19
19
7-27

HEDL-TME 71-48
DECEMBER 1971

MASTER

FFTF OUTLET REGION
FEATURE MODEL
LOCALIZED POOL VELOCITIES

HANFORD ENGINEERING DEVELOPMENT LABORATORY
UNITED STATES ATOMIC ENERGY COMMISSION

Operated by

CONTRACT AT(45-1)-2170

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

**HANFORD ENGINEERING
DEVELOPMENT LABORATORY**

RICHLAND, WASHINGTON

operated by

WADCO CORPORATION

a subsidiary of Westinghouse Electric Corporation
for the

UNITED STATES ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(45-1)-2170

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

**FFTF OUTLET REGION
FEATURE MODEL
LOCALIZED POOL VELOCITIES**

L.M. Polentz
D.L. Ballard
F.H. Nunamaker

December 1971

**HANFORD ENGINEERING DEVELOPMENT LABORATORY
UNITED STATES ATOMIC ENERGY COMMISSION**

Operated by

CONTRACT AT(45-1)-2170

ABSTRACT

Measurements were made of the local velocity of fluid in a scale model of the FFTF reactor pool at a number of selected locations in a one-third sector. The purpose of the measurements was twofold:

(1) To determine the flow pattern above the reactor core and in the outlet pool, and (2) To determine the magnitude and direction of the fluid velocity at representative points to permit an estimate of the possibility of flow-induced vibration of the reactor pool components.

The velocity was measured for a gross model flow rate (3010 gpm) which simulated actual reactor velocity. Data were taken at 20 planar positions and 12 elevations in the outer pool from an elevation at the top of the outlet nozzles up to near the pool surface. The measured velocities (speed, pitch angle, and yaw angle) are tabulated.

CONTENTS

	<u>Page</u>
1. INTRODUCTION	1
2. SUMMARY AND CONCLUSIONS	2
3. DISCUSSION	3
3.1 Test Program and Objectives	3
3.2 Test Apparatus	4
3.3 Results	6
3.4 Discussion of Results	6

APPENDIX

<u>Exhibit</u>	<u>Page</u>
A Experimental Data	AX-1
B Experimental Techniques	BX-1
C Study Planning Notes	CX-1

FIGURES

<u>Figure</u>	<u>Page</u>
1 Sodium Flow Through The FFTF Reactor Vessel	3
2 Plan View of Outlet Region Model Showing Location of Local Velocity Probes	5
3 Outlet Region Model Internal Arrangement	6
4 Magnitudes and Vertical Directions of Local Velocities in Section "A" of Figure 2	8
5 Magnitudes and Vertical Directions of Local Velocities in Section "B" of Figure 2	9
6 Magnitudes and Vertical Directions of Local Velocities in Section "C" of Figure 2	10

1.0 INTRODUCTION

The FFTF Reactor design utilizes a core configuration which consists of a closely packed array of ducts surrounded by a relatively thin layer of reflectors. The entire assembly is immersed in a pool of liquid sodium which occupies the free volume inside the vessel from the bottom to the cover gas zone near the top.

The heat is extracted from the core by the flow of the sodium coolant upward through the ducts. The resulting streams of coolant discharge from the top ends of the ducts and flow upward past the instrument trees, the IVHM's, and other components in the upper section of the reactor. The coolant streams then combine in the outlet pool and the coolant flows out of the vessel through three outlet nozzles.

When fluid flows past an object which is immersed in its stream, a cyclic phenomenon known as vortex shedding occurs. The vortex shedding produces a vibration-forcing function. If the frequency of the forcing function is near the natural frequency of the component in the flow stream, failure of the component can occur due to fatigue. It is necessary to ensure that the frequency of any forcing function apt to occur in the coolant discharge flow stream is sufficiently below the natural frequency of any of the immersed objects so that there is no danger of sympathetic vibration and resulting fatigue failure.

The vortex shedding frequency due to flow past a right circular cylinder is represented by a relationship called the Strouhal Number. The Strouhal Number is a function of the fluid velocity. The flow paths from the duct discharge to the vessel outlet nozzles are too complex to determine analytically with acceptable accuracy, so it was necessary to measure them and then use the measured velocities to determine the Strouhal Numbers. The resulting frequency of the forcing function was then compared with the natural frequency of the components in the vessel.

In addition, it is necessary that there be no points or areas of stagnation in the reactor. Such areas of stagnation could result in temperature differentials in the outlet region which could, in turn, cause functional or structural damage to reactor components. Since the coolant flow distribu-

tion pattern in the outlet region is too complex to lend itself to an accurate analytical analysis, it was necessary to measure and plot the pattern of flow.

2.0 SUMMARY AND CONCLUSIONS

Measurements of local velocities (speed, pitch angle, and yaw angle) were made in a 0.268 scale model of the FFTF reactor vessel outlet region, using water as the fluid. Three-dimensional Pitot tubes were used; a 1:1 ratio of velocity in the model versus velocity in the reactor was employed. The measurements were made at 20 selected locations and at 12 elevations.

The results of measurements showed that the following conditions can be expected in the September 1970 design of the outlet region of the FTR:

- No danger of sympathetic vibration of components in the outlet region of the FTR due to vortex shedding was detected as a result of this series of tests.
- The path of the coolant flow is vertically upward in the core zone. The flow then deflects horizontally at or near the pool cover-gas interface, flows outward at the top, and then passes downward near the vessel wall toward the outlet nozzles. (Figure 1)
- The maximum measured velocity was 15.5 ft/sec. This occurred at an equivalent elevation of 22 inches above the top of the outlet nozzle inside the FTR vessel (six inches in the 0.268 scale model). However, this velocity may have resulted from the jet effect of flow through the reduced opening in the top of the simulated core duct-instrument package assembly.
- The measured velocity at an equivalent elevation of 44 inches above the top of the outlet nozzles over the center of the core was 11.9 ft/sec. (12 inches in the 0.268 scale model)

- Local flow aberrations were caused by holes for the velocity probes through the instrument support plates and the vortex suppression plates.
- The velocities measured at the different locations below the tops of the outlet nozzles were generally below 2 ft/sec. However, at one location near the vessel wall the local velocity reached 3.5 ft/sec.

Further detailed results are given in Section 3.3 and in Exhibit A.

3.0 DISCUSSION

3.1 Test Program and Objectives

The test work described in this report was performed during the period from April through September 1970. The tests were made on the FFTF Outlet Feature Model at HEDL. A complete description of the model, including model design and hydraulic similitude considerations, has been previously

Figure 1. Sodium Flow Through The FFTF Reactor Vessel

reported.⁽¹⁾

Initially the goal of this work was to measure the local velocity of the fluid at different locations in the Outlet Model to determine the potential for flow-induced vibration of the different components in the vessel. It was this purpose that dictated the location of the points at which the velocity was measured. Later the investigation was broadened to determine the pattern of the flow in the vessel. All measurements were to be made under steady state conditions at a flow rate of 3010 gpm through the Outlet Model. This is the flow rate at which the velocity ratio of model/prototype is 1:1 (HEDL-TME 71-90).

The expected range of velocity of interest was from 1-15 ft/second. The expected pitch and yaw angles ranged from 0 to 360°. The desired accuracy of velocity measurement was $\pm 10\%$ or better.

3.2 Test Apparatus

Figure 2 gives a plan view of the model showing the location of the velocity probes*, and Figure 3 shows the location of the probes with respect to in-vessel components. These locations are as follows:

- Over the core active zone--PV-3, PV-5, PV-7
- Near the IVHM--PV-16, PV-19
- Near the instrument tree--PV-10, PV-18
- Near the vessel wall above the outlet nozzle--PV-11
- In the free pool next to the vessel wall--PV-13, PV-14, PV-15, PV-17
- In the free pool--PV-1, PV-4, PV-8
- In the free pool next to the core barrel--PV-2
- Inside and near to the core barrel--PV-6, PV-9, PV-12
- Near to the core restraint actuator--PV-20

(1)HEDL-TME 71-90, "FFTF Outlet Region Feature Model, Final Report on All Air Entrainment Test Series," May 1971.

* The devices selected to measure the local velocities were 5-hole Pitot tubes obtained from a commercial vendor as discussed in Exhibit B.

The locations of the velocity probes were selected to investigate the probability of vortex-shedding induced vibration of the different components in a one-third sector of the FTR. It was also possible to group most of the probe locations into three vertical reference planes (Sections A, B, and C, Figure 2) around outlet nozzle number 3. This grouping permitted investigation of the flow pattern in these three planes. Further details on the test apparatus are given in Exhibit B. Study planning notes are reproduced as Exhibit C.

Figure 2. Plan View of Outlet Region Model Showing Location of Local Velocity Probes

3.3 Results

Figures 4,5 and 6 show magnitude and direction of velocities in the three vertical planes at elevations ranging from 12 inches below the top of the outlet nozzle of the model to 39 inches above the nozzle. The detailed experimental data are given in Exhibit A.

3.4 Discussion of Results

The locations at which the local fluid velocities were measured were, in

Figure 3. Outlet Region Model Internal Arrangement

the main, next to components in the vessel. The locations with respect to the internal components are shown in Figure 3.

Many of these locations were selected initially because of their proximity to the various components which were most likely to vibrate as a result of the impinging velocity. However, in many cases the presence of the components affected the magnitude and direction of the local velocity and caused instability of flow, and eddy currents.

An irregularity in the flow pattern was visually apparent at elevations 36 inches and above due to the vortex suppression plate. The vortex suppression plate is an assembly of two sets of perforated plates which extend horizontally across an internal section of the vessel. The purpose is to suppress or eliminate any vortices which might form in the liquid and which might cause entrainment of gas. The vortex suppression plate assembly is 0.50 inch thick overall and is located with the lower face at an elevation of 39-3/8 inches. The plates are perforated with 1/8 inch diameter holes on 3/16 inch centers.

One-inch diameter holes were drilled through the plates to permit passage of the tip of the Pitot tube [see Figures B-1 and B-2 of Exhibit B.] When the tip of the Pitot tube is within eleven inches of the vortex suppression plate, there is a relatively large opening in the plate assembly directly above the tip of the Pitot tube. The fluid can flow through this unobstructed opening much more freely, and with a lower pressure drop, than it can flow through the small openings in the plate assembly. It is, then, reasonable to assume that a larger portion of the fluid will flow through the hole around the probe than will flow through an equal area of the adjacent sections of the vortex suppression plate. This would result in a greater fluid velocity in the vicinity of the sensing probe and would explain the apparent irregularity.

The instrument support plate is located at 37 inches elevation. It consists of three pieces of solid plate with holes drilled so that the tubes simulating the closed loops and the control rods can pass through. There are also holes for the probe at locations PV-3, PV-5, and PV-7. The rest of the area presents a barrier to the flow of the fluid which passes up through the core. The effect of the barrier and the local holes is evidenced by

Figure 4. Magnitudes and Vertical Directions of Local Velocities in Section "A" of Figure 2

Figure 5. Magnitudes and Vertical Directions of Local Velocities in Section "B" of Figure 2

Figure 6. Magnitudes and Vertical Directions of Local Velocities in Section "C" of Figure 2

the sudden increase in velocity at the 37.5-inch elevation at PV-3 in Figures 4, 5, and 6, for the reasons discussed previously.

These sudden increases in velocity indicate that the measured local velocities cannot be assumed to be average velocities. The indications are that there is channelling up through the core, but the extent of the channelling could not be determined by measuring the local velocities at only three locations. It would be necessary to make a group of radial velocity traverses, and such was not possible with the existing test setup.

It was also observed that the velocity measured at a particular location varied when the position of the sensing tip was changed by rotating the probe 180° about its axis. The change in the sensed velocity was noted at almost all elevations for locations PV-3, PV-5, and PV-7. The variation ranged from 5 percent to as much as 30 percent at 30 inches elevation at PV-5. The apparent angles of flow also varied a small amount. This illustrates that there are definite variations in the fluid velocity in the core section and that no satisfactory "average" velocity can be determined from measurements at only three points at any one level.

Instability of flow was noted at a number of different locations, especially where the velocity was less than 2 ft/sec. In some cases the direction of flow varied as much as 90° in a short span of time. In other cases the variations in the direction of the flow were continuous and indicated the presence of eddies. These phenomena are discussed further in Exhibit A.

EXHIBIT A
EXPERIMENTAL DATA

This Exhibit records experimental data for probes PV-1 through PV-20 at the elevations listed below, where "0" represents the top of the inside of the outlet nozzles of the model.

- Elevation 39"
- Elevation 37.5"
- Elevation 36"
- Elevation 34"
- Elevation 30"
- Elevation 24"
- Elevation 18"
- Elevation 12"
- Elevation 6"
- Elevation (-) 6"
- Elevation (-) 12"

The figures show the direction and magnitude of the local fluid velocities at different horizontal planes in the outlet model. The magnitudes of each measured velocity, and of its horizontal component, are shown in the figures as well as the pitch and yaw angles. The scale of the vector is 0.42 inch = 10 ft/sec. The shorter of the two vectors represents the magnitude and direction (yaw angle) of the component of flow in the horizontal plane and is drawn to scale except where the body of the vector is dotted. When a dotted line is used, it means that the velocity, or component of velocity, is less than 2.0 ft/sec and only the direction of flow is shown.

The pitch angle is the angle between the horizontal component vector and the total velocity vector. A note is also added at each location where the fluid velocity is not horizontal to tell whether the direction of flow is up or down from the horizontal.

The yaw angle is the angle between north and the source of the flow measured in a counterclockwise direction. The angle between north and the horizontal component vector, measured in a counterclockwise dimension, equals the yaw angle + 180°.

Notes regarding phenomena observed during tests at the different probe locations are included.

OUTLET REGION VELOCITY TEST
ELEVATION 39"

PROBE LOCATION	P ₁ -P ₂	P ₄ -P ₅	YAW ANGLE	PITCH ANGLE	VELOCITY FT/SEC
* PV-1	1.250	2.625	164°	+28°	2.712
PV-2	4.312	2.500	102°	0°	4.979
* PV-3	7.188	7.125	116°	+88°	6.699
* PV-4	---	---	---	---	---
PV-5	8.781	6.813	45°	+85°	6.670
* PV-6	1.125	-0.875	113°	+43°	2.274
* PV-7	5.188	-3.938	81°	+51°	5.041
* PV-8	---	---	---	---	---
PV-9	---	---	---	---	---
PV-10	NA	NA	NA	NA	NA
PV-11	0.250	-0.219	152°	+52°	1.073
* PV-12	---	---	---	---	---
PV-13	2.000	0.500	284°	+19°	3.350
PV-14	2.563	0.063	57°	+10°	3.88
PV-15	2.188	0.563	98°	-40°	3.513
* PV-16	1.125	0.875	123°	+37°	2.673
PV-17	2.250	0.031	101°	+9°	3.628
* PV-18	---	---	---	---	---
PV-19	4.156	0.094	182°	+9°	4.933
* PV-20	---	---	---	---	---

NOTE : --- INDICATES VELOCITY WAS NOT GREAT ENOUGH TO MEASURE.
NA DATA NOT AVAILABLE AT THIS ELEVATION DUE TO OBSTRUCTIONS.
* INDICATES DATA COLLECTED WITH SUPPRESSION PLATE PLUGGED.

OUTLET REGION VELOCITY TEST
ELEVATION 37.5"

PROBE LOCATION	P ₁ -P ₂	P ₄ -P ₅	YAW ANGLE	PITCH ANGLE	VELOCITY FT/SEC
* PV-1	7.125	4.937	98°	+35°	6.652
PV-2	2.968	-0.062	104°	+8°	4.163
PV-3	12.063	8.688	44°	+63°	7.804
PV-4	---	---	---	---	---
PV-5	21.59	11.78	17°	+80°	10.45
* PV-6	5.438	0.250	118°	+12°	5.601
* PV-7	5.313	1.875	43°	+69°	5.180
* PV-8	0.563	-0.250	162°	-21°	1.894
* PV-9	6.250	0.875	162°	+15°	6.010
PV-10	---	---	---	---	---
PV-11	0.812	0.0	123°	+7°	2.180
PV-12	---	---	---	---	---
PV-13	1.531	0.093	289°	+13°	2.383
PV-14	2.469	-0.125	85°	+5°	3.77
PV-15	2.562	0.0	90°	-54°	3.811
* PV-16	4.813	-1.875	132°	-15°	5.470
PV-17	2.688	0.0	197°	+9°	3.968
PV-18	---	---	---	---	---
PV-19	5.125	-1.125	168°	-5°	5.483
PV-20	1.375	1.219	95°	-90°	2.934

NOTE : --- INDICATES VELOCITY WAS NOT GREAT ENOUGH TO MEASURE.
* INDICATES DATA COLLECTED WITH SUPPRESSION PLATE PLUGED.

EXHIBIT A (cont'd)

OUTLET REGION VELOCITY TEST
ELEVATION 36"

PROBE LOCATION	P ₁ -P ₂	P ₄ -P ₅	YAW ANGLE	PITCH ANGLE	VELOCITY FT/SEC
* PV-1	3.438	1.00	111°	+21°	4.414
PV-2	1.125	-0.219	100°	-3°	2.561
* PV-3	5.969	6.813	192°	+89°	5.422
* PV-4	11.91	1.125	120°	+13°	8.34
PV-5	4.38	0.97	13°	+66°	4.71
PV-6	6.34	-0.938	117°	+2°	5.96
PV-7	8.63	-3.13	16°	+60°	6.64
PV-8	10.88	0.56	153°	+12°	7.93
PV-9	3.375	-0.250	150°	+12°	4.49
PV-10	8.344	-1.375	216°	-2°	6.92
PV-11	1.250	-0.875	128°	-36°	2.912
PV-12	5.906	-0.937	176°	+62°	7.12
PV-13	0.687	0.031	265°	+11°	2.002
PV-14	1.687	-0.781	83°	-20°	3.27
PV-15	2.281	-0.219	74°	-60°	3.611
* PV-16	1.063	-0.500	132°	-21°	2.634
PV-17	3.468	-1.657	179°	-22°	4.713
PV-18	5.156	-2.000	102°	-15°	5.67
PV-19	3.312	-1.875	162°	-27°	4.664
PV-20	1.844	0.094	88°	-58°	3.240

NOTE: * INDICATES DATA COLLECTED WITH SUPPRESSION PLATE PLUGGED.

OUTLET REGION VELOCITY TEST

ELEVATION 34"

PROBE LOCATION	P ₁ -P ₂	P ₄ -P ₅	YAW ANGLE	PITCH ANGLE	VELOCITY FT/SEC
PV-1	0.937	0.344	112°	+23°	2.313
PV-2	0.218	-0.062	232°	-67°	1.162
* PV-3	7.063	5.438	54°	+85°	5.978
* PV-4	4.437	-5.500	119°	+23°	4.556
* PV-5	7.750	2.500	334°	+68°	6.259
* PV-6	1.875	-1.688	116°	-40°	3.732
* PV-7	5.813	-4.500	102°	+44°	5.594
* PV-8	6.813	-6.250	146°	+34°	5.593
PV-9	---	---	---	---	---
* PV-10	2.375	-0.375	239°	-2°	3.666
PV-11	2.157	0.281	137°	-45°	3.488
* PV-12	1.750	0.125	189°	+3°	3.175
PV-13	0.782	0.625	199°	-20°	2.419
PV-14	1.250	0.843	123°	-23°	2.736
PV-15	2.562	-0.250	340°	-61°	3.827
* PV-16	0.625	-0.313	129°	-20°	2.025
PV-17	1.031	-0.187	182°	-56°	2.247
PV-18	---	---	---	---	---
PV-19	0.688	-0.562	182°	-38°	2.202
PV-20	0.969	-0.531	72°	-78°	2.489

NOTE : --- INDICATES VELOCITY WAS NOT GREAT ENOUGH TO MEASURE.

* DATA COLLECTED WITH SUPPRESSION PLATE PLUGGED.

ELEVATION 34"

EXHIBIT A (cont'd)

OUTLET REGION VELOCITY TEST

ELEVATION 30"

PROBE LOCATION	$P_1 - P_2$	$P_4 - P_5$	YAW ANGLE	PITCH ANGLE	VELOCITY FT/SEC
PV-1	---	---	---	---	---
PV-2	0.188	-0.031	205°	-68°	1.041
PV-3	16.09	12.63	63°	+85°	9.02
PV-4	0.656	0.219	95°	+64°	1.85
PV-5	4.13	5.38	97°	+78°	4.45
PV-6	---	---	---	---	---
PV-7	10.88	0.625	119°	+64°	7.42
PV-8	1.031	0.500	162°	+73°	2.31
PV-9	---	---	---	---	---
PV-10	---	---	---	---	---
PV-11	2.063	-1.032	188°	-76°	3.620
PV-12	---	---	---	---	---
PV-13	1.687	-0.750	287°	-73°	3.238
PV-14	2.00	-0.719	65°	-70°	3.49
PV-15	2.062	0.656	336°	-82°	3.634
PV-16	---	---	---	---	---
PV-17	2.436	-1.250	263°	-77°	3.938
PV-18	---	---	---	---	---
PV-19	0.375	0.0	217°	-56°	1.457
PV-20	1.281	-0.782	310°	-81°	2.866

NOTE: --- INDICATES VELOCITY WAS NOT GREAT ENOUGH TO MEASURE.

OUTLET REGION VELOCITY TEST
ELEVATION 24"

PROBE LOCATION	P ₁ -P ₂	P ₄ -P ₅	YAW ANGLE	PITCH ANGLE	VELOCITY FT/SEC
PV-1	---	---	---	---	---
PV-2	0.250	-0.031	205°	-62°	1.197
PV-3	18.38	17.56	230°	+90°	9.65
PV-4	0.563	0.344	27°	+64°	1.69
PV-5	18.03	21.34	99°	+30°	9.40
PV-6	---	---	---	---	---
PV-7	14.5	8.22	131°	+77°	8.50
PV-8	0.688	0.063	93°	+64°	1.89
PV-9	---	---	---	---	---
PV-10	---	---	---	---	---
PV-11	2.219	-1.062	228°	-74°	3.741
PV-12	---	---	---	---	---
PV-13	1.969	-0.813	293°	-72°	3.488
PV-14	0.594	-0.344	110°	-80°	1.95
PV-15	2.688	-1.375	342°	-77°	4.141
PV-16	---	---	---	---	---
PV-17	2.063	-1.125	295°	-78°	3.632
PV-18	0.219	0.219	158°	+87°	1.05
PV-19	0.188	-0.031	202°	-63°	1.041
PV-20	2.094	-0.812	315°	-71°	3.588

NOTE: --- INDICATES VELOCITY WAS NOT GREAT ENOUGH TO MEASURE.

OUTLET REGION VELOCITY TEST

ELEVATION 18"

PROBE LOCATION	P ₁ -P ₂	P ₄ -P ₅	YAW ANGLE	PITCH ANGLE	VELOCITY FT/SEC
PV-1	---	---	---	---	---
PV-2	0.375	-0.094	223°	-66°	1.490
PV-3	29.81	20.94	63°	+88°	11.2
PV-4	0.563	0.219	27°	+64°	1.69
PV-5	16.09	21.63	132°	+90°	9.30
PV-6	---	---	---	---	---
PV-7	14.9	11.59	117°	+87°	8.47
PV-8	0.406	0.094	66°	+54°	1.43
PV-9	---	---	---	---	---
PV-10	0.188	-0.031	76°	+60°	0.98
PV-11	2.031	-0.937	244°	-75°	3.572
PV-12	---	---	---	---	---
PV-13	1.500	-0.781	299°	-77°	3.089
PV-14	1.250	-0.594	54°	-75°	2.81
PV-15	2.375	-1.156	334°	-77°	3.884
PV-16	---	---	---	---	---
PV-17	1.750	-1.000	296°	-79°	3.318
PV-18	0.250	0.313	337°	+80°	1.10
PV-19	0.250	-0.031	336°	-62°	1.197
PV-20	1.750	-0.844	317°	-76°	3.323

NOTE : --- INDICATES VELOCITY WAS NOT GREAT ENOUGH TO MEASURE.

OUTLET REGION VELOCITY TEST
ELEVATION 12"

PROBE LOCATION	P ₁ - P ₂	P ₄ - P ₅	YAW ANGLE	PITCH ANGLE	VELOCITY FT/SEC
PV-1	---	---	---	---	---
PV-2	0.312	-0.063	228°	-64°	1.347
PV-3	28.13	22.94	94°	+86°	11.9
PV-4	---	---	---	---	---
PV-5	18.39	20.69	119°	+90°	9.54
PV-6	---	---	---	---	---
PV-7	12.53	10.72	117°	+86°	7.95
PV-8	0.469	-0.156	42°	+60°	1.55
PV-9	---	---	---	---	---
PV-10	0.344	-0.157	77°	+60°	1.33
PV-11	1.469	-1.063	244°	-80°	3.055
PV-12	---	---	---	---	---
PV-13	0.687	-0.438	70°	-83°	2.098
PV-14	0.969	-0.563	40°	-79°	2.49
PV-15	1.875	-1.0	327°	-78°	3.464
PV-16	---	---	---	---	---
PV-17	1.562	-0.875	311°	-79°	3.163
PV-18	0.312	0.157	335°	+74°	1.25
PV-19	0.344	0.0	336°	-56°	1.396
PV-20	1.406	-0.750	318°	-79°	2.998

NOTES: --- INDICATES VELOCITY WAS NOT GREAT ENOUGH TO MEASURE.

OUTLET REGION VELOCITY TEST
ELEVATION 6"

PROBE LOCATION	$P_1 - P_2$	$P_4 - P_5$	YAW ANGLE	PITCH ANGLE	VELOCITY FT/SEC
PV-1	---	---	---	---	---
PV-2	0.469	-0.062	228°	-62°	1.640
PV-3	49.81	63.13	105°	+90°	15.5
PV-4	---	---	---	---	---
PV-5	16.125	19.34	117°	+90°	8.9
PV-6	---	---	---	---	---
PV-7	19.750	15.97	36°	+87°	10.0
PV-8	0.466	-0.625	36°	+20°	1.49
PV-9	---	---	---	---	---
PV-10	0.531	-0.156	77°	+60°	1.65
PV-11	0.781	-0.531	285°	-84°	2.232
PV-12	---	---	---	---	---
PV-13	0.375	-0.031	93°	-60°	1.462
PV-14	0.719	-0.375	27°	-77°	2.140
PV-15	1.375	-1.187	66°	-90°	2.933
PV-16	0.437	-0.375	279°	-39°	1.770
PV-17	1.281	-0.688	341°	-78°	2.862
PV-18	0.344	0.094	340°	+67°	1.32
PV-19	0.437	0.0	336°	-56°	1.573
PV-20	1.156	-0.594	321°	-77°	2.712

NOTES : --- INDICATES VELOCITY WAS NOT GREAT ENOUGH TO MEASURE.

OUTLET REGION VELOCITY TEST

ELEVATION 0"

PROBE LOCATION	P ₁ - P ₂	P ₄ - P ₅	YAW ANGLE	PITCH ANGLE	VELOCITY FT/SEC
PV-1	---	---	---	---	---
PV-2	0.531	-0.094	230°	-63°	1.750
PV-3	3.66	1.44	268°	+70°	4.280
PV-4	0.438	-0.313	357°	+45°	1.450
PV-5	NA	NA	NA	NA	NA
PV-6	---	---	---	---	---
PV-7	4.28	5.13	63°	+90°	4.590
PV-8	0.39	-0.562	24°	+20°	1.280
PV-9	---	---	---	---	---
PV-10	0.438	-0.156	78°	+60°	1.5
PV-11	NA	NA	NA	NA	NA
PV-12	---	---	---	---	---
PV-13	---	---	---	---	---
PV-14	0.750	-0.250	292°	-67°	2.130
PV-15	0.875	-0.5	228°	-84°	2.367
PV-16	---	---	---	---	---
PV-17	0.813	-0.406	26°	-76°	2.272
PV-18	0.313	0.0	390°	+63°	1.270
PV-19	0.313	0.031	336°	-56°	1.332
PV-20	1.0	-0.50	321°	-76°	2.520

NOTES:

NA- DATA NOT AVAILABLE AT THIS ELEVATION DUE TO OBSTRUCTIONS.
 --- INDICATES VELOCITY WAS NOT GREAT ENOUGH TO MEASURE.

EXHIBIT A (cont'd)

OUTLET REGION VELOCITY TEST

ELEVATION -6

PROBE LOCATION	P ₁ - P ₂	P ₄ - P ₅	YAW ANGLE	PITCH ANGLE	VELOCITY FT/SEC
PV-1	---	---	---	---	---
PV-2	0.625	-0.094	239°	-62°	1.873
PV-3	NA	NA	NA	NA	NA
PV-4	---	---	---	---	---
PV-5	NA	NA	NA	NA	NA
PV-6	---	---	---	---	---
PV-7	NA	NA	NA	NA	NA
PV-8	---	---	---	---	---
PV-9	---	---	---	---	---
PV-10	---	---	---	---	---
PV-11	NA	NA	NA	NA	NA
PV-12	---	---	---	---	---
PV-13	---	---	---	---	---
PV-14	1.5	0.0	197°	-55°	3.503
PV-15	0.625	-0.437	85°	-64°	2.011
PV-16	---	---	---	---	---
PV-17	0.375	-0.188	58°	-76°	1.544
PV-18	---	---	---	---	---
PV-19	-0.375	-0.031	4°	-56°	1.958
PV-20	0.894	-0.406	324°	-75°	2.302

NOTES:

- NA DATA NOT AVAILABLE AT THIS ELEVATION DUE TO OBSTRUCTIONS.
 --- INDICATES VELOCITY WAS NOT GREAT ENOUGH TO MEASURE.

OUTLET REGION VELOCITY TEST

ELEVATION -12

PROBE LOCATION	$P_1 - P_2$	$P_4 - P_5$	YAW ANGLE	PITCH ANGLE	VELOCITY FT/SEC
PV-1	---	---	---	---	---
PV-2	0.469	-0.125	271°	-66°	1.665
PV-3	NA	NA	NA	NA	NA
PV-4	---	---	---	---	---
PV-5	NA	NA	NA	NA	NA
PV-6	---	---	---	---	---
PV-7	NA	NA	NA	NA	NA
PV-8	---	---	---	---	---
PV-9	---	---	---	---	---
PV-10	---	---	---	---	---
PV-11	NA	NA	NA	NA	NA
PV-12	---	---	---	---	---
PV-13	---	---	---	---	---
PV-14	1.438	-0.063	197°	-58°	3.475
PV-15	---	---	---	---	---
PV-16	---	---	---	---	---
PV-17	0.094	-0.063	67°	-83°	0.776
PV-18	---	---	---	---	---
PV-19	0.438	-0.062	326°	-62°	1.587
PV-20	0.718	-0.375	326°	-77°	2.137

NOTES:

- NA - DATA NOT AVAILABLE AT THIS ELEVATION DUE TO OBSTRUCTIONS.
- INDICATES VELOCITY WAS NOT GREAT ENOUGH TO MEASURE.

ELEVATION -12"

EXHIBIT A (cont'd)

NOTES REGARDING PHENOMENA OBSERVED DURING TESTS AT THE DIFFERENT PROBE LOCATIONS

PROBE LOCATION PV-1

Elevation 0

Visual observation of the yarn indicates an approximate pitch angle of 40° from vertical, and flow is upward. The yarn moves about $\pm 10^\circ$ on yaw angle.

P_1 on the vertical manometer oscillates $\pm 1/8"$. P_2 and P_3 were difficult to keep balanced. P_4 and P_5 remained stable at this elevation.

Elevation 6 in.

Visual observation of the yarn indicates an approximate pitch angle of 0° to 15° from vertical. Flow is upward. The yarn appears to swirl at times. The yaw angle moves in an arc of about 270° . The yarn does not remain stable long enough to establish the yaw angle, and at times it wraps around the probe $\pm 360^\circ$ plus.

P_2 and P_3 change $\pm 3/32$ from a balanced position on the vertical manometer. P_4 and P_5 remained stable at this elevation.

Elevation 0

A recheck at this elevation indicates a yaw angle of 138° . The yarn is still very unstable and the above remarks for zero elevation are valid for this recheck.

Elevation 12 in.

Visual observation of the yarn indicates a pitch angle of 10° to 25° . Flow is upward. The pitch and yaw angles indicated by the yarn at this elevation still fluctuate, but stability is much improved over the 0 and 6" elevations. The yarn still coils around the probe occasionally, in a counter-clockwise direction. On the vertical manometer P_1 varies $+3/32$ in. - 0 P_2 and P_3 change $\pm 1/16$ in from a balanced position. P_4 and P_5 remained stable at this elevation.

Elevation 18 in.

Visual observation of the yarn indicates a pitch angle of 10° to 25° from the vertical. Stability of the yarn is much improved, with the yarn only occasionally coiling around the probe. Velocity seems to be less at this elevation, although this

could be due to improved stability of the yarn.

P_1 on the vertical manometer oscillates $\pm 1/16$. P_2 and P_3 remain balanced $\pm 1/32$. P_4 and P_5 are stable.

Elevation 24 in.

Visual observation of the yarn indicates a pitch angle of 30° to 35° from vertical. Flow is upward. The yarn still occasionally coils around the probe. The yaw angle appears to be the same as at the 18" elevation.

P_1 on the vertical manometer oscillates $\pm 1/16$. P_2 and P_3 remained stable. P_4 and P_5 remained stable. Conditions seem improved at this elevation.

Elevation 30 in.

Visual observation at this elevation is very difficult due to obstructions and distortion. A very rough estimate of the pitch angle is 35° to 40° . Flow is upward and easterly.

Elevation 36 in.

Visual observation of the yarn is very difficult. Flow appears to be in an easterly direction and horizontal. However, the yarn is in view only at times. At the end of this test probe number 1 will be installed and another set of data taken at this elevation.

Elevation 36 in.

P_2 and P_3 on the vertical manometer oscillate $\pm 1/8$ from a balanced position. P_4 and P_5 remain stable. After recording three sets of data at 103° yaw angle, readjusted the probe to try to improve the yaw angle stability. There was a very slight improvement at 103.5° . Three sets of data were recorded at this new setting.

Elevation -12 in

The yarn appears to drift lazily 360° horizontally and pitch angle from 0° to 90° upward. The manometer reading showed no change when the yaw angle changed.

Elevation -6 in

Same as -12 in elevation

NOTE:

At the following locations the probe is above the lower instrument support plate. This plate is not prototypical. The rechecks were made with Probe no. 1.

Elevation 36 in.

Unable to estimate pitch angle. It appears to be nearly horizontal.

Elevation 37.5 in.

Same as 36 in. elevation.

Elevation 39 in.

Same as 36 in. elevation.

PROBE LOCATION PV-2

Elevation -12 in.

Direction of flow is downward. A very rough estimate of the pitch angle is 30° to 40° from the vertical. The velocity appears to be low at this elevation, as the movements of the yarn are very slow.

Elevation -6 in.

Direction of flow is downward. Estimated pitch angle is between 20° and 30° from the vertical.

Elevation 0

Direction of flow is downward. Estimated pitch angle is 20° to 30° from the vertical.

Elevation 6 in.

Direction of flow is downward. Estimated pitch angle is 30° to 40° from the vertical.

Elevation 12 in.

Direction of flow is downward. Estimated pitch angle is 30° to 40° from the vertical. There is an occasional movement of the yarn to a near horizontal position.

Elevation 18 in.

Direction of flow is downward. Estimated pitch angle is 30° to 40° from the vertical.

Elevation 24 in.

Direction of flow is downward. Estimated pitch angle is 20° to 30° from the vertical. A significant increase in the instability of the yarn is apparent at this elevation. It also appears that there has been a decrease in velocity. The yarn is very lazy in its movements.

Elevation 30 in.

Direction of flow is downward. A very rough estimate of the pitch angle is 20° to 30° from the vertical. The velocity appears to be very low at this elevation. At times the yarn appears to hang from the probe.

Elevations 34, 36, 37.5, and 39 in.

Unable to view the yarn at this elevation due to obstructions.

PROBE LOCATION PV-2

Elevation 0

From visual observation of the yarn, the flow is in a downward direction. The pitch angle is 20° to 30° from the vertical. Yaw angle estimated, 170° .

Elevation 6 in.

From visual observation of the yarn, the flow is downward. The pitch angle is approximately 20° to 30° from the vertical. The yaw angle is approximately 170° . At this elevation the yarn appears to be in a more turbulent zone. The yarn occasionally coils around the probe in a clockwise rotation, and at times it is briefly in a horizontal or in an up position.

Elevation 12 in.

Same as 6 in. elevation with a slight change in yaw angle. Yaw angle $\sim 160^\circ$.

Elevation 18 in.

Visual observation of the yarn indicates a downward flow and a pitch angle of 10° to 20° from the vertical. The yaw angle varies between 130° and 160°. The yarn at times appears to be neutrally buoyant and coils around the probe.

Elevation 24 in.

Visual observation of the yarn indicates a downward flow in a northeasterly direction. Unable to estimate pitch and yaw angle due to obstruction and view-port distortion.

Elevation 30 in.

Difficulty in seeing the yarn due to distortion. However, the yarn appears to be in a nearly horizontal position.

Removed probe no. 4 and installed probe no. 1. The direction of flow appears to be horizontal and easterly. In adjusting the probe, the maximum differential pressure is less than 1/8" of water. ($P_1 - P_2$, $P_4 - P_5$). P_4 and P_5 very nearly balance on the vertical manometer. P_4 is within $\pm 1/64$ in. of P_5 .

Elevation 36 in.

From the south view-port, the yarn indicates an easterly direction of flow. Looking at the pool surface, the direction of flow appears to be westerly. Data will be recorded for both directions. Pitch angle appears to be nearly horizontal. Probe response is about equal in either yaw angle position.

PROBE LOCATION PV-3

Elevation 0

The probe is in contact with the top of the driver tube.

Elevation 6 in.

Velocity measurement of this elevation is influenced by the jetting action from the driver tube coolant discharge.

Elevation 12 in.

Considerable difficulty in determining the yaw angle.

Elevation 18 in.

Everything operates well at this elevation.

Elevation 24 in.

It was very difficult to maintain P_2 and P_3 in a balanced position at a yaw angle of 76.6°. P_2 and P_3 would vary $\pm 1/4$ in. from a balanced position.

Elevation 30, 36, 37.5 and 39 in.

Everything seems okay.

PROBE LOCATION PV-3

Elevation 0

It is difficult to measure the yaw angle. Pressures P_2 and P_3 fluctuate $\pm 1/32$ inch. After recording the first two sets of data at 0 in. elevation and a yaw angle of 266.2°, the probe was rotated 180°. P_2 and P_3 would not balance at this angle. The differential pressures were also too great to keep them on the manometer panel. P_2 and P_3 would however balance at 117.6°, two sets of data were recorded at this angle.

Elevation 6 in.

Three sets of data were recorded at 264.3° yaw angle. The probe was then rotated 180°. P_2 and P_3 would not balance at this angle. Yaw was then adjusted to 102.6°. At this setting P_1 had to be valved off to keep P_5 on the manometer panel. After recording two sets of data for P_4 and P_5 , P_5 was then valved off and P_1 opened. Two sets of data for P_1 and P_2 were then recorded. There was difficulty in establishing the yaw angle at 102.6°. The probe did not respond well, $\pm 2^\circ$ at 102.6°.

Elevation 12 in.

The probe response for a yaw angle of 92° was still poor but somewhat improved from the 6 in. elevation.

At 18 in. elevation the 61.1° yaw angle is still difficult to obtain.

The 24, 30, 36 inch elevation conditions were much improved.

Data were collected using No. 1 and No. 4 probes fitted with a length of hose to restrict flow going up and around probe.

PROBE LOCATION PV-4

Elevations 0 and 6 in.

Unable to see the yarn attached to the probe. Recorded two sets of data $\sim 180^\circ$ apart.

Elevation 12 in.

The ΔP , $P_1 - P_2$ changes $\sim 3/32$, $P_4 - P_5 \sim 1/16$ on the vertical manometer.

Elevations 18, 24, and 30 in.

Everything okay.

Elevation 36 in.

Probe no. 4. Data out of the range.

There is difficulty in keeping P_2 and P_3 balanced at this elevation. This problem has occurred with both probes (1,4). P_3 appears to be wandering. It varies from $P_2 + 1/8$, -0 (at 319°).

At 118° yaw angle pressures P_2 and P_3 go out of balance $\pm 1/2$ in. The change is much more rapid than at previous probe locations.

All data recorded at this elevation were taken at the best balanced positions of P_2 and P_3 . However, P_2 and P_3 were never balanced longer than 5 to 10 seconds.

PROBE LOCATION PV-5

Remarks:

The probe is coming into contact with some tube in the model. The probe was later found to be making contact with the CL-2 mixing probe. This may cause difficulty in running the velocity and mixing tests simultaneously.

When rotated 180° , tip of probe is in contact with some internal member (tube).

Elevation 0

The velocity probe comes in contact with the top of the driver tube. Unable to measure velocity at this elevation.

Elevation 6 in.

There is a jetting action from the driver coolant discharge at this elevation.

Elevations 12 and 18 in.

Everything operates well.

Elevation 27 in.

At all previous elevations, when adjusting the probe to measure the yaw angle, an increase in the yaw angle causes an increase in P_2 and a decrease in P_3 . However, at this elevation and a yaw angle of 106.8° an increase in yaw angle increased P_3 and decreased P_2 .

Elevations 30, 36, 37.5, and 39 in.

Everything operates well.

PROBE LOCATION PV-6

Remarks:

At the 0, 6, 12, 18, and 24 in. elevations the pitch angle is approximately 30° to 35° from the vertical. Flow is upward.

At the 30 in. elevation, the pitch angle is approximately 45° to 50° . Flow is upward.

At the 36" elevation the pitch angle appeared to be almost horizontal (0°). Visual observation of the yarn is very difficult at this elevation.

Visual observation of the yarn which is attached to the lower end of the probe was utilized in determining the correct yaw angle at all elevations.

It was noted that at this probe location the pressures showed a greater oscillation than at any of the previous locations, approximately $\pm 1/8$ in. H_2O . The oscillation was more pronounced on P_1 and P_5 .

PROBE LOCATION PV-7

Elevations 0, 6, 12, 18, 24, 30, and 36 in.

The probe location is in the core. Visual observation of the yarn attached to the probe is impossible due to obstructions at all elevations.

The data recorded at the 36 in. elevation 7-28-70 were taken with only fifteen minutes balance time. Another set will be recorded later giving the manometer additional time to balance.

Elevation 0 and 6 in.

P_1 pressure varies $\pm 3/16$ in.

Elevation 12 in.

Probe response is poor when adjusting for a yaw angle of 111.4° . P_1 pressure varies $\pm 1/8$ in.

Elevation 18 in.

The pressure response is poor when the probe is adjusted to measure the yaw angle. P_1 varies $\pm 1/8$ in. I shut the loop down, with P_2 and P_3 balanced at a yaw angle of 7.4° . The following set of data was taken after startup without making any adjustments to probe settings. P_2 and P_3 returned to a balanced position. Used a five minute waiting period after P_2 and P_3 balanced before recording the data.

Elevation 24, 30, 36, 37.5, and 39 in.

Probe response still is slow.

PROBE LOCATION PV-8

Elevation 0

Visual observation of the yarn indicates a pitch angle of $\sim 40^\circ$ to 50° from the vertical. Flow is upward.

Elevation 6 in.

Visual observation of the yarn indicates a pitch angle of $\sim 40^\circ$ to 45° from the vertical. Flow is upward.

Elevation 12 in.

Visual observation of the yarn indicates a pitch angle of $\sim 30^\circ$ to 40° from the vertical. Flow is upward.

Elevation 18 in.

Visual observation of the yarn indicates a pitch angle of $\sim 10^\circ$ to 20° from the vertical. Flow is upward.

Elevation 24 in.

Visual observation of the yarn is difficult at this elevation due to obstructions. A rough estimate of the pitch angle is 20° from the vertical. Flow is upward.

Elevation 30 in.

Unable to see yarn at this elevation. Did not rotate probe 130° as adjustment of probe for yaw angle continued in a plus direction as it had at previous elevations.

Elevation 36 in.

Unable to see yarn at this elevation. The data at this elevation approach the maximum range of probe no 4. However, recorded three sets of data using this probe as we would not have time to make a probe change this evening.

Elevation 36 in.

Probe no. 1 has been installed. Probe response at both yaw angles is good, however at 326° the data recorded are at the maximum end of the range for this probe.

PROBE LOCATION PV-9

Elevation 0

The general direction of flow appears to be upward. Pitch angle $\sim 40^\circ$ to 50° from the vertical. The yarn is very unstable at this elevation. It changes vertical direction as well as yaw direction, and at times appears to be floating.

$P_1 - P_2$ on the vertical manometer is generally balanced, and at times drifts negative. Data would indicate we are operating beyond the range of this probe. Will install no. 1 probe at a later time.

Elevation 6 in.

The yarn is changing direction constantly. It does not stabilize in any particular direction to reasonably establish the yaw or pitch angle. The yarn appears to be almost floating.

Elevation 12 in.

The yarn is much more stable than at the two previous elevations, but it still shows considerable drift. The yarn appears to be almost floating. Pitch angle 40° to 50° from vertical (very rough estimate). Flow is generally upward.

Elevation 18 in.

It is very difficult to establish a pitch angle due to distortion through the view port. A very rough estimate is 20° to 30° from vertical. Flow is upward. Unable to establish a yaw angle by observing the yarn.

Elevation 24 in.

Direction of flow is upward. Pitch angle 30° to 40° from vertical.

Elevation 30 in.

Unable to see yarn well enough to establish a pitch angle.

Elevation 36 in.

Unable to see yarn at this elevation.

The direction of flow in this location (PV-9) at elevations 0 and 6 in. seems very unstable. The yaw angle appears to reverse between 6 in and 12 in. Pressures P_1 , P_2 , P_3 , P_4 , and P_5 were all equal at times.

PROBE LOCATION PV-10

Elevation 0

Visual observation of the yarn indicates a pitch angle of 10° to 20° from the vertical. Flow is upward.

Elevation 6 in.

Visual description at this elevation is identical to 0 elevation.

Elevation 12 in.

Visual description at this elevation is the same as 0 elevation.

Elevation 18 in.

Visual observation of the yarn indicates a pitch angle of 20° to 30° from vertical. Flow is upward. The yarn appears to be floating more at this elevation.

Elevation 24 in.

At this elevation the direction of the flow is generally upward. However, the yarn often moves down the probe and coils around it in a counter-clockwise direction. The yarn appears to be floating most of the time. A very rough estimate of the pitch angle is 30° . The yarn is very unstable at this elevation.

Elevation 30 in.

The yarn is very unstable at this elevation. Flow appears to be generally upward. Unable to estimate yaw angle due to instability of the yarn.

Elevation 36 in.

Changed probes for this elevation. Yarn indicates a nearly horizontal pitch angle.

PROBE LOCATION PV-11

Elevation 0

Unable to check this location. The probe comes into contact with the flange around the discharge nozzle.

Elevation 6 in.

Unable to see yarn at this elevation due to obstructions. By raising the probe up about three inches the yarn is visible and indicated the flow is downward.

Elevations 12, 18, 24, and 30 inches

Flow at these elevations is downward.

Elevation 36 in.

Flow appears to be about 80° from vertical and downward. Visual observation at this elevation is difficult as the yarn seems to be influenced by the flow going up around the probe and through the vortex suppression plate.

Elevations -2, -6, and 0 in.

Unable to obtain data at these elevations as the probe comes into contact with the outlet nozzle flange at -4 in. and cannot be lowered beyond that elevation.

Elevations 6 and 12 in.

Unable to view yarn at this elevation due to obstructions.

Elevation 18 in.

Direction of flow is downward. Unable to estimate yaw or pitch angle due to the angle of viewing the yarn.

Elevations 24 and 30 in.

Direction of flow is downward. It appears to be almost vertical. Pitch angle is very difficult to estimate because of the angle of sight.

Elevation 34 in.

Flow appears to be downward. Unable to estimate yaw and pitch angles, however, the direction of the flow appears to have moved towards the horizontal.

Elevation 36 in.

The yarn goes up toward the opening in the suppression plate. The P_4 - P_5 differential

is very unstable. Also P_2 and P_5 vary $\pm 1/8"$ from a balanced position.

Elevations 37.5 and 39 in.

The yarn moves up into the suppression plate opening.

PROBE LOCATION PV-12

Elevation 0

Flow is 80° to 90° from vertical and appears to be slightly downward.

Elevation 6 in.

Flow is 80° to 90° from vertical and appears generally to be slightly upward.

Elevation 12 in.

Flow is generally upward. The yarn appears to be almost floating and moves in all directions, including downward at times. It also coils around the probe counter-clockwise. The pitch angle appears to be ~ 50° to 80° from vertical.

Elevation 18 in.

Unable to estimate pitch angle due to instability of the yarn. Flow appears to be upward.

Elevation 24 in.

Pitch angle appears to be ~ 20° to 30° from the vertical. Direction of flow is upward but the yaw angle appears to be reversed. The yarn seems to almost sink at times as if there were not enough flow to keep it moving.

Elevation 30 in.

Stability of the yarn seems greatly improved at this elevation. Pitch angle ~ 20° to 30° from vertical.

Elevation 36 in.

Stability is good at this elevation. Pitch angle ~ 90° from vertical.

PROBE LOCATION PV-13

Elevation 0

Flow is generally upward. The yarn is very unstable at this elevation making it very difficult to estimate the pitch angle. The yarn is in a downward direction ~ 40% of the time.

Difficulty in balancing P_2 and P_3 . $P_1 - P_2$ is negative 80% of the time.

Viewing the yarn at this location (PV-13) will be difficult at all elevations due to distortion.

Elevation 6 in.

Flow is downward. Unable to estimate pitch angle.

Elevation 12 in.

Flow is downward. Unable to estimate pitch angle due to distortion.

Elevation 18 in.

Unable to see the yarn at this elevation. However, lowering the probe ~ 1 inch makes the yarn visible. The direction of flow is downward. Unable to estimate pitch angle due to distortion.

Elevation 24 and 30 in.

Unable to see yarn at these elevations. Will assume a downward flow and install No. 1 probe for 36 in. elevation.

Elevation 36 in.

Unable to see the yarn. Probe SK-3-15531 (No. 1) installed. Will record data ~ 180° apart.

The probe responds well at 258° yaw angle, but very poorly at ~ 70° to 90°. An adjustment of 20° for yaw angle makes very little, if any, change in the pressures indicated on the manometer.

Elevation -12 in.

Flow is upward. Estimated pitch angle ~ 20° to 30° from vertical.

Elevation -6 in.

Flow is upward. Estimated pitch angle ~ 30° to 40° from vertical.

Elevation 0

The yarn is very instable at this elevation. Flow appears to be generally upward. Estimated pitch angle ~ 40° to 50° from vertical.

Elevation 6 in.

Direction of flow appears to be downward. Unable to estimate yaw or pitch angle due to the angle of viewing the yarn. Will record data ~ 180° apart. The yarn is very unstable and frequently changes direction, ~ 180°. Velocity would appear to be very low as the movement of the yarn is very lazy. Probe response to yaw angle adjustments is very poor. Balancing P_2 and P_3 has been time consuming.

Elevation 12 in.

Flow appears to be downward. Unable to estimate yaw and pitch angles due to the angle of viewing the yarn.

Elevation 18 in.

The yarn is not visible at this elevation.

Elevation 24 in.

The yarn is not visible at this elevation.

Elevations 30, 34 and 36 In. Probe No. 2

The yarn is not visible at these elevations.
9-24-70

Elevation 34 in.

Note different yaw angles using Probes 1 and 2.

Elevation -6 in.

At ~ 90° $P_1 - P_2$ is negative and < 1/2 in. At 270° P_1 through P_5 appear almost equal.

Elevation -12 in.

$P_1 - P_2$ < 1/2 in. Considerable time was spent trying to balance P_2 and P_3 . $P_1 - P_2$ was never greater than 1/4 in. even though the probe was rotated 360°. Due to the low velocity I did not continue to try to determine the yaw angle.

Probes No. 1 and No. 2 and No. 4 were used at 0, -6 and -12 in. elevations.

PROBE LOCATION PV-14

Elevation 0

Flow is downward. Approximate pitch angle, 20° to 30° from vertical.

Elevation 6 in.

Flow is downward. Approximate pitch angle 30° to 40° from vertical.

Elevation 12 in.

Flow is downward. Approximate pitch angle 30° from vertical.

Elevation 18 in.

Flow is downward. Approximate pitch angle 20° from vertical.

Elevation 24 in.

Flow is downward. Approximate pitch angle 30° from vertical.

Elevation 30 in.

Flow is downward. Approximate pitch angle 30° from vertical.

Elevation 36 in.

Flow appears to be downward. Approximate pitch angle 100° to 110° from vertical. Some difficulty in estimating pitch angle due to distortion.

Elevation 0

Flow is downward. A rough estimate of the pitch angle is $\sim 45^\circ$ to 50° from vertical. Visibility of the yarn is poor at this elevation.

Elevation 6 in.

Flow is downward. Estimated pitch angle $\sim 50^\circ$ from vertical. Yaw angle would appear to be $\sim 330^\circ$ but P_2 and P_3 will not balance at that angle. This may be due to view-port distortion and an inaccurate estimate of the yaw angle.

Elevation 12 in.

Flow is downward. Estimated pitch angle $\sim 10^\circ$ to 20° from vertical.

Elevation 18 in.

Flow is downward. Estimated pitch angle $\sim 10^\circ$ to 20° from vertical.

Elevation 24 in.

Flow is downward. Estimated pitch angle 10° to 20° from vertical.

Elevation 30 in.

Flow is downward. Estimated pitch angle $\sim 20^\circ$ to 30° from vertical. Some difficulty in establishing the yaw angle. Response of probe is poor.

Elevation 36 in.

Flow appears to be horizontal. Estimated pitch angle, $\sim 90^\circ$ from the vertical.

Elevation 37.5 in.

Flow is downward. Estimated pitch angle 60° to 80° from the vertical. Difficulty in recording data at this elevation. The yarn wraps around the probe tip, cutting off some pressure. The yarn does not unwind once it is in this position. Correction requires rotating the probe, and waiting for the manometer to balance, but this lengthens the test considerably.

Elevation 39 in.

Unable to establish direction of flow. It would appear to be upward, however, the yarn will go up through the probe opening in the suppression plate and come back out. The yarn still wraps around the probe at times in a clockwise direction and will not unwrap.

Elevation -12 in.

Flow appears downward. Pitch angle $\sim 20^\circ$ to 30° from vertical. The yarn is very unstable. It has been very difficult to balance P_1 and P_2 .

Elevation -6 in.

Conditions same as at -12 in. elevation.

Elevation 34 in.

Flow appears downward. A very rough estimate of the pitch angle is $\sim 40^\circ$ to 50° from the vertical.

PROBE LOCATION PV-15

Elevation 0

Flow is downward. Approximate pitch angle is 10° to 20° from vertical.

Elevation 6 in.

Visual description is the same as 0.

Elevation 12 in.

Visual description is the same as at 0.

Elevation 18 in.

Flow is downward. Approximate pitch angle 10° from vertical.

Elevation 24 in.

Flow is downward. Approximate pitch angle 20° to 30° from vertical.

Elevation 30 in.

Flow is downward. Approximate pitch angle 0° to 10° from vertical.

Elevation 36 in.

Flow is downward. Approximate pitch angle 30° to 40° from vertical.

Elevation 0

Flow is downward. The pitch angle as indicated by the direction of the yarn varies from 30° to 0° to 30° from the vertical but mostly points vertically downward at 0° from the vertical.

Elevation 6 in.

Flow is downward. The pitch angle is $\sim 0^{\circ}$ from the vertical.

Elevation 12 in.

Same as at 6 in.

Elevation 18 in.

Same as at 6 in.

Elevation 24 in.

Same as at 6 in.

Elevation 30 in.

Flow is downward. Pitch angle $\sim 10^{\circ}$ from vertical.

Elevation 34 in.

Same as at 30 in.

Elevation 36 in.

Flow is downward. Pitch angle $\sim 10^{\circ}$ to 20° from vertical.

Elevation 37.5 in.

Flow is downward. Pitch angle $\sim 10^{\circ}$ to 30° from vertical.

PROBE LOCATION PV-17

Note:

At the 18 and 24 in. probe elevations, was unable to determine the yaw angle. It does not seem as though the probe has enough sensitivity. The probe did not respond well to adjustments at any of the first six elevations (0 to 30 in). At 36 in. the probe response was much better, although still sluggish.

Elevation 0

Flow is downward 20° to 30° from vertical.

Elevation 6 in.

Flow is downward 15° to 20° from vertical.

Elevation 12 in.

Flow is downward 30° to 35° from vertical.

Elevation 18 in.

Flow is downward 30° to 35° from vertical.

Elevation 24 in.

Flow is downward 35° to 40° from vertical. Encountering difficulty is estimating the pitch angle due to view-port distortion.

Elevation 30 in.

Flow is downward 30° to 40° from vertical.

Elevation 36 in.

Unable to estimate pitch angle, as the yarn tends to go up toward the hole for the probe, that is in the suppression plate.

Elevation -11 in.

Flow appears to be generally downward. Approximate pitch angle is 60° from vertical. The flow at this elevation appears to be very unstable. The yarn will move to a nearly horizontal position and at times will wrap around the probe in a clockwise direction. The velocity appears to be very low.

Elevation -6 in.

Flow is downward. Estimated pitch angle ~ 30° to 40° from vertical. The yarn is still unstable and at times will move to a horizontal position. Stability is improved at this elevation, however.

Elevation 0

Flow is downward. Estimated pitch angle ~ 20° to 30° from vertical. Stability of the yarn is improving.

Elevation 6 in.

Flow is downward. Estimated pitch angle ~ 10° to 20° from vertical. Probe response has been poor at this elevation.

Elevation 12 in.

Flow is downward. It is very difficult to establish a pitch angle at this elevation as the direction of flow is toward the observer. A very rough estimate is 20° to 30° from the vertical.

Elevation 18 in.

Flow is downward. Unable to estimate pitch angle as flow is toward the observer.

Elevation 24 in.

Flow is downward. Unable to estimate pitch angle.

Elevation 30 in.

Flow is downward. Unable to estimate pitch angle as the direction of the flow is towards the observer.

Elevation 34 in.

Flow is downward. Due to distortion this operator was unable to establish pitch angle. Due to distortion in viewing, the yarn data will be recorded 180° apart.

Elevation 36 in.

Flow is downward. Unable to estimate pitch angle due to distortion. Data will be recorded ~ 180° apart. At 9°, $P_1 - P_2$ is negative. Probe no. 2.

The direction of flow appears to be upward with the no. 1 probe in this location. The yarn attached to this probe is $\sim 1/2"$ higher on the probe, than on no. 2 probe. Unable to establish yaw angle. Will record data $\sim 180^\circ$ apart

Elevation 37.5 in.

Observing the yarn at this elevation is very difficult due to distortion. The yarn appears to be going up into the opening in the suppression plate. Data will be recorded $\sim 180^\circ$ apart.

Elevation 39.0 in.

The yarn flows upward through the suppression plate opening. Two sets of data will be recorded $\sim 180^\circ$ apart.

PROBE LOCATION PV-18

Elevation 0

Flow is upward. Approximate pitch angle 10° to 30° from vertical.

Elevation 6 in.

Flow is upward. Approximate pitch angle 20° to 30° from vertical.

Elevation 12 in.

Flow is upward. Approximate pitch angle 20° to 30° from vertical.

Elevation 18 in.

Flow is upward. Approximate pitch angle 20° to 30° from vertical. A slight increase in the instability of the yarn is observed at this elevation. The yaw angle will reverse $\sim 180^\circ$ briefly at times.

Elevation 24 in.

Flow is upward. Approximate pitch angle 30° to 40° from vertical. The velocity appears to be very low at this elevation as the yarn floats at times. The yarn is very unstable in reference to the yaw angle. Due to this instability two sets of data have been recorded at $\sim 180^\circ$ apart.

Elevation 30 in.

Observing the probe at this elevation is very difficult due to the angle of the view-port to the probe. Unable to estimate pitch angle. The flow appears to be nearly horizontal or slightly downward at this elevation.

Elevation 36 in.

Unable to see the yarn at this elevation. Data are out of the range of probe No. 4. Necessary to install probe No. 1.

At this elevation the probe is very close to the instrument tree support plate and bracket.

Lowering the probe ~ 0.2 in. the yarn is visible and indicates a nearly horizontal flow.

PROBE LOCATION PV-19

Elevation 0

Flow appears generally downward. The yarn is very unstable and moves in an upward direction at times. Unable to estimate pitch angle. Yarn appears to be almost floating.

Elevation 6 in.

The yarn is very unstable at this elevation, floating in almost all directions. Flow appears to be slightly upward. Unable to estimate pitch angle.

Elevation 12 in.

Flow appears to be upward. A very rough estimate of pitch angle is 40° to 80° from vertical. Yarn is very unstable and almost floats at times. The probe is not responsive to adjustments for yaw angle.

Elevation 18 in.

Unable to establish a definite direction of flow. It appears to be nearly horizontal. The yarn seems to hang from the probe at times, then sweeps upward to an almost vertical position, and then drops to a horizontal position momentarily.

Elevation 24 in.

Flow is generally downward, with the yarn occasionally moving upward. Yarn still appears to be hanging from the probe at times. Approximate pitch angle 30° to 40° from vertical.

Elevation 30 in.

Flow is downward. Approximate pitch angle 30° to 40° from the vertical. There is a definite increase in velocity at this elevation. Yarn stability has improved and it does not appear to float.

Elevation 36 in.

Flow is downward. Approximate pitch angle 110° from the vertical.

Elevation -12 in.

Flow appears to be downward. Estimated pitch angle $\sim 40^{\circ}$ to 50° from the vertical. Very difficult to estimate pitch angle due to distortion. The yarn at times will move to a nearly horizontal position

PROBE LOCATION PV-19

Elevation -6 in.

Flow is downward. Estimated pitch angle $\sim 30^{\circ}$ to 40° from vertical.

Elevation 0

Flow appears to be generally downward. A very rough estimate of the pitch angle is $\sim 40^{\circ}$ to 50° from the vertical. The yarn is very unstable at this elevation, and will at times move to an upward position. Velocity appears to be low.

Elevation 6 in.

Flow appears to be upward with an approximate pitch angle of 60° from the vertical. The data, however, indicated that the flow is downward. The yarn is very unstable and is downward at times.

Elevation 12 in.

Flow is generally upward with an approximate pitch angle of 40° from the vertical. The yarn is very unstable and moves to a down position at times

Elevation 18 in.

Flow is generally upward. The yarn is very unstable, making it impossible to estimate the pitch angle. The velocity appears to be very low, as the yarn floats around very slowly with an occasional burst of movement. Data again do not agree with the visual observation of the yarn.

Elevation 24 in.

Flow is generally upward. The yarn is still very unstable, making it impossible to estimate the pitch angle. Velocity appears to be very low. After rotating the probe approximately 180° the data still appear to be good. The direction of the yarn, however, is now generally downward, indicating a downward flow. The yarn is still very unstable with frequent movements to an upward position. Probe response to yaw angle adjustments is very poor.

Elevation 30 in.

Stability of the yarn is much improved at this elevation. Flow is downward.

Estimated pitch angle 40° to 60° from the vertical. There appears to be an increase in velocity at this elevation.

Elevation 34 in.

Flow appears to be downward. Estimated pitch angle $\sim 60^{\circ}$ to 70° from the vertical.

Elevation 36 in.

Flow is downward. Estimated pitch angle $\sim 70^{\circ}$ from vertical.

Elevation 37.5 in.

Flow is downward. Estimated pitch angle $\sim 80^{\circ}$ from vertical.

Elevation 39 in

Flow appears to be downward. Estimated pitch angle $\sim 80^{\circ}$ to 90° from the vertical.

PROBE LOCATION PV-20

Elevation 0

Flow is downward. Approximate pitch angle 20° to 30° from vertical.

Elevation 6 in.

Flow is downward. Approximate pitch angle 20° to 30° from vertical.

Elevation 12 in.

Flow is downward. Approximate pitch angle 10° to 20° from vertical.

Elevation 18 in.

Flow is downward. Approximate pitch angle 10° to 20° from the vertical.

Elevation 24 in.

Flow is downward. Approximate pitch angle 10° to 20° from the vertical.

Elevation 30 in.

Flow is downward. Approximate pitch angle 10° to 20° from vertical.

Elevation 36 in.

Flow is downward. Approximate pitch angle 0° to 15° from vertical.

Elevation -12 in.

Flow appears to be downward. The yarn is somewhat unstable. Estimated pitch angle ~ 20° to 30° from vertical.

Elevation -6 in.

Flow is generally downward. Pitch angle ~ 30° to 40° from the vertical. The yarn at times, will move toward the horizontal and tend to wrap around the core restraint tube.

Elevation 0

Flow is downward. A very rough estimate of the pitch angle is ~ 20° to 30° from the vertical. Stability of the yarn is improving with increasing elevation of the probe.

Elevation 6 in.

Flow is downward. Estimated pitch angle ~ 30° to 40° from the vertical.

Elevation 12 in.

Flow is downward. Estimated pitch angle ~ 30° to 40° from the vertical.

Elevation 18 in.

Flow is downward. Estimated pitch angle ~ 30° from the vertical.

Elevation 24 in.

Flow is downward. Estimated pitch angle ~ 30° from the vertical. The flow tends to reverse the yarn in respect to the yaw angle. Will record data ~ 180° apart.

Elevation 30 in.

Flow is downward. Some difficulty in viewing the yarn at this elevation due to the obstructions. A very rough estimate of the pitch angle is ~ 20° to 30° from the vertical. Data will be recorded 180° apart.

Elevation 34 in.

Direction of flow is downward. A very rough estimate of the pitch angle is ~ 10° to 30° from vertical. Data will be recorded ~ 180° apart.

Elevation 36 in.

Unable to view the yarn at this elevation due to obstructions. Note different yaw angle and velocities at ~ 180°. The yaw angle of 81.6° was last data point recorded before shut down on 9-30-70. The second set of data recorded at 85.6° was the first set of data recorded 10-1-70 after startup. At 248° P_2 and P_3 drift $\pm 3/32$ in. from a balanced position.

Elevation 37.5 in.

Unable to view the yarn at this elevation due to obstructions. It appears that P_2 and P_3 balance at ~ 294°. The probe comes into contact with the restraint tube at ~ 290°.

Elevation 39 in.

Unable to see yarn at this elevation.

EXHIBIT B

EXPERIMENTAL TECHNIQUES

EXHIBIT B
EXPERIMENTAL TECHNIQUES
VELOCITY SENSORS

Sensor Selection

A study was made of the literature to learn what types of devices had been used by others to measure local velocities of water. The bulk of the published information concerns measurement of air velocities, but some work has been done on measuring local water velocities principally in research on ship hulls and propellers. Most of these investigators used 5-hole Pitot tubes which they built and calibrated themselves.

Other types of local velocity measuring devices investigated included the hot-wire anemometer and a laser device. The laser device could not be used because it required two clear lines of sight to each point at which the velocity was to be measured, and this was not available in our current vessel model. The hot-wire anemometer had certain features which would have made its use more desirable for some velocity-measuring requirements, e.g., response time, but which were of no benefit in this particular investigation. Moreover, the hot-wire anemometer device is more difficult to use, it requires a much greater learning time, and utilizes more expensive analysis equipment. In addition it exhibits other disadvantageous features when used to measure water velocities. Because of the shortness of time and limited funding availability, plus the lack of any advantage for this particular case, the decision was made to use the 5-hole Pitot tube.

A search for vendors of 5-hole Pitot tubes unearthed only one source. The price and availability were considerably better than could have been achieved in-house, so the velocity measuring devices were purchased.

These probes can measure velocity accurately through a vertical angle of 80° ($\pm 40^\circ$ from the axis of the center pressure-sensing hole). The expected velocities ranged from vertically up to vertically down--a range of 180° . Three different probes were purchased to cover the total expected range. A fourth probe of a different design was also purchased. Sketches of the tips of these four probes are shown in Figure B-1. An entire probe is shown in Figure B-2.

Figure B-1. Velocity Probe Configurations

Sensor Calibration

The probe obtained had been used only for measuring velocities of air and the vendor had no data on its use to measure velocities of water. However, the Reynolds numbers for the range of velocities being considered ranged from 1930 to 29,000 which indicated that the calibration curves supplied with the probes should be applicable to water flow as well as to the air flow from which they had been derived. A sample probe was purchased from the vendor and checked with the aid of a water-flow test assembly in the basement of 321 Building. The calibration curves were found to hold for water flow within the necessary accuracy.

These calibration curves are given in Figures B-3, B-4, B-5, B-6 and B-7.

Sample Calculations

Probes Nos. 1, 2, and 3 are similar. Probe No. 4 is of a different design and requires a slightly different method for calculation of the velocity and the pitch and yaw angles.

The range of applicability of the different probes is as follows:

- Probe No. 1 is effective for pitch angles between +30° and -30°.
- Probe No. 2 is effective for pitch angles between -30° and -90°.
- Probe No. 3 is effective for pitch angles between +30° and +90°.
- Probe No. 4 is effective for pitch angles between +30° and +90°.

In all cases the probe is rotated until the two indicated static pressures, P_2 and P_3 , balance. Balancing of these two pressures occurs when both pickup points are at equal angles to the direction of flow and the plane of the center-line of the probe is parallel with the direction of flow. The yaw angle is then read directly from the yaw-angle measuring device.

The indicated total pressure is the pressure P_1 , and P_2 is the indicated static pressure. $P_1 - P_2$ is the indicated velocity-head pressure. The true velocity-head pressure, $P_t - P_s$ (total pressure-static pressure), is a function of the probe and also of the angle of impact of the stream velocity. This true pressure is read off the calibration graph for the probe used.

Figure B-2. Velocity Measuring Probe

Figure B-3. Probe No. 1 Calibration

Figure B-4. Probe No. 2 Calibration

Figure B-5. Probe No. 3 Calibration

Figure B-6. Probe No. 4 Calibration For Pitch Angle Pressure Coefficient

Figure B-7. Probe No. 4 Calibration For Velocity Pressure and Total Pressure

The pitch angle is determined from measurement of the difference in the total pressure sensed at pickup points of pressures P_4 and P_5 . The relationship between this differential pressure and the indicated velocity-head pressure is an empirical one and is determined by testing the probe. Curves of the pitch angle plotted against the ratio $(P_4 - P_5)/(P_1 - P_2)$ were supplied by the manufacturer. (Figures B-3, B-4, B-5, B-6 and B-7)

A sample data point for probe No. 1 at location PV-1 at an elevation of 34 in. shows values of 0.937 in. of water for $P_1 - P_2$ and 0.344 in. of water for $P_4 - P_5$.

$$(P_4 - P_5)/(P_1 - P_2) = 0.344/0.937 = 0.367$$

From the calibration curves for this probe shown in Figure B-3, the pitch angle is $+23^\circ$, and $(P_t - P_s)/(P_1 - P_2) = 1.06$. The total pressure coefficient for this pitch angle is zero, so $P_{\text{total}} = P_1$.

The velocity-head pressure then equals $1.06 (P_1 - P_2) = 0.993$ in. of water.

$$\text{The velocity } v = \sqrt{2gh} = 8.02 \sqrt{0.993/12} = 2.31 \text{ ft/sec}$$

Another point, for probe No. 4, at location PV-3 and 18-in. elevation, shows values of 23.81 in. of water for $(P_1 - P_2)$ and 20.94 in. of water for $(P_4 - P_5)$.

$$(P_4 - P_5)/(P_1 - P_2) = 20.94/24.81 = 0.844$$

From Figure B-6 the pitch angle equals 28° . The axis of the probe is at an angle of 60° with the horizontal so the pitch angle of the flow equals $28+60 = 88^\circ$.

For the 28° pitch angle $(P_t - P_s)/(P_1 - P_2) = 0.94$ from Figure B-7

$$P_t - P_s = 0.94 \times 24.81 = 23.37 \text{ in. of water} = \text{velocity head}$$

$$v = \sqrt{2gh} = 8.02 \sqrt{23.37/12} = 11.2 \text{ ft/sec}$$

Test Equipment Setup

A new top was made for the outlet model, with holes at the 20 locations at which it was desired to measure the velocity. A sealed nozzle assembly was made to fit on the hole at the location at which the probe was to be inserted, to provide a leak-tight connection where the probe entered the vessel.

To permit access to the locations at which velocity measurements were desired, holes were drilled through the vortex suppression plate and the tube guide (instrument tree support plate).

A manual traverse unit was used to orient the velocity measuring probe. The traverse unit was equipped with a vertical scale and protractor. The probe was held in the traverse unit with the aid of a clamp. Locating equipment was attached to the head of the outlet model to permit rapid orientation of the probe at each location.

The probe is shown in place in Figure B-8 which also shows the location of the 20 different points of entry through the top cover of the model. Figure B-9 shows a closeup of the probe in place. These figures also show the height measuring standard and the protractor. The protractor zeroing device is shown in detail in Figure B-10.

The readouts of the 5-hole Pitot tube are pressures--static pressure plus velocity head at each of the sensing points. The pressures can be measured electrically by pressure transducers or they can be measured with the aid of manometers. The range of differential pressure over the range of velocities to be measured, 1-15 ft/second, was from 0.187 inches of water to 42.0 inches of water. The high pressure is 225 times the low pressure. Differential pressure transducers were found to cover the range with reasonable accuracy, but the cost of the transducers plus accompanying instrumentation was greater than could be justified so it was decided to use differential manometers.

The fluid in each of the pressure sensing lines was water, so an ordinary water U-tube manometer such as is used to measure air pressure could not be used. It was also necessary to bleed all air out of the lines before measurements could be taken at each new location. Because of these factors, plus cost and convenience of operation at the test facility, vertical-tube water manometers were selected, rather than U-tube mercury manometers. The mano-

meters were made of vertical transparent plastic tubes connected to a header at the top (Figures B-11 and B-12). The pressure-sensing lines were carefully flushed with water before measurements were taken. The pressure of the air in the header was then adjusted until the levels of water in the two tubes were in the readable range. Readings of the differential pressures were then made directly in inches of water.

To save time, an external, high-pressure supply of water was used to purge the air out of the pressure-sensing lines before each test.

Pressure measurement with a manometer entails a change of volume in the manometer tube and a corresponding flow of liquid from the higher pressure sensing point. With very small diameter capillary tubing the response time can be so slow as to make the measurement prohibitively expensive in both time and manpower. An extremely sluggish response also results in poor accuracy. The response time of the proposed Pitot tube system was analyzed and satisfactory system dimensions were determined.

A problem which arose was that of the low differential pressure reading of 0.187 inch resulting from a velocity of 1.0 ft/second. This is too small to be read accurately on an ordinary vertical water manometer with pressurized air back pressure. An effort was made to utilize inclined manometers to obtain greater accuracy, but this did not meet the desired success. An analysis of the overall velocity requirements indicated that local velocities less than 2.0 ft/second were not particularly important. A velocity of 2.0 ft/sec produces a velocity head of 0.745 inch which could be read with reasonable accuracy on the vertical manometer water tubes used. Readings of less than one-half inch water differential were ignored as the velocity at such locations was so low as to be unimportant.

Data Taking Procedure

To measure the velocity at a particular location, the probe was inserted, the vessel was sealed, and then the vessel was pressurized. The pressure-sensing lines were then flushed with water using a relatively high pressure supply of air-free water to remove all air in the pressure measuring system. The probe was adjusted to the desired height and rotated until the pressures sensed by the two holes equally spaced laterally from the center hole balanced.

Figure B-8. Top of Outlet Region Model

Figure B-9. Close-Up of Probe in Place

Figure B-10. Protractor Zeroing Device

Figure B-11. Air Back Pressure Manometer Schematic

Figure B-12. Vertical Tube Manometer

The probe was then located parallel to the local velocity and the yaw angle was noted on the protractor. The indicated velocity head was recorded as were also the pressures sensed at the two sensing points above and below the center hold. These latter two pressures indicated the pitch angle in reference to the axis of the probe.

The pressures at the two lateral sensing points would balance as long as the axis of the probe and the local flow streamline were in the same plane, so the probe was then rotated approximately 180° until the two pressures balanced again. A new set of readings was taken at this point. The two sets were compared and true direction of flow determined from the data.

Where the tip of the probe was visible through one of the observation ports in the outlet model, a piece of yarn attached to the tip of the probe indicated the direction of flow and only one set of measurements was necessary. At those locations where the probe could not be seen, two sets of measurements were made. Also, where review of the readings indicated that the pitch angle was outside of the range of accuracy of the probe being used, the pitch angle was estimated. The probe was then removed and the proper probe for that direction of flow was used to measure the velocity.

Flow Instability

Where flow instability occurred, it was readily noted by fluctuations in manometer readings or by fluctuating motions of the piece of yarn attached to the tip of the probe.

In many cases the yarn could be seen to flutter and change direction. This was especially true where the local velocity was low (under 2 ft/sec). In some cases (PV-19 at 18 inches and 24 inches) the yarn was seen to vary in direction from vertically up to horizontal in a short span of time. In other instances the yarn wrapped around the probe. In addition, there were cases where the direction of the yarn was different from that of the velocity measured at the sensing points of the probe, perhaps two inches away. These visual observations indicated fluctuating flow patterns and the presence of eddies in the vessel.

Data Aberration

Aberrations were noted in the core section data. The fluid enters

the outlet pool vertically with a high jet velocity at the bottom. This jet velocity was measured by the probe only when the sensing tip was in the jet. The tip of the probe used to measure vertical velocity was bent at an angle with its axis. Rotating the probe about its axis caused the tip to move laterally enough so that a few degrees of rotation could move the tip completely out of the jet. The other seeming aberration was that taking an assumed average vertical velocity in the core (locations PV-3, PV-5, and PV-7) and multiplying it by the open transverse area in the core gave an apparent volume of flow which exceeded the flow rate into the vessel.

The instrument support plate is located at 37 inches elevation. There is a tube guide at the top of the core section. It consists of three pieces of solid plate with holes drilled so that the tubes simulating the closed loops and the control rods can pass through. There are also holes for the probe at locations PV-3, PV-5, and PV-7. The rest of the area presents a barrier to the flow of the fluid which passes up through the core. The effect of the barrier and the local holes is evidenced by the sudden increase in velocity at the 37.5-inch elevation at PV-3, PV-5, and PV-7.

These sudden increases in velocity in themselves do not explain the apparent error in the mass balance mentioned above, but they do indicate that the measured local velocities cannot be assumed to be average velocities. The indications are that there is channelling up through the core, but the extent of the channelling could not be determined by measuring the local velocities at only three locations. It would be necessary to make a group of radial velocity traverses, and such was not possible with the existing test setup.

It was also observed that the velocity measured at a particular location varied when the position of the sensing tip was changed by rotating the probe 180° about its axis. The change in the sensed velocity was noted at almost all elevations for locations PV-3, PV-5, and PV-7. The variation ranged from 5 percent to as much as 30 percent at 30 inches elevation at PV-5. The apparent angles of flow also varied a small amount. This illustrates that there are definite variations in the fluid velocity in the core section and that no satisfactory "average" velocity can be determined from measurements at only three points at any one level.

EXHIBIT C

STUDY PLANNING NOTES

The notes in this Exhibit were reproduced directly from correspondence and study records.

Selection of an Instrument to Measure Local Velocities in the Outlet Model

Statement of Problem

Select a velocity measurement device to obtain localized water velocities in the Outlet Model.

Conclusions and Recommendations

Satisfactory measurements of the magnitude and direction of local velocities can be obtained with a five-hole pitot tube sensor.

By using a 1/4 diameter probe with 10' of 0.100" I.D. tubing in a 3/4" diameter probe extension, plus an estimated 20' of 1/8" I.D. plastic tubing connected to a 1/8 I.D. manometer tubes the time for stabilization of a reading should be on the order of one to two minutes.

It is recommended that a 3-dimensional probe be purchased and tested in our laboratory.

Discussion

It is necessary to measure the localized velocity of the water at various points in the Outlet Model vessel. The range of velocity of importance is from 1 ft/sec to 15 ft/sec. The required accuracy is $\pm 5\%$ or better. It is necessary to measure the direction of flow, i.e. pitch and yaw, as well as the speed. We are interested in the steady-state conditions so the response time of the measuring instrument is not important except as it affects the time to do the job. That is, the response time need not be measured in milliseconds or even seconds. A few minutes, two or three, would be fast enough.

A review of the literature and discussion of the problem with others who have had experience with similar problems, both in-house and outside, indicate that for our requirements, the best type of velocity measuring device is the pitot tube. Other methods which have been used are the hot-wire and hot-film and a hot-film velocity measuring device. There is also a local-velocity measuring device which utilizes crossed laser beams. This device was not considered since it would be impossible to obtain two clear lines of sight through the points at which the velocity is to be measured. The hot-wire and hot-film devices are relatively sophisticated and require computer analysis of the information picked up by the sensors. They are much more difficult to use and are probably considerably more expensive. They do not

appear to offer any advantage for our requirements, so they were not investigated in depth.

Pitot tube devices have been used successfully to measure the magnitude and direction of local velocities by many different investigators. The type of probe most frequently used is a spherical probe with five holes. One hole is placed in the front of the sphere to read total pressure (static pressure plus velocity head). The other four are placed behind the forward hole equidistant from it and displaced by 90° from each other. These four are used to measure the pitch and the yaw. Spherical probes have been used at a number of different test laboratories. As far as is known, all of these organizations made and calibrated their own probes. However, one source of commercially made five-hole Pitot tubes has been found.

Two types of probes are available, see probes nos. 3 and 4, Figure B-1. The wedge-shaped tip is less sensitive to minor changes in angle and is the type recommended for this application.

The wedge-type probe is available in different diameters from 1/8" to 3/8". A 1/8" diameter probe was tested in our laboratory and the response time required to obtain a single reading was on the order of one hour, using manometers for differential pressure measurement. Examination of the design showed that this slow response time was due to the size of the capillary tubes in the sensor head. By going to a 1/4" diameter probe and making other changes in the system, the response time can probably be reduced to approximately one minute. The analysis is attached. One minute response time should be adequate for our requirements. If it is desirable to reduce the response time further, to a few seconds or less, this can be done by using pressure transducers in place of the manometers.

The manufacturer supplies calibration curves with the probes, but these charts are made using air as the fluid. Calibrations are made at 0.2 and 0.4 Mach numbers. These correspond to Reynolds Numbers of 29,200 and 58,400. The velocities of interest in the Outlet Model will give Reynolds Numbers between 1930 and 29,000. The manufacturer could not supply any information regarding the use of its probes with water or at low Reynolds Numbers, so we will have to calibrate the probes with water for the range of velocities over which we plan to use them. Hopefully, the calibration will match the air calibration and we will then be able to use the calibration data supplied with the probes, and

we will need three different probes to ensure measurement of all possible directions of velocity. However, it has been reported ('Review of Pitot Tube', R. G. Folsom, Transactions of the ASME, October 1956) that changes in the pressure coefficient characteristics of pitot-static tubes may be expected at Reynolds Numbers below 2300.

Estimate of Response Time of 1/8-in. O.D. Pressure-Sensing Probe

The probe which was tested in our laboratory was a 1/8" O.D. probe, 12" long. The pressure transmitting capillaries are 0.020" I.D. The manometer tube is 1/4" I.D. To obtain a reading, it is necessary for water to flow through a capillary tube and raise the height of the fluid in the manometer to the point where the pressure on top of the manometer column plus the pressure head exerted by the column of fluid equals the pressure sensed by the probe.

The flow through the capillary will be laminar.

Assume water at 68°F $w = 62.4 \text{ lb/ft}^3$ $\rho = 1.94 \text{ slug/ft}^3$

$\mu = 1.0 \text{ centipoise} = 2.09 \times 10^{-5} \text{ lb sec/ft}^2$

The head loss through the tube will equal $f (L/D) (v^2/2g)$

Where $f = 64/Re = 64 \mu / (\rho D v)$

Then $h_L = 32 \mu L v / (\rho g D^2) = 128 \mu L Q / (\pi g \rho D^4)$

Where Q = flow rate through capillary

The relationship for velocity through the capillary - $v = \rho g h_L D^2 / (32 \mu L)$

The rate of flow into the manometer tube = $v \times A$ through the capillary tube or

$$\frac{dQ}{dt} = \frac{\rho g h_L D^2}{32 \mu L} \times \frac{\pi}{4} D^2 = \frac{\rho g h_L D^4 \pi}{128 \mu L}$$

The rate of flow into the manometer tube equals $A_M dh/dt$ where A_M - inside cross sectional area of the manometer tube and dh/dt = rate of change of height of fluid in the manometer tube h = height of fluid in the manometer tube above or below the balance point. This is also the difference in head between the measured pressure and the pressure in the manometer tube or it equals the head available to cause flow through the capillary. This head is decreasing so $dQ/dt = A_M dh/dt$

$$-A_M dh/dt = \frac{\pi \rho g h D^4}{128 \mu L}$$

$$\frac{dh}{h} = - \frac{\pi \rho g D^4}{128 \mu L A_M} dt$$

Integration gives $h = h_0 e^{-kt}$ where $k = \frac{\pi \rho g D^4}{128 \mu L A_M}$

For our case $\frac{\pi \rho g}{128 \mu} = \frac{\pi \times 1.94 \times 32.2}{128 \times 2.09 \times 10^{-5}} = 7.34 \times 10^4$

or $k = 7.34 \times 10^4 D^4 / (L A_M)$ where L = length of capillary tube in ft, D = I.D. of capillary tube in ft, and A_M = inside cross-sectional area of manometer tube in ft^2

For the 1/8" diameter probe, $D = 0.020" = 1.667 \times 10^{-3} \text{ ft}$
 $D^4 = 7.72 \times 10^{-12} \text{ ft}^4$

The manometer tube has a 1/4" I.D. so $A_M = 3.41 \times 10^{-4} \text{ ft}^2$ $L = 1 \text{ ft}$

For this case, $k = 7.34 \times 10^4 \times 7.72 \times 10^{-12} / (1 \times 3.41 \times 10^{-4}) = 0.00166$
 $h = h_0 e^{-0.00166t}$

To change the height of fluid in the manometer from 1 ft to 0.050", $h/h_0 = 0.050/1 = 0.050$
 $0.050 = e^{-0.00166t}$, $t = 3300 \text{ seconds or } 55.0 \text{ min}$

The response time can be reduced by three different methods: (1) increase the diameter of the capillary tube, (2) reduce the length of the capillary tube, and (3) reduce the inside area of the manometer tube.

By going to a 1/4" diameter probe, the I.D. of the capillary tube can be increased to 0.017" (0.065 O.D. x 0.009 wall). This gives $D = 3.92 \times 10^{-3} \text{ ft}$, $D^4 = 2.36 \times 10^{-10} \text{ ft}^4$

The manometer tube I.D. can be reduced to 1/8". This will increase the effect of capillarity in the manometer tube, but since we are measuring difference in heights in two manometer tubes, the differences will cancel each other.

1/8" I.D. gives $A_M = 8.52 \times 10^{-5} \text{ ft}^2$

Holding the length of the probe at 1.0 ft gives $k = 0.203$. For this system the time required to change the height in the manometer from 1 ft to 0.050" would equal

$0.00417 = e^{-0.203t}$ $t = 27.0 \text{ secs or } 0.450 \text{ min}$, which is easy to live with for this case.

The effect of the different parameters on response time can also be examined in a general way

$$h/h_0 = e^{-kt} \text{ so } \ln(h/h_0) = -kt$$

where $\ln$ = natural logarithm which will be negative since h/h_0 is less than one
 For a given manometer movement, the response time will be inversely proportional to k where $k = 7.34 \times 10^4 D^4 / (L A_M)$. So response time is

- o inversely proportional to the fourth power of the capillary tubes
- o proportional to the length of the capillary tube
- o proportional to the square of the I.D. of the manometer tube

For the two cases considered --

$$\frac{t_2}{t_1} = \left(\frac{0.020}{0.047} \right)^4 \left(\frac{1 \text{ ft}}{1 \text{ ft}} \right) \times \left(\frac{0.125}{0.250} \right)^2 = 0.0329 \times 1 \times 0.250 = 0.00823$$

or the response time for the 1.0 ft long, 1/4" diameter probe and 1/8 I.D. manometer tube will be only 0.00823 as long as for the 1.0 ft long, 1/8" diameter probe $55.0 \text{ min} \times 0.00823 = 0.452 \text{ min}$

The response time could also be reduced by using low displacement pressure transducers for measuring the differential pressures

Check the effect of the instrument lines on the response time. Assume 10 ft of tubing through the probe plus 20 ft of plastic tubing to the manometer

For laminar flow the response time will be proportional to L/D^4

For 3/4" O.D. tubing with 0.120 wall, I.D. = 0.510. To hold five pressure transmitting tubes, the largest tube diameter would equal 0.510/3 = 0.170 so could use 5/32 O.D. tubing x 0.028 wall with I.D. = 0.100. The capillary in the 1/4" diameter probe has 0.047 I.D. The relative times for stabilization of the level in the manometer tube for the two parts of the system would equal -

$$(D_1/D_2)^4 \times (L_2/L_1) = (0.047/0.100)^4 \times (10/1) = 10/20.3 = 0.493$$

For the instrument tubing assume an I.D. of 0.125". The relative time would equal $(0.047/0.125)^4 \times (20/1) = 20/50 = 0.400$

For the composite system

1 ft of 0.047 I.D. capillary + 10 ft of 0.100 I.D. tubing + 20 ft of 0.125" tubing

$$h_L = \frac{128 \mu (dQ/dt) L}{\pi g \rho D^4} \text{ for each part}$$

$$\text{for the composite system } h_L = \frac{128 \mu (dQ/dt)}{\pi g \rho} \left(\frac{L_1}{D_1^4} + \frac{L_2}{D_2^4} + \frac{L_3}{D_3^4} \right)$$

where dQ/dt = flow rate in ft^3/sec

$$L_1/D_1^4 = 1/(0.047/12)^4 = 4.24 \times 10^9$$

$$L_2/D_2^4 = 10/(0.100/12)^4 = 2.08 \times 10^9$$

$$L_3/D_3^4 = 20/(0.125/12)^4 = 1.71 \times 10^9$$

Compare flow rate through 1 ft long capillary tube and complete system for same head loss $128 \mu / (\pi g \rho) = \text{same for both cases}$

$$\left(\frac{dQ}{dt} \right)_{\text{capillary}} \frac{L_1}{D_1^4} = \left(\frac{dQ}{dt} \right)_{\text{system}} \left(\frac{L_1}{D_1^4} + \frac{L_2}{D_2^4} + \frac{L_3}{D_3^4} \right)$$

$$(dQ/dt)_{\text{capillary}} = 8.03/4.24 (dQ/dt)_{\text{system}} = 1.89 (dQ/dt)_{\text{system}}$$

so the addition of 10 ft of 0.100" I.D. tubing plus 20 ft of 0.125" I.D. tubing will almost double the response time. But this doubled time will still only be approximately one minute and so will be acceptable for the purpose of this experiment

II

Determination of Applicability of Air-Calibration Curves to Water Flow

A 5-hole Pitot tube of the type to be used to measure the local velocities in the outlet model was tested in the HEDL hydraulic laboratory in the basement of the 321 Building. The Pitot tube was tested to determine how well the calibration curve supplied with it applies to the measurement of water flow. The vendor uses their sensors only with air and only has use and calibration information for air flow.

In the test setup, water was caused to flow through a test section formed of a Lucite cylinder. The sensing head of the velocity-measuring probe was placed at the center of the section, the shaft of the probe extended through the side of the test section through a special swivel joint. From the flow rate, the average fluid velocity through the test section was then determined with the aid of the relationship--

$v_{\text{max}} = v_{\text{ave}} (1.43 \sqrt{f} + 1)$ where f equals the friction factor which is a function of Reynolds Number, Re , and the relative roughness of the pipe $Re = \rho D v / \mu$, a function of fluid density, velocity, viscosity, and pipe diameter. This relationship was developed by Prandtl, Nikuradse, and von Karman. The constant (1.43) in the equation was changed from the theoretical value of 1.32 as the result of test data.

The pitch angles of the probe test positions were measured with a protractor.

The results of the test showed that the calibration curves supplied with the Pitot tube were applicable for the measurement of water velocities. A copy of the reduced data is attached.

From the results of the laboratory tests with the 5-hole Pitot tube it was estimated that a test at one angle and flow velocity can be completed in one hour. This includes setting the probe, adjusting it, adjusting the flow, and making all necessary readings after stabilization of the system.

A tentative test procedure for measuring the local velocity at a selected point in the Outlet Model is as follows:

- 1 Shut off water pump
- 2 Release air from Outlet Model vessel. The top of the Outlet Model is approximately three feet above the top of the water reservoir tank, so there will not be any problem from water rising in the Outlet Model when the air pressure is released.
- 3 Remove blind flange from top of vessel above location which velocity is to be measured
- 4 Tilt probe at angle and insert end into hole
- 5 Carefully push probe into vessel on a slant until the probe can be held vertical
- 6 Push flange along probe to vessel top and bolt into place
- 7 Locate end of probe at level at which velocity is to be measured.
- 8 Tighten seal by hand
- 9 Locate and attach manual traverse unit and orient probe.
- 10 Pressurize vessel.
- 11 Start water flow and let flow stabilize
- 12 Open pressure to high-pressure differential manometers
- 13 Rotate probe to determine yaw angle and read angle
- 14 Read differential pressures on manometers If any differential pressure is less than 2.0 inches of water, use the inclined manometers
- 15 Read and record pressures and angle.
- 16 Shut off inclined (low-range) manometers, if used.
- 17 Loosen knurled nut and raise probe six inches with the aid of the manual traverse unit.
- 18 Repeat steps 13, 14, 15, 16, 17 until the desired number of velocity measurements has been made

It is estimated that a series of velocity measurements at one cover location, a single vertical traverse, will take about half a day, including air pressure release, insertion of probe, re-pressurization stabilization of flow, determination of yaw angle, measurement of required pressures, recording of data, and location of probe.

The proposed procedure is preliminary and is subject to modification as the result of experience gained during testing.

TEST DATA

Calculations based on A.S.M.E. Flowmeter Computation Handbook

Pipe I.D. = 6.42 in.

Orifice diameter = 4.030 in.

$$\beta = \frac{d}{D} = \frac{4.030}{6.42} = 0.628$$

From A.S.M.E. flange taps 6-in. pipe $\beta = 0.628$ $I = 93.391$

$D =$ I.D, Inches

$h_w =$ Manometer diff
in. of water

$\gamma_f =$ spec. wt. of flowing
fluid lb/ft³

$q_f =$ ft³/hr

$w_h =$ lb/hr

$F_R =$ Reynolds Number factor - see p. 125 (graph) flange taps 6-in. pipe.

$F_a =$ Area factor from graph P. 141 (thermal expansion factor) $F_a = 1.000$
(very nearly)

Assume water at 70°F, in air, specific weight, $w = \gamma_f = 62.236$ lb/ft³ p. 97

pipe $R_e = \frac{\rho D v}{\mu} = \frac{w D v}{g \mu}$ $g \mu = 6.5 \times 10^{-4}$ lb/ft. sec. p. 98

$$R_e = \frac{62.23 \times 0.535 \times v}{6.5 \times 10^{-4}} = 5.12 \times 10^4 \times v$$

$$v = \frac{\text{gpm}}{60 \times 7.48} \times \frac{1}{A} \quad A = 0.785 \times 0.535^2 = 0.225 \text{ ft}^2$$

$$v = \text{gpm}/101 = 0.00990 \times \text{gpm}$$

$$R_e = 507 \times \text{gpm}$$

Test Section

Max. Velocity vs. Average Velocity

Lucite tube 5-7/16 I.D. 5.438 in. I.D. D = 0.452 in.
 $A_{ID} = 23.2 \text{ in.}^2 = 0.1612 \text{ ft.}^2$

$$R_e = \frac{\rho D v}{\mu} = \frac{1.94 \times 0.452}{2.09 \times 10^{-5}} \times \frac{\text{gpm}}{60 \times 7.48 \times 0.1615} = 579 \times \text{gpm}$$

Assume smooth pipe

Maximum velocity (at center of pipe) = $(1.43 \sqrt{f} + 1) \times \text{ave. vel.}$

$$\text{ave. Vel} = \frac{\text{gpm}}{60 \times 7.48 \times 0.1615} = 0.0138 \times \text{gpm}$$

Diff. in. H ₂ O	Q gpm	R _e x 10 ⁻⁵	f	1.43√f	v _{max} /v _{ave}	v _{ave} ft/sec	v _{max} ft/sec	v _{max} v _{ave}
143	725	4.20	0.0136	0.167	1.167	10.00	11.67	1.167
119	650	3.76	0.0139	0.169	1.169	8.96	10.47	1.168
70	500	2.89	0.0146	0.173	1.173	6.90	8.10	1.174
24	300	1.74	0.0161	0.181	1.181	4.14	4.89	1.182
10.9	200	1.16	0.0174	0.189	1.189	2.76	3.28	1.190
2.7	100	0.58	0.0199	0.202	1.202	1.38	1.66	1.204
0.8	50	0.29	0.0233	0.218	1.218	0.69	0.840	1.218

Manometer ΔP in. H ₂ O	gpm from Calibration Curve	R _e	F _R *	Calc. Flow gpm
		Based on flow as read from calibration curve		
2	86	43,600	1.008	86.6
4	122	61,800	1.007	122.5
6	149	75,500	1.006	150.0
10	191	96,800	1.004	193
14	226	114,500	1.0035	228
20	270	137,000	1.003	273
40	388	196,500	1.002	385
60	468	237,000	1.002	472
80	534	271,000	1.001	544
100	597	303,000	1.001	608
120	654	332,000	1.001	667
140	709	359,000	1.0005	722
160				

*F_R from curve pl30 A.S.M.E. Flowmeter Handbook

6" pipe, flange taps β = 0.628

$$q_f = \text{ft}^3/\text{hr} \quad \text{gpm} = \frac{q_f \times 7.48}{60} = \frac{q_f}{8.02}$$

$$q_f = F_R \times 6.42^2 \times 93.391 \sqrt{h_w/62.24} = 488 \times F_R \sqrt{h_w}$$

$$\text{gpm} = 60.8 \times F_R \sqrt{h_w} = \text{calculated flow rate}$$

III

Localized Velocity Measurements for the Outlet Model

The prime purpose of measuring the magnitude and direction of the velocity of the liquid at various locations in the Outlet Model is to determine the characteristics of the vibration forcing function produced by the liquid. The resulting vibration forcing function is due primarily to the cyclic phenomenon of vortex shedding. The vortex shedding frequency due to flow past a right circular cylinder is represented by a relationship called the Strouhal Number, $S = ND/v$, where: N = frequency of vortex formation, Hz; D = diameter of cylinder, ft.; and v = fluid velocity, ft/sec. It has been found that for Reynolds Numbers between 100 and 200,000, the Strouhal Number is relatively constant at 0.20. However, it has also been found that for bundles of tubes, depending upon the geometry of the grouping, the Strouhal Number may vary from 0.10 to as high as 0.80. In addition, it has been learned that if a member has been caused to vibrate for any reason, that vibration will continue under the influence of the forcing function produced by vortex formation over a Strouhal Number which may span almost the same 0.10 to 0.80 range.

It has been determined that the range of natural frequencies of components in the vessel may go as low as 20 Hz.

The principal components subject to vibration, or which could transmit vibration forces to other members, are the core and reflector tubes. In the Outlet Model, these tubes are 1.375 in. in diameter.

Combining these factors, taking the low end of the vibration spectrum, gives $S = 0.1146 \times 20/v$ or $v = 2.29/S$. The low end of the velocity range of particular interest would then range from $v = 2.29/0.10 = 22.9$ ft/sec. to $v = 2.29/0.80 = 2.86$ ft/sec.. The forcing vibration frequency for static members would occur at $v = 2.29/0.20 = 11.45$ ft/sec. It would appear from this that velocities below 2.0 ft/sec. would be of little interest.

The local velocities are being measured with a 5-hole Pitot tube. The differential pressures are measured by means of vertical-tube water manometers. The gas pressure on top of the liquid in the Outlet Model is maintained at 5 to 6 psi. This corresponds to 11.5 ft. to 13.85 ft. of water. It is thus not feasible to use open-topped manometer tubes, so air pressure is applied to the tops of the manometer tubes to maintain the levels within the readable range on the manometer board. Due to the long lengths of connecting tubing, entrained air, and other factors, it is extremely difficult to measure differential heads smaller than 1/2 in. of water. Also, the accuracy is not good at the low differentials.

The relationship between velocity and velocity head at the low velocities is as follows.

v, ft/sec.	1	2	3	4
Δh , in. of water	0.186	0.744	1.675	2.97

For the reasons given above, it is therefore proposed that localized velocities be measured down to a lower limit of 2 ft/sec.

At $v = 2$ ft/sec.

$$R_e = 1.94 \text{ slugs/sec.} \times 0.1146 \text{ ft.} \times 2 \text{ ft/sec.} / (2.09 \times 10^{-5} \text{ lb/sec./ft}^2)$$

$R_e = 21,300$ which is well within the range of applicability of the Strouhal Number used.

DISTRIBUTION OFFSITE

Copies

15 AEC RDT/HQ
 Director, RDT
 Asst. Dir for Nuclear Safety
 Asst. Dir for Plant Engr., RDT
 Asst. Dir for Project Mgmt, RDT
 FFTF Project Manager, RDT:PM (3)
 Asst. Dir for Reactor Engrg, RDT
 Control Mechanisms Br, RDT:RE
 Core Design Br, RDT:RE (2)
 Reactor Vessels Br, RDT:RE
 Asst. Dir for Engrg Standards: RDT
 LMFBR Project Manager, RDT:PM
 Fast Reactor Safety Br, RDT:NS

17 AEC Advisory Comm. Reactor Safeguards

2 AEC Tech Info Center

1 AEC Idaho Operations Office
 Director Nuclear Technology Div.

3 Argonne National Laboratory
 LMFBR Program Office
 EBR-II Operations (ANL-CO)
 Irradiation Coordinator (ANL-ID)

1 Aerojet Nuc. Co.
 Idaho

1 Allied Chemical Corp.
 J. A. Buckham - Idaho

3 Atomics International
 Westinghouse Hanford Co., Resident Mgr.
 FFTF Program Office
 FBR Project Manager

1 Atomic Power Development Assoc.
 Document Librarian

1 Babcock & Wilcox Co.
 Atomic Energy Division
 S. H. Esleeck

Copies

2 Bechtel Corp.
 Westinghouse Hanford Co., Resident Mgr.
 Project Admin., FFTF

2 Combustion Engineering
 1000 MWe Study Manager
 Librarian

3 General Electric Co.
 Advanced Products Operation
 L. F. Fidrych
 Nucleonics Laboratory Mgr.

2 Gulf General Atomic
 General Atomic Division Proj. Dept.
 GCFR Program

1 Liquid Metal Engineering Center
 Director

2 Liquid Metal Information Center
 Director

2 Oak Ridge National Laboratory
 W. O. Harms
 P. Partiarca

1 United Nuclear Corporation
 Research and Engrg Center Library

23 Westinghouse Electric Corp.
 J. J. Taylor, General Manager
 Breeder Reactor Divisions
 Advanced Reactor Division (14)
 Westinghouse Hanford Co., Prog. Mgr.
 Manager, FFTF Eng.
 Manager, LMFBR
 E. A. DeZubay (2)
 F. H. Grochowski
 E. H. Novendstern
 P. J. Wood

DISTRIBUTION ONSITE HANFORD

Copies

3	<u>AEC Richland Operations Office</u> T. A. Nemzek J. M. Shivley R. M. Poteat
3	<u>Battelle-Northwest</u> Technical Library
1	<u>Bechtel Corporation</u> W. A. Smith (Richland)
2	<u>RDT Site Representatives</u> F. R. Standerfer
2	<u>Vitro-Hanford Engineering Services</u> J. M. Frame
30	<u>Westinghouse Hanford Company</u> D. L. Ballard (3) H. T. Knight F. J. Leitz J. Muraoka H. Leigh G. J. Rogers J. E. Werle J. F. Wett J. M. Yatabe L. R. Sweetin Jan Spalek D. C. Frick L. M. Polentz (3) F. H. Nunamaker W. C. Kinse1 D. Gray B. H. Noordhoff T. W. Withers Technical Publications (3) Document Control (5)