



## **Model and Test Equipment Preparation**

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Model Test and Evaluation of an Advanced Axial Flow Waterjet Pump  
Designed for the Coastal Commercial Ship Sealift Application***

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**MODEL AND TEST EQUIPMENT PREPARATION**

**System:**

Model and Test Equipment Preparation for the Water Tunnel Testing and Evaluation of an Advanced Axial-Flow Waterjet Pump Designed for the Coastal Commercial Ship Sealift Application

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Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Center for the Commercial Deployment of Transportation Technologies (CCDoTT) at California State University, Long Beach.

## **FOREWORD**

CDI Marine Systems Development Division (CDIM-SDD) prepared the work described in this working paper for the Center for the Commercial Deployment of Transportation Technologies (CCDoTT) at California State University, Long Beach. The principal point of contact at CDIM-SDD was Mr. John Purnell. The principal point of contact at CCDoTT was Mr. Stan Wheatley.

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## **1.0 INTRODUCTION**

The water tunnel model testing of an advanced axial-flow waterjet pump is to be performed using a 7.5-inch diameter impeller model assembly in a water tunnel. The baseline design concept is a 90-inch diameter waterjet pump (for 50-knot application), giving a scale ratio for the model of 1:12<sup>(1)</sup>. The pump model will be tested in the 24-inch water tunnel at the Carderock Division, Naval Surface Warfare Center (CDNSWC) in West Bethesda, Maryland. The pump model tests are necessary to characterize the performance and cavitation characteristics of the full-scale pump. As part of this process, this report will discuss the setup and instrumentation of the pump model in the water tunnel so that the data taken can be understood and the data notations can be oriented to the model setup. During the setup, some revisions to the initial setup plans were made for convenience and other reasons that will be covered.

## **2.0 BACKGROUND**

Commercially available large waterjets are based on using mixed-flow impellers. These mixed-flow impellers require a significantly greater amount of transom width for their installation than would be required if axial-flow impeller designs were used. High-speed ship designs need low-drag configurations, which favor long, narrow hullforms, and waterjets are the most logical means of propulsion due to their low-drag arrangement and good performance. Also, high speed requires a significant amount of installed power and will require multiple waterjet units to absorb that power on ships of sealift size. Simply stated, the large mixed-flow designs are too wide to fit in the slender high-speed hullforms. In basic terms, three axial-flow waterjets can be placed in the same general transom width as two comparable mixed-flow waterjets to provide 50 percent more power and thrust from the same transom width. In addition, the axial impeller waterjets are 15 to 20 percent lighter than the comparable mixed-flow unit, and weight is critical with regard to high-speed ships. Axial-flow waterjets are an enabling technology for high-speed ships, and CCDoTT has been instrumental in efforts to develop a large axial-flow waterjet. This effort represents a third phase of CCDoTT work towards that end.

The present water tunnel pump model test will look at the performance and cavitation characteristics of a scaled axial-flow waterjet. The pump model and other test support components were manufactured by NuCon Corporation from CDIM-SDD supplied designs. NuCon Corporation is a machining company located in Lavonia, Michigan, specializing in precision 5-axis machining since 1973, and was selected to build the pump model and components. Previous good experience with NuCon on several efforts made them the best known choice. The completed pump model and components were received from NuCon on 2 February 2005 and were delivered to the water tunnel at CDNSWC the next day. Details of the parts manufactured by NuCon are covered in earlier task reports for this present CCDoTT effort<sup>(2, 3)</sup>. The stator bearing and the 2-inch stub shaft that runs inside the stator bearing were existing pieces that would be part of the final pump model assembly. These pieces were sent to NuCon when they began their effort to assure their proper fit in the final assembly. Figure 1 shows the main individual parts that were delivered from NuCon with a 6-inch ruler in the foreground for reference. Figure 2 shows a stack-up of the model pump assembly sitting on the stator adaptor, which forms part of the tunnel mounting as well as providing diffusion for the flow exiting the nozzle section of the pump model.



Figure 1. Pump Model Assembly Components



Figure 2. Stack-up of Pump Model Components on the Stator Adaptor

### 3.0 SETUP DETAILS

#### 3.1 Pump Model Setup

The pump model was basically setup in the tunnel as had been shown in the drawing package of Reference 3. One modification was to rotate clockwise by 45 degrees, when viewed from the front, the stator and shroud assembly when it was mounted. With 8 stator blades, which are spaced at 45 degrees apart, this rotation had no effect on the internal arrangement, nor would it be expected to affect anything. The benefit of the rotation was to put all the Laser Doppler Velocimetry (LDV) view ports in an upward facing direction and make them more convenient and accessible for mounting static taps and the LDV apparatus. There is not much room in the tunnel test section, especially with the model mounted inside, and someone must usually climb inside the tunnel test section to make most changes. The LDV apparatus had to be manually repositioned and secured to the shroud or inlet tube for each of the numerous view ports. View ports were also used for static pressure readings when they were not needed for the LVD apparatus, so pressure line tubing also had to be rearranged for each LDV move. Helicoiled mounting points had been precisely arranged on the shroud and inlet tube during fabrication to precisely align and orient the LDV with each individual view port window. Figures 3 and 4 show the new vertical orientation of the view ports between the rotor/stator and in the nozzle, respectively. These views are looking forward from behind the pump and looking through the stator, with the new vertical orientation identified. The view port numbering sequence and significance will be discussed later with their measurement purpose.

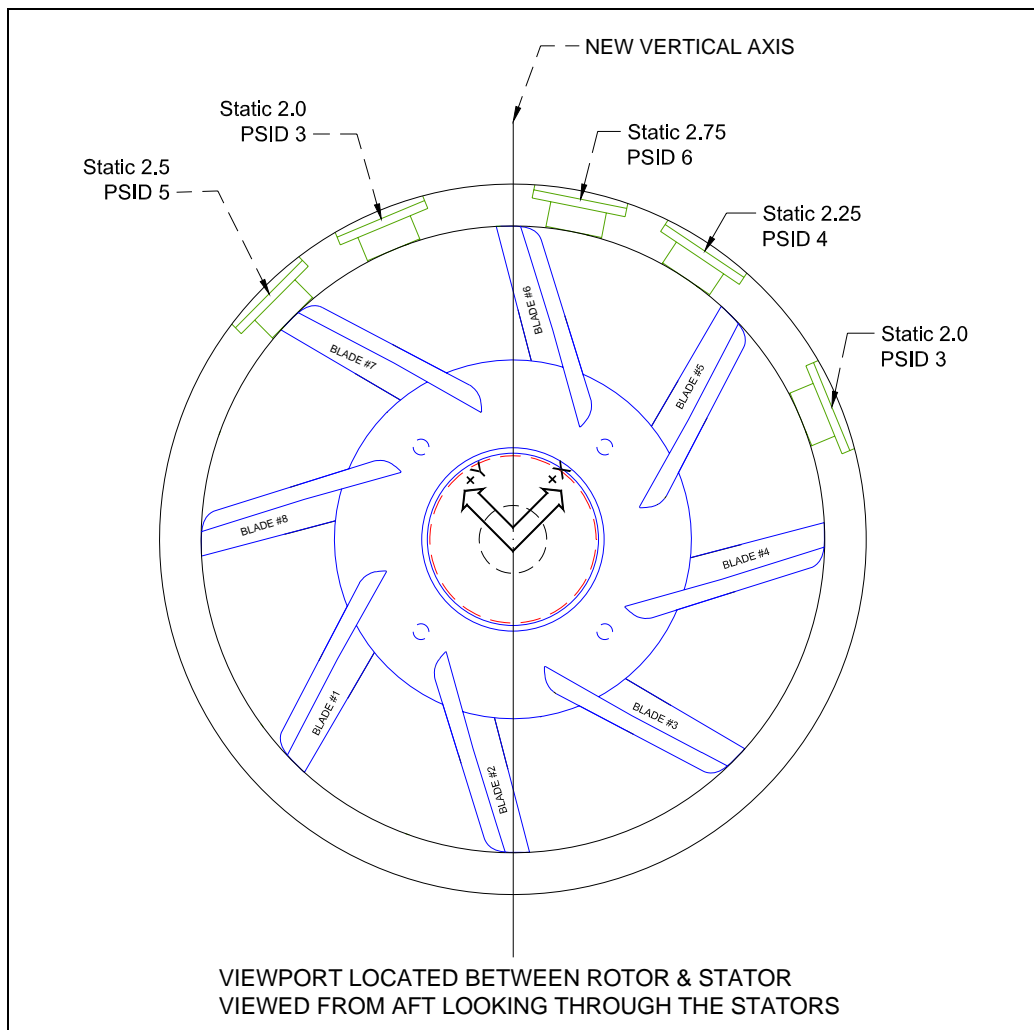


Figure 3. View Port Orientation and Identification for the Rotor and Stator Gap

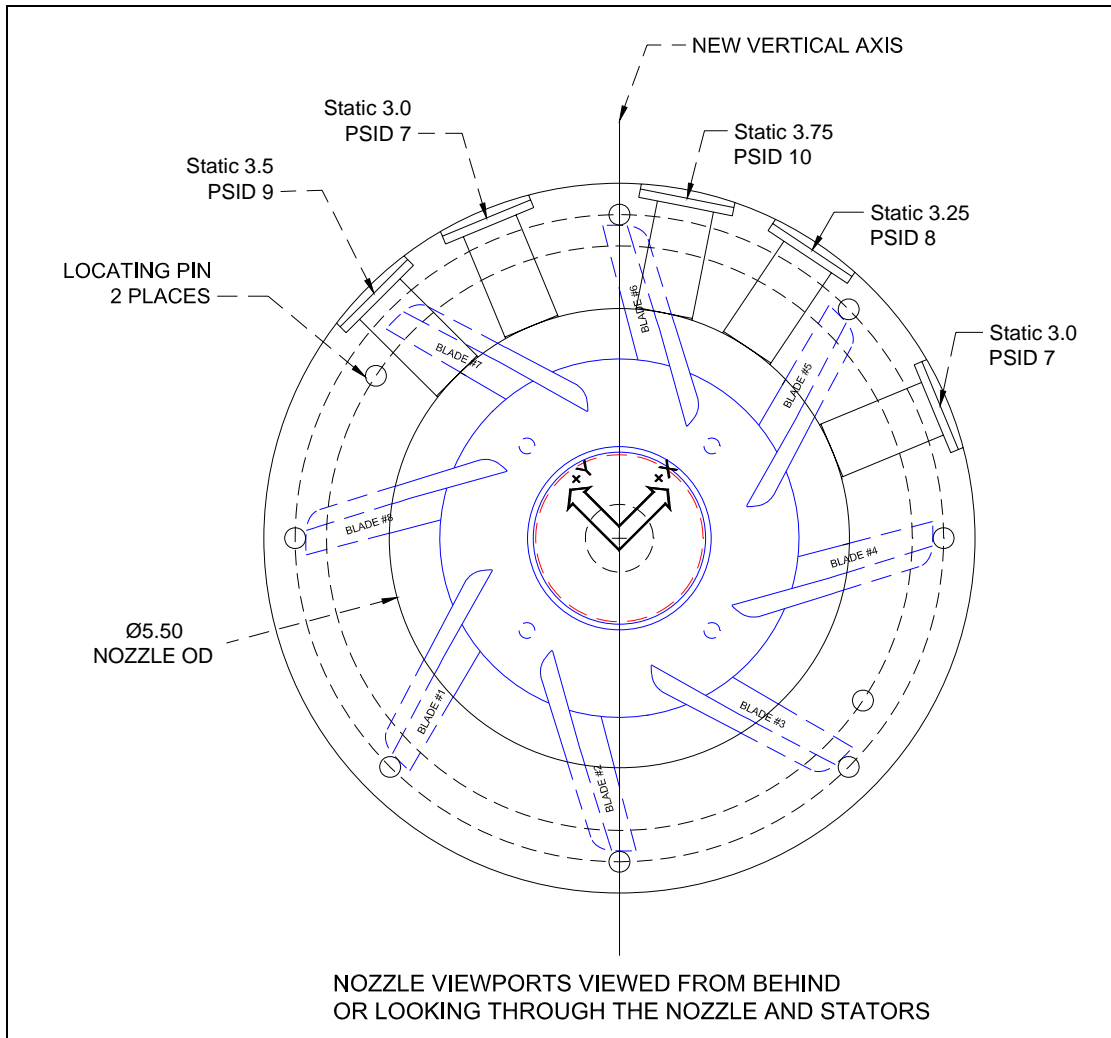


Figure 4. Nozzle View Port Orientation and Identification

There were two sets of locating pinholes drilled in the nozzle end of the shroud and in the stator adaptor that the shroud mounts to. The locating pins are indicated on Figure 4 for the shroud. With the shroud rotated by 45 degrees, as discussed above, the locating pins in the shroud and the stator adaptor no longer lined up and thus could no longer be used. The boltholes on the stator adaptor that align with the helicoiled fittings on the aft nozzle face of the shroud were more than sufficiently aligned to accurately align the shroud with the stator adaptor.

The drawing package of Reference 3 included a diffuser that was mounted downstream of the pump exit flow. The diffuser would normally be needed for evaluating off-design flows that are greater than the design flow. Under these higher off-design flow conditions, there is not sufficient headrise across the pump to match the tunnel pressure without extra diffusion of the pump exit flow to raise its exit pressure to match the tunnel pressure. The diffuser would typically be used for this added diffusion and was available from a previous test. However, an alternative to using the diffuser for the high off-design flows could be employed for these tests. The water tunnel was blanked off at its upstream inlet so that all tunnel flow passed through the inlet bellmouth going to the model pump. With this arrangement, the water tunnel circulation pump could be run to create a pressure difference between the inlet bellmouth and the tunnel test section where the pump model exit was located. This worked like the diffuser in reverse, raising the pressure at the inlet bellmouth sufficiently to allow the pump to match the tunnel test section exit pressure. By running the tunnel circulation pump at different speeds to create different

pressure differences between the inlet bellmouth side of the tunnel and the tunnel test section where the pump exit was located, different high off-design flows could be run. Since this procedure worked successfully, the diffuser was not necessary and was not used. Figure 5A shows the baseline model assembly (from Reference 3) with the diffuser, and Figure 5B shows the model assembly without the diffuser. Figure 5B is identical to Figure 5A except for the diffuser and is the basic arrangement tested. The arrangement of Figure 5B, without a diffuser, provided sufficient pressure recovery using the circulation pump to run the necessary high off-design flow cases.

The inlet tube is a clear acrylic tube that connects the inlet bellmouth with the inlet side of the pump rear drive shroud. The inlet tube is identified as Find No. 13 on Sheet 1 of the drawing package, Reference 3. This acrylic tube was available at CDNSWC and was available from previous testing that had been done at the water tunnel for CDIM-SDD. The basic dimensions of this inlet tube are shown on Sheet 7A of the drawing package and were obtained from the previous test drawing package. The 7.5-inch inside diameter, 8.0-inch installation lip, and 8.5-inch outside diameter of this tube would all match the present model pump installation requirements having the same values. During model assembly, the inlet tube did not fit tightly. Measurements indicated that the inlet tube had shrunk about 1 percent radially since it was last used about 2 ½ years before. The inside diameter was now 7.42 inches instead of 7.5 inches. The only explanation is that the acrylic shrunk over time due to reasons unknown, as it was correctly sized during the previous testing. There was not sufficient time to procure and fabricate another piece without a lengthy delay in the testing.

To correct the inlet tube, an approximate 3-degree taper was machined at the end of the tube inside diameter to bring its inside diameter back up to the 7.5-inch inside diameter of the rear pump drive shroud. This taper was about ¾ of an inch long and occurred directly in front of the pump inlet face. There are four LDV view ports located on that end of the inlet tube and these view ports end almost where this taper begins. These view ports will be viewing the section of inlet tubing that has a 7.42-inch inside diameter and that will be accounted for in the analysis.

The inlet tube did not fit tightly inside the lip of the rear drive shroud to which it mates at one end. An approximate 4-mil strip of thin clear plastic was glued to the lip to successfully remove the excess clearance. The tight clearance here is important to prevent leakage flow between the interior and exterior of the pump housing which would adversely affect the data to be taken.

### **3.2 Pressure Measurements**

The preliminary data that has been taken required an understanding of the details of the measurements and the location where measurements were taken. The first measurements that were taken involved the calibration of the inlet bellmouth. There are two sets of four static taps, equally spaced circumferentially, located on the bellmouth. The first set of four static taps is located near the inlet of the bellmouth and the second set is equally spaced near the bellmouth throat. The forward set of static taps is grouped together as are the other aft set of four, and the differential pressure between the two is used to determine flow rate. The bellmouth differential pressure is being recorded as PSID-1 in the spreadsheet data being received from CDNSWC. The bellmouth differential pressures were calibrated to the flow rate using LDV data. LDV velocity profiles were taken at the pump inlet face station, denoted as station 3 in Figure 5B, for a range of bellmouth differential pressures or flow rates. These velocity profiles were integrated to determine the different flow rate and calibrated against the bellmouth differential pressures to predict flow rate based on that bellmouth pressure difference. Four equally spaced view ports were located at the pump inlet face, Station 3 of Figure 5B. These four view ports should all see the same velocity profiles, as everything upstream of each view port is the same. Thus, velocity profiles were only taken using a single view port.

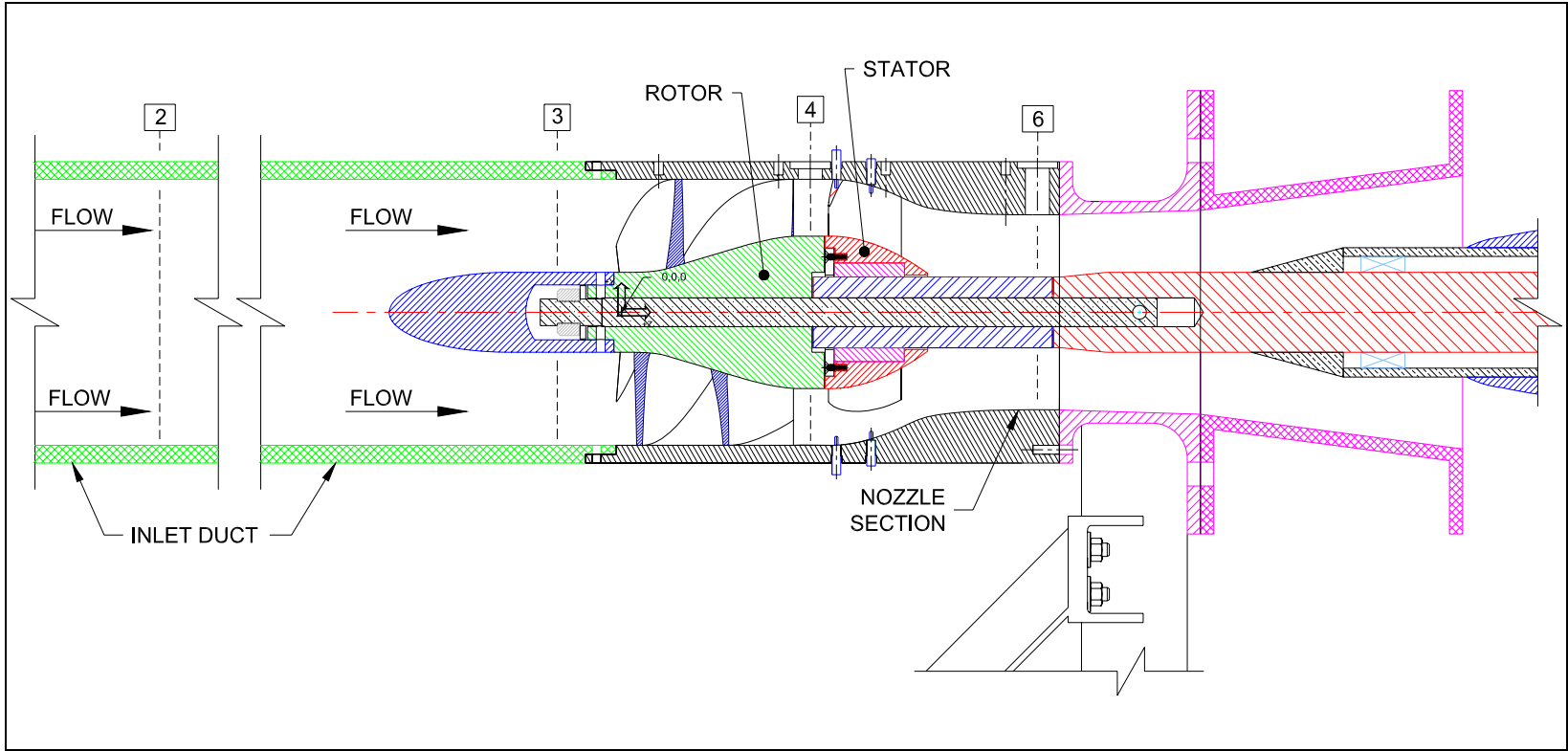


Figure 5A - Model Pump Assembly with Diffuser

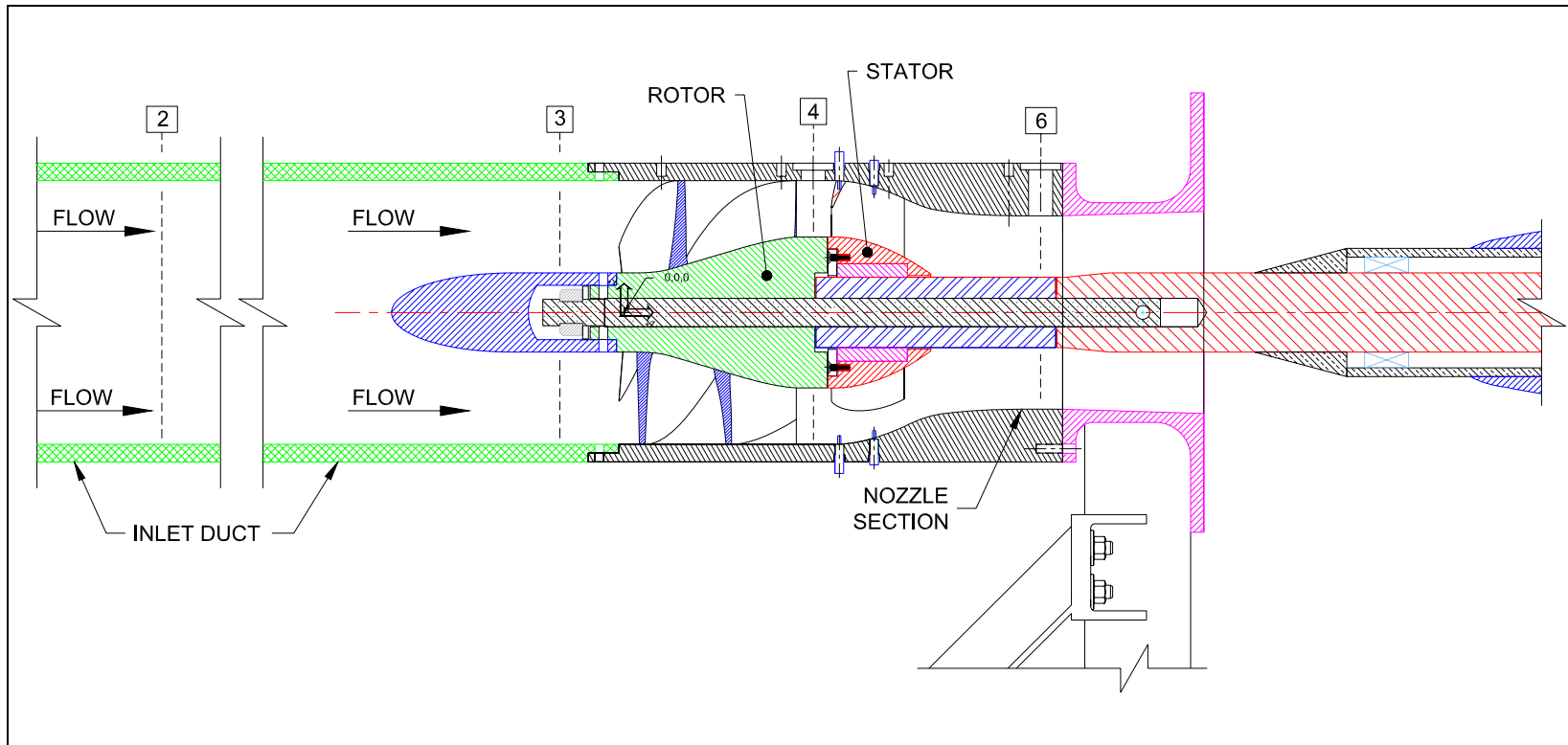


Figure 5B - Model Pump Assembly without Diffuser

The view ports serve two functions depending on the present test requirement. The primary function of the view ports is to provide a place for a window for the LDV to operate through to measure the radial distribution of the axial and tangential velocity fields below each window. When not used by the LDV, a plug incorporating a static tap was placed in the view port location to measure wall static pressure at that location. Figure 6 shows examples of the wall static inserts for the different depth view ports. The base of these static tap inserts was contoured to match the contour of the inside diameter of the rear drive shroud at the view port location. The LDV inserts look similar to Figure 6, but had a hollow center core with a piece of flat, optically-clear glass at the base. The flat glass is necessary for the LDV and does not contour to the inside diameter surface, but was mounted so that it was tangent to the high point of the surface arc and did not protrude into the flow. The slight recess on either side is unavoidable, but was not significant enough that it should affect the flow to any degree.



Figure 6. View Port Static Tap Inserts

The static taps for the station 3 view ports were tied together to provide a single averaged static reading at the inlet face of the pump. This location was used as the reference location for all the other differential pressure readings that were taken across the pump model and assembly. There are five view ports located in the space between the rotor and stator blades (station 4 of Figure 5B), and there are five view ports located in the nozzle straight section (station 6 of Figure 5B), with the view port cross sections shown in Figures 3 and 4, respectively. These view ports are set up to cover a complete stator passage in one-quarter increments based on the fact that all the stators would act the same. Figure 3 shows the view ports located between the rotor and stators, and these view ports are located forward of the stator blades shown in that figure. It should be noted that the rotor/stator gap was increased for the model, compared to scaling the full-scale design, in order to allow room for these view ports, but, being a straight section of channel, the impact should be negligible. Two view ports (labeled Static 2.0, PSID 3) are located to be in front of the mid channel of the stator passage. The decimal in Static 2.0 refers to the mid channel location, while the PSID 3 is the CDNSWC designation for the differential pressure reading location. These two view ports should have the same readings and are tied together. For the locations between the rotor and stator gap shown in Figure 3, the identification of the static taps, their associated differential pressure gage identification, and their relative location in front of the stator channel near the wall are as follows:

<u>Static Tap</u>	<u>Pressure Gage ID</u>	<u>Description of General Location</u>
Static 2.0	PSID 3	Forward of the Stator Mid Channel
Static 2.25	PSID 4	Forward Halfway between Stator Mid Channel and Pressure Surface
Static 2.5	PSID 5	In Front of Stator Leading Edge
Static 2.75	PSID 6	Forward Halfway between Stator Mid Channel and Suction Surface

Five view ports are located in the nozzle section of the model, as shown in Figure 4. These view ports all have the same circumferential location as the view ports described above that were located between the rotor and stator gap. The view ports in Figure 4 are in a straight section of the smaller diameter nozzle location and would correspond to station 6 in Figure 5B. The view ports in Figure 4 are located aft of the stator blades, which are shown for general reference in the figure.

<u>Static Tap</u>	<u>Pressure Gage ID</u>	<u>Description of General Location</u>
Static 3.0	PSID 7	In the Nozzle Directly Downstream and Inline with Static 2.0
Static 3.25	PSID 8	In the Nozzle Directly Downstream and Inline with Static 2.25
Static 3.5	PSID 9	In the Nozzle Directly Downstream and Inline with Static 2.5
Static 3.75	PSID 10	In the Nozzle Directly Downstream and Inline with Static 2.75

During the cavitation and performance testing, the tunnel pressure will be lowered to control the Net Positive Suction Head (NPSH) in front of the pump inlet face, where NPSH is the total pressure above vapor pressure at that location. Dynamic pressure can be obtained from the flow rate, and the vapor pressure is known from the water temperature. Readings of the static pressure at this location will be required in order to determine the NPSH, and additional pressure readings will be needed.

### **3.3 LDV Measurements**

The LDV will be used to measure the radial distribution of axial and tangential velocities in the pump model through the view ports at three locations: the pump inlet face, the rotor/stator gap, and the exit nozzle. The LDV measures velocities in the 2-D plane normal to the beam direction. Additional apparatus would be needed inside the pump flow channel in order to obtain the radial component of velocity, which would obstruct flow and affect pump performance. The LDV locations being used all have a straight section of channel, which would have a very small radial component of flow velocity. Any small value of radial velocity would have a negligible impact on the analysis due to its small value compared to the other larger velocity components.

A two-component, argon ion laser (5 watt) is being used for the velocity measurements. The laser head was mounted parallel to the pump model shaft axis. A 45-degree mirror was located in the laser apparatus, directly above the view port, to direct the laser beams through the view port. A precision linear actuator moved the laser head forwards or backwards, relative to the pump axis, to move the fixed focal length beam intersect point to different radial locations in the pump flow channel below the view port. Figure 7 shows the laser apparatus mount to the inlet duct in the bottom right-hand corner. The laser head is a silver cylinder on the middle, far right side of the apparatus.

The LDV measures the velocity field at the focal point or intersection of its two beams. The intersection of the beams creates a spherical like region of about 3 millimeters in diameter. Light scattered by minute particles in the water in this region is sensed by the laser and translated into the velocity components. The laser can measure close to the walls, but needs to keep its beam intersection region off the wall or light scatter from the wall will affect the readings.

It is taking on the order of approximately two minutes to get a properly averaged LDV reading at each radial setting. LDV data is being taken on the pump with the tunnel test section unpressurized. The bulkhead connector that feeds the LDV cabling and wires into the tunnel is not pressure rated and has to operate with equivalent pressures on both sides. Bubbles in the water can affect the LDV readings. Bubbles have collected on the 45-degree mirror in the laser apparatus under certain conditions, and a tube to direct a jet of water to flush the mirror was installed and operated as needed.



Figure 7. Laser Apparatus Mounted to the Inlet Duct in the Lower Right-hand Corner

For low-flow off-design conditions, the higher headrise through the pump at these conditions requires that additional flow restriction or resistance be placed downstream of the pump in order to be able to run these conditions. A circular ring of radial flow restrictors, as shown in Figure 8, was clamped to the exit of the stator adaptor where the pump model flow exited back into the tunnel test section. The open section in the middle of the flow restrictor fit around the rear drive shaft. By placing different thicknesses of rubber tubing on the radial arms of the flow restrictor, flow rates could be changed by the change in restrictor flow area and, thus, its pressure drop. Flow rates as low as 50 percent of the design flow could be obtained with this flow restrictor. However, under sufficiently low-flow off-design cases, the restrictors would form a vapor cavity around the tubes due to their increased pressure drop requirement. This would eventually shed enough tiny bubble nuclei into the tunnel to start affecting the LDV readings. For the low off-design flows, it will be necessary to run the pump model at lower rpm settings in order to reduce the amount of pressure drop across the restrictors.



Figure 8. Flow Restrictor with Low Blockage (left) and High Blockage (right)

### **3.4 Torque and RPM Measurements**

The water tunnel is equipped with instrumentation and controls to set and maintain the drive motor RPM, which drives the pump model, within a very narrow range once the desired RPM setting is input. The tunnel drive motor is rated for 150 horsepower and the planned testing would, at most, only require on the order of 50 horsepower. Maximum planned model pump RPM is 2440, which is well within the tunnel drive motor capability. The tunnel drive motor is instrumented with a Himmelstein Precision Strain Gage Load Cell to determine the drive shaft input torques. Tare torques need to be taken with the rotor removed to correct for tunnel driveline losses. The drive shaft is also instrumented to measure the thrust force it is seeing from the pump rotor operation.

### **3.5 Kiel Probes**

ONR intends to provide funding to CDNSWC to take Kiel probe readings of total pressure in the pump model. This data would be taken at the pump inlet face, the rotor/stator gap, and the nozzle. This data would be taken at radial increments at each of the view port locations. Some of the view port inserts will be modified or new inserts made to hold the Kiel probes. The final arrangements are still being worked on by CDNSWC. These tests will likely be undertaken after the present performance and cavitation testing is essentially complete. The LDV data that has been taken will be of benefit in better aligning the Kiel probes with the flow, particularly in the rotor/stator gap when significant tangential flow will exist. This data will be used by CDNSWC for comparison with CFD pump model predictions. This data will also benefit the analysis and correlation of the pump model performance data that is presently underway.

## **4.0 CONCLUSIONS**

The pump model has been received from NuCon in good order and has been installed in the 24-inch water tunnel at CDNSWC. Measurement equipment and instrumentation, as described, has been installed. Additional information and lessons learned during the setup are discussed.

## **5.0 REFERENCES**

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2. "Status Report: Contract Award and Model Components", CDIM-SDD Report No. 790-2, prepared for CCoTT FY04 Project 7. PE 2.29 Task No. 7.3, December 2004.
3. "Drawing Package of Model and Setup Components", CDIM-SDD Report No. 790-3, prepared for CCoTT FY04 Project 7. PE 2.29 Task No. 7.4, December 2004.