vs Blade to Blade Displacement. (Angle measurements corrected to average yaw probe reading at station 2-2 on pressure side of blade.)

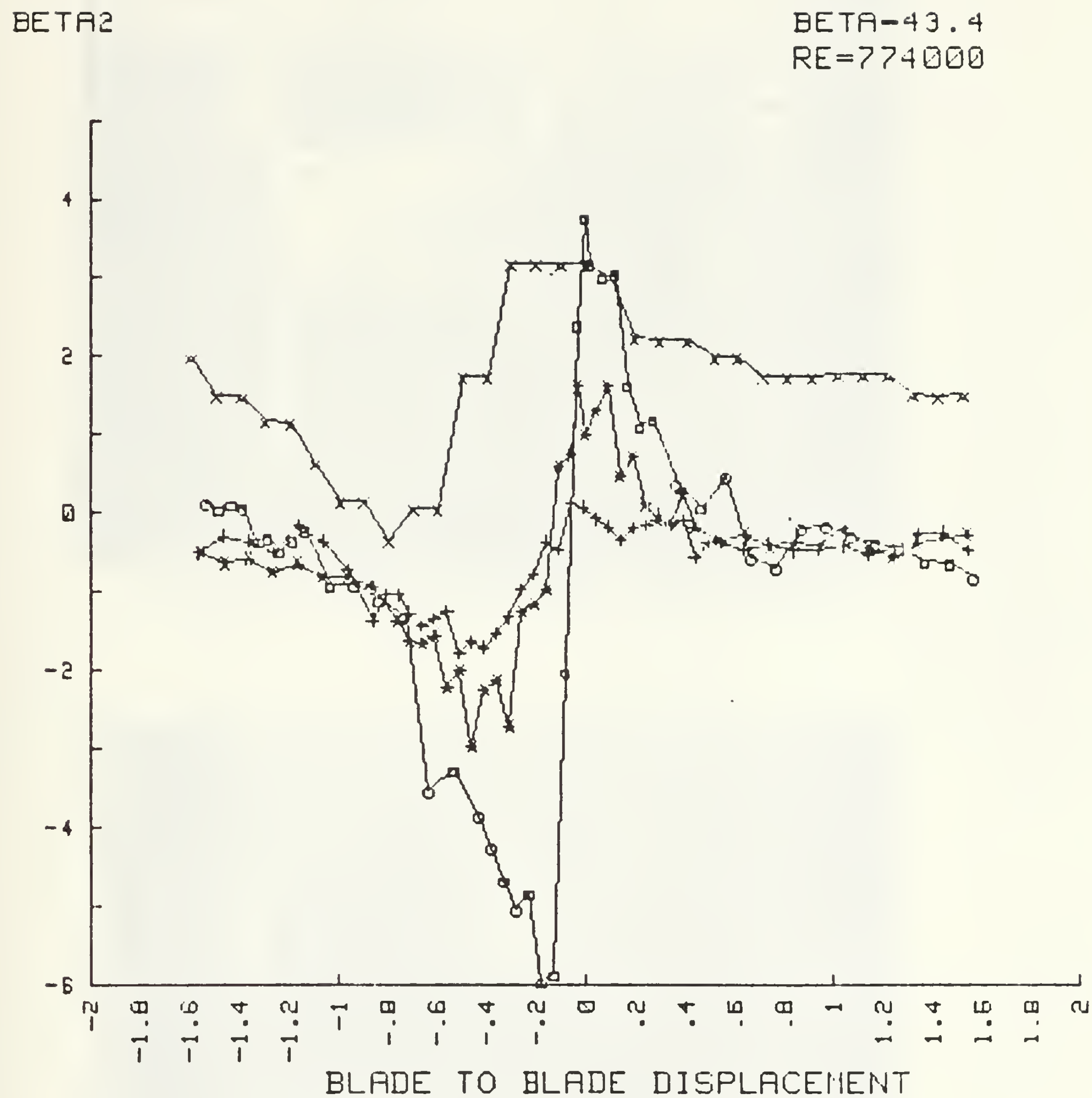

Figure A32. Comparative Plots of Beta2 Vs Blade to Blade Displacement. (Angle measurements corrected to average yaw probe reading at station 2-6 on pressure side of blade.)

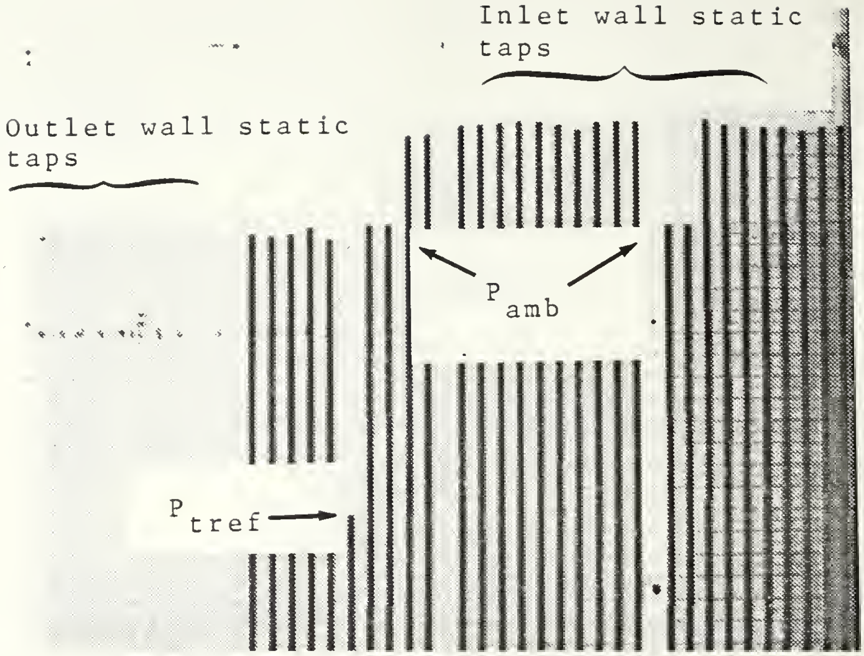

Figure A33. Test BD6250 β_1=40.3°

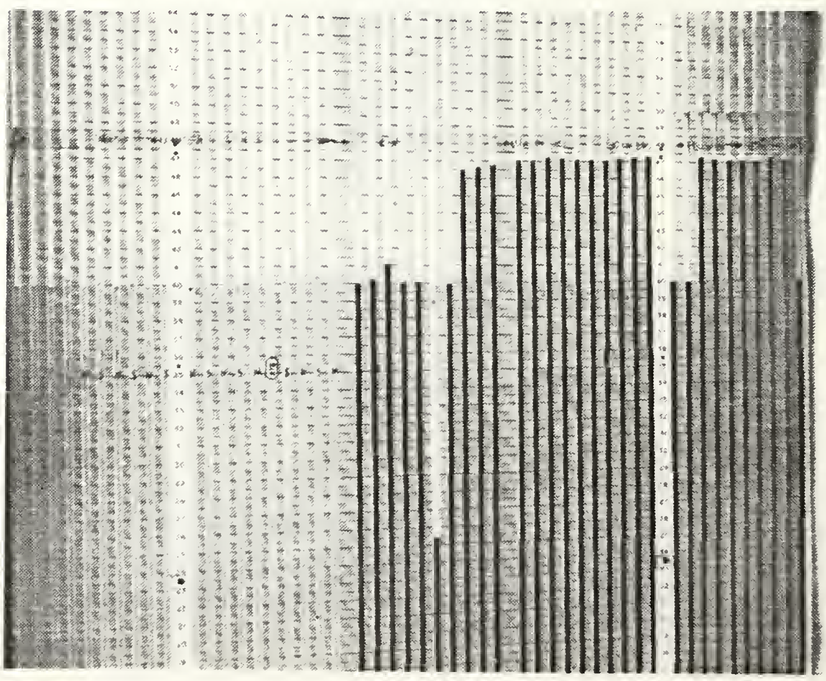

Figure A34. Test BD6260 β_1=43.4°

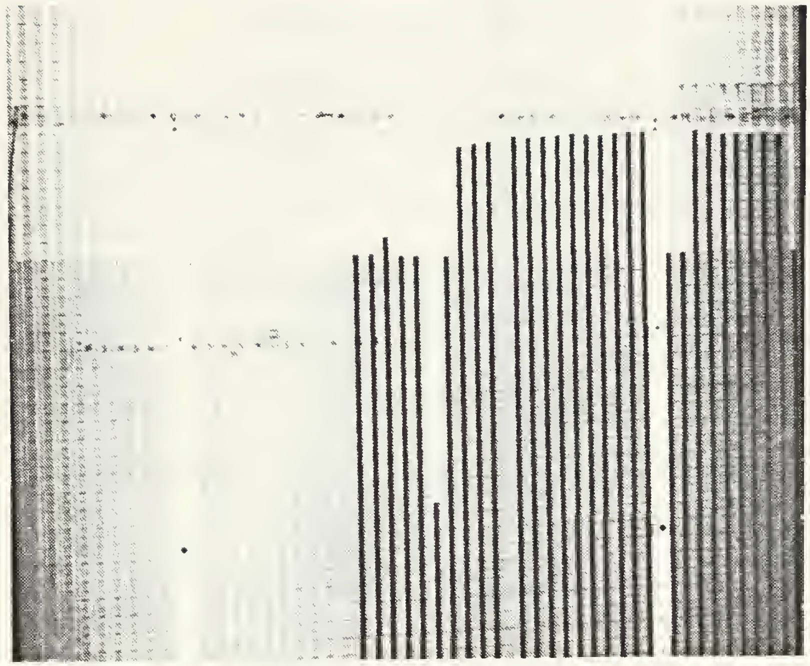

Figure A35. Test BD6261 β_1=43.4°

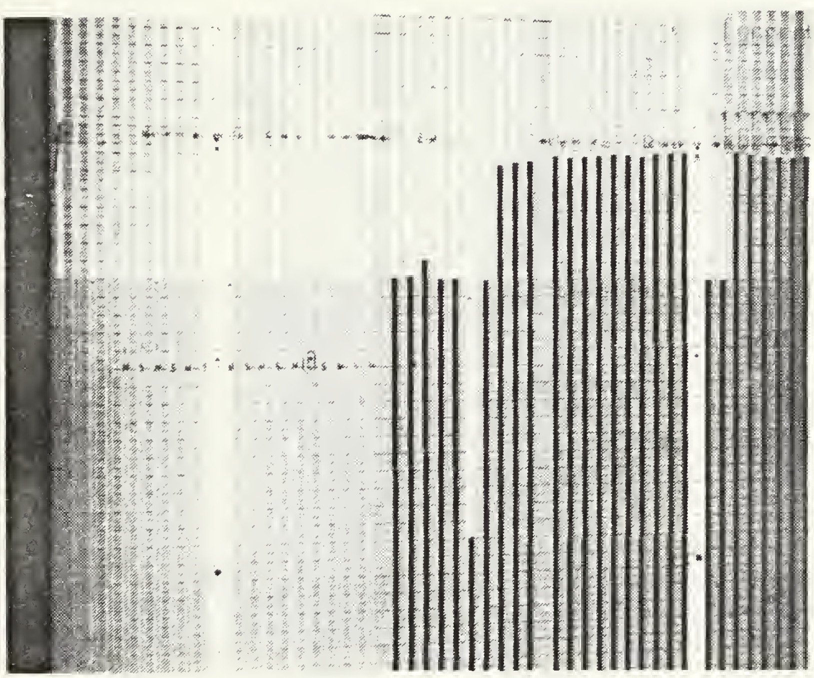

Figure A36. Test BD6263 β_1=43.4°

APPENDIX B

BLADE SURFACE PRESSURE DISTRIBUTIONS

Surface pressure coefficients for the instrumented blades are given in Table B.1 through Table B.4. The tables give the pressure tap locations, coefficient of pressure given by Eq. (C-5) in Appendix C (using upstream and downstream reference conditions), local Mach number and nondimensional velocity.

TABLE B.1

CENTER BLADE DATA

Beta=40.3   Re=774000

X/C	Y/C	Cp1	Cp2	Mach	Xvel
*****	*****	*****	*****	*****	*****
PRESSURE SIDE CENTER BLADE					
.0007	.0054	.3498	.0202	.2206	.0982
.0160	.0019	.3380	.0021	.2225	.0990
.0319	.0066	.3822	.0701	.2151	.0957
.0479	.0112	.3584	.0334	.2191	.0975
.0858	.0215	.3301	-.0101	.2238	.0996
.1218	.0303	.3272	-.0145	.2243	.0998
.1956	.0452	.3523	.0240	.2201	.0980
.2695	.0576	.4374	.1550	.2055	.0915
.3433	.0663	.4561	.1838	.2021	.0900
.4192	.0716	.4351	.1515	.2059	.0917
.4930	.0736	.3937	.0878	.2131	.0949
.5669	.0727	.3833	.0718	.2149	.0957
.6407	.0678	.4140	.1190	.2096	.0933
.7146	.0601	.4045	.1044	.2112	.0940
.7884	.0487	.4223	.1318	.2081	.0927
.8283	.0411	.4343	.1502	.2060	.0917
.8683	.0327	.4318	.1464	.2065	.0919
.9082	.0230	.4125	.1167	.2099	.0934
.9481	.0123	.3494	.0196	.2206	.0982
.9880	.0006	.2060	-.2011	.2435	.1082
SUCTION SIDE CENTER BLADE					
.0160	.0227	-.6576	-1.5299	.3540	.1564
.0319	.0310	-.5209	-1.3196	.3386	.1497
.0479	.0389	-.4268	-1.1747	.3276	.1449
.0858	.0563	-.4439	-1.2011	.3296	.1458
.1218	.0710	-.4558	-1.2194	.3310	.1464
.1956	.0970	-.5045	-1.2943	.3367	.1489
.2695	.1170	-.5422	-1.3524	.3410	.1508
.3433	.1309	-.4569	-1.2211	.3311	.1465
.4192	.1399	-.3209	-1.0118	.3148	.1394
.4930	.1432	-.2233	-.8617	.3027	.1342
.5669	.1412	-.1089	-.6857	.2880	.1277
.6407	.1339	-.0013	-.5200	.2735	.1214
.7146	.1209	.0908	-.3783	.2605	.1157
.7884	.1021	.1607	-.2708	.2503	.1112
.8283	.0895	.1861	-.2317	.2465	.1096
.8683	.0755	.2061	-.2008	.2434	.1082
.9082	.0593	.2240	-.1733	.2407	.1070
.9481	.0407	.2349	-.1566	.2390	.1063
.9880	.0206	.2416	-.1462	.2380	.1058

TABLE B.2

ADJACENT BLADES

Beta=40.3 Re=774000

X/C	Y/C	Cp1	Cp2	Mach	Xvel
PRESSURE SIDE LEFT BLADE					
.1218	.0303	.4448	.1664	.2041	.0909
.4192	.0716	.4292	.1425	.2069	.0921
.8283	.0411	.3314	-.0081	.2236	.0995
SUCTION SIDE LEFT BLADE					
.1218	.0710	-.2627	-.9222	.3077	.1363
.4192	.1399	-.3104	-.9956	.3136	.1389
.8283	.0895	-.1181	-.6998	.2892	.1283
PRESSURE SIDE RIGHT BLADE					
.1218	.0303	.4773	.2164	.1982	.0883
.4192	.0716	.4424	.1628	.2046	.0911
.8283	.0411	.3449	.0128	.2214	.0985
SUCTION SIDE RIGHT BLADE					
.1218	.0710	-.4980	-1.2844	.3359	.1486
.4192	.1399	-.3468	-1.0517	.3180	.1408
.8283	.0895	.3366	-.0001	.2227	.0991

TABLE B.3

CENTER BLADE DATA

Beta=43.4   Re=774000

X/C	Y/C	Cp1	Cp2	Mach	Xvel
********	********	********	********	********	********
PRESSURE SIDE CENTER BLADE					
.0007	.0054	-.1328	-.9028	.2903	.1288
.0160	.0019	.6264	.4196	.1670	.0745
.0319	.0066	.5628	.3087	.1803	.0804
.0479	.0112	.5187	.2319	.1890	.0842
.0858	.0215	.4580	.1263	.2004	.0892
.1218	.0303	.4364	.0886	.2043	.0910
.1956	.0452	.4386	.0924	.2039	.0908
.2695	.0576	.5018	.2025	.1922	.0856
.3433	.0663	.5164	.2279	.1894	.0844
.4192	.0716	.4892	.1806	.1946	.0867
.4930	.0736	.4481	.1089	.2022	.0900
.5669	.0727	.4351	.0863	.2045	.0911
.6407	.0678	.4572	.1248	.2005	.0893
.7146	.0601	.4437	.1014	.2030	.0904
.7884	.0487	.4579	.1261	.2004	.0893
.8283	.0411	.4684	.1443	.1985	.0884
.8683	.0327	.4647	.1378	.1991	.0887
.9082	.0230	.4396	.0942	.2037	.0907
.9481	.0123	.3813	-.0074	.2140	.0953
.9880	.0006	.2460	-.2430	.2362	.1050
SUCTION SIDE CENTER BLADE					
.0160	.0227	-1.5235	-3.3252	.4422	.1940
.0319	.0310	-.8514	-2.1545	.3747	.1653
.0479	.0389	-.5648	-1.6554	.3431	.1517
.0858	.0563	-.4652	-1.4819	.3315	.1467
.1218	.0710	-.4457	-1.4478	.3292	.1457
.1956	.0970	-.4409	-1.4396	.3287	.1454
.2695	.1170	-.4312	-1.4226	.3275	.1449
.3433	.1309	-.3342	-1.2537	.3158	.1399
.4192	.1399	-.2022	-1.0237	.2993	.1327
.4930	.1432	-.1040	-.8528	.2865	.1271
.5669	.1412	.0036	-.6652	.2719	.1207
.6407	.1339	.0953	-.5056	.2589	.1150
.7146	.1209	.1707	-.3743	.2478	.1101
.7884	.1021	.2186	-.2909	.2405	.1069
.8283	.0895	.2371	-.2586	.2376	.1057
.8683	.0755	.2530	-.2309	.2351	.1046
.9082	.0593	.2656	-.2090	.2331	.1037
.9481	.0407	.2732	-.1957	.2319	.1032
.9880	.0206	.2803	-.1834	.2308	.1026

TABLE B.4

ADJACENT BLADES

Beta=43.4 Re=774000

X/C	Y/C	Cp1	Cp2	Mach	Xvel
PRESSURE SIDE LEFT BLADE					
.1218	.0303	.4510	.1141	.2016	.0898
.4192	.0716	.4497	.1118	.2019	.0899
.8283	.0411	.4109	.0441	.2088	.0930
SUCTION SIDE LEFT BLADE					
.1218	.0710	-.0884	-.8256	.2845	.1262
.4192	.1399	-.1191	-.8790	.2885	.1280
.8283	.0895	.0107	-.6529	.2709	.1203
PRESSURE SIDE RIGHT BLADE					
.1218	.0303	.5392	.2677	.1850	.0824
.4192	.0716	.4862	.1753	.1952	.0869
.8283	.0411	.3887	.0056	.2127	.0947
SUCTION SIDE RIGHT BLADE					
.1218	.0710	-.4592	-1.4715	.3308	.1464
.4192	.1399	-.2050	-1.0286	.2997	.1328
.8283	.0895	.3820	-.0062	.2138	.0952

APPENDIX C

BLADE SURFACE PRESSURE COEFFICIENTS AND REYNOLDS NUMBER

C1. COEFFICIENT OF PRESSURE

The compressible coefficient of pressure on the blades in a cascade is conventionally defined as:

$$C_P = \frac{P - P_1}{1/2\ \gamma\ M_1^2\ P_1} \qquad \text{(C-1)}$$

where P is pressure, M is Mach number and the subscript 1 denotes upstream conditions. In previous work carried out in the rectilinear cascade C_P was defined incompressibly using bars to denote mass averaged quantities as:

$$C_P = \frac{\dfrac{P}{P_{tref}} - \dfrac{\overline{P_1}}{P_{tref}}}{\dfrac{\overline{P_{tref} - P_1}}{P_{tref}}} \qquad \text{(C-2)}$$

where the referenced total pressure was measured in the tunnel plenum and the mass averaged upstream quantities were derived from upstream probe survey data. This data was taken immediately before the surface pressures were recorded.

In the present work the definition in Eq. (C-1) was used rather than that in Eq. (C-2). Mass averaged quantities were again introduced and local measurements were divided by tunnel reference conditions derived from plenum and atmospheric pressures as outlined by Duval [Ref. 9]. The development of the revised C_p is as follows:

Dividing Eq. (C-1) by reference conditions and using massed averaged quantities upstream,

$$C_p = \frac{\dfrac{P}{P_{tref}} - \dfrac{\overline{P_1}}{P_{tref}}}{1/2\ \gamma\ \dfrac{M_1^2}{M_{ref}^2}\ \dfrac{P_1}{P_{tref}}} \cdot \frac{1}{M_{ref}^2} \qquad \text{(C-3)}$$

It can be shown that the Mach number can be written in terms of the dimensionless velocity, X as:

$$M^2 = \frac{X^2}{1 - X^2} \left(\frac{2}{\gamma - 1}\right) \qquad \text{(C-4)}$$

Substituting this term into Eq. (C-3) the definition for C_p becomes:

$$C_p = \frac{\left(\frac{P}{P_{tref}} - \frac{\overline{P_1}}{P_{tref}} \right) \left(\frac{1 - X_{ref}^2}{X_{ref}^2} \right)}{\frac{\gamma}{\gamma - 1} \frac{P_1}{P_{tref}} \frac{X_1^2}{X_{ref}^2} \frac{1 - X_{ref}^2}{1 - X_1^2}} \qquad \text{(C-5)}$$

The expression for C_p in Eq. (C-5) was used in the present data reduction. Again, the barred quantities are obtained from upstream probe surveys.

C2. REYNOLDS NUMBER

The Reynolds number was determined from the average flow conditions going into the blading. Reynolds number was defined as:

$$\overline{Re} = \frac{1}{\Delta s} \int_{s_1}^{s_2} \frac{\rho \, V \, c \, ds}{\mu} \qquad \text{(C-6)}$$

where $\Delta s = s_2 - s_1$ is an interval in the blade to blade direction. The static density, ρ, can be written as:

$$\rho = \rho_t \left(1 + \frac{\gamma - 1}{2} M^2\right)^{-\left(\frac{1}{\gamma-1}\right)} \qquad \text{(C-7)}$$

Substituting for Mach number using Eq. (C-4):

$$\rho = \rho_t \left(1 - X^2 \right)^{\left(\frac{1}{\gamma-1}\right)} \qquad \text{(C-8)}$$

In terms of X and stagnation quantities, the density can be written as:

$$\rho = \frac{P_t}{R\ T_t} \left(1 - X^2 \right)^{\left(\frac{1}{\gamma - 1}\right)} \qquad \text{(C-9)}$$

With the dimensionless velocity X defined as

$$X = \frac{V}{V_t} \qquad \text{(C-10)}$$

and $c_p = \frac{R\ \gamma}{\gamma - 1}$

$$V_t = \sqrt{2\ c_p\ T_t} = \left(\frac{2\ R\ \gamma\ T_t}{\gamma - 1} \right)^{1/2} \qquad \text{(C-11)}$$

Hence by substitution

$$\rho V = \frac{P_{tref}}{R\ T_t} \left(1 - X^2 \right)^{\left(\frac{1}{\gamma - 1}\right)} X \left(\frac{2\ R\ \gamma\ T_t}{\gamma - 1} \right)^{(1/2)} \qquad \text{(C-12)}$$

and using Eq. (C-12) into Eq. (C-6)

$$Re = \frac{c}{\Delta s} \int_{s_1}^{s_2} \left(\frac{2\ \gamma}{R\ T_t\ (\gamma - 1)} \right)^{1/2} \left(\frac{P_t\ X\ (1 - X^2)^{\left(\frac{1}{\gamma - 1}\right)}}{\mu} \right) ds \qquad \text{(C-13)}$$

APPENDIX D

PNEUMATIC PROBE CALIBRATION AND MEASUREMENT UNCERTAINTY

D1. SCANIVALVES AND TRANSDUCERS

The Scanivalves incorporated 2.5 PSI (69 inches of water) differential transducers. Prior to their use, the Scanivalves were cleaned using Freon and dry nitrogen to eliminate small uncertainties found in the zero differential outputs. Following the cleaning procedure, repeatability of zero was maintained to within 1/100th inch of water. The experiments expected to involve measurements ranging to 20 inches of water pressure differential or 29% of the transducers' full range. Checks of the linearity of the transducers were made over the anticipated operating range using a 36 inch water manometer graduated in tenths of an inch. The transducers were found to be linear to within 0.36% of the calibration range.

D2. PROBE CALIBRATION

Three probes, identified in Table D.1 were individually calibrated using the seven-inch free-jet calibration tunnel (Fig. D1). The conical probe was calibrated differently from the cylindrical probes. A fourth probe was used to measure yaw angle at the upstream position (station 1), the first downstream position (station 2-1), and the far downstream position (station 2-6). Each of the calibration processes will be described separately.

TABLE D.1

PNEUMATIC PROBES (UNITED SENSOR CORP.)

PROBE NUMBER	TYPE
USP100	Five Hole Cylindrical (DA-125)
USP200	Five Hole Conical (DC-125)
A 847-1	Five Hole Cylindrical (DA-125)

1. Cylindrical Probes

The cylindrical probes (Fig. D2) were held fixed at zero yaw angle and were calibrated at five different velocities and seven different pitch angles. Velocities ranged from 150 to 350 feet per second. Pitch angles ranged $\pm$ 6°. The derived calibration surface expressions gave an accuracy of fit to the calibration data from -2.3% to 1.6% for velocity and from -0.6° to 0.7° for pitch angle. These were maximum errors and typical deviations were $\pm$ 1% velocity and $\pm$ 0.5° pitch.

2. Conical Probe

The conical probe (Fig. D3) was calibrated from 100 to 350 feet per second. At each velocity the probe was calibrated for $\pm$ 4° pitch in increments of 2° with yaw angle set at zero, and for $\pm$ 4° in yaw angle in increments of 2° with pitch angle set at zero. Two sets of calibration surface approximations were derived. First, surfaces for reduced velocity (X) and pitch angle (ϕ) were derived in terms of the pressure coefficients (β) and (Γ), as was used in all previous work, where:

$$\beta = \frac{P_1 - P_{23}}{P_1} \quad \text{(D-1)}$$

$$\Gamma = \frac{P_4 - P_5}{P_1 - P_{23}} \quad \text{(D-2)}$$

The individual subscripts above denote the probe pressure ports, and the two-symbol subscripts denote the arithmetic average of the pressures individual ports. Second, surfaces for reduced velocity (X) and yaw angle (α) were derived in terms of β and θ where:

$$\theta = \frac{P_2 - P_3}{P_1 - P_{23}} \quad \text{(D-3)}$$

The surface expressions for the velocity and pitch angle gave an accuracy of fit of -2.2% to 0.5% for the velocity and ±0.2° for the pitch angle. The surface expression for the yaw angle gave an accuracy of fit of -0.15° to 0.4° in the yaw angle described by:

$$\alpha = \alpha(\beta, \theta) \quad \text{(D-4)}$$

The data from the conical probe were reduced similarly to those from the cylindrical probes and similarly to all previous work, except that the surface approximation in Eq. D4. was used to correct the yaw angle recorded by the data aquisition system after the probe had been adjusted to balance P_2 and P_3 as closely as possible. These procedures overcame the problem of insensitivity in the angle adjustment in regions of low dynamic pressure (near-wake). Corrections ranged from zero outside the wake to a maximum of 3° at the second station downstream of the test blading.

3. Yaw Probe

The upper cylindrical probe measured a greater flow angle change through the blade wake than did the conical probe at stations near the blades. A special yaw probe sensitive to tranverse gradients (Fig. D4) was built. It was used to measure flow angle only. The probe was nulled in the calibration free jet and otherwise not calibrated.

D3. PROBE VERIFICATION TEST

The two cylindrical probes were checked by first conducting detailed surveys in their normal positions. Then the positions of the two probes were exchanged and the surveys repeated at the same operating conditions. A summary comparison of the downstream velocity distribution to the mass-average upstream distribution when the probes were exchanged is shown in Table D.2. The results of integrating the two sets of surveys over two different blade passages to obtain blade element performance parameters are shown in Fig. D5.- D7. Since the loss coefficient, diffusion factor and AVDR involve either differences between or ratios of of downstream to upstream quantities, these results are a convincing verification of the accuracy of the measurements.

TABLE D.2

RESULTS OF CYLINDRICAL PROBE VERIFICATION CHECK

Quantity	Difference In Measurement
Loss Coefficient	7.31%
Diffusion Factor	3.3%
AVDR	0.578%
Inlet Air Angle	-0.48°
Outlet Air Angle	0.71°

D4. YAW ANGLE

Several corrections to the flow angle indicated by the probe were necessary. The flow out of the calibration tunnel was found not to be horizontal but was directed downward at an angle of +0.05°. The cascade was at a slope of +0.2°. The probe mounts allowed an attachment error of +0.7° and the uncertainty in the vernier reading on the probe mounts was ±0.2°. In order to use a common reference on the cascade and on the calibration tunnel, the conical probe yaw angle scale was set with reference to horizontal using a precision level and a reference bar on the probe shaft. When this procedure was followed, the yaw angle uncertainty was reduced to ±0.4°. For tests in which the leveling procedure was not followed, the yaw angle measured by the cone probe outside the wake on the pressure side was set equal to the measurement obtained using the yaw probe, for which the leveling procedure had been strictly adhered to.

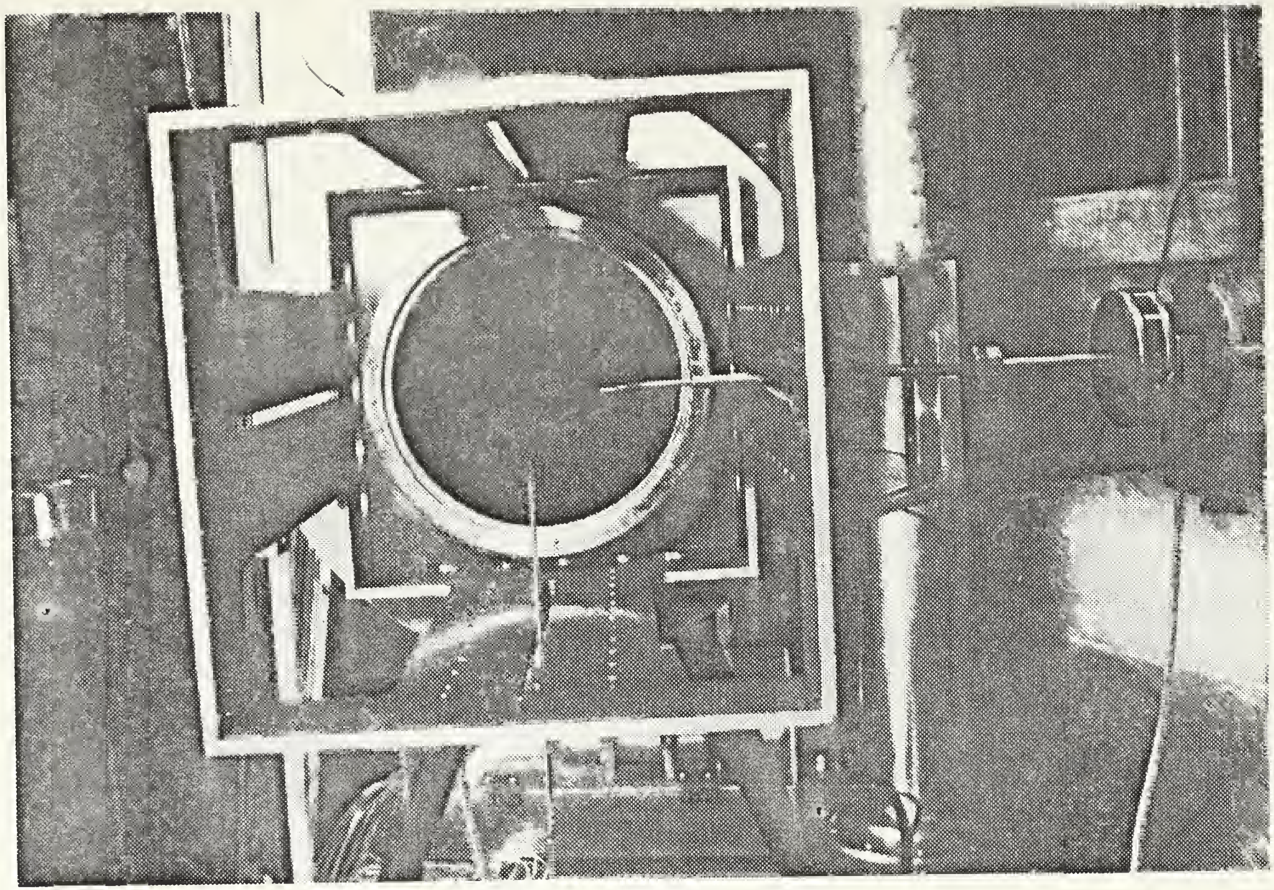

Figure D1. Probe Calibration Tunnel

Figure D2. Cylindrical Probe Showing Tip and Sensing Ports

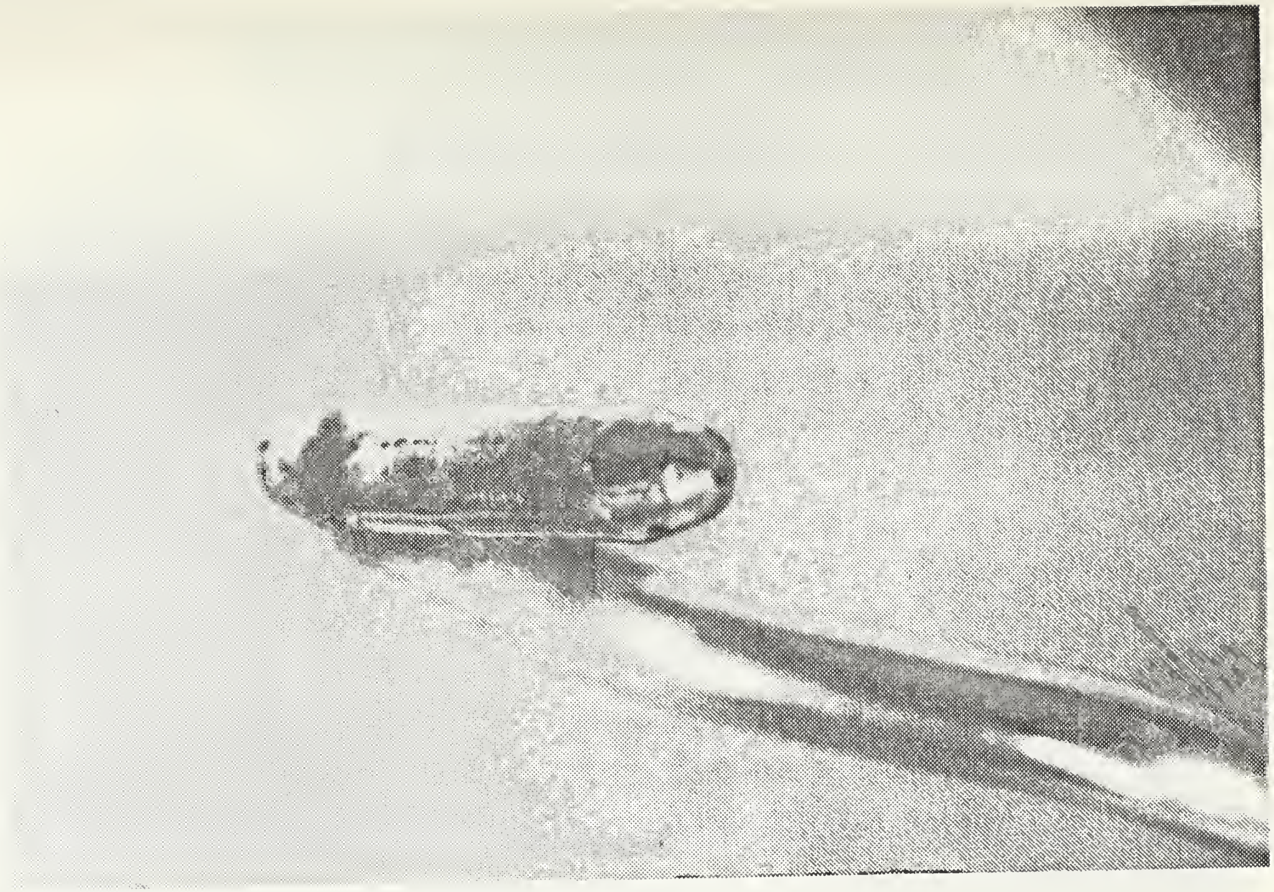

Figure D3. Conical Probe Showing Tip and Sensing Ports

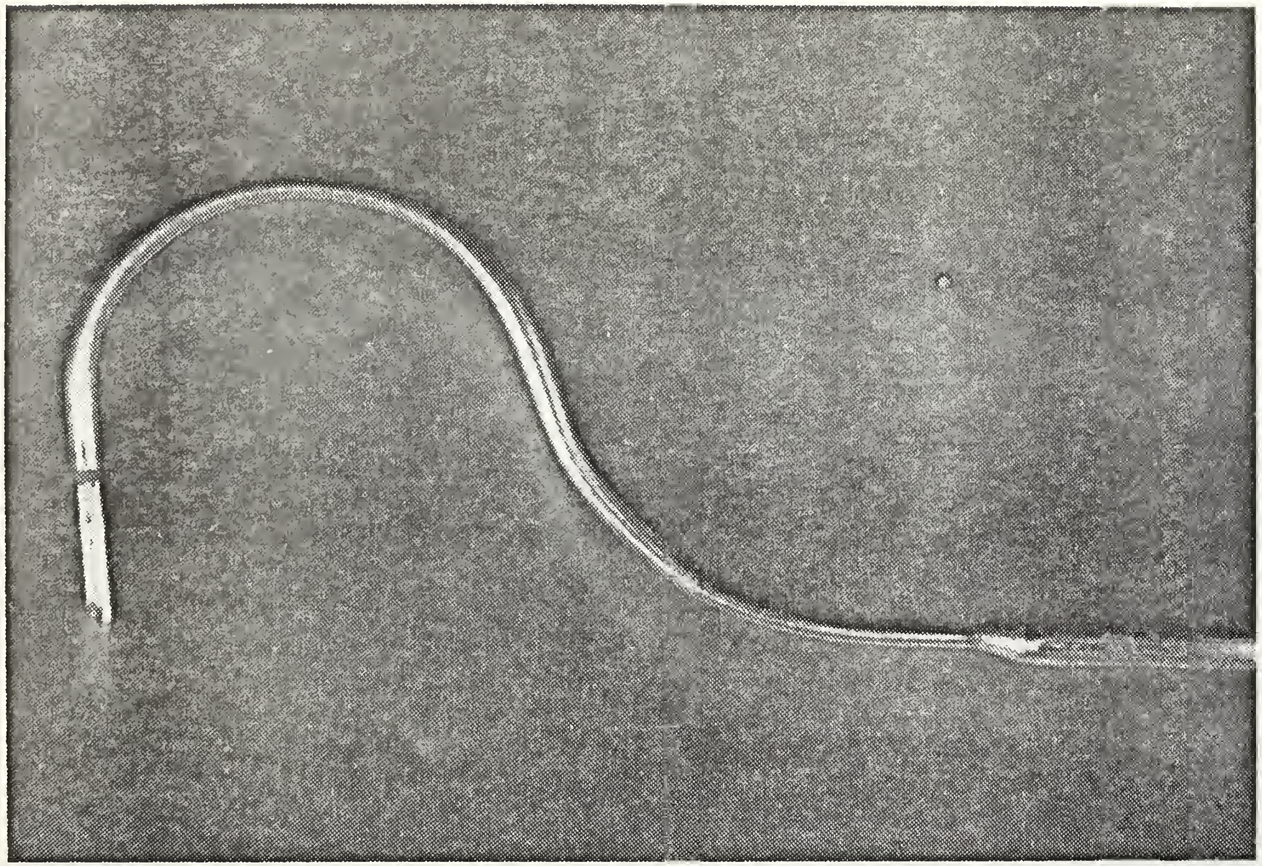

Figure D4. Yaw Probe

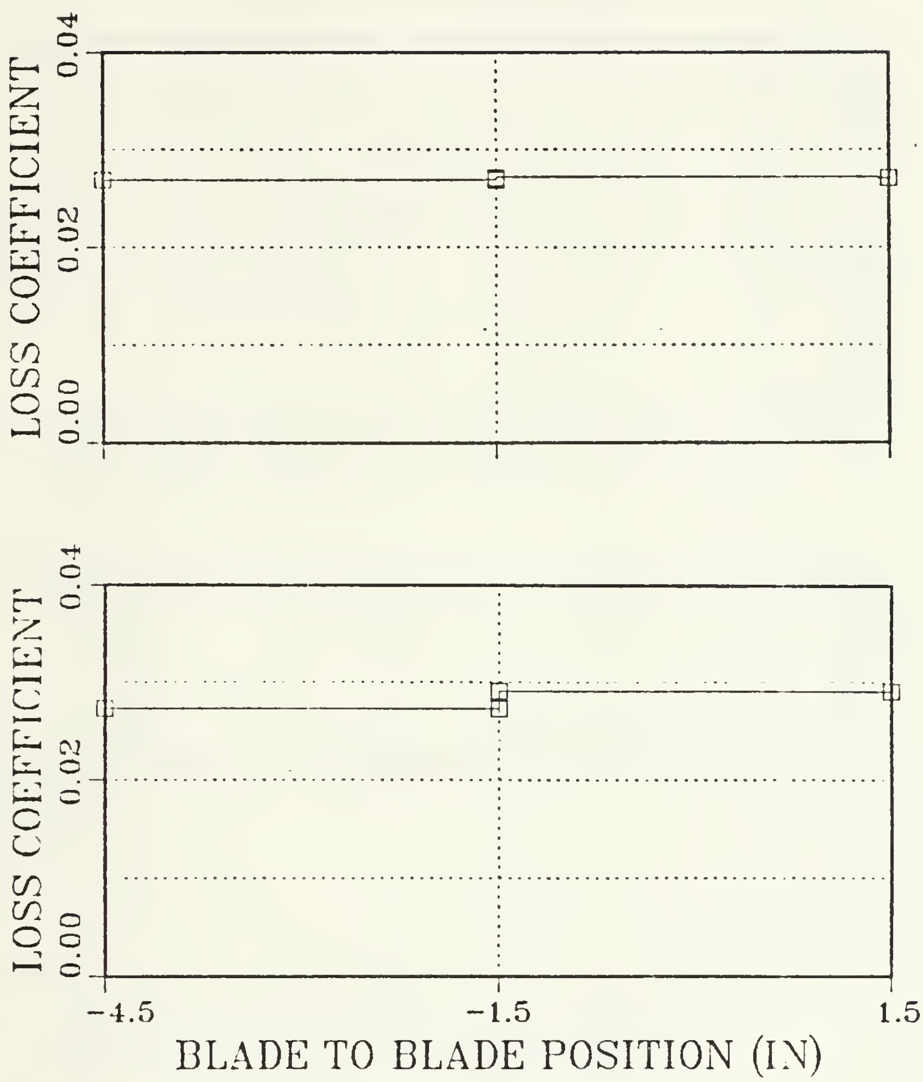

Figure D5. Comparative Plot of Loss Coefficient Vs Blade to Blade Displacement. (Two 5 hole cylindrical probes were exchanged in position and compared in the same flow conditions.)

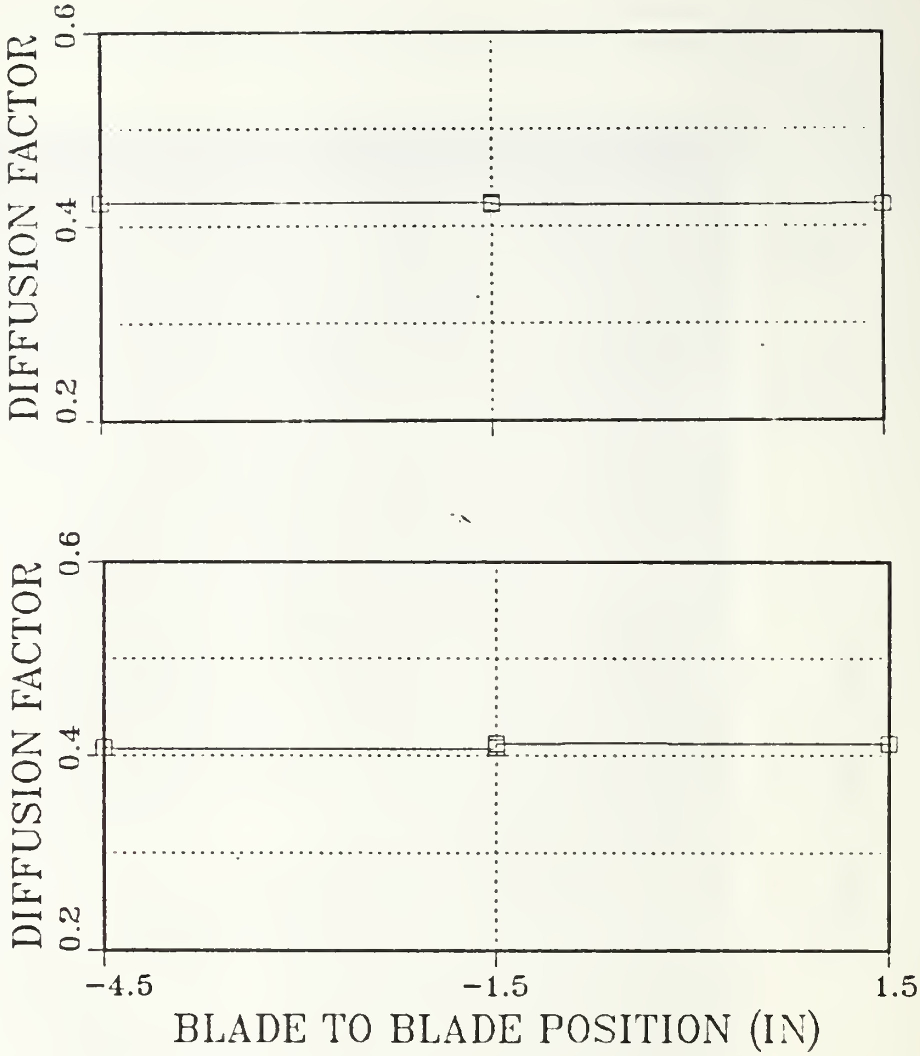

Figure D6. Comparative Plot of Diffusion Factor Vs Blade to Blade Displacement. (Two 5 hole cylindrical probes were exchanged in position and compared in the same flow conditions.)

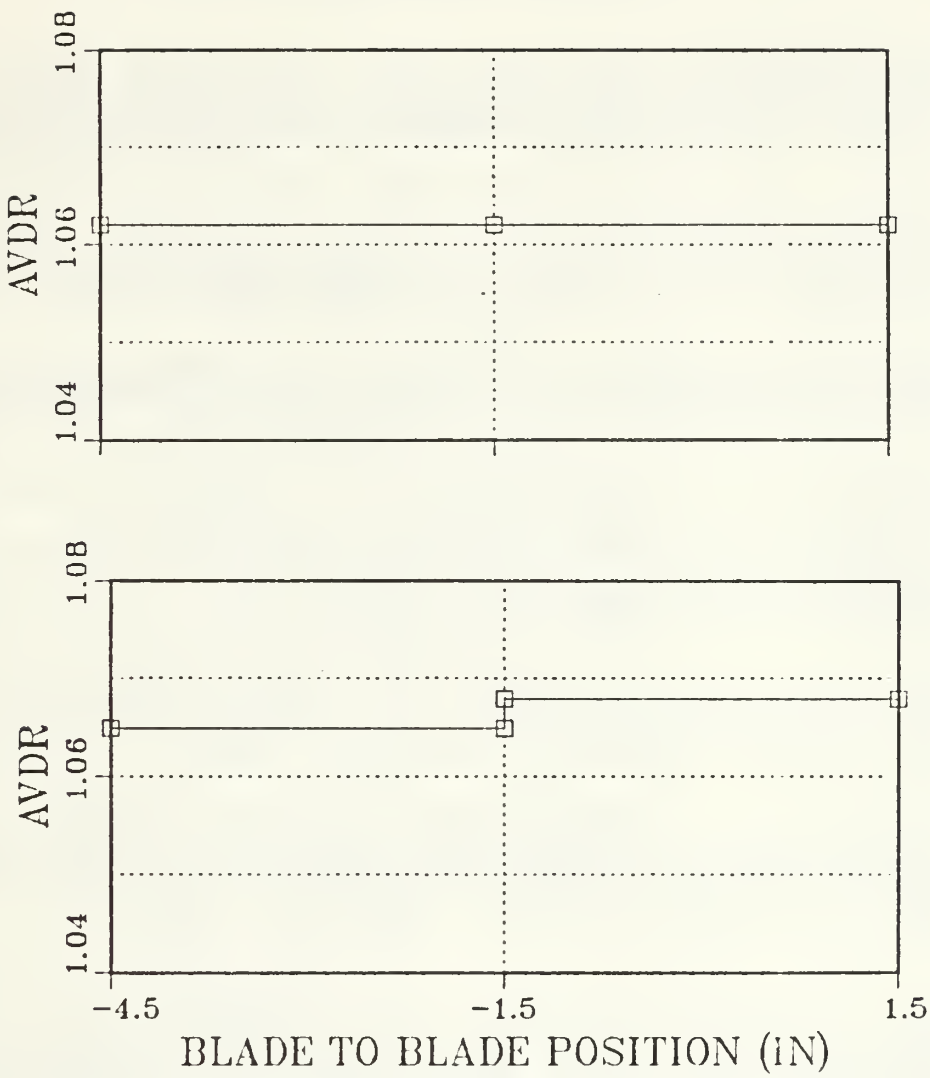

Figure D7. Comparative Plot of AVDR Vs Blade to Blade Displacement. (Two 5 hole cylindrical probes were exchanged in position and compared in the same flow conditions.)

LIST OF REFERENCES

1. NASA Technical Memorandum 82763, The Use of Optimization Techniques to Design Compressor Blading, by Nelson L. Sanger, Lewis Research Center, Cleveland, Ohio, 1982.

2. Hobbs, D.E. and Weingold, H.D., "Development of Controlled Diffusion Airfoils For Multistage Compressor Applications," Journal of Engineering For Gas Turbines and Power, Volume 106, April 1984, pp. 271-278.

3. Koyuncu,Y., Report of Tests of a Compressor Configuration of CD Blading, M.S. Thesis, Naval Postgraduate School, Monterey, California, March 1984.

4. Sanger, N. L., and Shreeve, R.P., "Comparison of Calcu lated and Experimental Cascade performance for Controlled-Diffusion Compressor Stator Blading," Journal of Turbomachinery, Volume 108, Number 1, July 1986, pp. 42-50.

5. Rose,C.C. and Guttormson, D.L., Installation and Test of a Rectilinear Cascade, M.S. Thesis, Naval Postgraduate school, Monterey, California, 1964.

6. McGuire, A.G., Determination of Boundary Layer Transition and Separation On Double Circular Arc Compressor Blades In A Large Subsonic Cascade, M.S. Thesis, Naval Postgraduate School, Monterey, California, September 1983.

7. Naval Postgraduate School Contract Report NPS67-80-001CR, Procedures and Computer Program From Approximation of Data (With Application To Multiple Sensor Probes), by H. Zebner,1980.

8. Naval Postgraduate School, Turbopropulsion Laboratory Technical Note, 82-03, Computer Software For The Calibration Of Pneumatic And Temperature Probes, by F. Neuhoff, 1982.

9. DuVal, D. A., Evaluation Of a Subsonic Cascade Wind Tunnel For Compressor Blade Testing, M.S. Thesis, Naval Postgraduate School, Monterey, California, September 1980.

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