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LDA Experiments – Flow Characterization of the NRC-IOT Cavitation and Water Re-circulating Tunnel

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Introduction

Flow characterization experiments were conducted at the NRC-IOT cavitation and water re-circulating tunnel http://iot-ito.nrc-cnrc.gc.ca/. These experiments were a part of a task for the 25th ITTC Uncertainty Analysis Committee (http://ittc.sname.org/). Flow characteristics of the test section were measured with a two-component Dantec LDA (Laser Doppler Anemometer) system. The fibre-optic head of the LDA was mounted on a 3-dimensional traversing system. The long term temporal velocity stability at various tunnel velocities was measured at the centerline of the test section over a time period of about 100 to 120 minutes. The spatial variation across the test section (velocity uniformity) was also measured via LDA profile sweeps. All 3-velocity components were measured using the LDA head looking from the bottom and from the side windows of the test section. From the bottom window of the test section, the axial and transverse velocity components (x and y velocities) were measured. From the side window, however, the axial and vertical velocity components were measured (x and z velocities). Together, LDA measurements from the bottom and the side windows provide a 3-D volumetric water velocity profile in the test section.

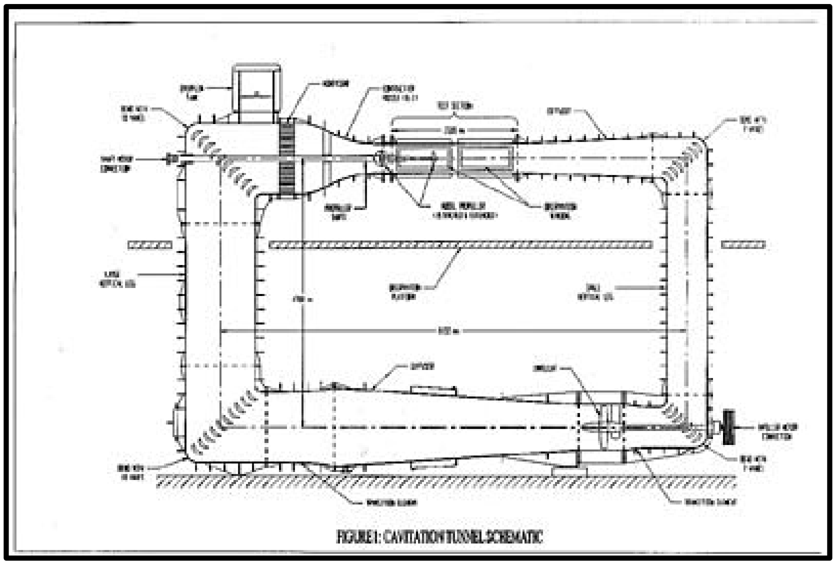


Figure 1: Design Sketch for the NRC-IOT Cavitation Tank

The experiments were conducted at the center of the forward window in the test section. Tests for two different water nominal speeds were completed (1.6 m/s & 6.0 m/s, in the test section). These speeds are typical of low and medium tunnel testing speeds. It is aimed that high water speed experiments (> 9 m/s) are to be conducted in future dates.

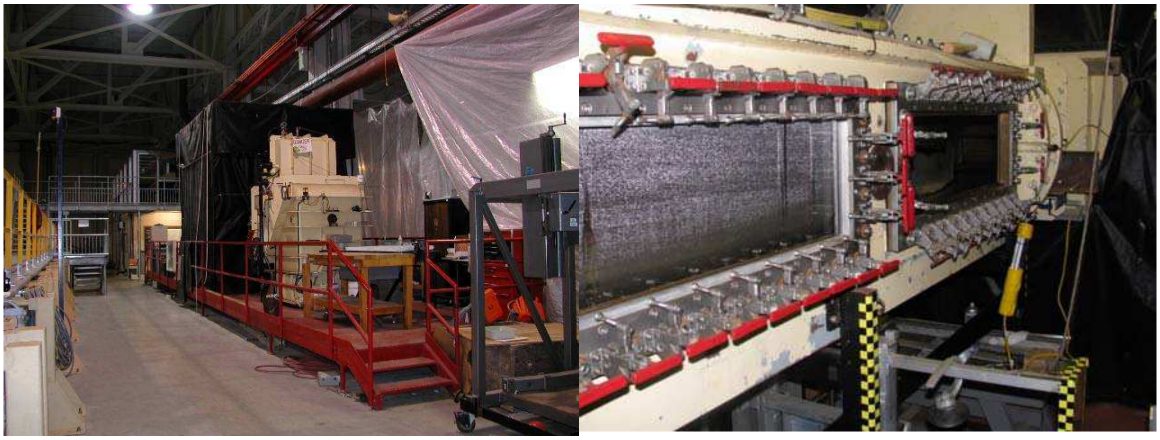
All experiments at the center of the test window were repeated at distances of ± 250 mm ("aft" and "fwd" tests).

In this paper, the results of this experimental work are reported. Velocity Temporal Stability (VTS) and Velocity Spatial Uniformity (VSU) results are provided. A comparison between the present NRC-IOT test results and those from much larger cavitation tunnels (in Japan and the US) is provided.

NRC-IOT Cavitation and Water Circulating Tunnel - Descriptions and History

In 1956, The National Research Council of Canada acquired a cavitation tunnel from Kempf and Remmers, a German manufacturer. Its engineering design work goes back to 1955, and various documents indicate that actual commissioning tests were performed at the NRC Ottawa in 1956 and 1957.

In 1984, the tunnel was dismantled and moved from Ottawa to NRC-IOT (in St. John's, NL). Since then, the tunnel underwent through several major upgrades. This included the control system, the Data Acquisition System (DAS), the 6-component dynamometer, the opens-boat apparatus, and the Dantec LDA components and software.



a) General View

b) Test Section

Figure 2: The NRC-IOT Cavitation Tank

Laneville et al (2005) presented a detailed history of the NRC-IOT K-09 Cavitation and Water Tunnel. They reported that in 1956 and 1957, Kempf and Remmers supplied 4 identical water tunnels to various clients (test section 500 mm X 500 mm and maximum water speed of 11 m/s). They are:

i)	K-08	for Vosper Ltd., Portsmouth, England
ii)	K-09	for NRC, Ottawa, Canada
iii)	K-10	for Ship-Model Research Institute, Zagreb (former Yugoslavia)
iv)	K-12	for Statens Skepps oprovning sanstalt, Goteborg, Sweden.
v)		

The tunnel is designed for maximum flow velocity (in the 500 mm X 500 mm test section) of 11 m/s, although historically experimental work at the NRC-IOT is limited to a maximum of 9 m/s). A sketch for the K09 engineering design is given in Fig. 1, and pictures of the tunnel (as it stands at NRC-IOT now) are given in Fig. 2. The tunnel is made up of 5 mm thick steel sheets assembled by welding; it is divided into 14 sections. The inlet and outlet of each section are identified by numbers, the inlet of the impeller section is given number 1. Doucet (1999) conducted a feasibility study for building a larger water tunnel at the NRC-IOT.

a) LDA Head & Traversing System b) Dantec LDA Laser & Processor.

Figure 3: The NRC-IOT Dantec LDA system

Flow Characterization Experiments

The present test program required running tests using empty tunnel condition (no model in the test section) at various water velocities. The long-term temporal velocity and stability at various tunnel velocities were measured at the centerline of the test section over a time period of about 100 to 120 minutes. The spatial variation across the test section "or velocity uniformity" was also measured and analyzed

The two LDA head positions considered are: 1) the LDA head is installed under the bottom window of the test section, and it is pointing upwards (Z direction), and 2) the LDA head is installed on the outside of the side window of the test section, and it is pointing across the test section (Y direction).

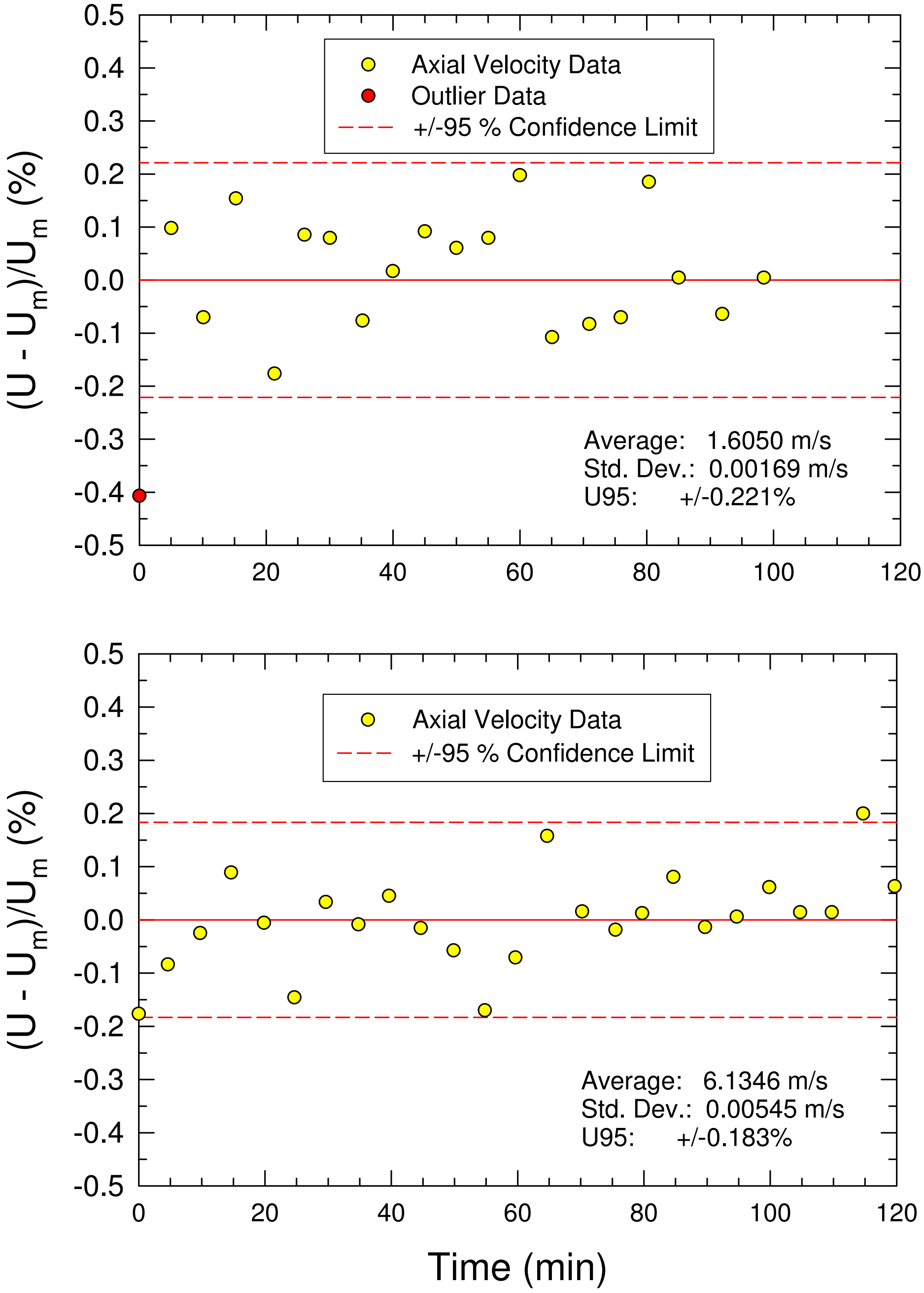


Figure 4. Temporal Stability of Test Section Axial Velocity

Flow velocities in the test section of the tank were measured with a two-component Dantec LDA system (Fig 3). In the case where the LDA head was mounted under the bottom window, both axial and lateral (X and Y) velocities of the water were measured. In the case where the LDA head was mounted laterally, both axial and vertical (X and Z) velocities of the water were measured. Consequently, by combining the results of experiments from the bottom window with those from the side window, 3-D velocity measurements are obtained.

Since the head of the LDA can be mounted on a traversing system (meaning the LDA head can move back and forth, Fig. 3), experiments that target area velocity contours (velocities for X-Y contours, and/or velocities for X-Z contours) can be conducted.

By combining the results of velocity contour experiments from the bottom window with those from the side window, complete 3-D velocity volumetric iso-profiles can be obtained (although now-days, 3-D LDA systems are commercially available)

The analysis of the results from the centerline tests will provide information regarding long-term temporal velocity stability at various tunnel velocities. However, the profile test results will provide information regarding the spatial variation across the test section "or velocity uniformity".

Tests Matrix and Testing Objectives

Two different velocities were completed (1.5 m/s and 6.0 m/s). Tests for 9 m/s are planned for future phases of the project. It is hypothesized that water velocities of 1.5 m/s and 6.0 m/s are representative for low and medium water speed tests, respectively. Velocity of 9 m/s is considered high-speed water tests.

Table 1: Test Matrix

Centre Line Experiments		Section Profiles	
Bottom-up	Side In	Bottom-up	Side In
1.50 m/s	1.50 m/s	1.50 m/s	1.50 m/s
6.0 m/s	6.0 m/s	6.0 m/s	6.0 m/s

The test program (Table 1) required measurements of flow velocities for 1000 to 2000 data point (target sampling rate was 100 to 200 Hz.), wait for 5 minutes, and then collect another 1000 to 2000 data points. This processes is repeated for at least 20 times. Note that it takes several seconds to collect the required 1000 to 2000 data points (thus averaged and mean flow values are realistic). For example, the total time needed for a centreline test is 20 times 5 minutes (almost 2 hours per test).

The time histories for each test segment (1000 to 2000 data points) were recorded; their mean value and standard deviation were obtained. Thus, the overall final output from a test is 20 mean data points and their corresponding 20 standard deviations (each spaced about 5 minutes apart). Figures 4 shows typical results from the 20 mean data points.

For the profile experiments (LDA sweeps), the LDA head was programmed to move on the traversing system (Fig. 3). Tests on a grid of about 300 points were conducted, and for each point of the grid, 1000 to 2000 measurements were collected. If the LDA head changed position every 5 minutes, one sweep tests lasts about 5 hours.

Test Results and Discussion

`Temporal Velocity Stability

The results for set points of 1.5 and 6.0 m/s are presented in Fig 4 for measurements through the floor of the test section. As the figure indicates, the data are randomly scattered about the mean value over the total time interval of the measurement. For the velocity at the set point of 1.5 m/s, the measured velocity was 1.6050 ±0.0035 m/s (±0.22 %) at the 95 % confidence limit, while for the 6.0 m/s set point the velocity was 6.1346 ±0.0054 m/s (±0.18 %).

In both cases, the measured velocity was 0.1 m/s higher than the set point. The source of the difference is probably lack of calibration of the pressure transducer for the dynamic pressure measurement (or an error in the control algorithm).

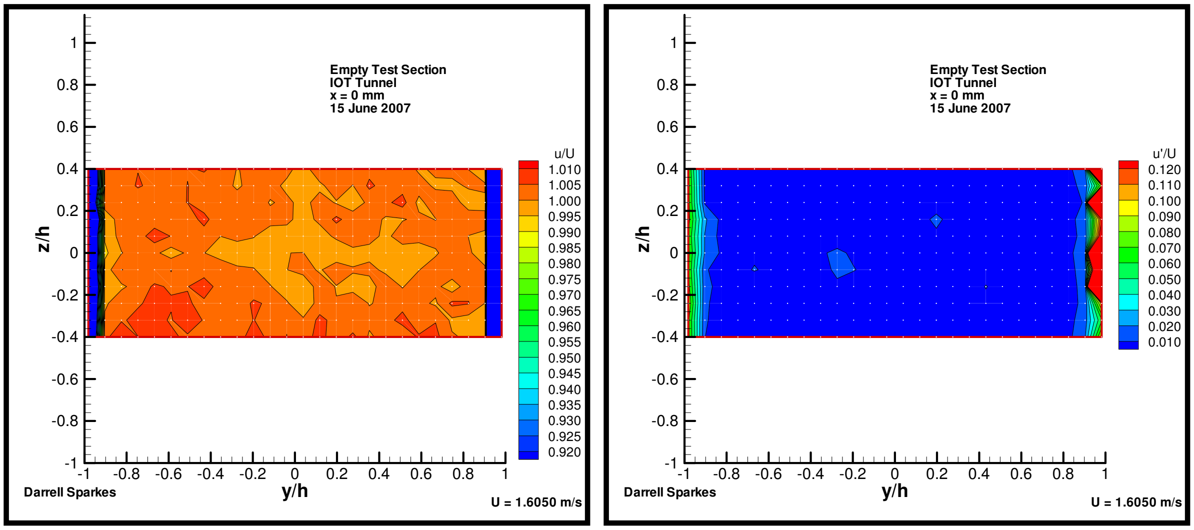
Velocity Spatial Uniformity

Velocity profiles were measured at 3 locations in the test section with 250 mm between each profile. At each station, the profiles were measured through a side window and bottom window. With this combination of measurements, all 3-velocity components were measured: U (axial), V (transverse), and W (vertical). The measurement area was 200 x 485.3 mm or 38.8 % of the tunnel cross-sectional area. The grid size was 20 x 19.4 mm with the 19.4 mm dimension along the probe axis. Velocity was measured at a total of 288 points. The velocity at each point was computed from a time series of approximately 1000 points. The results of the measurements are summarized in Table 2.

The results in Table 1 are for measurements outside the boundary layer. Table 2a gives a summary for the axial velocity component and it includes the number of spatial data points used in the statistics (N). From the last column of the table, the range of values for the test section velocity uniformity is between 0.41 and 0.84 % at the 95 % confidence level.

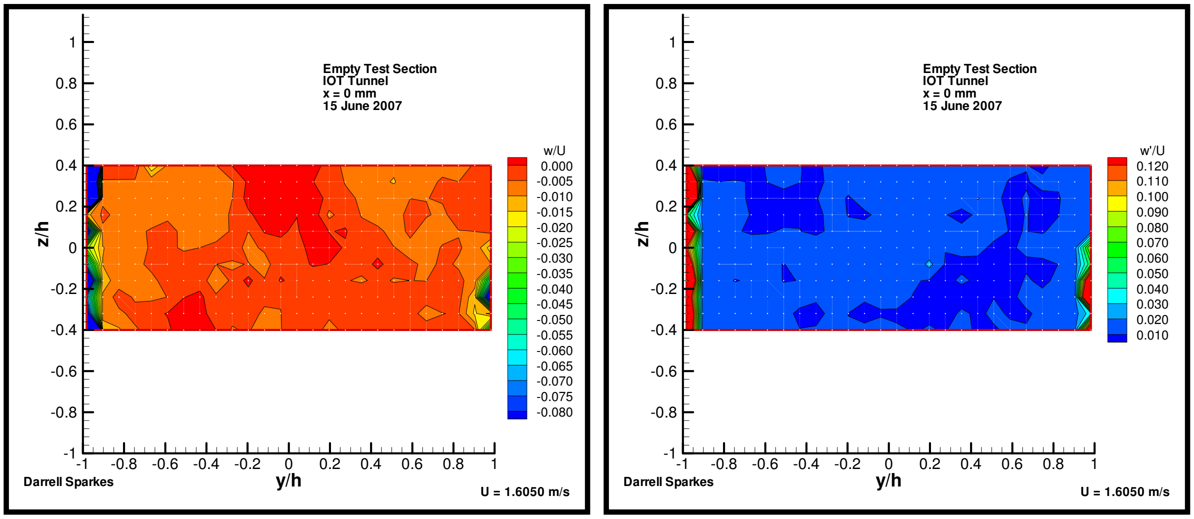
Similar data are included in Table 2b for the velocity components normal to the axial velocity. The results for the relative turbulence intensities, v'/Uo and w'/Uo, are similar to those for the axial component. The spatial variation in velocity for the vertical component is similar to the axial, where the range of values is 0.65 to 1.1 %. For some reason, the values for the traverse component, V/Uo, are high with a range of 0.84 to 9.5 %. Values above 2 % are likely an instrument noise problem related to location of the probe. A beam blocker may be required for beams reflected back into the probe.

Table 2 contains the average relative turbulence intensity (u'/Uo) outside the boundary layer. Typically, this value is 1 % or less. This value is a measure of the noise level of the LDA (and not the test section turbulence). For a good water tunnel, the relative turbulence intensity is about 0.1 to 0.2 %.



a) Axial Velocity Profile

b) Axial Relative Turbulence Intensity



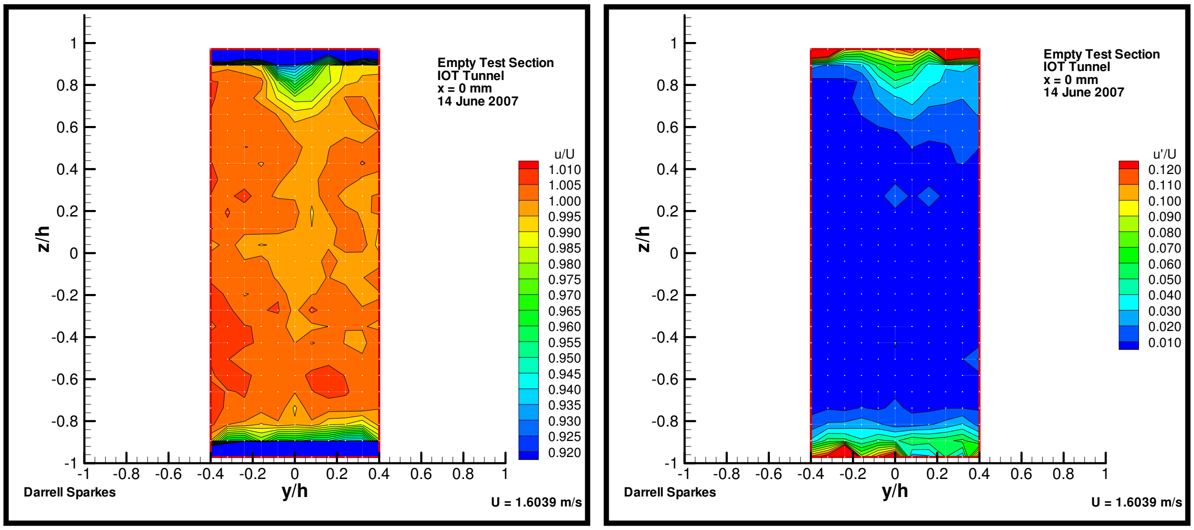
c) Vertical Velocity Profile

d) Vertical Relative Turbulence Intensity

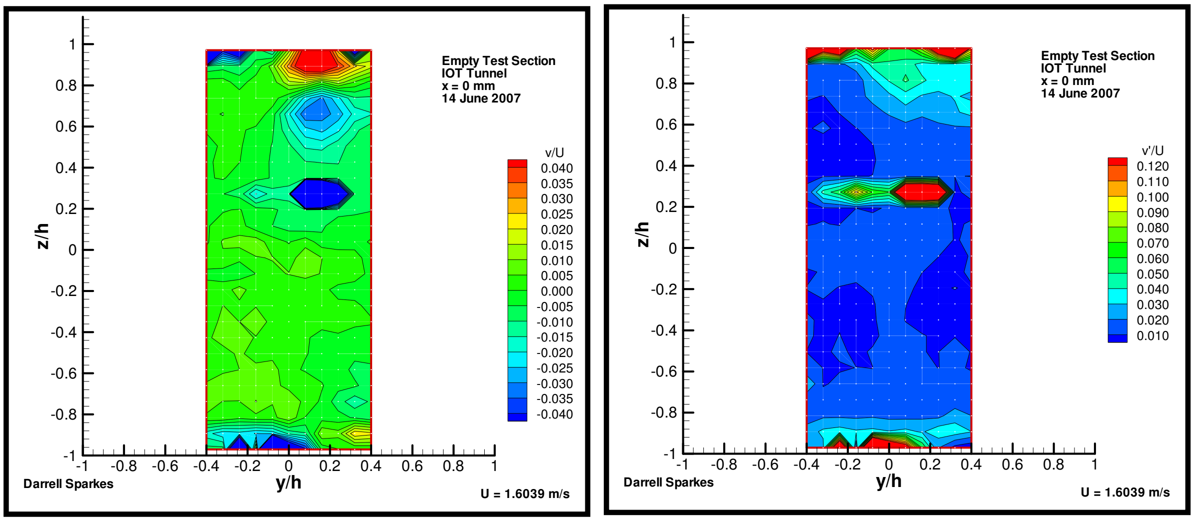
Figure 5. Velocity Profiles at 1.5 m/s from Side Window

Contour plots for one test condition at the center profile for a tunnel set point of 1.5 m/s are shown in Figs. 5 and 6 (for vertical and lateral LDA head positions, respectively). The location of the wall boundary is quite evident in these plots, particularly for the relative turbulence intensity. The values are highest near the wall. The velocity gradient is also evident for the axial profiles.

Figure 6 has the axial and vertical velocity contour plots for the measurements through the side window. The variation in the colors outside the boundary layer is an indication of the velocity uniformity. These results are similar to those previously described by Mori et al (2007) and Park et al. (2005).



a) Axial Velocity Profile b) Axial Relative Turbulence Intensity



c) Transverse Velocity Profile d) Transverse Relative Turbulence Intensity

Figure 6 Velocity Profiles at 1.5 m/s from Bottom Window

For this particular case (in Fig 6), the results from the bottom window for the axial and transverse velocities, U and V, in are quite different. In particular, the boundary layer at the top of the test section in the figure has a noticeable bulge. This bulge is caused by a vortex that is indicated in Figs 6c and 6d. This phenomenon also appears in the 6.0 m/s data, which were acquired at the same time. This feature disappeared in subsequent tests (2 months after the first set of tests was completed).

Another anomaly that is apparent in the transverse velocity only appears in Fig 5c and 5d at slightly above the centerline. At y/h = 0.27, three (3) points have a value of over 20 % for the relative turbulence intensity when the neighbouring points have values near 1 %. Clearly, these high values are not associated with the flow and are noise in the LDA system apparently due to reflections from the window.

Table 2a: Spatial Uniformity of Axial Velocity, U

Date	Probe	x	N	Uo	U/Uo	u'/Uo	Std Dev	U95
	Orientation	(mm)		(m/s)			(m/s)	(%)
6/15/2007	Horizontal	0	264	1.6051	1.0018	0.00777	0.00474	0.591
7/07/2007	Horizontal	250	253	1.6134	0.9993	0.00789	0.00519	0.643
7/03/2007	Horizontal	-250	264	1.6030	1.0001	0.00789	0.00649	0.810
7/10/2007	Horizontal	-250	264	1.5988	1.0008	0.00746	0.00507	0.634
6/14/2007	Vertical	0	218	1.6039	1.0013	0.00876	0.00610	0.761
9/26/2007	Vertical	250	220	1.6232	1.0021	0.00683	0.00442	0.544
9/26/2007	Vertical	-250	242	1.6134	0.9992	0.00740	0.00594	0.736
6/15/2007	Horizontal	0	264	6.1355	0.9996	0.00831	0.01247	0.406
7/09/2007	Horizontal	250	253	6.1534	0.9987	0.00815	0.01525	0.496
7/03/2007	Horizontal	-250	264	6.1177	0.9990	0.00840	0.02265	0.740
7/10/2007	Horizontal	-250	264	6.1135	1.0001	0.00759	0.02077	0.679
6/13/2007	Vertical	0	242	6.1422	0.9971	0.00939	0.02494	0.812
9/26/2007	Vertical	250	242	6.1331	1.0033	0.00776	0.02578	0.841

Conclusions

These results demonstrate that the IOT tunnel has relatively high quality flow characteristics similar to other water tunnels, such as the LCC (Large Cavitation Channel in the US). The long-term velocity stability of the tunnel is between ±0.18 and ±0.22 % at the 95 % confidence level for velocities of 1.6 and 6.1 m/s for duration of 100 to 120 minutes in comparison to ±0.15 % from Park, et al (2005). The long-term stability is sufficiently low that it has minimal influence on the measurement of the spatial variation of the velocity.

The spatial variation of axial velocity is between ±0.41 and ±084 % in comparison to ±0.34 to ±0.6 % from Park, et al. (2005). Mori, al. (2007) have reported a variation of ±1 %. For the vertical velocity, the non-uniformity in the IOT tunnel is between ±0.65 and ±1.1 % in comparison ±1.8 to ±2.3 % from Park, et al. (2005). The high variability in the transverse component for the IOT tunnel appears to be an LDA noise problem.

Some of the spatial variation in velocity from Mori, et al. (2007) seems to be caused by imperfections in the windows. The spatial variation was different when measured from each side of the tunnel. Such a possibility may exist in the work of Park, et al. (2007). The thinner windows in the IOT tunnel may have less effect.

Table 1b: Spatial Uniformity of Transverse, V, and Vertical, W, Velocities

x (mm)	V/Uo	v'/Uo	Std Dev (m/s)	U95 (%)	W/Uo	w'/Uo	Std Dev (m/s)	U95 (%)
0					-0.00392	0.0108	0.0062	0.769
250					-0.00200	0.0115	0.0081	1.007
-250					-0.00461	0.0114	0.0066	0.828
-250					-0.00444	0.0107	0.0087	1.087
0	-0.0049	0.0163	0.0426	5.310				
250	-0.0053	0.0107	0.0772	9.514				
-250	-0.0008	0.0133	0.0193	2.396				
0					-0.00457	0.0086	0.0199	0.649
250					-0.00418	0.0094	0.0244	0.794
-250					-0.00747	0.0093	0.0292	0.953
-250					-0.00654	0.0088	0.0349	1.143
0	-0.0021	0.0113	0.0517	1.684				
250	-0.0033	0.0090	0.0259	0.845				

A vortex flow appears near the top of the test section for the IOT tunnel at both velocities. This vortex did not occur in subsequent measurements. The cause should be investigated so that this flow disturbance does not re-appear in the future.

Finally, the mean axial velocities at set points of 1.5 and 6.0 m/s are higher by 0.1 m/s as measured by the LDA system. This discrepancy should be investigated. The calibration of the differential pressure transducer for the tunnel set point should be checked, and the control system algorithm should be reviewed. A differential pressure measurement will not be reliable at low pressures. A digitally controlled shaft speed on the pump may provide a more stable flow, particularly at very low speeds.

References

- Doucet M. (1999): Cavitation Tunnel Feasibility Study. NRC-IOT. CR 1999 12
- Laneville A. and Williams C.D. (2005). The Cavitation and Water Recalculating Tunnel of the NRC-IOT. IOT Report
- Mori, Takayuki, Naganuma, Kenji, Kimoto, Risa, Yakushiji, Ryo, and Nagaya, Shigeki, 2007, "Hydrodynamic and Hydroacoustic Characteristics of the Flow Noise Simulator," ASME Paper FEDSM2007-37531, 5th ASME/JSME Joint Fluids Engineering Conference, San Diego, American Society of Mechanical Engineers, New York.
- Park, Joel T., Cutbirth, J. Michael, and Brewer, Weseley H., 2005, "Experimental Methods for Hydrodynamic Characterization of a Very Large Water Tunnel," Journal of Fluids Engineering, Vol. 127, No. 6, pp. 1210-1214