CCDoTT
Center for the Commercial Deployment
of Transportation Technologies

Axial Flow Pump Model Testing

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Project 7
Model Test and Evaluation of an Advanced Axial Flow Waterjet Pump
Designed for the Coastal Commercial Ship Sealift Application

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AXIAL-FLOW PUMP MODEL TESTING

System:

Axial-Flow Pump Model Testing 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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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 being performed using a 7.5-inch diameter model impeller, stator, and nozzle assembly in the 24-inch water tunnel at Carderock Division, Naval Surface Warfare Center (CDNSWC). The water tunnel has been specially set up for the design point and off-design point performance and cavitation testing of the pump. Appropriate instrumentation and procedures are in place to perform the requisite testing. Laser Doppler Velocimeter (LDV) apparatus is being used to obtain details of the flow field velocities at several important locations to help establish the flow rates and to better assess performance. Tunnel pressures, downstream flow restrictors, and/or circulation pump speed are controlled to establish desired operation point conditions for the performance and cavitation test runs. This report will discuss the testing of the pump model in the water tunnel so that the data that is taken can be better understood and put in proper context.

2.0 BACKGROUND

Commercially available large waterjets are based on using mixed-flow pump 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. This is illustrated in Figure 1 with a comparison of the two types of pump designs on a representative transom. In addition, the axial impeller waterjets are 15 to 20 percent lighter in installed weight per unit 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. CCDoTT has been instrumental in efforts to develop a large axial-flow waterjet[1] and this effort represents a third phase of CCDoTT work towards that end.

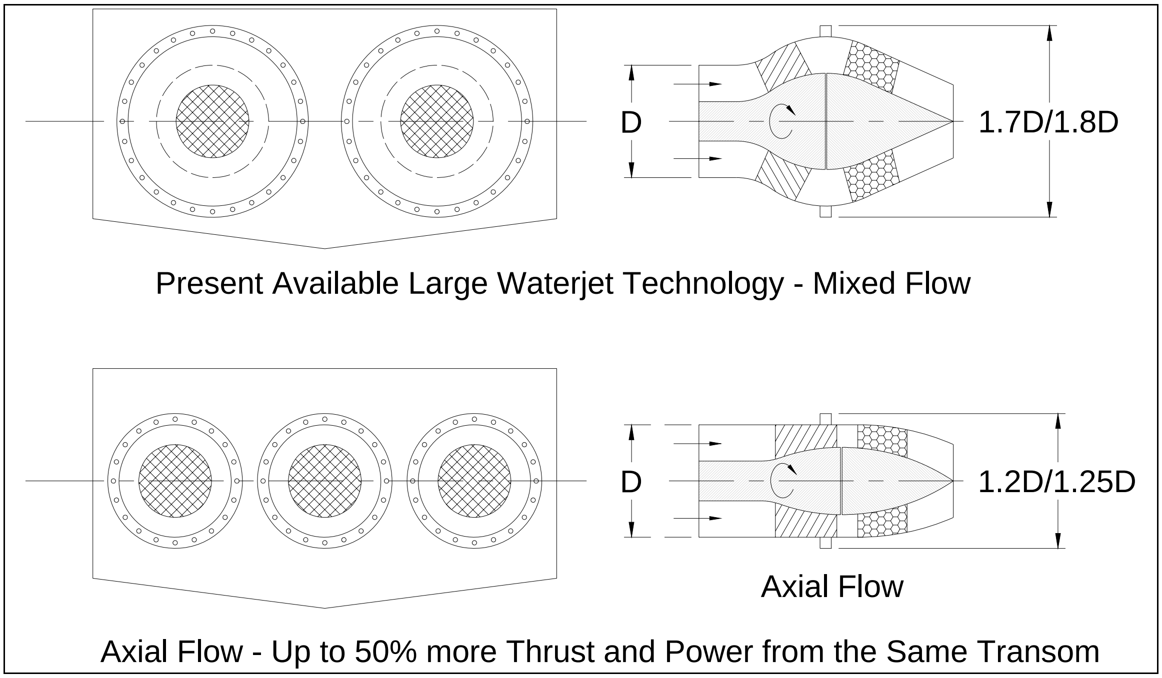

Figure 1 – Installation Advantages of Axial-Flow Pumps Over Mixed-Flow

The present water tunnel pump model testing is examining the performance and cavitation characteristics of a scaled axial-flow waterjet. The water tunnel testing allows the basic full-scale pump performance to be determined from the use of the appropriately scaled model. Figure 2 shows the instrumented model axial pump assembly installed in the water tunnel and ready for testing. Previous experience[2] with testing of a pump in the water tunnel was important in helping set up this test. The water tunnel testing allows the pump to be tested separately from the remainder of the waterjet system to determine its performance. Later self-propulsion tests of a suitable hull model with scaled waterjet inlets can then be tested and later combined with the pump performance results to determine the overall waterjet system performance for the full-scale craft.

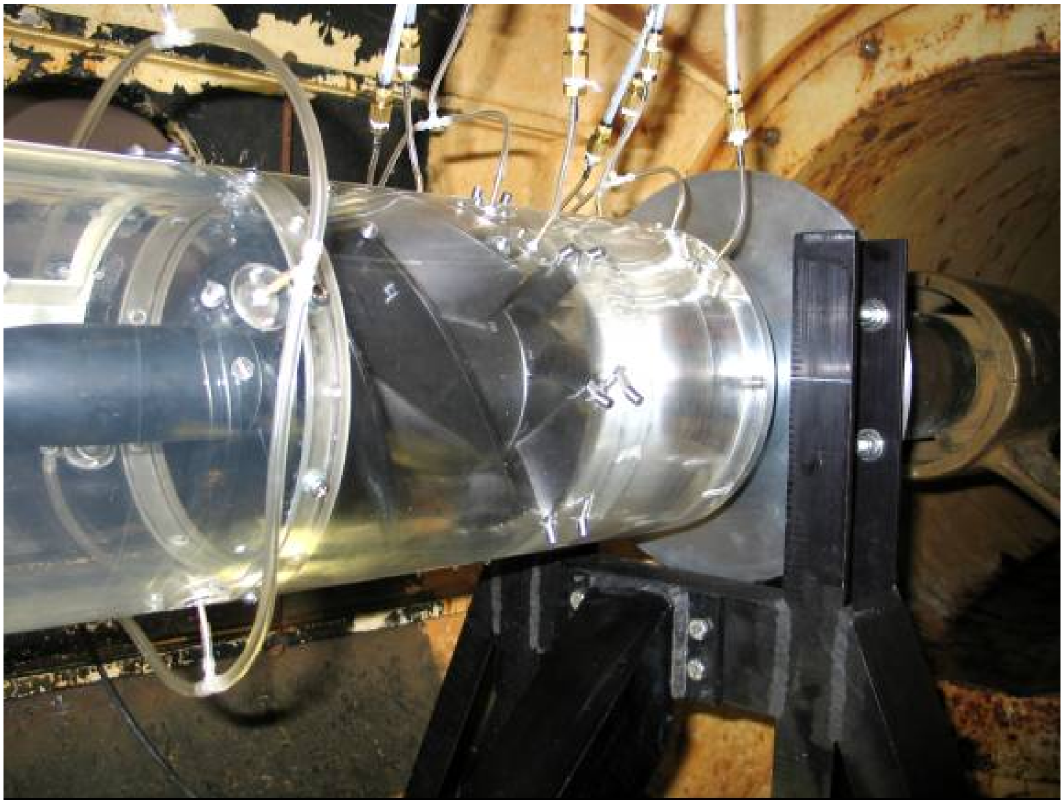

Figure 2 – Instrumented Pump Model Assembly in the Water Tunnel

3.0 TESTING DETAILS

Figure 3 shows the layout arrangement of the axial-flow model pump assembly in the test section portion of the 24-inch water tunnel. The components and instrumentation for the test set-up were described in previous CCDoTT reports.[3,4] The water tunnel has been specially set up to perform the pump tests. The inlet of the water tunnel test section has been blanked off so that all tunnel flow must pass through the inlet bellmouth that feeds only the pump model. This has many benefits in setting the pump flow rate and tunnel conditions for testing that would be difficult to do without this arrangement. With this arrangement, the water tunnel circulation pump can be used to create a pressure differential between the inlet bellmouth side of the tunnel, which influences the pump inlet conditions, and the water tunnel test section, where the pump exit nozzle is located. This is an important feature to help run the range of off-design flow conditions.

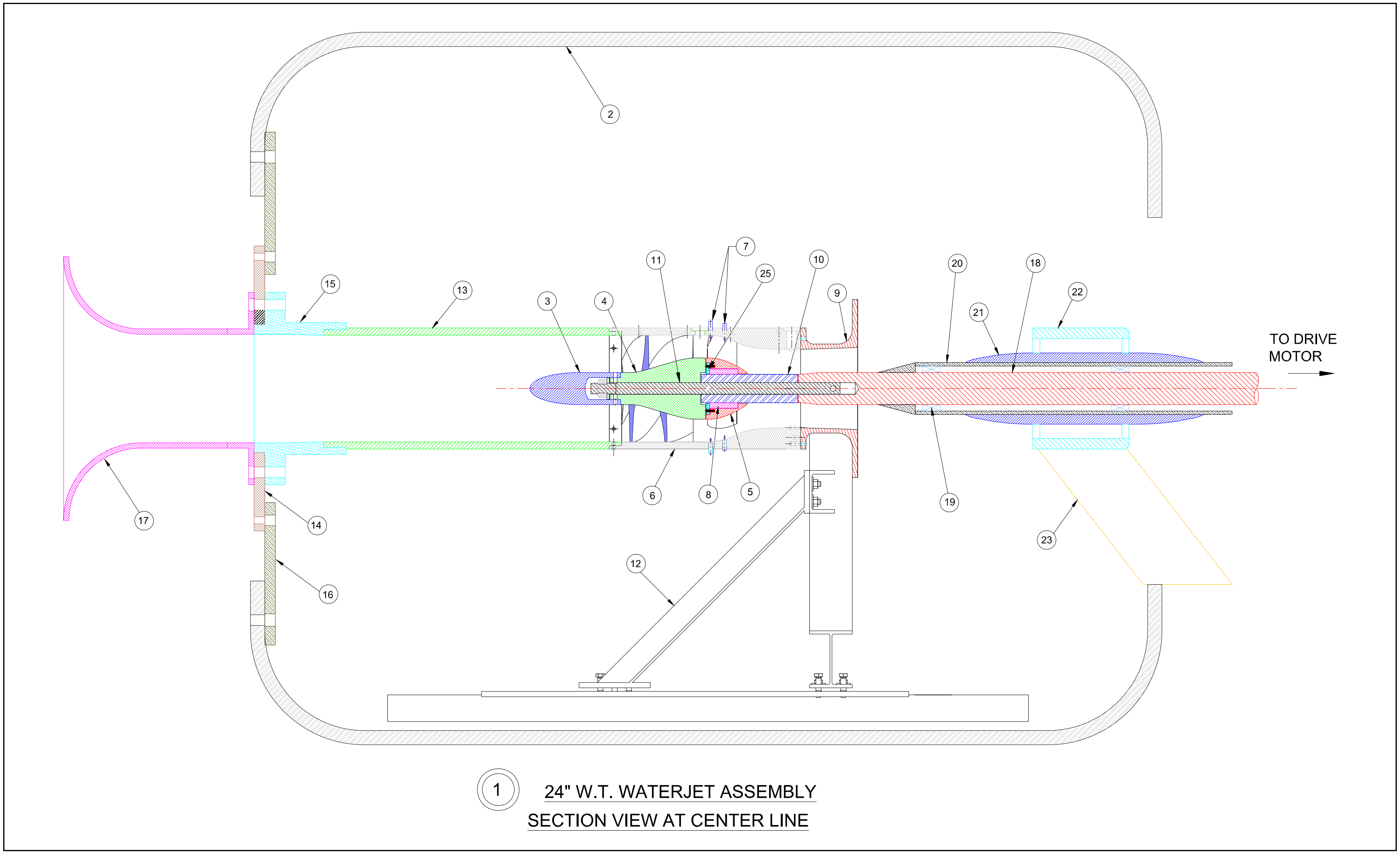

Figure 3 – Axial Pump Model Set-Up in the Water Tunnel Test Section

3.1 Inlet Flow Measurements

Knowing the flow rate through the pump is the first critical step in the testing. The upstream inlet bellmouth has two sets of static taps, with one set near the beginning of the bellmouth and the other set at the throat region of the bellmouth. The differential static pressure reading between these two sets of static taps will give a direct indication of the flow rate due to the acceleration of the flow through the bellmouth, causing an almost directly related change in the differential static pressure. By calibrating the bellmouth static pressure change with known values of flow rate, the bellmouth differential static pressure can be used to measure and set the flow rate through the pump.

To establish known flow rates through the pump, Laser Doppler Velocimeter (LDV) readings of the velocity field at Station 3, as shown in Figure 4, which is just in front of the pump inlet face, were made for different static pressure drop readings across the inlet bellmouth. By integrating the detailed axial velocity profile that was taken at multiple radial locations across this station, one is able to determine the flow rate at Station 3 for that pressure drop reading. The integrated flow rate at the pump inlet face is the same flow rate as through the inlet bellmouth since all tunnel flow must pass through both, and both must have the same flow rate. In this manner, the inlet bellmouth could be calibrated with known flow rates and then used to establish flow rate settings for later performance and cavitation testing runs.

The inlet LDV runs at Station 3 are also important for establishing the inlet conditions to the pump, which need to be known for later evaluation of the pump performance. The LDV readings at Station 3 will record the axial and tangential components of velocity at that location. The LDV will only read the velocities in the plane normal to its beam so that radial velocity components are not measured. However, Station 3 is located between two parallel surfaces and, in that arrangement, the radial velocity component would be insignificant compared to the other two velocity terms. LDV measurement at Station 4, the rotor/stator gap, and Station 6, the nozzle, is shown in Figure 4. These stations are also located in regions where the wall sections are parallel and where radial velocity components in the flow field would be negligible.

3.2 Tare Tests

Tare tests are run to determine the correction to torque data that are required to account for the torque loss associated with the water tunnel drive system. With the impeller removed, the water tunnel drive system is run through a range of rpm's and the torques are recorded. This is the amount of torque that is lost in the water tunnel drive system prior to the pump model and is not associated with the pump performance. This amount of torque is subtracted from the torque values obtained with the impeller operating at each rpm to determine the torque requirements of the pump rotor only. Torques are also corrected for any initial instrument offsets, with offsets taken just prior to, and normally just after, a series of test runs.

3.3 Performance Measurements

Performance runs are made to ultimately establish the head-flow characteristics of the pump as well as its power requirements and hydraulic efficiency. These tests are run over a range of flows at different pump rpm's so that design and off-design conditions are covered. Various flow rates through the pump could be set by use of the tunnel circulation pump and/or additional flow resistance rods installed at the exit of the pump. During the performance runs, multiple wall differential static data is taken at locations between the pump inlet location at Station 3 in Figure 4 and the rotor/stator gap and the nozzle throat at Stations 4 and 6, respectively, of Figure 4. The wall static pressure differentials give information on the change in wall static pressures between locations and will be supplemented with data from LDV surveys and Kiel probe data to generate the representative head-flow curve. All this data will additionally determine the effective horsepower transmitted into the water by the pump impeller and what remains at the nozzle section so that rotor efficiency and overall pump hydraulic efficiency can be obtained at the various operating conditions.

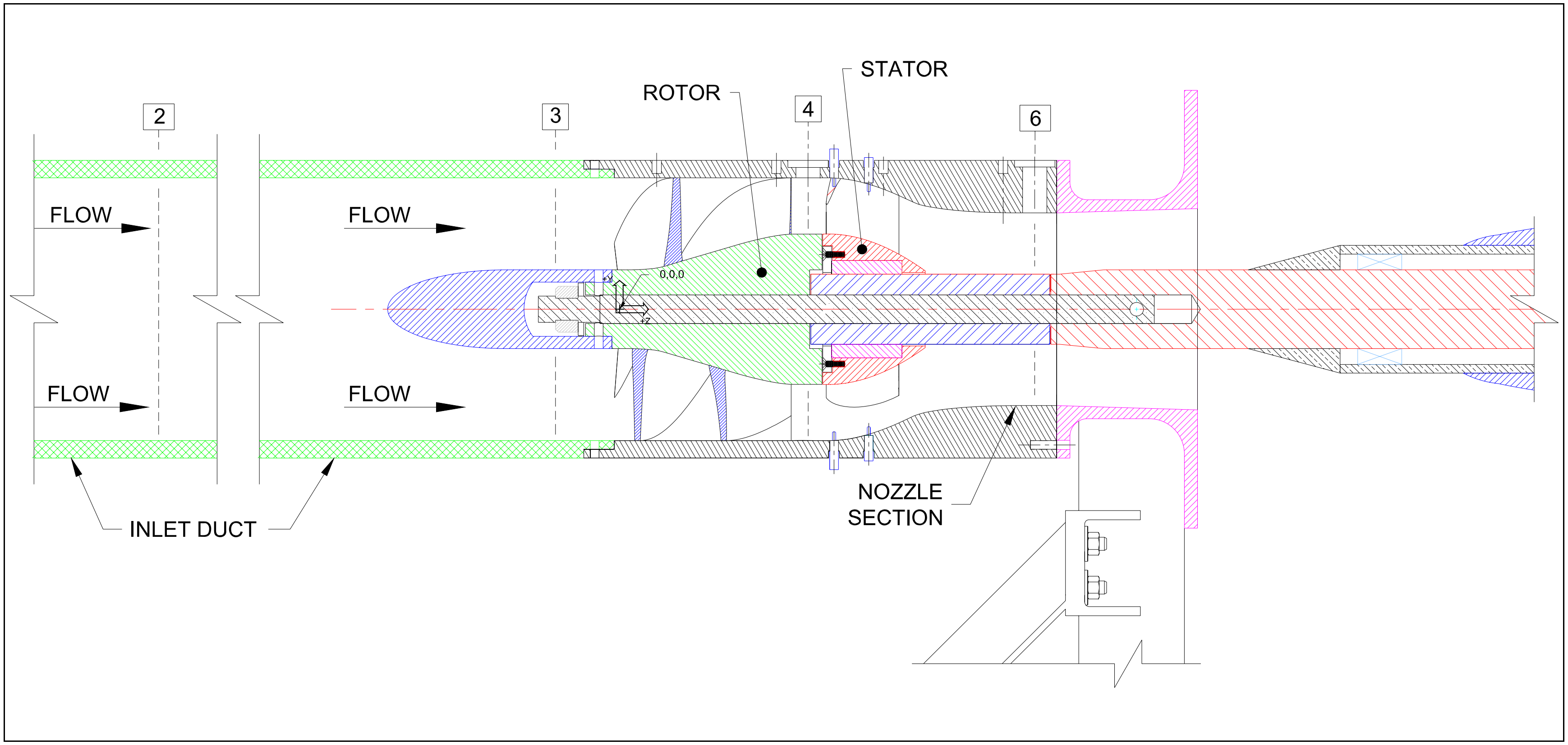

Figure 4 – Model Pump Assembly with Measurement Stations

The water tunnel drive motor is set up to measure the water tunnel drive shaft torque. Corrections to torque are made to account for initial instrumentation offsets and drive system torque losses up to the pump using the tare test results. The resulting corrected torque values are the values of torque required to drive the pump rotor at its various test conditions. Knowing the input torque to the rotor and its rpm is all that is needed to determine the input horsepower requirement for the pump model rotor. Later determination of the effective power transmitted to the flow will be used to determine the hydraulic efficiencies of the pump at the different conditions tested and for the individual components.

3.4 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 of importance along the pump: the pump inlet face, the rotor/stator gap, and the exit nozzle. The conditions at the pump inlet face determine what is going into the pump. The conditions in the rotor/stator gap are important in determining the performance of the rotor. The conditions in the nozzle are needed in determining the overall performance of the system as well as evaluating the performance of the stator/nozzle combination. 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, and this 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 much larger magnitude of the other velocity components. Figure 5 shows the LDV in operation measuring velocities in the nozzle throat section. The laser head is mounted outside the pump shroud and parallel to the axis of the pump. A 45-degree mirror deflects the constant focal length beam into the pump channel flow through the special view ports. By moving the laser head back and forth, parallel to the pump axis, the beam focal point is shifted to different radial locations in the flow channel for measurements.

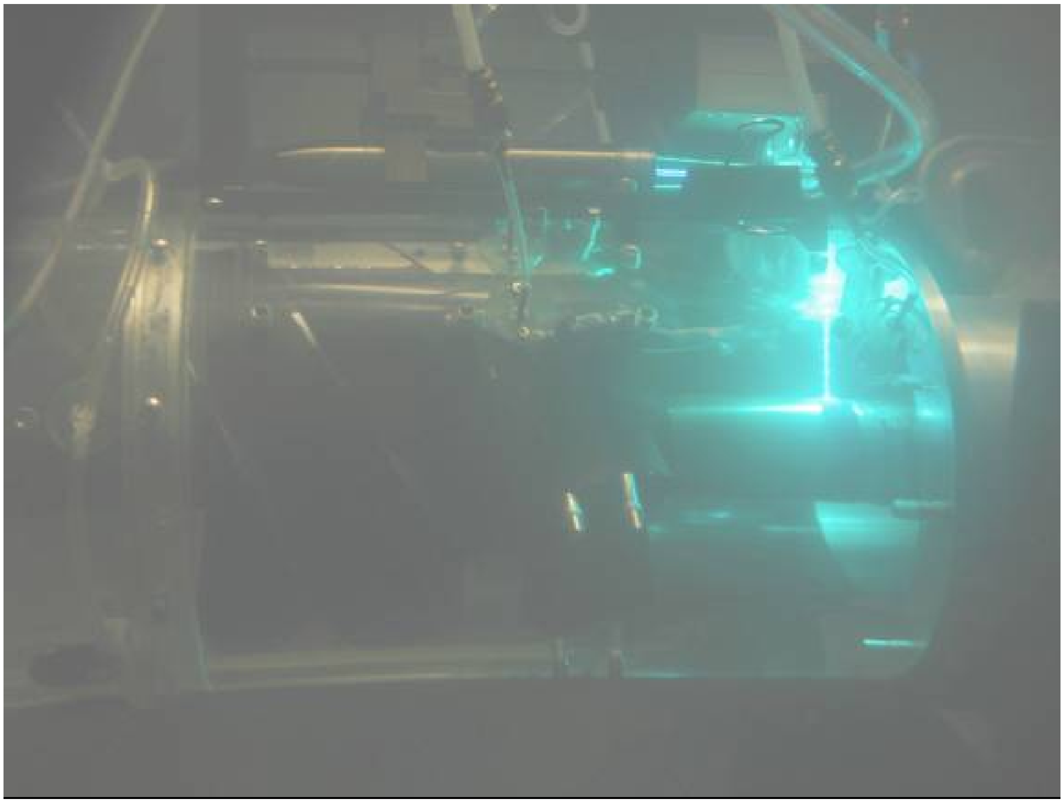

Figure 5 - Laser Operating in the Nozzle Throat Section

The LDV data will give the velocity distribution of the flow at different radial locations across the channel. These velocity measurements can be used for several objectives. The integration of the axial velocity components across the channel can be used to determine flow rate. The vector sum of the measured axial and tangential velocities at each radial location will give the absolute component of the velocity, since radial contributions are considered insignificant. The absolute velocity is used to determine the dynamic pressure at its location. Later Kiel probe readings of total pressure will be obtained at the same locations. Subtracting the dynamic pressures from the Kiel probe total pressures will determine the static pressure profiles at the various measurement stations. The static profiles will be used determine any corrections to the pump performance data that has been initially calculated using wall static pressures, which can’t account for a static profile.

3.5 Cavitation Runs

Cavitation runs will be made to determine the likely cavitation performance of the pump. During the cavitation runs, 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. The tunnel pressure is actually being used to control static pressure at the pump inlet face, which is the static pressure part of the NPSH term. At the pump inlet face, dynamic pressure can be obtained from the flow rate setting at the known inlet flow area, and the vapor pressure of water is known from the water temperature. Later Kiel probe data, which will determine the static pressure profile at this location, will be reviewed for any additional static pressure corrections that may be required in order to properly determine the NPSH.

The presence of cavitation does not necessarily degrade performance, as a pump can operate with some amount of cavitation present, although this is not desirable on a continuous basis, but is acceptable for more transient operation such as during periods of acceleration. When the amount of cavitation present becomes excessive, the pump can no longer maintain its headrise and the pump enters cavitation breakdown where the headrise begins to fall off, usually in a dramatic form with any further decrease in NPSH. Cavitation breakdown is normally classified as the point where there is a 3% reduction in the pump total headrise from its noncavitating condition. For the present cavitation run tests, the pump total headrise was calculated from the differential pressure measurement across from Station 3 to Station 6 of Figure 4 and the known flow rate, which was kept near constant during the cavitation runs. Cavitation runs will be runs with decreasing NPSH until breakdown occurs, then the NPSH will be increased to measure the recovery from breakdown and determine any hysteresis effects. Cavitation on the rotor is also observed with the use of a strobe light timed to the shaft speed and blade count, which will make an individual rotating blade appear to be stationary. Photos and video recordings of the significant parts of the cavitation tests are part of the test plan.

3.6 Kiel Probes

ONR has requested CDNSWC to take Kiel probe readings of total pressure in the axial-flow pump model for later planned comparison with CFD modeling of the pump. 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 that should correspond to locations of other data taken during this testing. Some of the view port inserts will be modified, or new inserts made, to hold the Kiel probe and CDNSWC has a final arrangement. These tests will be undertaken after the present performance and cavitation testing has been completed. 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. However, the Kiel probe can tolerate a significant angular mismatch with the absolute flow velocity vector and still properly measure total pressure in the flow. 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 DISCUSSION

The pump model has been installed in the water tunnel and testing has been in progress. The pump model is being successfully operated at speeds up to 2000 rpm. At this speed, the 7.5-inch pump model is absorbing about 27-28 horsepower. Maximum pump speeds could be 2440 rpm where the pump would absorb about 51 horsepower. The pump model stator blades are pinned to the acrylic housing to hold them stationary, with two pins per stator blade that are inserted into the stator blades and held by the acrylic housing. This arrangement is necessary in order to have the clear acrylic housing, which is necessary for observation purposes during the cavitation testing, and is the only practical means of securing the aluminum stator blades to the acrylic housing. The pins are made of very high-strength stainless steel to keep the required pin diameter that is inserted into the stator blades to a minimum. However, the scaled-down thickness of the model aluminum stator blades does not leave a great excess of aluminum thickness around the pins in the stator blades. Modified stress calculations indicate that the pin arrangement is within stress limits; however, there is a danger of the pins tearing through the blades that will only increase with stator blade loading, which increases with the cube of the test rpm. At present, testing has not exceeded the 2000 rpm mark, as good data can be obtained up to this present rpm range without pushing the loadings on the pump model arrangement too far too soon.

5.0 CONCLUSIONS

Testing is well underway and no significant testing problems have been encountered to date.

6.0 REFERENCES

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