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FLOW MEASUREMENTS BEHIND A ROTOR OPERATING IN A BOUNDARY LAYER.(U)

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The Pennsylvania State University
Institute for Science and Engineering
APPLIED RESEARCH LABORATORY
Post Office Box 30
State College, Pa. 16801

NAVY DEPARTMENT

NAVAL SEA SYSTEMS COMMAND

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FLOW MEASUREMENTS BEHIND A ROTOR OPERATING IN A BOUNDARY LAYER

M. L. Billet

Technical Memorandum
File No. TM 76-260
October 12, 1976
Contract No. N00017-73-C-1418

Copy No._______

The Pennsylvania State University
APPLIED RESEARCH LABORATORY
Post Office Box 30
State College, PA 16801

Prepared under the Naval Sea Systems Command General Hydromechanics Research Program administered by the David W. Taylor Naval Ship Research and Development Center, Bethesda, Md 20084, (Code 1505)

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: TM-76-260	2. GOVT ACCESSION NO.
	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): FLOW MEASUREMENTS BEHIND A ROTOR OPERATING IN A BOUNDARY LAYER	5. TYPE OF REPORT & PERIOD COVERED: Technical Memorandum
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): M. L. Billet	8. CONTRACT OR GRANT NUMBER(s): N00017-73-C-1418
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Applied Research Laboratory, P. O. Box 30, State College, PA 16801	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Sea Systems Command, Washington, DC 20362	12. REPORT DATE: October 12, 1976
	13. NUMBER OF PAGES: 30
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release. Distribution unlimited.
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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Flow
Rotor
Boundary Layer
Water Tunnel
Flow Velocity
Inlet Profile

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Flow measurements were made behind a rotor using a 5-hole probe. Results were obtained for nine (9) basic flow configurations produced by varying upstream conditions. In these experiments the boundary layer thickness is the same order of magnitude as the rotor radius. All tests were conducted in the 48-inch diameter water tunnel at a nominal velocity of 15 fps.

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391007

From: M. L. Billet

Subject: Flow Measurements Behind a Rotor Operating in a Boundary Layer

References: See Page 8

Abstract: Flow measurements were made behind a rotor using a 5-hole probe. Results were obtained for nine (9) basic flow configurations produced by varying upstream condition. In these experiments the boundary layer thickness is the same order of magnitude as the rotor radius. All tests were conducted in the 48-inch diameter water tunnel at a nominal velocity of 15 fps.

Acknowledgments: This report is based upon research conducted under the General Hydromechanics Research Program of the Naval Ship Systems Command, technically administered by the David Taylor Naval Ship Research and Development Center.

The author would like to thank Mr. David R. Stinebring who conducted most of the tests.

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INTRODUCTION

As part of a program on secondary flows, the velocity profiles behind a rotor were measured for various rotor operating flow coefficients and several upstream body configurations. These tests were conducted in the ARL 48-inch diameter water tunnel at a nominal velocity of 15 ft/sec. The velocity components were obtained by using a 5-hole probe.

Secondary flows are produced when the flow near the rotor wall which contain large velocity gradients does not have sufficient momentum to balance the pressure gradients imposed by the rotor. The result is a cross-flow component containing vorticity aligned in the streamwise direction which causes a deviation in the rotor outlet angles. This deviation depends on the velocity profile upstream of the rotor and the amount of turning in the flow. In some cases, this deviation from the primary flow becomes quiet large.

DESCRIPTION OF EXPERIMENTS

The experiments were conducted at Reynolds number of 8.8×10^5 based on rotor diameter. The test facility was the 48-inch diameter water tunnel located in the Garfield Thomas Water Tunnel Building of the Applied Research Laboratory at the Pennsylvania State University. The rotor was located near the end of an axisymmetric body where the boundary layer thickness is the same order of magnitude as the body curvature.

Results were obtained for body configurations with/without upstream appendages, with/without a screen on the nose of the axisymmetric forebody. Also, the rotor flow coefficient was varied from the design point. These basic flows are described in Table 1.

To reduce any effects produced by tunnel-wall interference, a "liner" was used in the test section. The resulting inner contour in the test section was determined by a potential flow solution for the body which approximated a streamline surface where the body is in a flow of infinite extent.

Five pressures were measured with the probe -- one total pressure, two static yaw pressures, and two static pitch pressures. The pressures were recorded only after the probe was nulled in the yaw plane and the angle recorded. This nulling state implied that the two static yaw pressures were equal in magnitude.

Variations in measured pressures caused by the pitch plane not being in null were accounted for by calibrating the probe in an open-jet tunnel. The calibration results are shown in Figure 1. More detailed information on the calibration of 5-hole probes can be found in Reference 1.

The velocity components were calculated using the measured yaw angle and the calibration for the pitch angle. This calculation was done by using the geometric relationships shown in Figure 2. The results are given in Tables 2 through 10.

The measurements were obtained in a plane located approximately one blade cord length downstream of the rotor. Because of the long distance traveled by the probe, data were obtained using two different supporting structures. One configuration uses a long supporting foil and the other uses a short supporting foil. A sketch is shown in Figure 3 of the location of the inlet and exit survey planes relative to the rotor.

DISCUSSION OF EXIT VELOCITY PROFILE

The mean velocity profiles are shown in Figures 4 through 12 and are listed in Tables 2 through 10. The following is the list of flow configurations for which the profiles were obtained:

Figure 4 - without upstream appendages, without screen, and rotor on design flow ciefficient (Basic Flow #1)

Figure 5 - without upstream appendages, without screen, and rotor 10% low in flow coefficient (Basic Flow #2)

Figure 6 - without upstream appendages, with screen, and rotor on design flow voefficient (Basic Flow #3)

Figure 7 - with upstream appendages, without screen, and rotor on design flow coefficient (Basic Flow #4)

Figure 8 - with upstream appendages, without screen, and rotor 10% high in flow coefficient (Basic Flow #5)

Figure 9 - with upstream appendages, without screen, and rotor 10% in flow coefficient (Basic Flow #6)

Figure 10 - with upstream appendages, with screen, and rotor on design flow coefficient (Basic Flow #7) appendages

Figure 11 - with upstream appendages, with screen, and rotor 10% low in flow coefficient (Basic Flow #8)

Figure 12 - without upstream appendages, with screen and rotor 10% low in flow coefficient (Basic Flow #9)

It is important to note that in all cases the normalized tangential velocity (V_θ/V_∞) does not approach zero at the wall, even though the rotor is so designed. This increase in the tangential velocity is a direct result of the secondary flows produced near the rotor wall. In all cases the normalized axial velocity ratio (V/V_∞) has a parabolic profile downstream of the rotor as a result of the loading of the rotor. This exit profile can be compared to the boundary layer profile shown in Figure 13 that would exist without the rotor. Also, the inlet velocity profile to the rotor included in Figure 13 are given in Reference 2.

A comparison of tangential velocity ratios (V_θ/V_∞) obtained with the rotor operating at $\phi=1.1\phi_d$ (Figure 8), $\phi=\phi_d$ (Figure 7), and at $\phi=0.9\phi_d$ (Figure 9) shows that as the flow coefficient increases the amount of turning decreases. Also, the axial velocity ratio (V/V_∞) decreases with increasing flow coefficient. This is particularly true near the body wall where $R' << Rp$.

The influence of upstream appendages on the measured profiles can be noted by comparing Figure 4 with Figure 7, and Figure 9 with Figure 5. It seems that adding upstream appendages causes an increase in both V_θ/V_∞ and V/V_∞ near the wall of the rotor hub.

SUMMARY

The tangential and axial velocities were measured downstream of a rotor for various rotor operating flow coefficients and several upstream body configurations. A comparison can be made with previously measured inlet profiles given in Reference 2. The body configurations where chosen to have large differences in velocity profiles near the wall but similar velocity profiles where most of the rotor loading occurs.

REFERENCES

1. Treaster, A. L., "The Calibration of Six Probes for Sensing Three-Dimensional Fluid Flow Properties," Applied Research Laboratory, TM 74-282, October 1974.

2. Billet, M. L., "Rotor Incoming Velocity Profile Measurements," Applied Research Laboratory, TM 76-254, October 11, 1976

TABLE 1

Basic Flow Configurations

Number	Upstream Appendages **	Upstream Screen	Rotor Flow Coefficient (ϕ)	Tip Design
1	No	No	$\phi = \phi_d$ *	Conical
2	No	No	$\phi = 0.9_d$	Conical
3	No	Yes	$\phi = \phi_d$	Conical
4	Yes	No	$\phi = \phi_d$	Conical
5	Yes	No	$\phi = 1.1\phi_d$	Conical
6	Yes	No	$\phi = 0.9\phi_d$	Conical
7	Yes	Yes	$\phi = \phi_d$	Conical
8	Yes	Yes	$\phi = 0.9\phi_d$	Conical
9	No	Yes	$\phi = 0.9\phi_d$	Conical

* ϕ_d = design flow coefficient $\equiv V_\infty / V_{tip}$

** The upstream appendages consisted of four struts placed at the 0°, 90°, 180°, 270° points on the axisymmetric test body.

TABLE 2

Tabulation of Velocity and Flow Angle Data for
Basic Flow #1

Model Configuration: Without Upstream Appendages
Without Screen
Design Flow Coefficient

R (inches)	Total Velocity (fps)	V_x (fps)	V_7 (fps)	Pitch Angle (ϕ)	Yaw Angle (Θ)	$\frac{V_x}{V_\infty}$	$\frac{V_\theta}{V_\infty}$	Turning Angle (ξ)
0.26	9.0	7.9	3.3	-18.6°	22.8°	0.53	0.22	12.4°
0.45	10.4	9.4	3.2	-16.6	18.8	0.63	0.21	11.8
0.65	11.5	10.7	3.4	-13.0	17.4	0.71	0.23	12.9
0.84	12.7	11.9	3.4	-13.5	16.0	0.78	0.23	12.9
1.03	13.6	12.9	3.4	-10.8	14.6	0.84	0.23	12.9
1.23	14.4	13.8	3.3	-10.1	13.4	0.90	0.22	12.4
1.42	14.8	14.3	3.0	- 9.9	12.0	0.93	0.20	11.3
1.61	15.3	14.8	3.1	- 9.5	12.0	0.96	0.21	11.8
1.81	15.6	15.2	2.9	- 8.7	10.7	0.98	0.19	10.9
2.00	16.0	15.6	2.6	- 9.6	9.6	1.01	0.17	9.8
2.19	16.0	15.6	2.2	- 9.4	8.0	1.00	0.15	8.3
2.39	16.1	15.8	2.0	- 9.6	7.1	1.00	0.13	7.6
2.00	15.8	15.4	2.7	- 9.4	10.0	1.02	0.18	10.2
2.19	15.8	15.4	2.3	- 8.9	8.6	1.02	0.15	8.7
2.39	15.5	15.2	2.0	- 8.9	7.4	0.98	0.13	7.6
2.58	14.9	14.7	1.5	- 8.4	6.0	0.95	0.18	10.5
2.77	14.2	14.0	1.1	- 7.3	4.4	0.90	0.07	4.2
2.97	13.2	13.1	0.5	- 8.3	2.3	0.86	0.03	1.9
3.16	13.6	13.4	0.3	- 8.9	1.2	0.89	0.02	1.1
3.35	13.8	13.7	0.2	- 7.2	1.0	0.91	0.01	0.7
3.55	14.2	14.0	0.2	- 9.6	1.0	0.93	0.01	0.7
3.74	14.5	14.4	0.3	- 7.9	1.0	0.95	0.02	1.1
3.93	14.9	14.7	0.3	- 8.4	1.2	0.96	0.02	1.1
4.12	15.2	15.1	0.4	- 7.8	1.6	0.97	0.02	1.5

TABLE 3

Tabulation of Velocity and Flow Angle Data for
Basic Flow #2

Model Configuration: Without Upstream Appendages
Without Screen
10% Low in Flow Coefficient

R (inches)	Total Velocity (fps)	V_x (fps)	V_7 (fps)	Pitch Angle (ϕ)	Yaw Angle (Θ)	$\frac{V_x}{V_\infty}$	$\frac{V_\theta}{V_\infty}$	Turning Angle (ξ)
0.26	8.8	7.4	4.1	-16.5	29.2	0.54	0.30	16.9
0.45	10.6	9.1	4.5	-16.5	26.0	0.67	0.33	18.4
0.65	11.5	10.4	4.2	-13.2	22.1	0.76	0.31	17.3
0.84	12.6	11.6	4.2	-12.3	20.0	0.85	0.31	17.3
1.03	13.5	12.6	4.2	-10.8	18.4	0.93	0.31	17.3
1.23	14.3	13.4	4.1	-10.8	17.0	0.99	0.30	16.9
1.42	14.8	14.0	3.9	- 9.8	15.7	1.03	0.29	16.1
1.61	15.3	14.6	3.8	- 9.7	14.5	1.07	0.28	15.7
1.81	15.7	15.0	3.6	-10.0	13.5	1.10	0.27	14.9
2.00	15.9	15.3	3.4	- 9.5	12.4	1.13	0.25	14.1
2.19	16.0	15.4	3.0	-10.0	11.0	1.14	0.22	12.5
2.39	15.9	15.4	2.6	- 9.8	9.6	1.13	0.19	10.9
2.00	15.7	15.2	3.1	- 9.7	11.5	1.12	0.23	12.9
2.19	15.7	15.2	2.8	- 9.6	10.3	1.13	0.21	11.7
2.39	15.4	15.0	2.4	- 9.0	8.9	1.11	0.18	10.1
2.58	14.7	14.3	1.9	- 8.8	7.6	1.05	0.14	8.0
2.77	13.8	13.6	1.6	- 6.8	6.5	1.00	0.12	6.8
2.97	11.5	11.4	0.4	- 8.2	1.8	0.84	0.03	1.7
3.16	12.2	12.0	0.2	-10.3	0.8	0.88	0.02	0.8
3.35	12.4	12.2	0.2	-10.2	0.8	0.90	0.02	0.8
3.55	12.7	12.5	0.2	- 9.6	1.0	0.91	0.02	0.8
3.74	13.0	12.8	0.3	- 9.2	1.3	0.93	0.02	1.2
3.93	13.2	13.0	0.3	- 9.1	1.3	0.95	0.02	1.2
4.12	13.4	13.2	0.3	- 9.3	1.3	0.96	0.02	1.2

TABLE 4

Tabulation of Velocity and Flow Angle Data for
Basic Flow #3

Model Configuration: Without Upstream Appendages
With Screen
Design Flow Coefficient

R (inches)	Total Velocity (fps)	V_x (fps)	V_7 (fps)	Pitch Angle (ϕ)	Yaw Angle (Θ)	$\frac{V_x}{V_\infty}$	$\frac{V_\Theta}{V_\infty}$	Turning Angle (ξ)
0.26	9.2	7.9	3.4	-20.7	23.2	0.53	0.23	12.8
0.45	10.6	9.5	3.5	-17.0	20.5	0.63	0.23	13.1
0.65	11.7	10.8	3.4	-14.8	17.5	0.72	0.23	12.8
0.84	12.8	12.0	3.3	-12.6	15.7	0.80	0.22	12.4
1.03	13.7	13.0	3.4	-11.5	14.8	0.86	0.23	12.8
1.23	14.4	13.7	3.4	-10.6	14.1	0.91	0.23	12.8
1.42	15.0	14.4	3.4	-10.0	13.4	0.95	0.23	12.8
1.61	15.4	14.8	3.3	- 9.7	12.4	0.98	0.22	12.4
1.81	15.8	15.3	3.0	- 9.5	11.2	1.01	0.20	11.3
2.00	16.0	15.5	2.9	- 9.2	10.4	1.02	0.19	10.9
2.19	16.1	15.7	2.6	- 9.1	9.5	1.03	0.17	9.8
2.39	15.9	15.5	2.3	- 9.3	8.3	1.01	0.07	3.8
2.00	15.7	15.3	2.8	- 9.1	10.3	1.01	0.19	10.6
2.19	15.7	15.3	2.5	- 9.3	9.3	1.01	0.17	9.5
2.39	15.4	15.1	2.1	- 8.8	7.9	1.00	0.14	7.9
2.58	14.7	14.5	1.6	- 8.0	6.5	0.96	0.11	6.1
2.77	13.8	13.6	1.2	- 7.0	5.2	0.90	0.08	4.6
2.97	12.1	12.0	0.3	- 6.1	1.6	0.79	0.02	1.1
3.16	12.5	12.4	0.2	- 8.8	0.8	0.82	0.01	0.8
3.35	12.7	12.5	0.2	- 9.8	0.7	0.82	0.01	0.8
3.55	13.3	13.1	0.2	- 9.5	0.7	0.86	0.01	0.8
3.74	13.4	13.3	0.2	- 8.2	1.0	0.88	0.01	0.8
3.93	13.6	13.5	0.2	- 7.9	1.0	0.89	0.01	0.8
4.12	14.0	13.8	0.3	- 8.4	1.2	0.90	0.02	1.1

TABLE 5

Tabulation of Velocity and Flow Angle Data for
Basic Flow #4

Model Configuration: With Upstream Appendages
Without Screen
Design Flow Coefficient

R (inches)	Total Velocity (fps)	V_x (fps)	V_7 (fps)	Pitch Angle (ϕ)	Yaw Angle (Θ)	$\frac{V_x}{V_\infty}$	$\frac{V_\theta}{V_\infty}$	Turning Angle (ξ)
0.26	10.3	8.8	3.4	-24.2	21.0	0.59	0.23	12.8
0.45	11.4	10.1	3.3	-21.8	18.2	0.67	0.22	12.4
0.65	12.5	11.3	3.5	-19.6	17.1	0.75	0.23	13.1
0.84	13.4	12.2	3.7	-17.4	17.0	0.81	0.25	13.9
1.03	14.1	13.0	3.9	-15.5	16.5	0.87	0.26	14.6
1.23	14.6	13.6	3.8	-14.5	15.5	0.91	0.25	14.2
1.42	15.1	14.2	3.7	-13.6	14.6	0.95	0.25	13.8
1.61	15.5	14.7	3.5	-13.0	13.4	0.98	0.23	13.1
1.81	15.8	15.1	3.2	-12.6	11.9	1.01	0.21	12.0
2.00	15.8	15.2	2.8	-11.8	10.6	1.01	0.19	10.6
2.19	16.0	15.5	2.6	-11.5	9.4	1.03	0.17	9.8
2.39	15.7	15.3	2.1	-10.9	7.9	1.02	0.14	7.9
2.00	15.8	15.2	3.2	-10.6	12.0	1.01	0.21	12.0
2.19	15.7	15.2	2.8	-10.0	10.5	1.01	0.19	10.6
2.38	15.2	14.8	2.4	- 9.8	9.3	0.99	0.16	9.1
2.58	14.4	14.1	2.0	- 9.5	8.0	0.94	0.13	7.6
2.77	13.4	13.2	1.6	- 7.7	7.0	0.88	0.10	6.1
2.97	11.7	11.5	0.5	- 9.2	2.7	0.77	0.03	1.9
3.16	12.1	11.9	0.3	-10.6	1.3	0.79	0.02	1.2
3.35	12.4	12.1	0.2	-11.7	1.1	0.81	0.01	0.8
3.55	12.6	12.4	0.2	-10.1	1.1	0.83	0.01	0.8
3.74	12.8	12.7	0.2	- 8.5	1.0	0.85	0.01	0.8
3.93	13.0	12.9	0.2	- 8.0	1.0	0.86	0.01	0.8
4.12	13.2	13.1	0.2	- 7.7	0.9	0.87	0.01	0.8

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TABLE 6

Tabulation of Velocity and Flow Angle Data for Basic Flow #5

Model Configuration: With Upstream Appendages
Without Screen
10% High in Flow Coefficient

R (inches)	Total Velocity (fps)	V_x (fps)	V_7 (fps)	Pitch Angle (ϕ)	Yaw Angle (Θ)	$\frac{V_x}{V_\infty}$	$\frac{V_\theta}{V_\infty}$	Turning Angle
0.26	10.6	9.0	2.4	-28.8	15.0	0.54	0.15	8.3
0.45	11.6	10.4	2.7	-22.0	14.7	0.63	0.16	9.3
0.65	12.6	11.5	3.0	-19.5	14.7	0.69	0.18	10.3
0.84	13.5	12.4	3.3	-17.6	14.9	0.75	0.20	11.3
1.03	14.1	13.1	3.4	-16.3	14.6	0.79	0.21	11.6
1.23	14.7	13.8	3.4	-15.0	14.0	0.83	0.21	11.6
1.42	15.0	14.2	3.6	-13.6	13.3	0.86	0.22	12.3
1.61	15.5	14.8	3.1	-13.0	11.9	0.89	0.19	10.6
1.81	15.8	15.2	2.9	-12.3	11.0	0.92	0.18	9.9
2.00	15.9	15.3	2.7	-12.3	10.0	0.92	0.16	9.3
2.19	16.0	15.5	2.3	-11.5	8.5	0.93	0.14	7.9
2.39	15.9	15.5	1.9	-10.5	7.1	0.93	0.12	6.6
2.00	15.9	15.4	2.9	-10.6	10.7	0.93	0.18	9.9
2.19	15.7	15.2	2.6	-10.0	9.5	0.92	0.16	9.0
2.39	15.2	14.8	2.1	- 9.7	8.2	0.89	0.13	7.3
2.58	14.5	14.2	1.6	- 9.3	6.6	0.86	0.10	5.5
2.77	13.6	13.4	1.2	- 8.0	5.2	0.81	0.07	4.2
2.97	12.6	12.4	0.6	- 9.4	2.6	0.75	0.04	2.1
3.16	12.9	12.7	0.3	-10.2	1.3	0.77	0.02	1.0
3.35	13.3	13.1	0.3	- 9.9	1.4	0.79	0.02	1.0
3.55	13.3	13.2	0.2	- 8.5	1.0	0.80	0.01	0.7
3.74	13.6	13.5	0.2	- 8.0	1.0	0.81	0.01	0.7
3.93	13.9	13.8	0.2	- 7.9	1.0	0.83	0.01	0.7
4.12	14.1	14.0	0.2	- 7.7	1.0	0.84	0.01	0.7

TABLE 7

Tabulation of Velocity and Flow Angle Data for
Basic Flow #6

Model Configuration: With Upstream Appendages
Without Screen
10% Low in Flow Coefficient

R (inches)	Total Velocity (fps)	V_x (fps)	V_7 (fps)	Pitch Angle (ϕ)	Yaw Angle (Θ)	$\frac{V_x}{V_\infty}$	$\frac{V_\theta}{V_\infty}$	Turning Angle (ξ)
0.26	10.4	8.9	3.9	-21.0	23.6	0.65	0.29	16.1
0.45	11.2	9.7	3.8	-21.1	21.5	0.71	0.28	15.7
0.65	12.3	10.9	4.3	-19.0	19.9	0.80	0.32	17.7
0.84	13.3	12.0	4.2	-17.0	19.2	0.88	0.31	17.3
1.03	14.0	12.8	4.4	-15.0	18.8	0.94	0.33	18.1
1.23	14.6	13.5	4.3	-14.3	17.8	0.99	0.32	17.7
1.42	15.1	14.1	4.2	-13.3	16.5	1.04	0.31	17.3
1.61	15.5	14.6	4.0	-12.6	15.4	1.07	0.30	16.5
1.81	15.8	14.9	3.8	-12.6	14.4	1.10	0.28	15.7
2.00	15.9	15.1	3.4	-12.3	12.8	1.11	0.25	14.1
2.19	15.9	15.2	3.1	-12.3	11.6	1.12	0.23	12.9
2.39	15.7	15.1	2.7	-12.2	10.0	1.11	0.20	11.3
2.00	15.9	15.2	3.6	-10.6	13.4	1.12	0.27	14.9
2.19	15.7	15.1	3.2	-10.5	12.0	1.11	0.24	13.3
2.39	15.2	14.7	2.8	-10.0	10.6	1.08	0.21	11.7
2.58	14.5	14.1	2.3	- 9.2	9.2	1.04	0.17	9.7
2.77	13.1	12.9	2.0	- 6.3	8.9	0.95	0.15	8.4
2.97	10.3	10.1	0.5	- 9.7	2.9	0.74	0.04	2.1
3.16	10.5	10.3	0.3	-11.8	1.6	0.76	0.02	1.3
3.35	10.7	10.5	0.2	-12.0	1.2	0.77	0.01	0.9
3.55	10.8	10.6	0.2	-11.3	1.0	0.78	0.01	0.9
3.74	11.1	10.9	0.2	- 9.7	0.9	0.80	0.01	0.9
3.93	11.1	10.9	0.2	- 9.5	1.0	0.80	0.01	0.9
4.12	11.3	11.2	012	- 8.8	0.9	0.82	0.01	0.9

TABLE 8

Tabulation of Velocity and Flow Angle Data for Basic Flow #7

Model Configuration: With Upstream Appendages
With Screen
Design Flow Coefficient

R (inches)	Total Velocity (fps)	V_x (fps)	V_7 (fps)	Pitch Angle (Θ)	Yaw Angle (ϕ)	$\frac{V_x}{V_\infty}$	$\frac{V_\theta}{V_\infty}$	Turning Angle (ξ)
0.26	10.1	8.8	3.6	-20.3	22.5	0.58	0.24	13.5
0.45	11.0	9.8	3.7	-17.2	20.9	0.65	0.25	13.9
0.65	12.2	11.0	3.9	-17.0	19.4	0.73	0.26	14.6
0.84	13.1	12.0	4.0	-15.3	18.6	0.79	0.27	14.9
1.03	13.9	12.8	4.1	-14.0	17.9	0.84	0.27	15.3
1.23	14.5	13.5	4.2	-12.2	17.1	0.89	0.28	15.6
1.42	15.0	14.1	4.1	-11.7	16.1	0.93	0.27	15.3
1.61	15.4	14.6	3.9	-11.6	15.0	0.96	0.26	14.6
1.81	15.7	15.0	3.7	-11.0	13.8	0.99	0.25	13.9
2.00	15.8	15.1	3.4	-10.8	12.8	0.99	0.23	12.8
2.19	16.0	15.4	3.2	-11.0	11.6	1.00	0.21	12.0
2.39	15.8	15.2	2.8	-11.1	10.5	0.98	0.17	10.6
2.00	15.8	15.1	3.4	-10.5	12.8	1.02	0.23	12.8
2.19	15.6	15.0	3.1	-10.1	11.8	1.01	0.21	11.7
2.39	15.1	14.6	2.7	- 9.5	10.4	0.99	0.18	10.2
2.58	14.4	14.1	2.3	- 8.6	9.2	0.95	0.15	8.7
2.77	13.3	13.1	2.0	- 7.0	8.5	0.88	0.13	7.6
2.97	10.5	10.3	0.5	- 9.5	3.0	0.70	0.03	1.9
3.16	10.8	10.6	0.5	-10.5	2.5	0.72	0.03	1.9
3.35	11.1	10.8	0.4	-12.5	2.0	0.73	0.03	1.5
3.55	11.2	11.1	0.3	- 8.1	1.8	0.75	0.02	1.1
3.74	11.7	11.5	0.3	-10.2	1.4	0.78	0.02	1.1
3.93	11.9	11.8	0.3	- 8.2	1.6	0.80	0.02	1.1
4.12	12.2	12.1	0.3	- 8.0	1.5	0.82	0.02	1.1

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TABLE 9

Tabulation of Velocity and Flow Angle Data for
Basic Flow #8

Model Configuration: With Upstream Appendages
With Screen
10% Low in Flow Coefficient

R (inches)	Total Velocity (fps)	V_x (fps)	V_7 (fps)	Pitch Angle (ϕ)	Yaw Angle (Θ)	$\frac{V_x}{V_\infty}$	$\frac{V_\theta}{V_\infty}$	Turning Angle (ξ)
0.26	9.6	8.1	3.7	-21.7	24.3	0.60	0.27	15.3
0.45	11.0	9.6	4.2	-16.8	23.7	0.71	0.31	17.3
0.65	11.7	10.4	4.2	-15.9	22.0	0.76	0.31	17.3
0.84	13.0	11.6	4.5	-16.6	21.0	0.85	0.33	18.4
1.03	13.8	12.6	4.6	-14.0	20.1	0.93	0.34	18.8
1.23	14.4	13.3	4.6	-11.8	19.0	0.98	0.34	18.8
1.42	15.0	14.0	4.4	-11.4	17.6	1.03	0.33	18.0
1.61	15.5	14.6	4.3	-11.3	16.5	1.07	0.32	17.7
1.81	15.8	14.9	4.1	-11.3	15.5	1.10	0.30	16.9
2.00	15.9	15.1	3.9	-11.1	14.3	1.11	0.29	16.1
2.19	16.0	15.3	3.5	-11.2	13.0	1.13	0.26	14.5
2.39	15.8	15.1	3.4	-11.1	12.6	1.11	0.25	14.1
2.00	15.8	15.0	3.8	-10.6	14.3	1.12	0.28	15.7
2.19	15.6	15.0	3.5	-10.4	13.0	1.12	0.26	14.5
2.39	15.2	14.6	3.1	-10.5	11.8	1.09	0.23	12.9
2.58	14.5	14.1	2.6	- 8.7	10.3	1.05	0.19	10.9
2.77	13.4	13.2	2.3	- 2.0	10.0	0.99	0.17	9.7
2.97	9.2	9.1	0.5	- 9.0	3.3	0.68	0.04	2.1
3.16	9.3	9.0	0.3	-13.5	2.0	0.66	0.02	1.3
3.35	9.7	9.5	0.3	-12.5	2.0	0.71	0.02	1.3
3.55	9.9	9.6	0.3	-13.4	2.0	0.72	0.02	1.3
3.74	10.1	9.9	0.2	-11.6	1.4	0.74	0.01	0.9
3.93	10.3	10.1	0.2	-10.7	1.4	0.75	0.01	0.85
4.12	10.7	10.4	0.3	-12.5	1.4	0.78	0.02	1.3

TABLE 10

Tabulation of Velocity and Flow Angle Data for
Basic Flow #9

Model Configuration: Without Upstream Appendages
With Screen
10% Low in Flow Coefficient

R (inches)	Total Velocity (fps)	V_x (fps)	V_y (fps)	Pitch Angle (ϕ)	Yaw Angle (Θ)	$\frac{V_x}{V_\infty}$	$\frac{V_\theta}{V_\infty}$	Turning Angle (ξ)
0.26	9.1	7.6	3.9	-19.8	27.4	0.56	0.29	16.1
0.45	10.5	9.2	4.1	-16.4	24.3	0.68	0.30	16.9
0.65	11.6	10.6	3.9	-14.2	20.2	0.78	0.29	16.1
0.84	12.7	11.8	3.9	-12.0	18.5	0.87	0.29	16.1
1.03	13.6	12.7	3.9	-11.3	17.2	0.93	0.29	16.1
1.23	14.3	13.5	4.0	-10.6	16.4	0.99	0.30	16.5
1.42	14.9	14.2	3.7	-10.5	14.8	1.04	0.27	15.3
1.61	15.4	14.7	3.7	- 9.6	14.0	1.08	0.27	15.3
1.81	15.7	15.1	3.5	- 9.8	13.0	1.11	0.26	14.5
2.00	15.9	15.3	3.2	- 9.8	11.9	1.11	0.24	13.3
2.19	16.1	15.6	3.1	-10.0	11.2	1.12	0.23	12.9
2.39	15.8	15.3	2.7	- 9.7	9.8	1.11	0.20	11.3
2.00	15.7	15.1	3.2	-10.0	12.0	1.11	0.24	13.3
2.19	15.6	15.1	2.9	- 9.6	10.7	1.11	0.22	12.1
2.39	15.3	14.9	2.5	- 9.3	9.5	1.10	0.19	10.5
2.58	14.6	14.3	2.0	- 8.7	8.1	1.05	0.15	8.4
2.77	13.7	13.5	1.7	- 5.8	7.0	0.99	0.13	7.1
2.97	10.5	10.5	0.4	- 5.1	2.0	0.77	0.03	1.7
3.16	11.0	10.7	0.3	-12.3	1.8	0.79	0.02	1.3
3.35	11.0	10.9	0.4	- 9.2	2.0	0.80	0.03	1.7
3.55	11.4	11.2	0.5	- 9.5	2.6	0.82	0.04	2.1
3.74	11.7	11.5	0.4	- 9.6	2.0	0.85	0.03	1.7
3.93	11.9	11.7	0.4	-10.1	2.1	0.86	0.03	1.7
4.12	12.2	12.0	0.4	-10.5	2.1	0.88	0.03	1.7

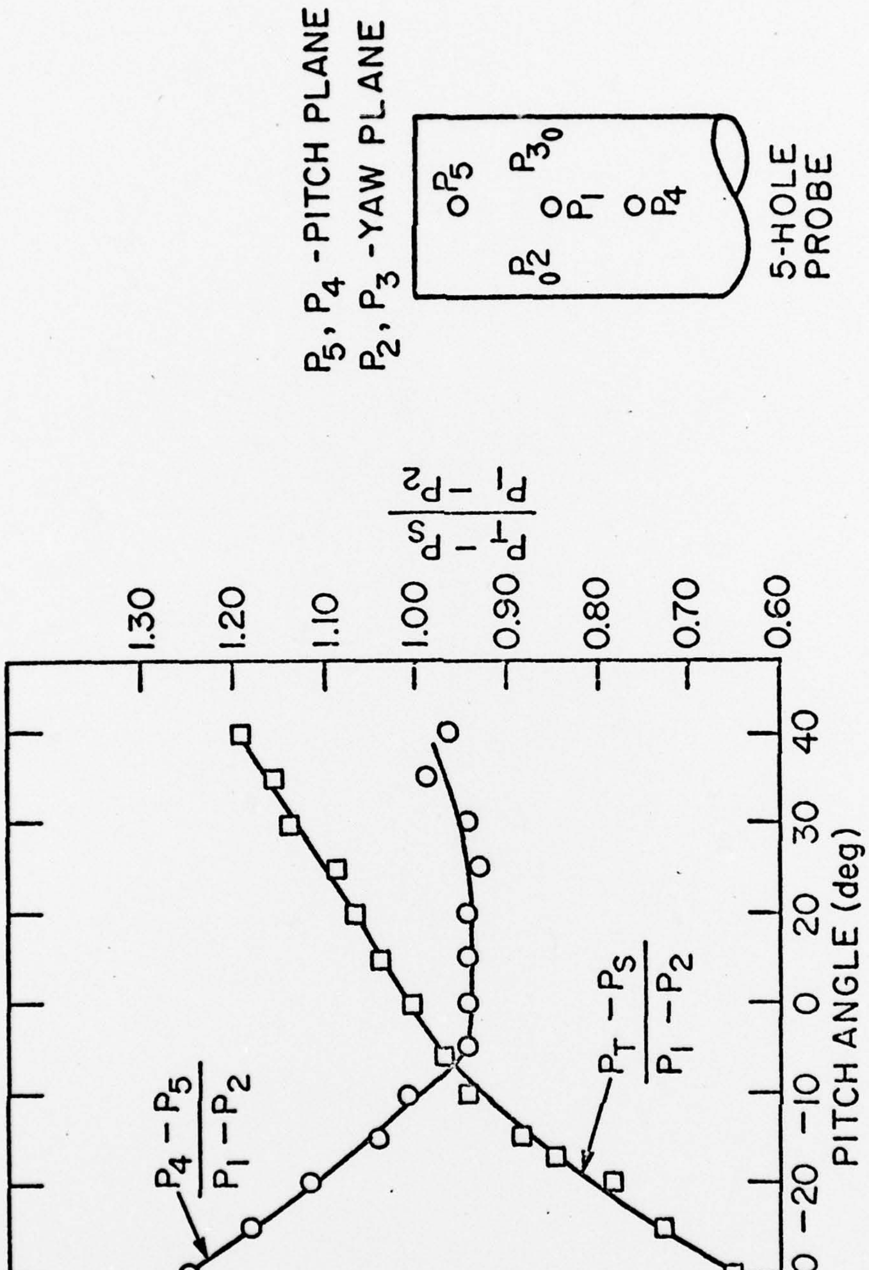

Figure 1 Calibration for 5-hole Probe

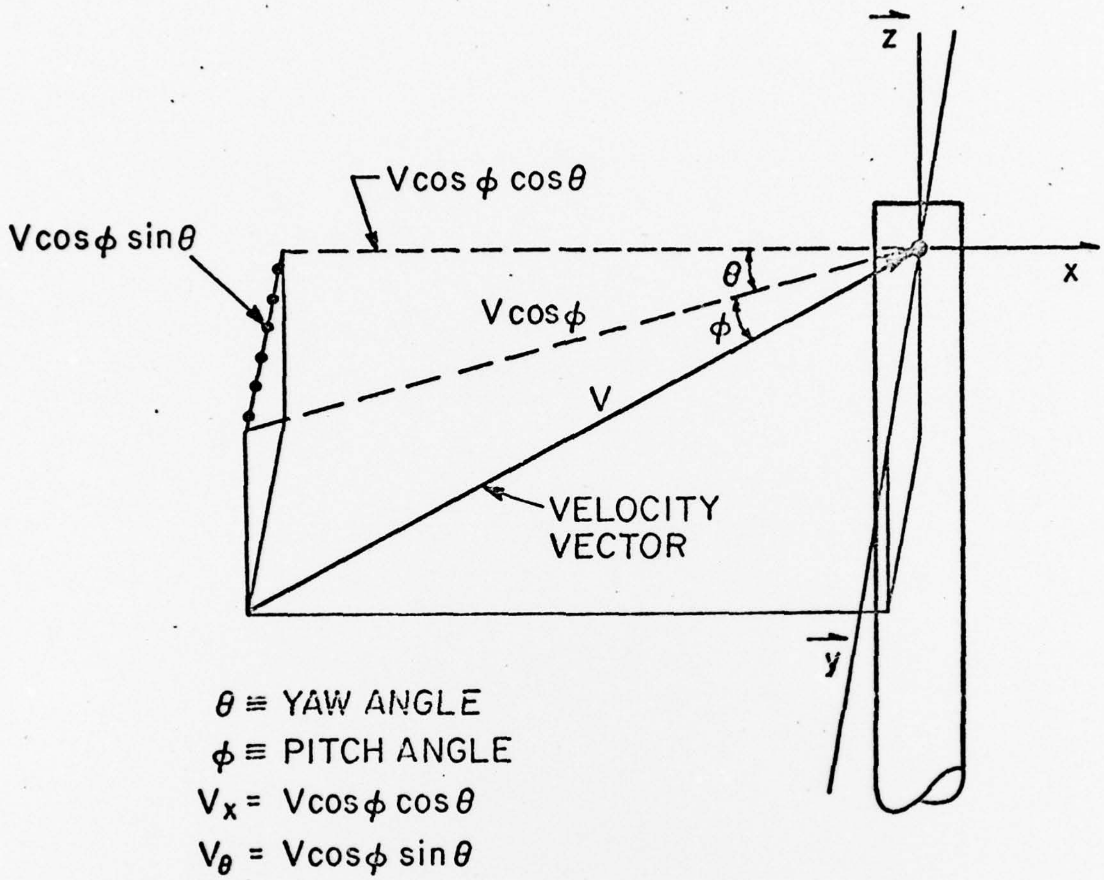

Figure 2 Schematic of Velocity Components

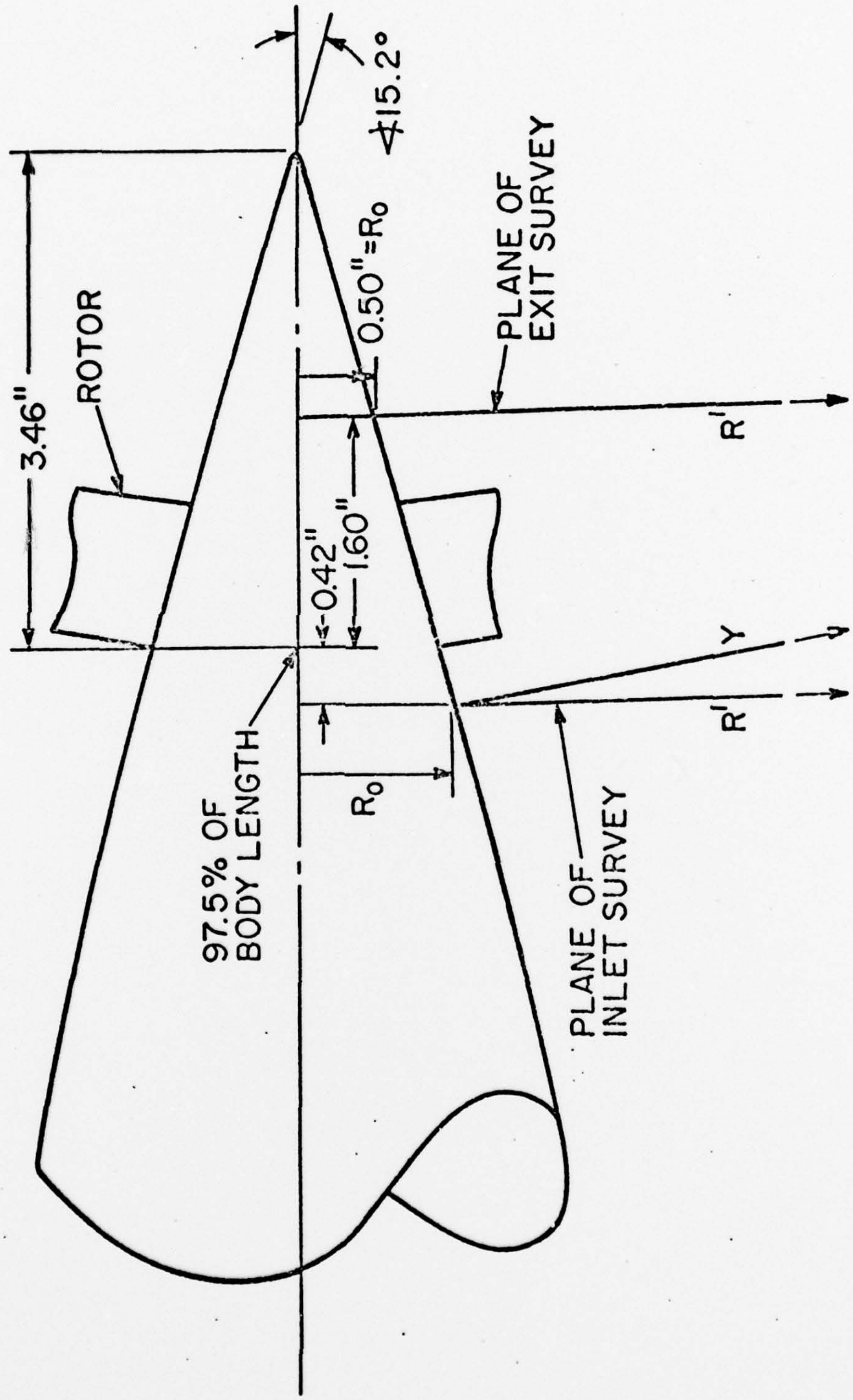

Figure 3 Schematic Showing Plane of Probe Survey

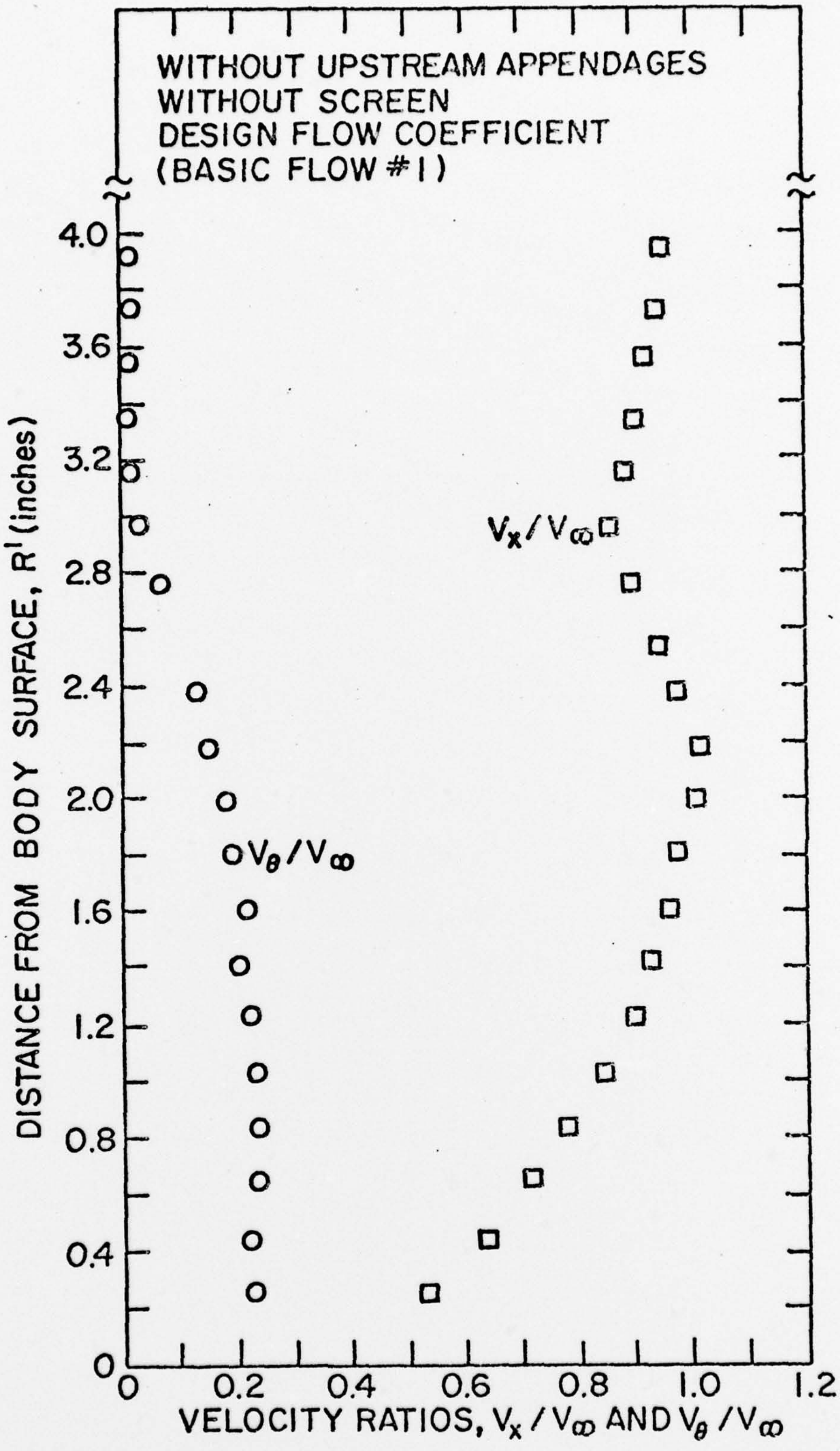

Figure 4 Velocity Ratios for Model Configuration Without Upstream Appendages, Without Screen, and Rotor on Design Flow Coefficient (Basic Flow #1)

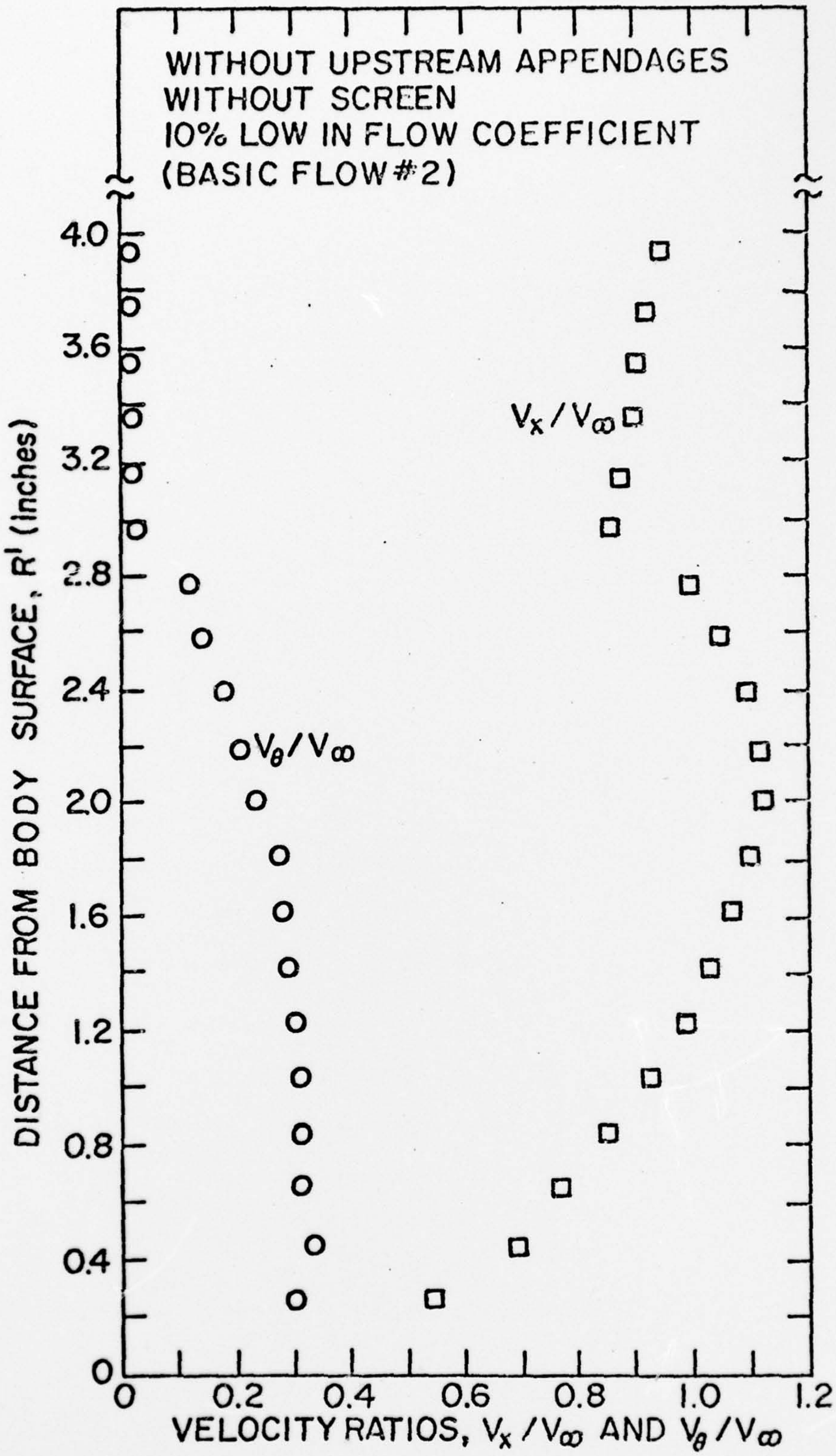

Figure 5 Velocity Ratios for Model Configuration Without Upstream Appendages, Without Screen, and Rotor 10% Low in Flow Coefficient (Basic Flow #2)

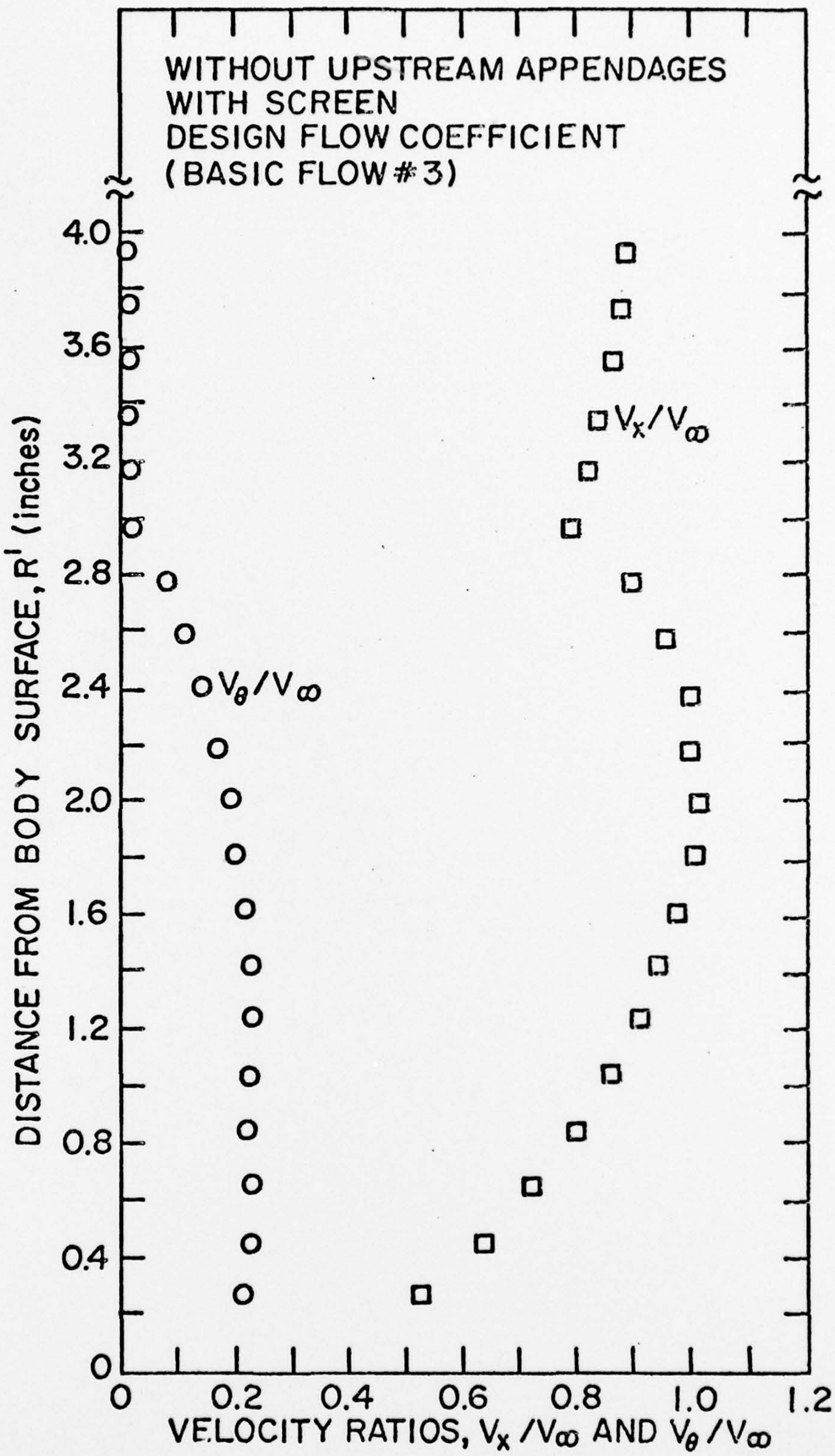

Figure 6 Velocity Ratios for Model Configuration Without Upstream Appendages, With Screen, and Rotor on Design Flow Coefficient (Basic Flow #3)

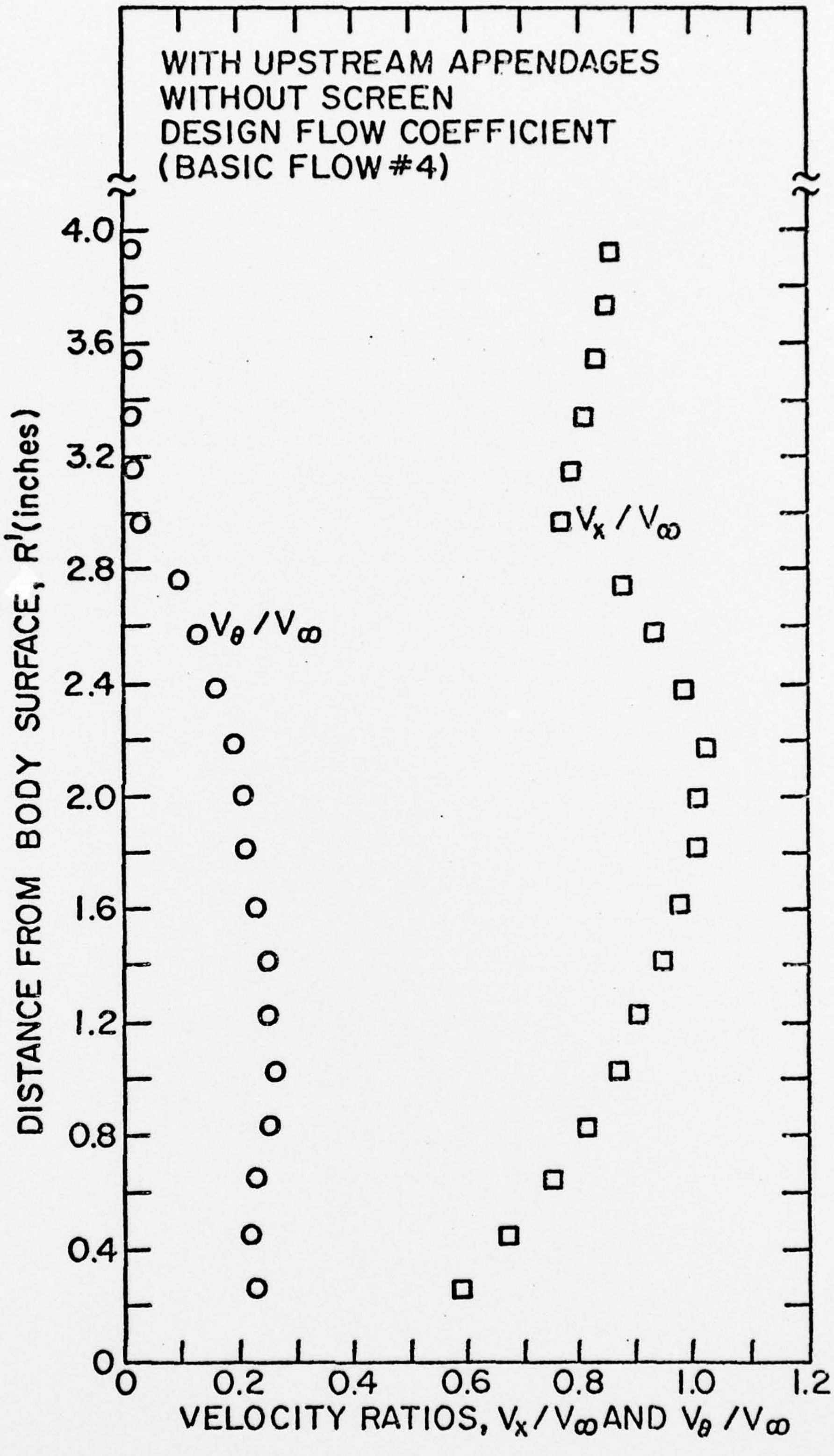

Figure 7 Velocity Ratios for Model Configurations With Upstream Appendages, Without Screen, and Rotor on Design Flow Coefficient (Basic Flow #4)

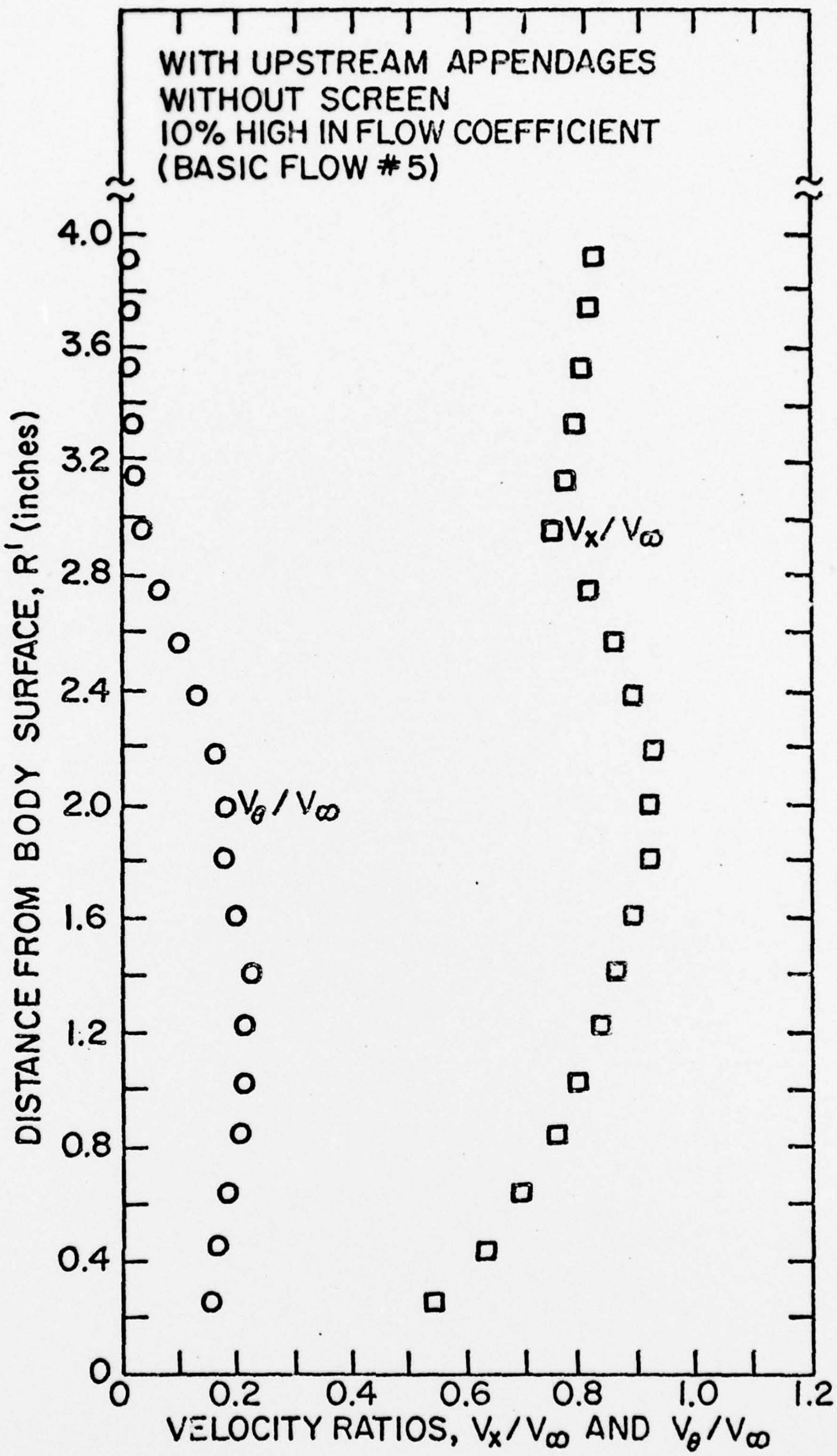

Figure 8 Velocity Ratios for Model Configuration With Upstream Appendages, Without Screen, and Rotor 10% Low in Flow Coefficient (Basic Flow #6)

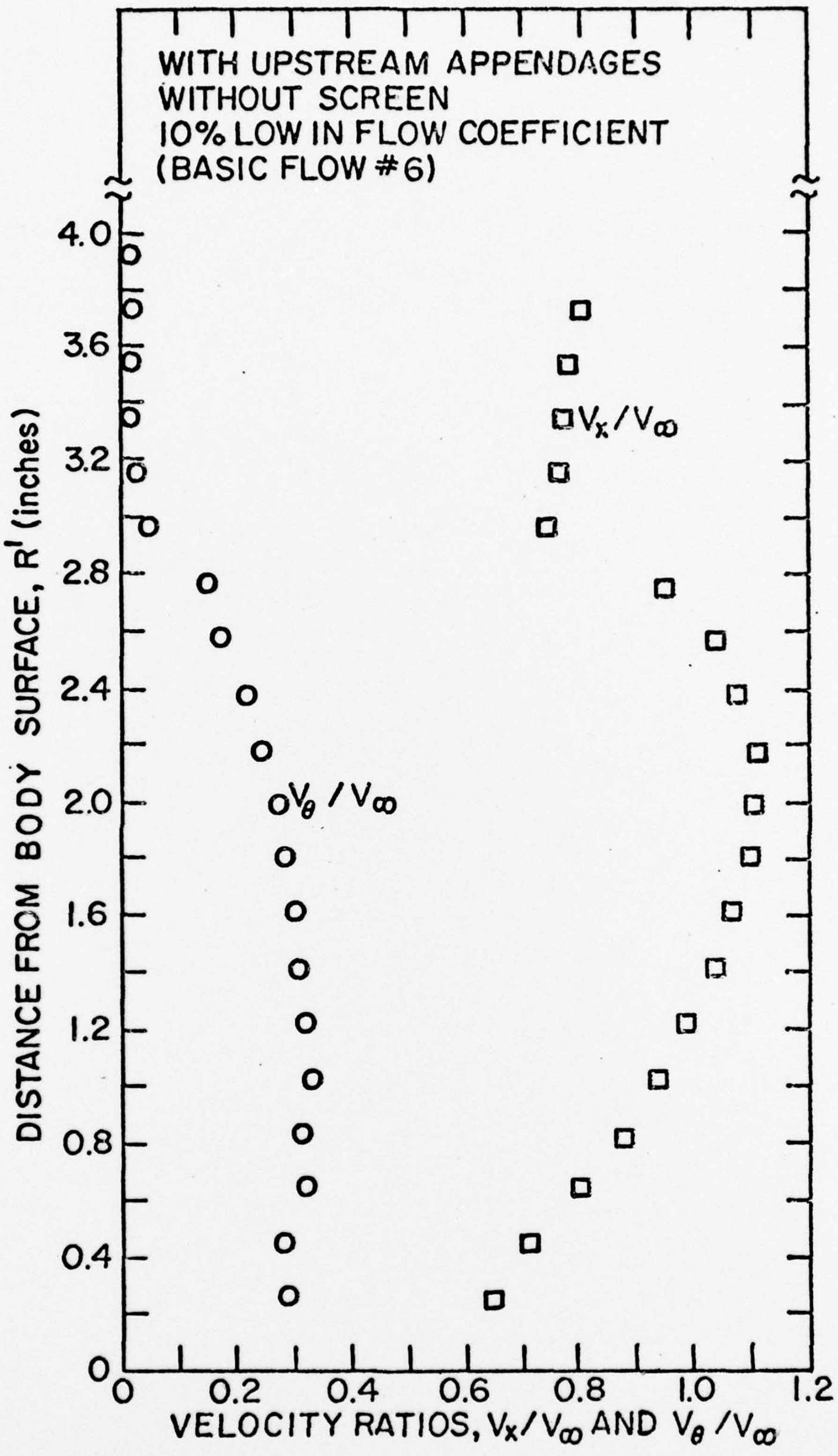

Figure 9 Velocity Ratios for Model Configuration With Upstream Appendages, Without Screen, and Rotor 10% High in Flow Coefficient (Basic Flow #5)

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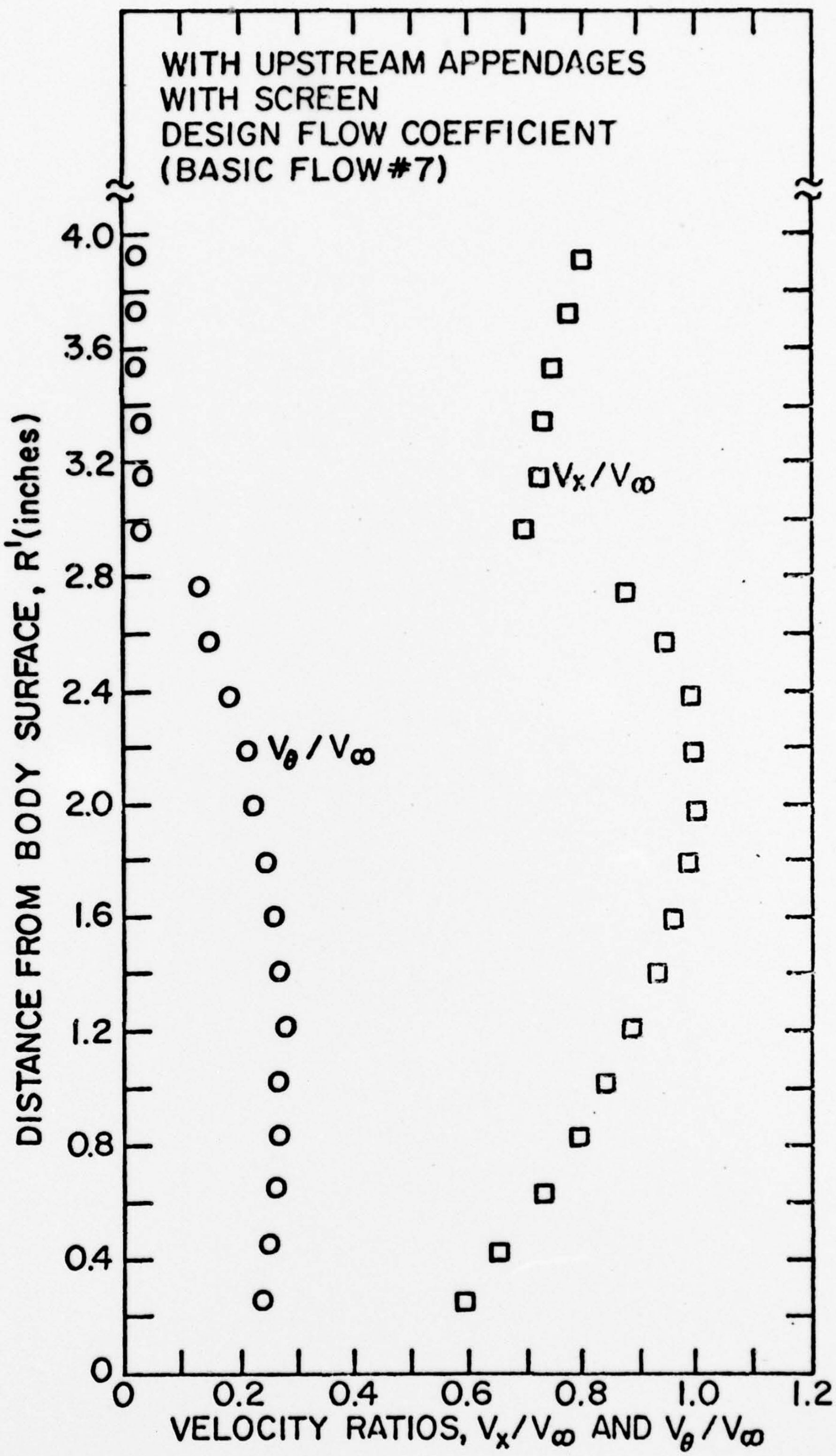

Figure 10 Velocity Ratios for Model Configurations With Upstream Appendages, With Screen, and Rotor on Design Flow Coefficient (Basic Flow #7)

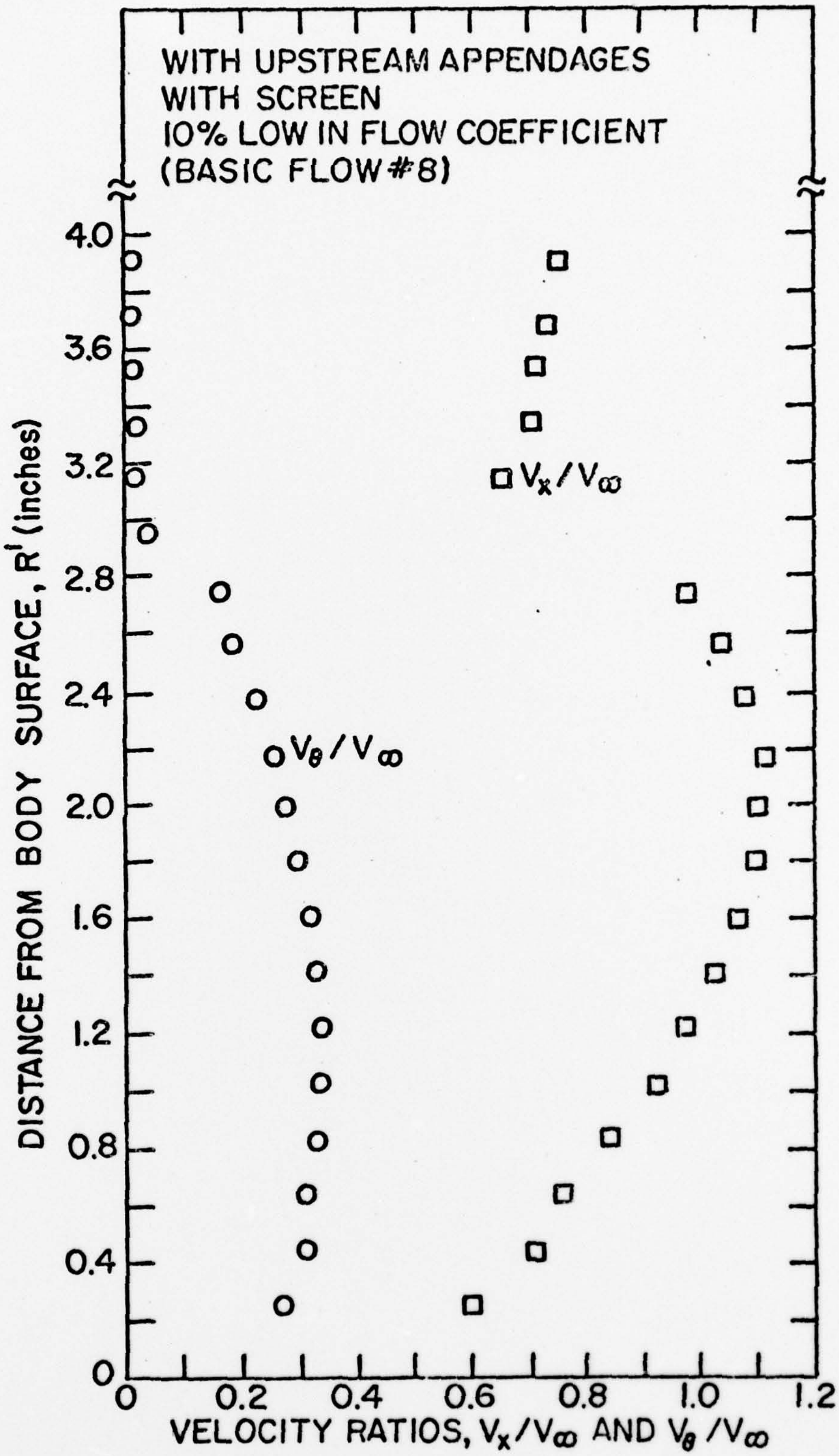

Figure 11 Velocity Ratios for Model Configurations With Upstream Appendages, With Screen, and Rotor 10% Low in Flow Coefficient (Basic Flow #8)

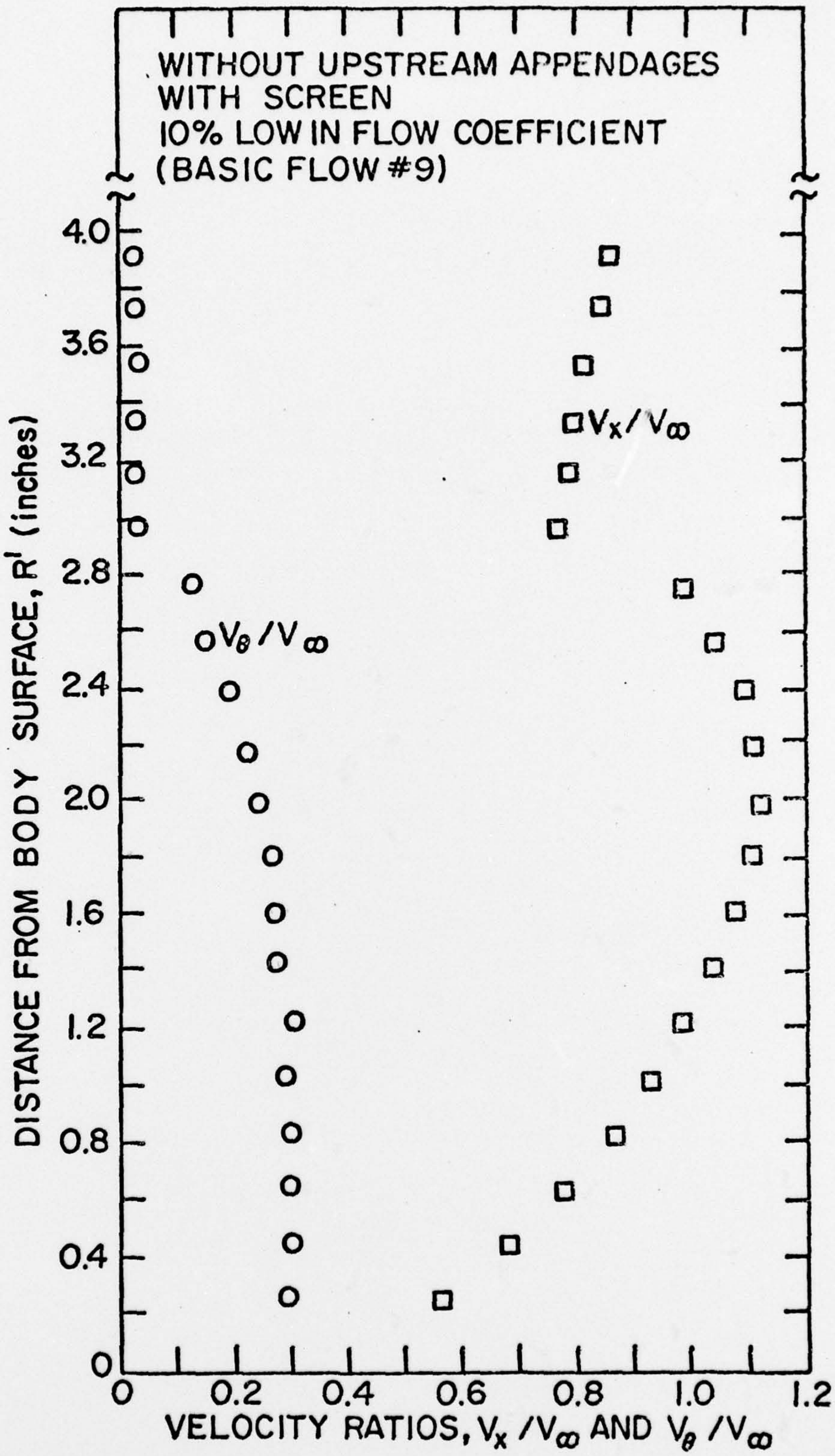

Figure 12 Velocity Ratios for MOdel Configuration Without Upstream Appendages, With Screen, and Rotor 10% Low in Flow Coefficient (Basic Flow #9)

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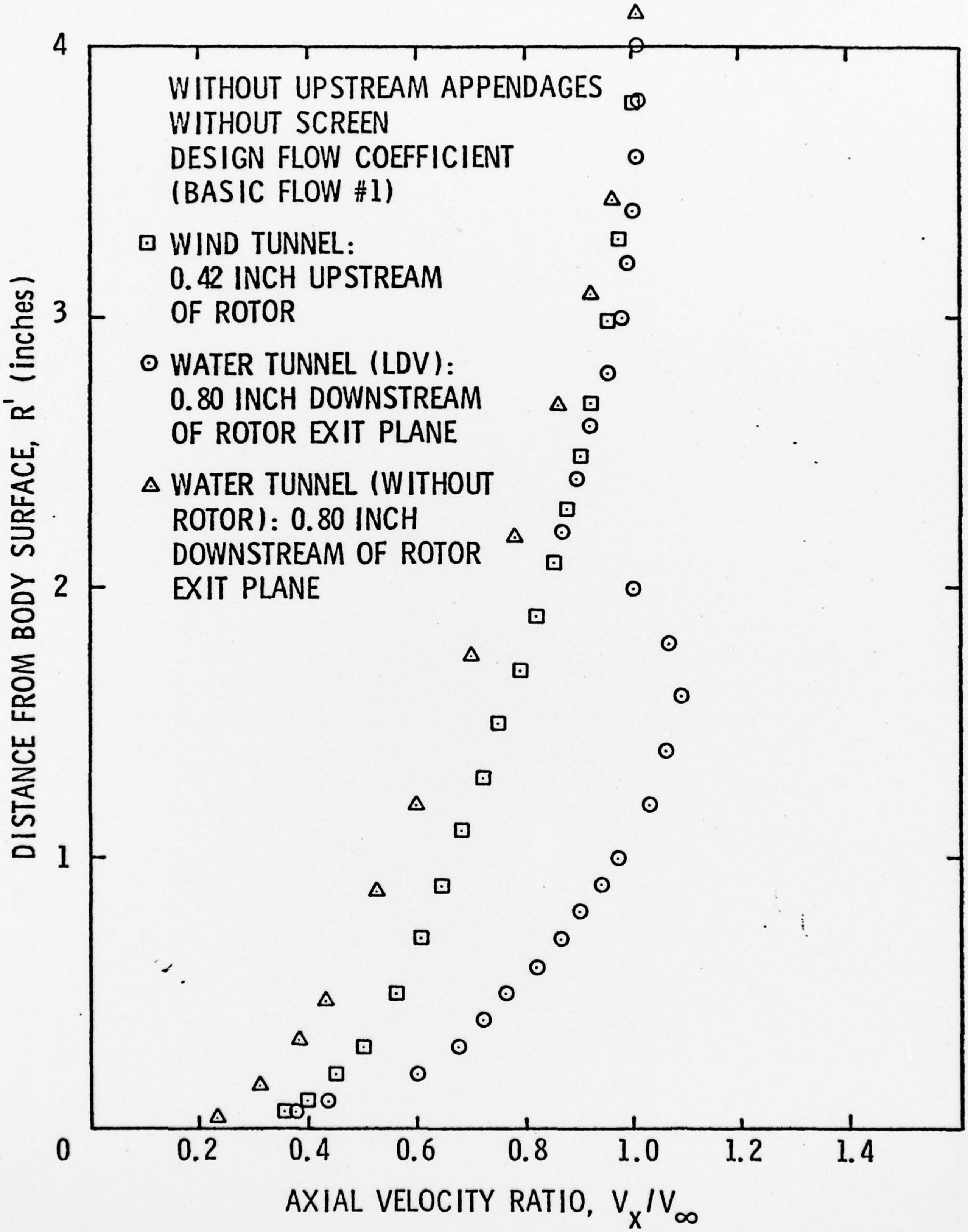

Figure 13 Axial Velocity Ratios for Model Configuration Without Upstream Appendages, Without Screen, and Rotor on Design Flow Coefficient (Basic Flow #1)